ELECTRIC ROAD VEHICLES FOR ISLAND COMMUNITIES

A study of the potential for introduction in the Scottish islands

By

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To my parents

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ABSTRACT

The advent of high-performance, traffic-compatible, electric road vehicles (EVs) has brought with it an increasing range of uses and this study is concerned with evaluating the suitability of EVs for a hitherto unresearched application for this emerging technology, namely the island communities of Lewis and Harris.

The stimulus for the renewed research and development of EVs has resulted largely from concerns about future energy supply, particularly of oil, and environmental conditions. An assessment of the state-of-the-art of EV technology and of traction battery systems in particular is presented. A strategy for development, commercialisation and diffusion is outlined which recognises the nature of the technology and its likely diffusion process. Market segments, such as island communities, which are suitable for early introduction must be identified. The islands of Scotland were chosen for investigation because of their current patterns of transport.

The assessment of potential for EV introduction focuses on the requirements of a personal means of transport in terms of factors such as operating performance, utility, reliability, ability to refuel adequately, safety of operation and disposal, economic advantage and acceptability to motorists. Various relationships are established between the state of EV technology and the potential for introduction in the islands.

A practical methodology for assessment which adopts a holistic approach is constructed. This is designed to be generally applicable to other similar EV assessments. The methodology employs a series of purpose-built computer simulation models and data collection techniques in order to model real life situations and systems as closely as possible, facilitating the evaluation of market potential and identification of barriers to EV introduction in the islands.

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INTRODUCTION

> "Concern for man himself and his fate must always form the chief interest of all technical endeavours - in order that the creations of our minds shall be a blessing and not a curse to Mankind. Never forget this in the midst of your diagrams and equations"
>
> Albert Einstein

Transportation plays a vital role in any developed economy and an increasingly important role in developing nations. It characterises modern life and is essential for economic activity as well as permitting a wide range of leisure activities. The motor car is a means of individual mobility and handles most human transportation. It has become an indispensable part of modern life, no longer a luxury but a consumer product. An awareness of the importance of transportation, coupled with the realisation that the present transport system is almost entirely based on fossil fuels which are limited in their duration, and which are liable to disruption of supply, has led to renewed interest in alternative transportation systems in the last two decades.

Electric vehicle technology is not new and it has a good pedigree. At the turn of the century, electric vehicles (EVs) were more common on the road than internal combustion engined vehicles (ICEs). However, since the early years of the century, economic and technological factors have led to the widespread use of ICEs, and the EV has been relegated to special applications such as the milk float where there is less demand for high vehicle performance in terms of speed and acceleration. The UK is unique in that it has retained an indigenous EV industry, largely due to the way in which the population expects its milk to be delivered, and this has provided a platform from which the technology is being developed to the stage where it might be able to undertake a more significant part of the transportation function. Modern high-performance, traffic-compatible electric road vehicles are capable of greatly improved performance characteristics compared to the standard low-performance milk float type of vehicle, and so they can be regarded as a new and different product. The present environmental pressures and trends, together with growing concerns about energy and oil conservation, flexibility in the energy base, and future dependency on foreign oil sources have provided strong new stimuli for the planning, organising, financing, production, and introduction of high-performance electric vehicles as substitutes for ICEs. In comparison to the ICE, the EV also offers certain advantages to the owner. These include cost savings, increased reliability, longevity, ease of operation and reduced maintenance and service requirements. Like any new technology or innovation, it is important that EV technology should be assessed and that the development and diffusion processes are managed in order to reduce uncertainty and maximise the benefits to society and individuals.

This study aims to carry out an assessment of EV technology and the arguments in favour of its development and diffusion, and to assess its suitability for a hitherto unexplored application. The limitations of EVs in terms of daily range and operating performance make them unsuitable for many motorists, but there are applications where these restrictions are less critical on the potential for EV introduction. The application which is examined in this study is that of the privately owned domestic vehicle in island communities. The islands used as the basis of the assessment were the islands of Lewis and Harris in the Outer Hebrides (and to a lesser extent the island of mainland Orkney). The pattern of vehicle usage in island communities such as these, along with several other factors, would seem to suggest that this application offers potential for the early introduction of EVs, and this study aims to examine and quantify this potential.

It is also the aim of this study to establish a practical methodology for the assessment of EV technology in specific applications. Most of the research efforts concerning EVs which have been undertaken in this country and overseas have concentrated on very specific, often narrow, aspects of EV development. There have been very few attempts to take a holistic or systems view of the entire subject, from scientific and technical problems to economic and sociological considerations. This is especially true of studies which have been concerned with evaluating the potential usefulness of EVs. By adopting such a narrow view many limiting assumptions have to be made and these can often be unrealistic. This study attempts to establish a methodology for assessment which takes a systems view of the subject and which evaluates the potential for EV introduction by looking at all relevant fields of study. This involves evaluating such things as the technical capabilities of the technology, the needs and characteristics of potential users, the economic effectiveness of EVs and the relevant market characteristics. The methodology relies heavily on the use of purpose-built computer simulation models which are used as the basis of extensive experimentation. Data for these models was collected from a variety of sources and by a variety of techniques including the design, construction, and implementation of appropriate data collection hardware.

SYNOPSIS OF THESIS

In section one, a general examination of EV technology, its benefits and the need for management of the diffusion process is presented. The current state of the EV industry both in the UK and worldwide (chapter 1), and the state-of-the-art of EV and component technology (chapter 2), need to be examined before a meaningful analysis of the wider implications of

EV introduction and the rationale for their development can be made. The case for the use of EVs centres primarily around their impact on energy and environmental problems as well as on the prospects for industry, and these areas are discussed in chapter 3.

The advent of high-performance, traffic-compatible, electric road vehicles has brought with it an increasing range of applications for which they can be used, and this in turn necessitates the management of the technology development and diffusion processes, in order to provide the link between the technology and the market (chapter 4). Suitable product design, development, manufacture, price, promotion and demonstration is required if the diffusion of EV technology is to be stimulated. Appropriate government assistance could also help in the establishment of an EV industry and market. Identification of suitable market segments for EVs is a key part of the technology management process and could help to stimulate their early introduction for suitable applications as well as acting as a catalyst for the wider diffusion process. Island communities were chosen as one particular application which merited closer investigation. The potential for EV introduction in certain Scottish islands is examined in detail in section 2.

The objectives of the analysis, the type of data that were required, the data collection process and the methodology employed in the assessment are presented in chapter 5. The potential for EVs is assessed by examining the various requirements of a personal means of transport. There are several basic qualities which vehicles must have in order to perform their intended function and these attributes are used as the basis of assessment in the remaining chapters.

The first stage in the examination of EV suitability is to assess how EVs would perform in the island situation with its associated terrain and the particular use patterns of island motorists (chapter 6). Both the technical operating characteristics and the usefulness of such a vehicle in terms of how much of the island transportation function it could fulfil are central questions which have to be answered.

The theoretical performance and utility measures calculated in chapter 6 do not necessarily reflect the 'realisable' or practically achievable utility of EVs in the islands. These initial measures need to be modified in terms of the technical reliability of the technology and also in terms of the ability to refuel adequately (chapter 7). Suitable recharging infrastructures are discussed and the adequacy of the island electricity distribution network is examined using computer simulation techniques.

Another aspect of concern for motorists is the inherent safety of the new vehicle technology. Safety aspects of EVs need to be examined both in terms of the inherent operating safety of the technology and also in the wider fields of safety of decommission and ultimate disposal (chapter 8).

Ultimately, a new technology will not be adopted in the market place unless it offers some advantage over the technology it is replacing. Chapter 9 examines the economic case for the use of EVs and the acceptability of EVs as expressed by the attitudes and preferences of island motorists.

Chapter 10 is a small case study where the methodology which has been established is applied to another potential island application for EVs - the case for grocery vans and school buses.

Any technology assessment would be incomplete without an examination of possible or likely future developments. Chapter 11 is concerned with highlighting some of the areas where progress in EV technology is being made and where future advances are probable. The objective of such an analysis is not simply to describe the technology but rather to examine the effect that possible future advances would have on the capabilities, desirability, usefulness and ultimately on the market potential for the high-performance electric road vehicle.

SECTION ONE

THE BACKGROUND TO ELECTRIC VEHICLE ASSESSMENT

CHAPTER 1

THE ELECTRIC VEHICLE INDUSTRY

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THE ELECTRIC VEHICLE INDUSTRY

> "If you continue to make your present caliber of automobile, and I my present quality of battery, the gasoline buggies will be out of existence in no time."
>
> Thomas Alva Edison
>
> to W C Baker, President of the Baker Motor Vehicle Co. of Cleveland 1902.

1.1 HISTORICAL DEVELOPMENT OF ELECTRIC ROAD VEHICLES

Electric traction has had a long history. The first battery powered electric road vehicles were built in 1888 by Professor Ayrton in America and in England by Walter Bersey. These were electric cars and in 1898 an electric car with a 36 h.p electric motor set the World land speed record at 39.24 mph. The following year this record was broken by Camille Jenatsy in Belgium who set a new record of 68.8 mph in his electric car 'La Jamais Contente'. The next 20 years saw electric cars becoming so popular that they were as common as, and competed with, steam and petrol powered cars, which were still very noisy and inconvenient. In 1910 there were 6000 registered electric cars in London alone, and at the same time many of the World's major cities were operating fleets of electric buses. On the commercial front, many operators in both Europe and America started to adopt electric delivery trucks in place of horse drawn vehicles in the early 1900's. Harrods, for example, operated a fleet of electric vans between 1919 and World War II.

Despite the popularity of the electric road vehicle, within a few years a series of developments and other factors led to the rise of the internal combustion engine vehicle (ICE) which took a substantial lead over the other two types of vehicle. The development of electric ignition in 1912 meant that ICE vehicles could be started more easily without cranking, thus cancelling out one of the advantages of the EV. Petrol was becoming plentiful and cheap, especially after the discovery of oil in Texas, and together with new technologies leading to improved ICE performance and production methods, these factors led people to concentrate on the petrol engined car. In the United States, the number of EVs produced in 1919 was 5000, whereas gasoline powered cars exceeded 1.6 million; and, by 1933, the number of electric cars was reduced to zero.

In the UK, the use of electric vehicles after 1920 was confined to more and more specific and specialised uses like trams, trolley buses, fork-lift trucks, milk floats, hospital vehicles and golf buggies. Many of these are still produced and used today because their pattern and type of usage is not suited to ICE vehicles. The EV has maintained a competitive edge in specific applications, most of which are very low speed and low performance uses. Because of the restrictive limitations of such vehicles in terms of range between recharge, speed, rate of recharge, acceleration and so on, they have been found to be suited primarily to applications where these parameters are not as important or critical as, for example, operating costs. The relative importance of the various vehicle parameters depends on the tasks which the vehicle is expected to carry out and, in the end, electric road vehicles will only be used where they have a relative advantage in some area which is regarded as the most critical one.

For most of the present century in this country EVs have played a small but important role in specialised applications but although they are still relatively rare, there has been a definite revival in interest since the mid 1960's. This has been stimulated for various reasons but primarily as a consequence of the increasing realisation that oil-based fuels are limited in their supply. The oil crises of 1973 and 1979 caused much concern over the future of oil supplies, and the United States in particular initiated an electric vehicle development programme for this reason. It might also be fair to say that throughout the developed and industrialised world, the last two decades have seen a dramatic rise in the level of concern over environmental issues. This has been manifest by the emergence in many countries of so called 'green' political organisations. Few national governments can ignore this reality and the electric vehicle has been seen as a more environmentally benign mode of transport than petrol powered vehicles. These issues are discussed more fully in chapter 3, but it is reasonable to say that these two pressures have been largely responsible for the upsurge of interest in the electric road vehicle. However, early expectations regarding the role of EVs have not yet been met. With hindsight it can be seen how unrealistically optimistic many of these expectations have been. In 1977 F Dierkins of the International Union of Producers and Distributors of Electrical Energy (UNIPEDE) estimated that "around the years 1985 to 1990, some 10% of the inner city traffic, in industrialised countries, and in cities with no very steep gradients, will be driven by electricity" [1]. Similarly, President Carter was recorded as promising electric vehicles comparable to the internal combustion vehicles of today before 1985. There are numerous records of similar claims that have not been met.

1.2 THE RECENT SITUATION

Britain is the only country in the World to have a well established EV manufacturing industry and this exists largely because of the way in which we expect our milk to be delivered. This has helped the UK to be well advanced in EV technology. In 1980, nine out of every ten electric road vehicles produced were for the dairy trade (see also table 1.1).

Multiple stop-start usage with limited mileage and speed is the ideal application for EVs as this is the type of driving where it exhibits maximum relative advantage. Specifications can be calculated to suit the individual pattern of usage and thus give greater economies over the ICE which is extremely inefficient under these conditions. (The wear and tear on an ICE, with its many moving parts, in such an intensely stop-start operation as milk delivery, is enormous. Also the EV consumes no energy when stationary.)

Of the previous door-to-door delivery services only milk delivery remains, although there are some other very specialised EVs in use such as airport or hospital vehicles. However, the market for milk delivery EVs is under threat as people are increasingly purchasing more and more of their milk from supermarkets and shops. In addition, milk consumption in the UK has been dropping by 2-3% per year recently, partly because of increased concern over healthy eating and the anti-cholesterol campaigns. By 1984 the number of milk floats had dropped from a relatively stable 30,000 to 26,000. In 1974 there were 2100 EVs sold for milk delivery but by 1985 this figure had fallen to 600. This fall is also reflected in the total population of EVs in Britain, which in 1979 stood at 45000 whereas in 1984 it was under 40000. Table 1 shows the number of road vehicle registrations in the UK in 1982 and 1983 [2].

TABLE 1.1 EV REGISTRATIONS (UK 1982 &1983)

END MARKET	1982	1983
Dairy	693	423
Street cleansing	37	56
Hospital	8	6
Van and other	85	34
TOTAL	823	519

In order to maintain the industry in this country and the technological lead which it has established it may be necessary to find alternative applications for EVs. (The above discussion relates only to road vehicles, as off-the-road EVs are becoming increasingly popular for applications such as goods handling, moving people in airports and amusement parks, underground mines, military establishments, golf carts and so on).

Since the resurgence of interest in EVs, research and development work pertaining to them has been diverse and wide reaching. In this country most effort has been concentrated on developing commercial vehicles, normally vans or trucks, as these are the applications which are expected to have the most potential. Commercial vehicles tend to have more predictable and regular use patterns and operators tend to place more importance on whole life operating costs. The sacrifice of some of the more cosmetic features associated with the ICE is not as important a consideration for many commercial operators as for the private motorist.

1.3 HIGH PERFORMANCE ELECTRIC ROAD VEHICLES - A DEFINITION

There are several descriptions of the type of vehicle dealt with in this study which attempt to distinguish it from the type of electric vehicle which has become familiar over a long period of time. The past 20 years has seen the development of vehicles with much improved performance in terms of speed, acceleration and daily range. Common understanding of the term 'electric road vehicle' conjures up pictures of the slow milk cart type vehicle which is not always popular with the public because of the nuisance it can be in traffic. This study however is concerned with what is often termed the high-performance or traffic-compatible electric road vehicle. At its most basic, it is simply a vehicle which has a portable electrochemical energy source and in which tractive effort is supplied by an electric motor. The Hybrid electric vehicle, which employs two or more sources of energy and/or tractive power, is not examined in this study primarily because of the lack of an economic case for its use. In chapter 9 it is shown that the economic case for the all-electric vehicle which only employs one drivetrain is still far from overwhelming. The Hybrid vehicle would require an additional power source and production costs would be much higher. Although it overcomes many of the limitations of the simple EV it can hardly be expected to compete on economic grounds. The high performance EV with which this study is concerned is characterised by its traffic compatibility. It is capable of keeping up with ICE traffic and not causing inconvenience. Typical top speeds are in the region of 50 to 70 mph, acceleration is generally lower but not significantly different from a diesel vehicle or small van. Operating ranges between recharges can be as much as 60 miles, and in some cases even more. Appendix 6 gives details of several recently developed EVs and in chapter 2 the state-of-the-art is discussed in more depth.

1.4 ELECTRIC VEHICLE PRODUCERS AND THEIR PRODUCTS

1.4.1 INTRODUCTION

The traditional low performance type EV has a well established industry surrounding it. There are four main producers in this country - Smiths Electric Vehicles, W&E Vehicles, M&M/Electricars and Wingrove & Rogers/Ross. In addition there are several smaller producers and specialists in the field.

When it comes to traffic-compatible vehicles, most of the major existing ICE manufacturers have been involved to some extent although their research programmes have not always been well publicised. There have also been several attempts to produce and sell EVs by small independent specialised companies, many of whom were established for the sole purpose of building them. The remainder of the attempts at development fall into a very different category however. There have been numerous cases of electric vehicles being built by enthusiasts and hobbyists and these attempts seem to have attracted more than their fair share of publicity. Many of these vehicles have exhibited surprisingly good performance characteristics but they do not seem to have been designed with costs or mass production in mind. They have been hand-built using an assortment of components and it is not proposed to discuss them here.

Generally there are two ways of building electric vehicles and getting them into the market place. The first is to build the best electric vehicle you can, and then see to what uses it can be put, and the alternative is to identify a particular segment of the market and its requirements and then build a vehicle specially for that segment. Both of these approaches have been adopted in the past, with special purpose EVs like the milk float on the one hand and highly publicised prototype electric cars on the other. The following is a summary of the major serious attempts at EV development, both by the existing ICE manufacturers and by specialists.

1.4.2 LUCAS CHLORIDE ELECTRIC VEHICLE SYSTEMS LTD

Two large electrical component manufacturers, Lucas Industries plc and Chloride Group plc joined forces with regard to their EV programmes in 1981. A new company was set up to coordinate the efforts, . it was called Lucas Chloride Electric Vehicle Systems Ltd (LCEVS) and was owned 60% by Lucas and 40% by Chloride. The objective was to develop and market fully integrated drivetrains for high performance electric vehicles in conjunction with major vehicle manufacturers. The 'drivetrain' is the electromechanical system between the vehicle energy source and the road. This includes the electronic controller, motor and transmission systems. Prior to this date, both companies had their own development programmes. Lucas became involved in 1968 as a result of the necessity to provide a mobile test bed to be used in a programme of R&D for traction applications using the zinc-air battery. Four years after it had begun, work on this battery system was stopped for technical reasons but experience gained in building and operating the test vehicle led the company to recognise the potential for a high performance EV and it was felt that by developing a lead-acid battery system, a commercially viable product could be made. The next 13 years saw a programme of vehicle development in which many test vehicles were constructed and operated to give valuable operating experience [3]. Fleet trials of EVs under the Lucas programme took place in 1975 with a batch of 16 vehicles [4].

The Joint company recognised the need for developing high performance, reliable drivetrains. The strategy was to use mass produced vehicle shells by cooperating with existing manufacturers. The participating companies were Bedford, Freight Rover, British Leyland and Karrier Motors. A Government subsidy was given for every EV drivetrain that LCEVS sold to these manufacturers and this subsidy was passed on to the final purchaser. A total of £5 million of Government money was given in a five-year agreement terminating in 1986. £1 million was given each year to match the £1 million contributed by both Chloride and Lucas. The vehicles used as the basis of the electric conversions were already produced in large quantities so there was little scope if any to reduce the cost of the standard element of the vehicle. Therefore the ability to produce a low cost EV lay primarily in the hands of the supplier of the electric drivetrain and depended on a design which enabled the adoption of the simplest possible way of marrying the vehicle and drivetrain together. The vehicles were assembled on standard assembly lines in batches and the drivetrain was designed for easy attachment to the vehicle. The motor and its controller were coupled into a sealed single-axle component which was simply bolted in where the engine would have been. The adoption of this strategy by LCEVS probably accounted for their relative success and section 4.3.4 examines the relevance of this strategy for the future development of EVs.

In 1984, LCEVS Ltd in conjunction with Bedford Commercial Vehicles and Freight Rover sold 179 electric versions of the one tonne vans produced by these two companies. These were the Bedford CF and the Sherpa vans respectively. In 1985 a further 125 vehicles were sold. For a description and details of the vehicles see appendix 6. The Post Office bought 80 vans to test with a view to replacement of many of their ICE vans if trials indicated encouraging results. 152 of the vehicles sold went to regional electricity boards. The South Eastern Electricity Board had already been undertaking trials of prototype electric vans for some years and the South of Scotland Electricity Board (SSEB) is currently operating the largest fleet of electric vans in this country. It has 80 vehicles. In addition the gas boards are operating around 24 electric one tonne vans. These electric conversions are capable of speeds of up to 60 mph and a range between recharges of around 60 miles. These vehicles were very successful technically and some were sold as far afield as Hong Kong, Australia, Denmark, Canada and Sweden. In the USA, General Motors, Bedford's parent company, had adopted the Bedford CF van and imported 37 of them for tests. GM had its own EV programme in the 1970's in which they spent over £72 million. In 1977 an EV Department was created at the GM Truck and Coach Division in Michigan with the objective of developing a first generation electric commercial vehicle for field evaluation. These were subsequently built and tested and results compiled [5]. In 1979 GM announced a major breakthrough in their research into nickel-zinc batteries. As a result they announced the establishment of a passenger car project centre and stated their intention to market 100,000 electric passenger cars by 1985 using nickel-zinc batteries [6]. Changes in consumer demand and projections of oil availability led GM to postpone these goals [7]. This project is now abandoned but they adopted the electric Bedford and imported them from Luton, renaming it the 'Griffon' [8]. These vehicles were bought at very high prices because of poor exchange rates and because the Government subsidy on the drivetrains was not available on vehicles for export. Each vehicle was sold at over

£14,000. However they performed very well and reports indicated that they were performing better than they had in this country. General Motors had plans to adopt the technology eventually and produce the vehicle in the States. It stated in 1984 that it had decided to make Bedford (its British subsidiary) into its worldwide centre for the development, manufacture and marketing of electric commercial vehicles [9]. In the short term, there were prospects for orders of possibly hundreds more vans from the UK. GM estimated in 1984 that British electric van sales would be in the region of 10,000 a year by 1989 [9], and customer response to the first electric vans in operation was complimentary enough to add weight to this prediction. The Electric Vehicle Development Corporation (EVDC) in the States, which was set up by the American equivalent of the Electricity Council in conjunction with the large utilities companies, adopted the Bedford van as their 1 tonne vehicle in their programme of EV development. LCEVS and Bedford had plans for continuous assembly line production of electric vans, which would further reduce costs. This was scheduled to commence in October 1986. Freight Rover had not taken such an active part in the electric van programme and it looked as if they were not going to proceed with it. All hopes were pinned on LCEVS and Bedford who seemed to be establishing a viable UK EV industry. Not only was this of value in developing the technology but it provided a vehicle which could be used to test future systems such as the sodium-sulphur battery. The Electricity Council had a vested interest in the Bedford vehicle for this reason and plans had been made to proceed with such tests. However, the LCEVS story came to an abrupt and premature end when General Motors, the parent company of Bedford Commercial Vehicles announced in 1986 that it was pulling out of EV development for short term financial reasons. The Luton plant ceased building the CF vans. In 1985 an Electricity Council expert in this area stated that if Bedford pulled out, the EV industry in this country would be set back about 10 years. The years following 1986 have certainly seen little movement. LCEVS has become Chloride Electric Vehicle Systems Ltd. after Lucas pulled out. It can not be said that there was no market for the vehicles but the financial backing, marketing ability, service and maintenance backup, provided by Bedford, were essential for the credibility of the product. A very short-sighted decision to end devlepment on the basis of short-term problems in the company resulted in the stagnation of EV development even although there was no reason to doubt its future success.

1.4.3 THE ENFIELD PROJECT

In the early 1970s, a company on the Isle of Wight started to produce a small electric car called the Enfield 8000. Originally the vehicles were intended for use on Greek islands and the company was owned by a Greek millionaire. In May 1976 the company ceased trading, although it was not bankrupt, after building 120 of the vehicles. Some of these were sold to South Africa, Canada and Russia. However, following the Buchanan Report on inner city transport in the mid 60's, the electricity industry started to take a serious interest in electric transport and in 1974 the Electricity Council bought 66 Enfield electric cars for long-term tests. The basic evaluation has been completed and various modifications have been made to the vehicle [10]. The Electricity Council employed Enfield's chief engineer after the company ceased trading to redesign and modify the vehicle. The original vehicle was found to be unreliable and it had a poor electrical system. It was considered to be badly engineered. The controller unit and charger were redesigned and a more suitable battery system was installed. The original batteries were not suited to traction uses, being heavy-duty starter batteries which were not capable of regular deep discharges. Battery lifetime mileage jumped from approximately 2000 miles to nearer 20,000 miles. Technical details of the Enfield project are obtainable from the Electricity Council but the single most important point to note is that although the original vehicle required substantial redesigning and modification, once the car had been 'de-bugged' and teething problems were dealt with, it proved to be a very reliable car. The inherent technology was proved to be sound although there was an evolutionary process involved in achieving this reliability. The same can be seen with the milk float which has proved to be an excellent vehicle for the tasks required of it, in terms of cost and reliability. Many of the problems experienced with high performance electric prototypes are of a 'teething' nature and should not be regarded as problems inherent to the technology.

1.4.4 THE SINCLAIR EXPERIMENT

Perhaps the Sinclair C5 has struck the worst blow to a modern EV industry since the resurgence of interest in electric transport because of the ridicule and scepticism which it attracted. Promoted initially as an electric 'car' and claiming much better performance characteristics than it later proved to be capable of, the C5 raised false hopes and caused much disappointment. It had a severely restricted range of around 20 miles and a top speed of 15 mph. Sir Clive Sinclair conceived it and pushed through its development against much advice [11]. Marketing research was inadequate in its extent and scope and the C5 did not fit any known market slot. Sir Clive had to invest £3.5 million of his own personal wealth before the launch, and by the time the C5 finally proved to be a market failure he had spent over £7 million of his own money. The C5 was found to be unreliable and unsafe by the AA [12], WHICH magazine [13], Motor magazine and the Consumers' Association amongst others. It was not traffic-compatible and offered little protection to the driver. Sinclair had intended the C5 to be the first of three electric cars, culminating in the C15, a four seater passenger car with a top speed of 80 mph and a range of "hundreds of miles". His timetable was to introduce this C15 by 1990. The C5 cannot be classed as a traffic-compatible or high-performance EV but it was the first exposure that many people would have had to the idea of electric road vehicles since the milk float. Public attitudes towards electric vehicles have probably been severely set back and it will take time to regain confidence.

1.4.5 VOLKSWAGEN

Volkswagen has been involved in all areas of vehicle development from reducing exhaust emissions to utilising alternative fuels. VW has been undertaking trials of 140 VW electric transporter vans and it has built several electric VW Golf cars. These have a top speed of 58 mph and a range of between 25 and 47 miles and will accelerate from 0-30 mph in 10 seconds [14]. The driving characteristics are reported to be almost indistinguishable from the ICE version. The vehicle was being sold for around £12,000 in 1985. The German Utilities Company RWE was operating some and reported enthusiastically on their performance. 10 VW Golf electrics were purchased by the Electric Power Research Institute (EPRI) in the States which is the equivalent of the UK Electricity Council. The EPRI has its own EV programme and the VWs are being tested by the largest of the American utility companies, the Tennessee Valley Authority. The Electricity Council rated the vehicle as being very good technologically but poor on performance. VW claims that there is a very important role for electric traction in the future and they intend to ensure that they are well positioned to have the vehicles of the future available in due time. For further details see reference [15].

1.4.6 PEUGEOT

In late 1984 Peugeot unveiled their electric version of the conventional Peugeot 205 car [16]. This represents the results of 18 years of continuous research into the viability of electric propulsion. What makes the research vehicle special is that the basic structure of the 205 is completely unmodified. In addition, the 205 Electrique is unusual in that it uses nickel-iron batteries which develop almost twice the power of conventional lead-acid batteries with no increase in weight or volume. This gives the car a top speed of 62 mph and a driving range in stop-start conditions of 87 miles. The maximum range quoted is 124 miles. Twelve six-volt batteries (with a combined weight of 300 Kg) together with the rest of the power train are housed in the existing engine compartment, leaving the interior and boot space intact. According to Peugeot, the battery life is estimated at 1500 cycles giving a 125,000 mile useful life. The 205 Electrique however is not intended for mass production or sale but is being used as a research vehicle to study and evaluate systems and concepts that may be integrated into future Peugeot vehicles [17].

1.4.7 HIL ELECTRIC

HIL electric aims to be Britain's first dedicated high performance electric road vehicle manufacturer. The managing director, John Holden, intends to import and manufacture a wide range of electric vehicles. He may be criticised with hindsight as being over optimistic in his market expectations. He has frequently been recorded making claims which have not been fulfilled. For example, in 1985 he stated that "by the end of 1986 we will have the widest range of electric vehicles and be the number one in the world" [18]. He also expected to be producing 5000 plus vehicles from early 1986. However Holden's approach, although very optimistic, is based on a belief that the market will lie with commercial and fleet users. He does not believe that the electric car will make ICE vehicles obsolete but he believes that some types of EV will be launched on to a ready market - city-centre and urban light delivery vans, three wheeler bubble cars for shopping or school runs and four wheel options for family outings [18]. In 1985 he had plans to market several types of EV,

1 A Danish three-wheel bubble car with a claimed maximum range of 30 miles and speed of 25 mph. Called the U36, it is much more robust

than the C5 and is more like a conventional bubble car. The plan was to build it in Tyneside using mostly 'all-British' components. The cost would be in the region of £1500 but could fall to £1000 at volumes of over 20,000 vehicles. There has been little mention of this vehicle since the collapse of the Sinclair C5.

2 The Danish designed Hope Whisper vehicle was launched in Denmark in 1983. It was developed with the Danish Government's backing. It is claimed to have a top speed of 50 mph and range of 62 miles. It is a four-seater car with a glass fibre body and lead-acid battery. It looks like a normal small car (see appendix 6). Hope is a computer company which has diversified into manufacturing the Whisper vehicle. The Chairman is Sir Jon Samuel who was the managing director of the Enfield company. In many ways the Whisper is said to resemble the Enfield car. The cost is expected to be in the region of £4400. The Whisper was launched very quietly in Britain in 1988 but an Electricity Council spokesman stated that the Whisper needed several improvements to make it more attractive, the acceleration was poor and the suspension was hard. It suffered from teething problems but could prove to be a reliable and comfortable vehicle after improvements were made. The Hope company switched its interest away from the UK market in favour of the US market so HIL electric would import it from the USA. Plans had to be delayed and the vehicle is still not being imported.

3 HIL also plans to supply battery-driven airport baggage handling, passenger steps and general use industrial trucks.

4 The vehicle which John Holden is currently developing and promoting enthusiastically is called the QT-50. In fact the basic QT vehicle can be produced in various versions including a chassis cab vehicle, pickup, minibus or car. There is a range of over 20 demountable body variants. It has a precision moulded ABS and Polyethylene body and

the mechanical parts are supplied by VOLVO. Once again it is very similar to a small car and looks quite attractive (see appendix 6 for full specifications). The vehicle will have a top speed of about 50 mph and a range with lead-acid batteries of about 50 miles. Holden plans to use sodium-sulphur batteries eventually and in September 1988 he stated that QT evaluation vehicles with sodium-sulphur batteries would be supplied in 1990. Such vehicles will be produced with a range of battery packs giving the vehicle different daily ranges. The version with the largest sodium-sulphur battery is expected to have a range of up to 120 miles and the battery used will weigh just over half of the weight of the lead-acid battery supplied with the basic version. Pilot production is now scheduled to start in March 1989 and the vehicle is to be sold for less than £7000 including battery and on-board charger. Holden claims that with an annual mileage of 10,000, the operator will save £890 per year. It is unclear how this figure was calculated but the variable operating costs per mile are quoted as being about one quarter of those associated with an 'equivalent' petrol van [19].

Holden's marketing plans have been postponed several times. Perhaps the market is not ready yet or perhaps he does not offer the product or backup services that operators want. However he remains confident and states "it is my ambition not only to create the market but through innovation and market volume maintain market share". He believes that his vehicles will be sold in 1989 and with sodium-sulphur batteries in the early 1990's.

1.4.8 FORD

EV research at Ford spans several decades and encompasses all aspects of EVs. Ford first demonstrated a complete research EV in 1966 when Ford of Europe developed the 'Comuta', a small city car. Its performance was reported to be quite limited. Since the mid 60's Ford have been researching into sodium-sulphur batteries. In 1982, Ford was awarded a Government research contract to develop a new integrated AC powertrain. The overall objective of this work is to demonstrate the feasibility of this advanced powertrain in a Ford Escort or equivalent size vehicle. Ford have already experimented with an electric conversion of a Ford Fiesta car. Other work has included the development of EV performance simulation programmes.

1.4.9 RENAULT

Renault have experimented with electric vans, electric versions of their Renault 4 and Renault 5 passenger cars (see section 1.5.5). Their prototype vehicles have used nickel-iron battery packs.

1.4.10 FIAT

Fiat have built several electric test vehicles in the last decade, ranging from the large Fiat Daily E2 van with a gross weight of 3750 Kg and a payload of 950 Kg, to the small 2-seater Zagato Elcar which weighs only 553 Kg and uses a 2 Kw motor. There is also the Zagato 250 electric car which is an electric equivalent to the Fiat Panda, and the Fiat 900 E/E2 van with a payload of 570 Kg. These vehicles have been tested in the USA by NASA [20], and feature in a European study [21]. Fiat have also been undertaking work on fuel cells and propulsion systems.

1.4.11 DAIHATSU

The Daihatsu Motor Company has been researching and developing the commercial use of electric vehicles since 1968, and, as the leading manufacturer of electric vehicles in Japan, has turned out various models. The company began to manufacture and distribute small electric cars in about 1977 and by 1980 had spent £3.8 million in this area. One of the most fully developed vehicles is an electric version of the Daihatsu Charade described in reference [22]. It is a direct conversion of the ICE model and uses a 96 Volt lead-acid battery. It has a top speed of 48 mph and a range of less than 45 miles. Daihatsu have also built a small electric van which has been tested in the USA by NASA [20].

1.4.12 OTHER MANUFACTURERS

Several other large vehicle manufacturers have been involved to varying extents - Karrier Motors in the UK, Chrysler, Saab-Scania, Kalmar in Sweden and British Leyland, to mention a few. In addition there have been several attempts by smaller companies or enthusiasts. Dunbar Dean is a small one-man company in Bournemouth which developed and built an electric utility van with a payload of 300 Kg (see appendix 6). Although the vehicle operated well and had a range of up to 100 miles, there was no market established. The vehicle was hand built and was not designed for mass production. It was priced at over £12000 and the few vehicles which were built are now being hired out to local operators in Bournemouth. This story is typical of many of the EVs built by EV enthusiasts. The Electric Vehicle Society in Britain is largely patronised by such enthusiasts.

1.4.13 SUMMARY AND CONCLUSIONS

An electric vehicle industry has existed in this country for nearly a century but the type of vehicles produced have been low-performance and special purpose in nature. The resulting component industries have grown up largely because of the demand created by the manufacture of these vehicles and the milk float in particular. Although many of these components such as motors, batteries, chargers and controllers are not directly suitable for high-performance EVs, the experience and expertise contained in the component industry has enabled the technology to be developed during the last 20 years to the level of the present high-performance EV. Although the technology is well advanced there would seem to be little commercial development and application. Research has been fragmented, lacking overall coherence and coordination. There have been pockets of interest and activity in the UK but no coordinated programme for commercial development apart from the LCEVS story. The low-performance vehicle market has been in decline recently with the reduced use of milk floats, and the high performance vehicle market has not yet been established. The Department of Industry reported to the House of Lords select committee in 1982 that,

> "The point is now being reached where developments which have taken place over the last 5 years can be utilised in vehicles for commercial operation, as distinct from the proving of prototypes" [23]

Research and development work has been carried out by the component industries such as Lucas and Chloride and by specialist and volume vehicle manufacturers. In addition, research at universities was estimated to be funded to the extent of about £300,000 in 1980 [24]. However, most of the developments hitherto have concentrated on the technology and there have been few techno-economic studies.

High-performance EVs have been built by enthusiasts as one-off projects with little serious thought to volume production. Many of the volume vehicle manufacturers have had an EV programme or project but the results have largely been limited to high cost prototypes which have simply been used as showpieces for public relations purposes. Again, there has been little thought for volume production or marketing, except in the long-term. The major vehicle manufacturers, although they have dabbled, are slow to change, perhaps because so much of the EV is not yet manufactured by the automotive industry. In addition, the recent slump in oil prices may be partially responsible for the lack of urgency and apparent apathy.

The most successful, and the only serious attempt at EV commercialisation has undoubtedly been the LCEVS/Bedford venture. However, any similar approach or attempt will face the same risk of discontinuity of involvement on the part of the cooperating vehicle manufacturer. Chapter 4 examines a suitable approach to the market and the necessity for management of the diffusion process.

1.5 INTERNATIONAL ACTIVITIES

1.5.1 INTRODUCTION

Interest in EV research and development has been widespread, with many industrialised countries having their own Government backed programmes. The stimulus for these programmes may vary and the particular emphases are correspondingly different. Some countries are more dependent on oil imports than others and so have vested interests in developing a diversified transportation system. This section looks at the formal activities of interested countries although up to date information is difficult to compile. Much of the following information is now several years old and the list is not exhaustive. It does however serve to illustrate the nature and extent of involvement internationally.

1.5.2 THE UNITED KINGDOM

Up until about 1976 the view had been taken that EVs were very much in the future, so Government interest focused on long term studies and the improvement of battery performance. This led to the support of the sodium-sulphur battery development (see section 2.7.6). However, after 1976 the Government took greater interest in EV development and the House of Lords Select Committee on Science and Technology conducted an enquiry into,

> "the potential of EVs in the light of future energy shortages, the state of their technological development and the resources available for research and development." [24]

A summary of their recommendations is given in appendix 9 along with a summary of Government supported projects. Government assistance has been mainly financial but the following measures have also been taken,

(a) The abolition of vehicle excise duty on EVs in the budget of 26 March 1980.
(b) Exemption from MOT testing by the D.O.T. under the Goods Vehicles (Plating and Testing) Regulations 1971 and the Motor Vehicles (Tests) Regulations 1981. This exemption is reportedly because of the excellent safety record associated with EVs.
(c) Exemption from National Tyre Approval for Commercial vehicles.

In the period 1972-83 the Government contributed £5.6 million to EV research and development. This contrasts with the situation in some countries where Government spending has been much greater.

In the UK there is no special fund or programme budget set aside by the Government for the development of EVs. Any applications for financial support must be channelled through normal routes and would usually fall within the scope of the support offered for innovation. This support is selective and the D.T.I. states that support will be given "to those projects which in our opinion have satisfied the criteria and are the most worthy of support in the light of competing claims for the limited funds available" [25]. Normally support would be in the form of a grant of up to 25% of the cost of the project and there is a maximum project cost of £5 million. However there are exceptions. Although there is no special EV development fund as in other countries, there is theoretically an unlimited source of funding available within the D.T.I. budget. Claims however will have to compete with all other types of innovative project, so funding is not as secure as in other countries.

1.5.3 USA

The mid seventies saw a resurgence of interest in the United States, primarily because of a growing realisation that US oil reserves were less than had previously been forecast, and the nation was becoming more and more dependent on oil imports. Transportation consumes about 25% of the total energy used in the USA each year and motor cars account for more than 50% of the total transportation sector energy. The oil crisis of

1973 had highlighted this situation. The USA seems to have been lured by the potentially huge passenger car market, and their first approach to EV development revolved around the electric car. In 1976 Public law 94-413 was passed by Congress to,

> "Authorise in the Energy Research and Development Administration (ERDA) a Federal programme of research, development and demonstration designed to promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles" [26].

The act was very adventurous and called for the manufacture and purchase of 2500 electric vehicles within 3 years of the Act and a further 5000 vehicles within 6 years of the Act. The vehicles were to be used by Government departments, individuals and business throughout the country. These figures were considerable revisions of the original proposals which called for 10,000 electric vehicles to be bought during the three years following the Act.

The Act also authorised the support of research programmes into EV design, batteries and all other aspects of EV technology. A state-of-the-art assessment was to be carried out in the first year [20], and performance standards were to be developed as a result of this information. These performance standards formed the basis of the criteria by which vehicles would be selected for purchase by the ERDA. The organisational entity within the ERDA which was set up to administer the programme was authorised to spend $160 million in the first five years of the programme and an additional $80 million on battery research. In fact over $200 million was spent in the first 6 years of the programme.

The approach taken by the programme may however be criticised on several grounds.

1 The Act and the programme were very biased in favour of developing electric cars instead of electric commercial vehicles. In contrast to most of the programmes in other countries, which recognise that commercial vehicles are the obvious and logical starting point for EV

introduction, the US programme was concerned with the mass private market.

2 Performance standards generated were unrealistically optimistic and even now, 12 years later, the high expectations have not been met [27]. Vehicles were not available which met the requirements laid down and consequently the number of vehicles specified for purchase was not reached. After four years and £130 million had been spent, only 165 vehicles had been delivered [28].

3 Contracts were given to the lowest tenders, which meant that innovative ideas generated by smaller manufacturers were often ignored. In addition, competitive tenders were often the result of shortcuts in vehicle design, safety, reliability and so on.

As a result, the programme failed to meet its objectives and after $200 million was spent only a small number of commercially viable vehicles resulted. Although work is continuing, it is doing so at a much reduced level. In 1982 the demonstration programme constituted only 1100 vehicles instead of the intended 7500. The number of companies manufacturing electric vehicles has reduced from a peak of 54 to 13. Since 1981 US policy has shifted towards greater reliance on the private sector to support large-scale technological innovations [29]. This policy shift led the DOE to cancel planned future phases of the EV demonstration programme. At the same time oil availability increased, oil prices dropped, and the enthusiasm for the use of electricity and alternative fuels for transport weakened.

In 1985 the US DOE was still providing $9.5 million for EV research and $10 million for battery research [11]. Battery research has recently been directed towards the development of a system suitable for a commercial van instead of domestic cars. Although the demonstration programme arguably failed, much basic and applied research has provided widespread results. The Jet Propulsion Laboratories has overseen a vast research programme into battery performance and management and advanced batteries. The large vehicle manufacturers have been working on such areas as computer simulation of EV performance (discussed in chapter 5), advanced batteries, motor technology, vehicle design and EV testing. An active participation has been undertaken by large organisations such as NASA, Exxon, General Electric, Globe, Gulf & Western, General Motors and Ford.

The Electric Power Research Institute (EPRI), which started its own EV programme in 1981, seems to be following a more logical approach [11]. This programme, which involves the large utility companies and has resulted in the establishment of the Electric Vehicle Development Corporation (EVDC), is aimed at the development, testing and demonstration of commercial vehicles. Instead of pre-specifying required performance characteristics, the programme is concerned with testing and learning from currently available vehicles. Vehicles have been bought from numerous sources including the UK and Germany and are being operated by utility companies. The Bedford electric van has exhibited first class performance and consequently has been adopted by the EVDC as their one tonne electric van. Considerable effort is being focused on battery research, and seven types of battery are being evaluated for near-term use [11]. It is a sad reflection on the American DOE programme that when the EPRI started its programme they were unable to find any suitable American vehicles [28].

1.5.4 JAPAN

About £11 million of Government money was spent in the period 1971-76 on the development of a number of prototype electric cars, buses and light trucks and on the development of suitable battery systems. The latest vehicles are attractive in appearance and of very advanced design. They use a hybrid battery system where iron-air or zinc-air batteries are used for their high energy density and long range ability whereas advanced lead-acid batteries are used to provide peak power for acceleration and hill climbing. Although very long ranges have been claimed (approaching 300 miles at a constant 25 mph) cycle life has been very poor. Mr G Harding who was in charge of the Lucas EV programme relates a humorous story concerning the incredible ranges that are claimed. When in Japan he asked the driver of an electric car which had just completed 300 miles in a test.on one charge how many cycles they got from the battery. The reply was "One of course, do you think we are magicians?" The 5 year development programme saw the development of these high performance vehicles but little attention seemed to be given to the commercial potential. However, after the termination of the programme, vehicle specifications were rewritten for vehicles which the Japanese believed they could produce and sell. Interestingly these specifications were very similar to those of the British electric vans described in section 1.4.2. Typical ranges quoted were more in the region of 60 miles and attention was sharply transferred to the case of the light commercial van instead of the passenger car, as it was realised that with only the lead-acid battery this was the most logical area for development. These vehicles were being sold in Japan in 1979 at reportedly very reasonable prices. A further £5 million was made available around this time and this was divided into two areas. About half of the money was given to the Japan Electric Vehicle Association to mount demonstrations with fleet users to try to get the vehicles into use. The other half was given to an association of EV developing companies.

1.5.5 FRANCE

Since 1971, Electricite de France has taken action intended to promote the development of EVs. During the period 1971-73, scientific and technical efforts were directed towards solving some of the major technical problems associated with electric traction. Research was concerned with such areas as battery performance, chargers and charging of batteries, motors and motor control devices and vehicle design. A development programme was submitted to the Interministerial Committee for Action to Protect Nature and the Environment which granted substantial financial aid in 1972 [31]. The programme allowed Electricite de France to construct and test 60 small electric cars using a Renault 4 frame and mechanical parts. 9 electric buses were also built with help from Sovel, and a number of other electric vehicles were built and tested with the cooperation of manufacturers and public bodies. From 1973 to 1975 the programme sought to encourage manufacturers to study and promote electric vehicles, components, batteries and motors. In particular, an agreement was signed between Electricite de France and Regie Renault. In 1975 a conference was held to discuss the results of the programme so far and to determine future policies. The principle of state-subsidised orders on the basis of clearly defined specifications was adopted and car manufacturers stated their readiness to study and manufacture EVs. It was decided not to direct effort towards electric cars but to concentrate on commercial and special purpose vehicles. The 'Group of Public Electric Vehicle Users' was established, comprising many of the large public bodies such as the French Post Office, Ministry of Health, Airport authorities and the Ministry of the Interior. The idea was to accumulate information on fleet user requirements and eventually to ask the public services to place orders for EVs with vehicle manufacturers. With this in mind a competition was launched by the Interministerial Electric Vehicle Group to find suitable electric vehicles. The winners would be entitled to be the sole suppliers of EVs to the public bodies. Interestingly the Lucas electric van won the competition and it would appear that the French Government rapidly lost interest in EV development. The prizes were forgotten. Government involvement seems to have been negligible until 1984 when Versailles was the host to the annual international EV symposium. At the symposium the French announced that they had decided that day to continue with a development programme.

In the private sector there have been several interesting programmes. Peugeot have been conducting research for over 16 years, culminating in the electric 205, and Renault have been working on electric versions of their popular Renault 5 using nickel-iron batteries. The battery manufacturers SAFT have been experimenting with a new design of nickel-iron battery. The history and goals of this programme are discussed in reference [21]. Nickel-zinc batteries are being researched by the French company Sergie and CGE have been conducting research on the sodium-sulphur battery since 1970. (Details in ref [21]).

1.5.6 WEST GERMANY

Between 1974 and 1977, the German Government spent about £7 million on battery research and on a bus demonstration programme. In addition, GES, a daughter company of the giant RWE electricity supplier, is believed to have spent about £25 million over the same period. A consortium was formed with VW, Daimler-Benz, MAN, Bosch, Siemens and Varta to work on electric vehicles, mainly delivery vans and buses. The Government was considering plans to subsidise the production and sale of electric VW Golfs, called the VW Citystromer, for use in Berlin. It was hoped to manufacture between 50 and 100 in the first year with the possibility of perhaps thousands more in the future. Government subsidies are more easily available in Berlin than in the rest of the country and they tend to be greater. It is interesting to note that the case for operating electric vehicles in Berlin is similar to the case for island communities. West Berlin can be regarded as an 'island' in that there are certain inconveniences connected with travelling out of the city. Although the city is not surrounded by water, many of the vehicles in it will never leave or will leave only very rarely.

1.5.7 SWEDEN

The Swedish Board for Technical Development in conjunction with Swedish industry has established a joint programme to test electric vehicles. The costs are shared equally by the Board and industry. In addition, the Board decided in 1977 to continue to invest about £80,000 per annum in battery research. The money comes from the Board's energy fund and most of the work is carried out at the Swedish Development Company (SUAB) [1]. Several private sector companies have also got research programmes. SAB NIFE has been developing nickel-iron batteries. Although these have not been manufactured commercially as yet, the company has been running a pilot plant for several years which produces approximately 2 MWh of batteries per year, the equivalent of 200 EV batteries [21]. Volvo have been conducting research into electric drives for some years and they have been involved in plans to market small electric cars in conjunction with small independent producers such as HIL Electric and the Danish MINI-EL vehicle.

1.5.8 FINLAND

EV activities in Finland began in 1974 when the state electricity company purchased two Enfield electric cars. In 1979 traffic tests of an AC trolley bus began and in 1980 the Finnish Post Office leased a VW-Electro-Transporter van from Germany. Another VW van was tested by a private electricity company. In 1982 the state oil company in cooperation with a battery manufacturer bought and tested a Fiat Ritmo EV conversion. In 1983 as a result of the signing of the COST (European COoperation in the field of Science and Technology) 302 agreement, an EV development project was initiated which is partly funded by the Finnish Ministry of Trade and industry. The aim of the project was to construct an EV with an AC motor, transistorised inverter and lead-acid batteries. Participants included the state oil company, Helsinki University, an electrical equipment manufacturer, the state electricity company and a subsidiary of

Saab-Scania [30]. Particular interest has been given to developing an EV for cold climate operation.

1.5.9 THE EUROPEAN ECONOMIC COMMUNITY

On 17th April 1978 the European Electric Road Vehicle Association (AVERE) was set up by the European authorities in Brussels. The EEC parliament was interested in the field of electric vehicles in as much that "they see in this field a new industrial possibility for the Common Market countries" [31]. Also, from 1982 to 1986 eleven European countries (Austria, Belgium, Denmark, Finland, France, Ireland, Italy, West Germany, Sweden, Switzerland and the UK) undertook under the auspices of the COST agreement, a joint research project on the technical and economic conditions for the use of electric road vehicles, known as project COST 302 [21].

1.5.10 OTHER COUNTRIES

Work in the Netherlands has been confined largely to universities. Eindhoven University of Technology began a project to optimise many of the limitations connected with EV technology [33]. Delft University undertook work on EV propulsion systems [34]. Belgium set up its own section of the AVERE which attempts to combine the forces of the relevant authorities, potential users, the scientific bodies, vehicle and component manufacturers and the electricity producers. The University of Brussels is working on EV drive systems and battery problems. The South African Government appointed a special committee to study the technical and technological feasibility of EVs. Members of this committee include amongst others the Electricity Supply Commission, the South African Railways and Harbours Commission, and some of the local universities. The sodium-iron chloride battery (see section 2.7.6) is also being developed by a South African company which currently possesses all the relevant patents. In Australia there has been Federal funding of £442K to 1981, most of which has been allocated to universities for electric van, car and battery development. The Brazilian Government has decided to investigate the possibility of using electric buses and trolley buses. The only substantial work being conducted in Italy is by Fiat and the Italian Electricity Board, which has promoted prototype development since 1973. The most recent programme has attracted funding of £446K and is being conducted along three lines, the study of propulsion systems, the study of an electric car, and, the finalisation of light commercial vehicles for production [36]. Information from Eastern Block countries is scarce but it is believed that Russia has a large EV programme [35]. Russia has traditionally manufactured and used large quantities of nickel-iron batteries and probably leads the field in this technology. Bulgaria is one of the largest manufacturers of electric forklift trucks in the world and in Poland a factory which makes gliders produced 300 electric vehicles in 1976 which were reported to be similar to certain American EVs. Performance was claimed to be 35 mph and a range of 45 miles [35]. Even the Iranian Government has shown interest in the possibility of using electric cars to reduce oil consumption and atmospheric pollution. It has initiated a research study to establish the state-of-the-art and the feasibility of EV use in Iran.

1.5.11 SUMMARY AND CONCLUSIONS

1 The main countries involved in EV development besides the UK have been the USA, Japan and West Germany, with work on a smaller scale by Australia, France, Italy and Sweden. The motivation behind USA involvement has been concern over future oil dependency and this has undoubtedly stimulated interest elsewhere. Although UK expenditure may appear small compared to some other countries, the UK has the advantage of an already existing indigenous EV industry and arguably greater success in the development and commercialisation of high-performance EVs. The world wide efforts of the last two decades have largely been the result

of Government encouragement in the light of energy and environmental problems. The stimulus has not come directly from the demands of the market place for EVs, although indirectly, it is the general demand for mobility and transport that necessitates the investigation of long-term options.

2 There has been little international cooperation and coordination as yet. With the exception of the USA, the UK and Japan, national EV programmes have been small and have largely consisted of testing a few vehicles in laboratory or field trials.

3 In many cases the enthusiasm and publicity surrounding high performance EV development has lessened in the last few years. This may be partly due to the recent slump in oil prices. In this country the termination of the LCEVS and Bedford project ended many hopes.

4 Most national EV programmes have concentrated on technical or engineering research and there have been few serious efforts to develop the technology to a marketable state. This study attempts to show that EV technology could have a significant impact in its present state-of-the-art.

5 Similarly, it is felt that nearly all the research efforts that have been undertaken in this country and overseas have concentrated on very narrow aspects of EV development. There have been very few attempts to take a systems view of the entire subject, from scientific and technical problems to economic and sociological considerations. The tendency to focus on too narrow a field of interest and ignore some very important factors means that many limiting assumptions have to be made and these can often be unrealistic.

CHAPTER 2

THE STATE-OF-THE-ART

CHAPTER 2

THE STATE-OF-THE-ART OF EV TECHNOLOGY

"The motor car is, more than any other object, the expression of the nation's character and the nation's dream."

E B White, "One Man's Meat"

2.1 INTRODUCTION

The last chapter presented the concept of the high-performance, traffic-compatible electric road vehicle and its capabilities, and reviewed recent international interest and development. Appendix 6 gives a review of some of the vehicles that have been made available recently. In this chapter a closer examination is made of the state-of-the-art and in particular of traction batteries. Such an analysis is essential in this type of study because it highlights the problems associated with EV development and those areas where further development is necessary.

The establishment of a widespread, commercially viable industry for traffic-compatible electric road vehicles is dependent on the continued development of the components which make up the vehicle drivetrain because it is these that affect vehicle performance and cost. It is commonly claimed that the EV is a battery research and development problem, and while the battery does have a large affect on vehicle range and life cycle costs, it is the complete drivetrain that determines how well the vehicle will function. Propulsion subsystem weight, efficiency and cost are related to the specific combination of components used. One of the major contributory factors to the low performance of EVs in the early stages of development was that the EV developer had to use whatever components could be obtained, no matter for what purpose the item was designed. This was especially true in the USA where experience of building EVs was more limited than in the UK. The EV of 10 years ago was usually powered by a DC series-wound motor made for a factory forklift truck. The motor's speed controller was generally built for the same purpose [1]. The EV industry in the USA had the problem that it was simply too small to exert leverage to get suppliers to perform the research and product development which was needed and the industry itself lacked the necessary financial resources. In the UK the position was somewhat different in that it was largely the component suppliers such as Lucas and Chloride that led the field of EV development.

However, various independent and Government backed research projects have resulted in valuable component development. The problem now would seem to be that these advanced components and systems remain in the laboratory or experimental test bed vehicles.

2.2 THE MOTOR CONTROLLER (see also appendix 8)

The driver of an EV varies the flow of power to the electric motor by varying the depression of the accelerator pedal. In all electric motors, regardless of size, at the start there must be a current limit to avoid burning out motor windings. This function of current limitation is performed by the controller unit. It may be simple or complex. For a lightweight golf cart, the controller might be simply a resistance electrically inserted between battery and motor; or switching of batteries might be arranged so that at the start, a relatively low voltage is impressed upon the motor. In both instances current is limited at start up of the motor in accordance with Ohm's law. As the motor gains speed, there is an automatic self-limiting current action, known as back electromotive force, generated within the motor and this serves to limit current flow. The initial current-limiting device may be completely withdrawn from the circuit as speed is gained.

Direct current motor controls from the simplest to the more sophisticated are : (1) temporary insertion of a resistance in series with the armature to limit current flow; (2) variation of battery voltage across the motor armature, obtained by battery switching; (3) the combination of resistance insert and voltage switching; and (4) the use of a solid-state "chopper" where the average voltage presented to the motor is reduced on starting by a time control of pulses. The cost of control units increases from method 1 to method 4. Appendix 8 gives more information on these alternatives. Except for all but the smallest vehicles, semi-conductor technology is now used in control systems. The environmental operating conditions in an EV are generally more favourable for the use of electric equipment than in an ICE because of the absence of heavy vibrations. Microprocessors are being developed which control EVs more efficiently. Very high reliability and a 'fail safe' system are essential, and equipment cost is extremely important. British controller technology is considered to be ahead of overseas competition with considerable opportunity for exports, especially to the US [2]. However, controllers have contributed to poor vehicle reliability. BL Technology stated in 1980,

> "Advanced electric road vehicles produced to date have suffered from poor reliability in the driveline components - particularly controller and auxiliary systems. These problems are not fundamental; they can be overcome with a properly conceived engineering development programme. Too many of today's electric vehicles are prototypes inadequately developed for commercial operation." [3]

AERE Harwell claims that the improvement of controllers and drivetrains which enable optimum use of battery energy will be one of the most important contributions to improving the cost effectiveness and market penetration of EVs [4].

2.3 MOTORS (see also appendix 8)

The present technology of propulsion systems for EVs is based on the DC motor whose mechanical performance is controlled by a "chopper" controller. This configuration allows satisfactory performance, smooth acceleration and regenerative braking. The motor size varies from 8 Kw for a small car to 50 Kw for a typical light duty delivery van. Basic designs are well established and development work is aimed at improving manufacturing methods in order to reduce costs and improve efficiency. The DC series wound motor is simple and reliable; it has a high starting torque which falls off gradually as speed is increased; and there is little possibility of overspeeding the motor. It is however low powered and speed falls going up hills.

New technological approaches are in the research and development stage, having the aim of achieving improvements in the following areas,

- weight and dimensions
- flexibility of design and application
- efficiency
- cost

There are a number of alternative motor systems suitable for EV use, each with its own particular merits, see fig 2.1. Appendix 8 gives more information on each of these. Table 2.1 presents a comparison of four motor types of 20 HP power rating.

FIG 2.1 MOTOR TYPES APPLICABLE TO ELECTRIC VEHICLES
(See also appendix 8)

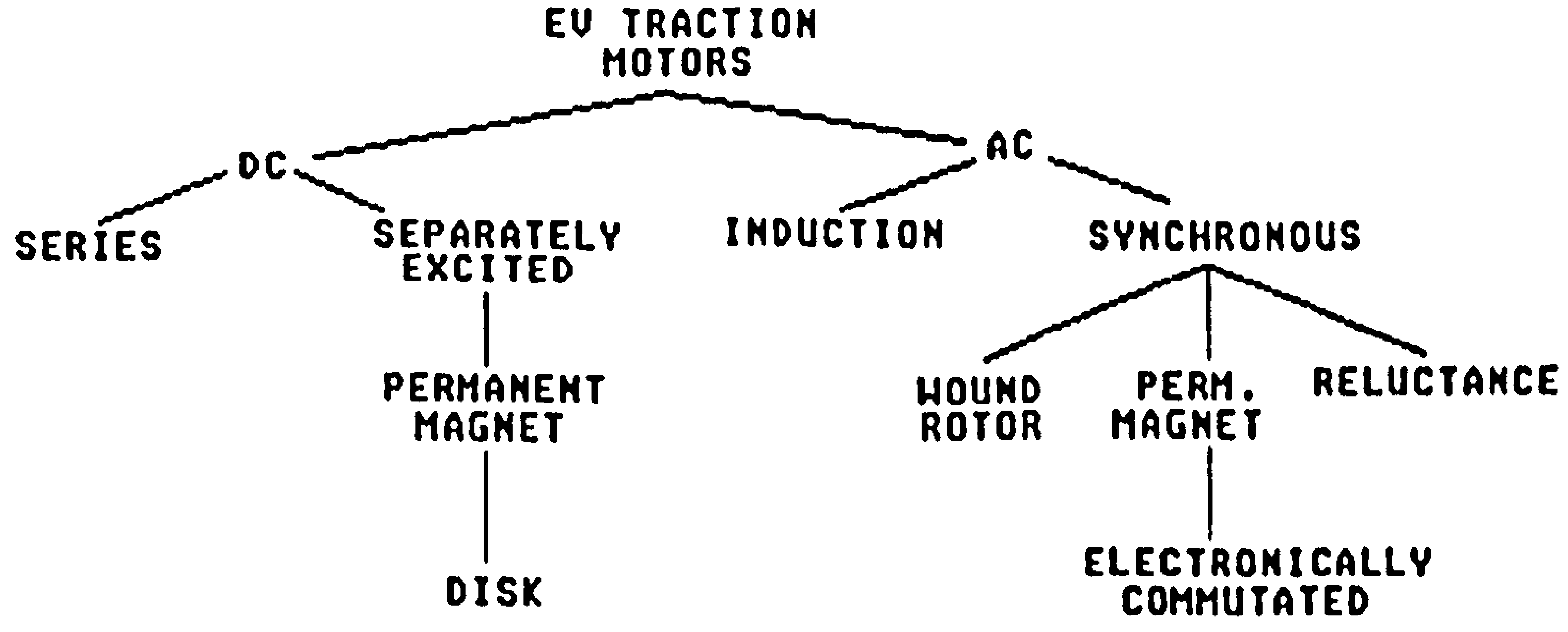


TABLE 2.1 COMPARISON OF 20 HP AVERAGE MOTOR QUANTITIES FOR LEADING EV MOTOR TYPES

	DC		AC	
	SERIES	SEPARATELY EXCITED	INDUCTION	PERMANENT MAGNET SYNCHRONOUS
Weight (Kg)	116	98	45	39
Dimensions	21"x14"diam	17"x12"diam	12"x12"diam	7"x18"diam
Max rpm	5000	5000	15000	15000
Max efficiency	0.85	0.90	0.92	0.95
Approx cost ratio	0.9	1.0	0.5	0.5

(see ref 17)

The size and weight of the two AC machines include the weight of an integral 3/1 reduction gear to provide a final output shaft of 5000 rpm in all cases. This table indicates the advantage of AC machinery, - smaller size, lighter weight, higher efficiency, and lower cost than equivalent DC machines. However, for use in propulsion, an AC motor must be driven from a variable frequency supply which can be expensive to achieve from a normal DC battery. The Ford company is working on an AC drive for EVs.

2.4 CHARGERS

The battery charger represents the link between the electricity supply network and the vehicle user. The charger-battery interface is perhaps one of the least efficient links in EV technology, typically between 70% and 90%, and there is scope for development of charger technology and, in particular, energy management. The use of microprocessor technology is allowing the development of "intelligent" chargers and battery management systems which can determine optimal charging rates and provide precise control of both charge and discharge regimes (see section 2.6.3). High frequency electronic switching techniques are being applied to the charger to improve efficiency and reduce size, weight and cost. Lightweight chargers permit amalgamation of the charger with the motor and controller, providing 'on-board' charging possibilities. The charger becomes an integral part of the vehicle and charging can be done wherever there is an electricity supply point. This is extremely important for range extension purposes and market acceptance (chapter 7).

2.5 BATTERIES

2.5.1 GENERAL DESCRIPTION

Perhaps the most important issue in the successful commercialisation of EV's is the development of a suitable battery power source. When considering the EV as a direct substitute for ICE vehicles, the battery is often quoted as the major barrier to the EV's successful competition with the ICE, although this is not necessarily the whole truth (see chapter 9).

All vehicles require energy to propel them and the present ICE vehicle is a very convenient and well developed machine which is not easily displaced by alternative energy sources. The energy stored on board a vehicle can take many different forms. One gallon of petrol stores nearly 50Kwh of energy and on average will transport a vehicle for approximately 30 miles. Present advanced lead-acid batteries (the only real contender at present) store approximately 40Wh/Kg. A gallon of petrol weighs 3.8 Kg, the equivalent weight of batteries stores only 152 Wh of energy. Because of the relative efficiencies of petrol engines and electric motors, petrol as an energy store is some 100 times lighter and takes up 40 times less space [5]. In addition, the battery powered EV takes around 2000 times the length of time to refuel than the ICE vehicle. These are really the major performance problem associated with battery propelled vehicles. There are three important indicators of battery performance which can be used to measure development progress and compare alternative battery systems.

1 SPECIFIC ENERGY. Specific energy is a measure of the battery stored energy per unit weight, normally quoted in watt-hours per kilogramme (Wh/kg). It is this measure which largely determines the range of the

vehicle since it is the weight of the battery that a vehicle can carry which normally determines what capacity of battery is used. In very small vehicles, the volume of the battery becomes more critical and this is measured in watt-hours per litre and is referred to as 'energy density'. Table 2.2 shows the nominal specific energy of various energy sources. However, this comparison can be misleading since the other fuels are expendable whereas batteries would be part of the delivery mechanism of the energy analogous to the heavy engine complex of the ICE.

TABLE 2.2 SPECIFIC ENERGY OF DIFFERENT ENERGY SOURCES

ENERGY SOURCE	SPECIFIC ENERGY (Wh/Kg)
Gasoline	12,300
Natural Gas	9,350
Methanol	6,200
Hydrogen	28,000
Coal (bituminous)	8,200
Lead-acid battery	40
Sodium-sulphur battery	150-300
Flywheel (steel)	12-30

(see ref [6])

2 SPECIFIC POWER. This is a measure of the power that can be usefully generated per unit weight of the energy source, measured in watts per kilogramme (W/Kg). It is the specific energy which determines the acceleration and hill climbing abilities of the vehicle, and in contrast to the specific energy, the specific power of most batteries is comparable to the energy sources of ICE vehicles. In general, an EV can equal or even exceed the speed and acceleration performance of conventional vehicles, although this may be accomplished at the expense of the energy or range characteristics of the EV. In the ICE vehicle, it is the engine that limits the power characteristics, not the fuel source itself. The specific power of a battery varies according to the state of charge so it is normally measured at 50% depth of discharge (DOD).

3 CYCLE LIFE. Battery cycle life is an extremely important consideration in the design characteristic of an electric vehicle battery and one which is crucial for establishment of the economic case for electric transportation which is heavily dependent on this cycle life (see section 9.2.7). By definition a 'cycle' is any discharge, regardless of depth, followed by a recharge. The figures commonly quoted for battery cycle life usually relate to tests where deep discharges in the range of 70-80% of total battery capacity have been used as the basis of calculation. British Standard 2550 recommends the use of 80% discharges for evaluation purposes. The rate at which the battery is discharged also affects battery cycle life. For testing purposes batteries are normally discharged over time intervals of two to three hours (commonly referred to as the two or three hour 'rate'). Battery failure is judged to occur when the energy storage capacity of the battery falls to a predetermined level. Under the British Standard mentioned above this predetermined level is taken to be when the battery can no longer provide 80% of its original rated capacity. For lead-acid batteries, this original capacity is defined as the energy that the battery can supply before the cell voltage falls below 1.7 Volts per cell.

Many of the performance limitations of EV's are due to the battery. Certainly the range, the acceleration and hill climbing capability in some cases, and to some extent the "fuel" costs, are all affected by the battery. Beyond these immediate effects, the long term cost of keeping an electric vehicle depends heavily upon the cycle life of the battery. The longer a battery lasts, the longer the time over which one can amortize the cost of the battery. It is clear therefore that the battery is a crucial factor, affecting both the performance and the economics of the advancing EV technology.

2.5.2 THE REQUIREMENTS OF A BATTERY POWER SOURCE

A storage battery is a remarkable source of energy. It can deliver large amounts of power instantly without noise, fumes or poisonous gases. The delivered electric power is easily transported where required. And the power can be readily converted into mechanical energy, light, heat or sound. It can also supply heavy overloads for short periods. In his study of batteries for electric vehicles, Sidney Gross [7] stated that they should have the following characteristics›

1. High specific energy (i.e Wh/kg)
2. Low manufacturing cost
3. Long life with low maintenance
4. Low self-discharge when not in use
5. High power rate for acceleration
6. Efficiently and quickly recharged
7. Small size
8. Safety in accidents
9. Readily available
10. Little special equipment required for handling the batteries

In addition to the above R M Dell [8] presents some additional parameters for consideration when evaluating battery systems,

1. Wide temperature range of operation
2. High cell voltage and stable voltage plateau
3. High electrical efficiency (ratio of energy input to energy output)
4. Reliability in operation
5. Ruggedness - resistance to abuse
6. Ability to withstand overcharge and over-discharge

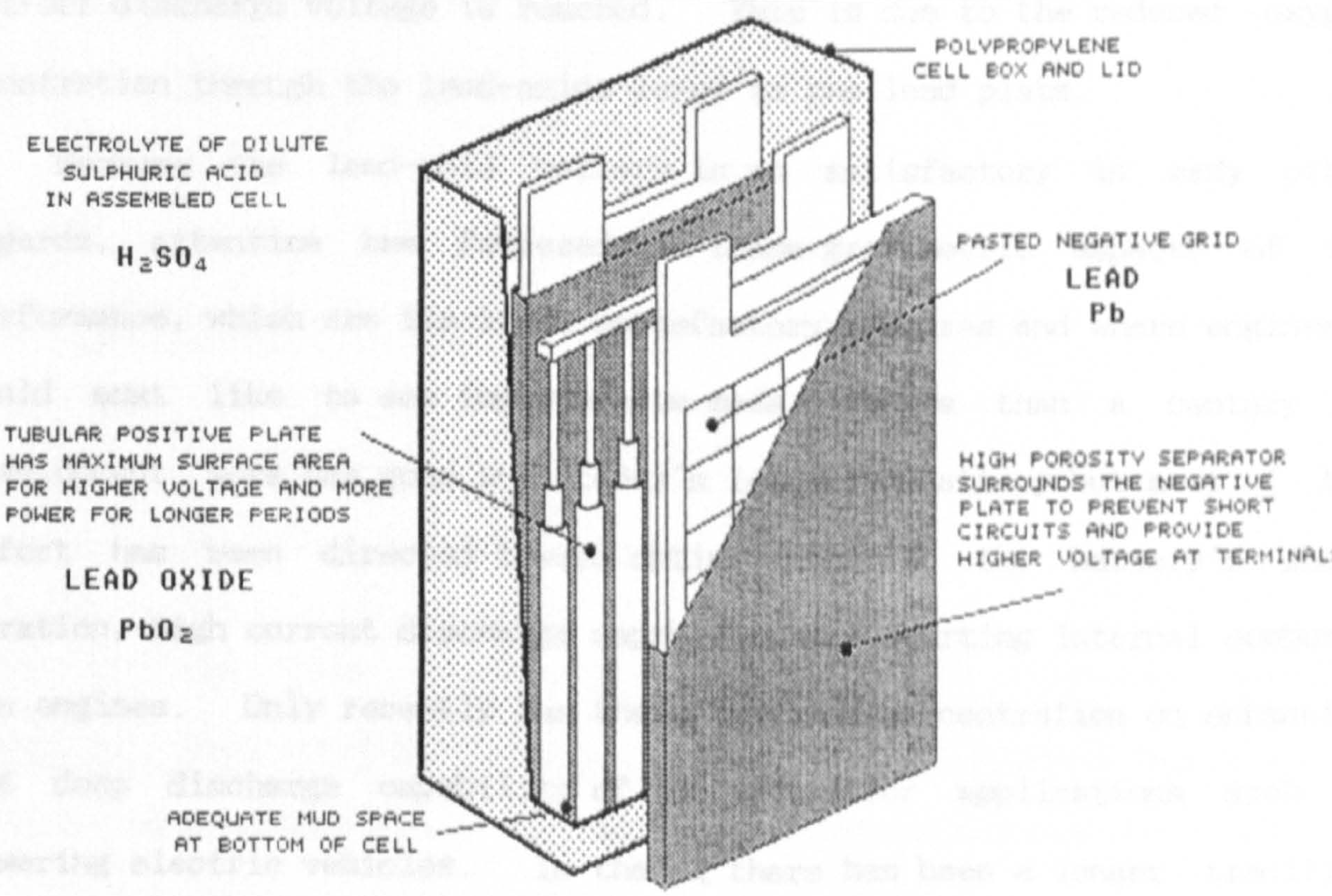
There are many different possible battery systems for EV use but the development of a successful, reliable, cost effective battery system for high performance electric road vehicles is a much greater task than that of developing a cell which operates successfully in the laboratory. Much effort has been devoted to the development of a suitable battery energy source, but since the first EVs took to the roads early this century the lead-acid battery has remained the most commonly used rechargeable power source for motive power applications.

2.6 THE LEAD-ACID TRACTION BATTERY

2.6.1 AN INTRODUCTION AND DESCRIPTION

The lead-acid battery, although invented as long ago as 1859 by Gaston Plante, is still the world's foremost secondary battery. Over 90% of secondary batteries are of this type. Lead-acid cells consist of positive and negative electrodes that are immersed in an electrolyte solution of sulphuric acid. When the cell is fully charged, the active material of the positive electrode is lead dioxide and the active material of the negative is lead. As the cell is discharged, the lead dioxide and the lead are converted to lead sulphate. Fig 2.2 shows how a typical lead-acid traction cell is constructed and the reactions that take place in the cell. During the process, the electrodes remain solid because lead, lead dioxide and lead sulphate are all relatively insoluble in sulphuric acid. The reactions are reversible, and the cell may be recharged to its initial state.

FIG 2.2 CONSTRUCTION OF CHLORIDE Co. TUBULAR PLATE LEAD-ACID CELL



CHEMICAL REACTION DURING CHARGE AND DISCHARGE

$$\underset{\text{POSITIVE PLATE}}{PbO_2} + 2H_2SO_4 + \underset{\text{NEGATIVE PLATE}}{Pb} \rightleftharpoons \underset{\text{POSITIVE PLATE}}{PbSO_4} + 2H_2O + \underset{\text{NEGATIVE PLATE}}{PbSO_4}$$

It is remarkable that, despite extensive research and development, no fundamentally new types of rechargeable battery have reached this stage of commercialisation in the past 75 years, excepting one or two small scale, expensive batteries for special applications. The success of the lead-acid EV battery may be ascribed to the fact that it is satisfactory on most counts. Considering the checklist of important characteristics above, it can be said that the lead-acid system is still the best compromise candidate at the present time. Many in fact believe that it will continue to be so for the short and medium term. It represents the state-of-the-art of EV propulsion technology. Its major failing is its high mass, which is reflected in poor numerical values for the specific power (W/Kg) and specific energy (Wh/Kg). In fact, the lead-acid battery has the lowest theoretical specific energy of all the alternatives but it is the best developed so far. This poor gravimetric performance stems in part from the high density of lead and in part from the fact that the utilisation of the active material is, typically, only about 25-30% before cut-off discharge voltage is reached. This is due to the reduced oxygen penetration through the lead-oxide layer to the lead plate.

Because the lead-acid battery is so satisfactory in many other regards, attention has focussed on these gravimetric aspects of its performance, which are its least satisfactory features and where engineers would most like to see improvements made. More than a century of development work has gone into today's lead-acid battery but most of the effort has been directed toward optimisation of the battery's short duration, high current discharge capability for starting internal combustion engines. Only recently has there been any concentration on enhancing the deep discharge capability of the system for applications such as powering electric vehicles. In the UK there has been a longer tradition of traction battery manufacture than in most of the rest of the world due to our use of electric vehicles for doorstep delivery of milk. The lead-acid cell has several advantages over emerging alternatives, which make it the present overall best compromise power source for EVs.

1. A large manufacturing industry already exists and the production processes, markets and distribution channels are all well established.
2. So far it has the lowest overall material costs of all the alternatives, although there is no intrinsic reason why this should be so. Production costs should be seen as different from simple material costs, but even taking this into account it is quite possible that a battery like the sodium-sulphur system could compete with lead-acid on retail cost grounds given a suitable scale of production (of course, cost comparisons can be based on several different parameters e.g delivered lifetime energy, battery capacity and so on).
3. In recent years the development of the lead-acid system has exhibited greater performance improvements than any other system. This may be due to the fact that more effort has gone into developing this system than most others and also that most of the alternatives are still at the laboratory stage of development.
4. There has been more field experience and therefore more understanding of lead-acid batteries than of any other system. Having stated this, the traction battery is a very complex power source and descriptions of its performance are not fully satisfactory. (See section 6.3.5 and section 9.2.7)

There are two types of electrode structures in lead-acid traction batteries: flat plate and tubular. The flat plate electrode has a centre skeleton made of lead alloy that has been coated with a paste-like mixture of the active material. In the tubular electrode, powdered active material is in a tubular envelope, usually of woven glass or polyester fibres.

Most of the advanced lead-acid cells in the UK are of the tubular plate design which has certain advantages over the traditional flat plate cells,

1 Energy can be delivered faster due to the increased mass and surface area of the active material and the ease with which acid circulates around the positive active material.
2 They are more compact.
3 Generally, their electrical capacity is greater for a given mass.

The power capability of some flat plate cells does however match that of the tubular type. In particular the flat plate cells produced by LUCAS exhibit the following characteristics,

1 They are less expensive to make and maintain, due to simpler construction.
2 They exhibit good power of recovery after periods of deep discharge.
3 Their ultimate failure is more gradual.
4 They exhibit exceptional resistance to mechanical shock and vibration.

There is a profusion of performance data quoted for lead-acid traction batteries and this seems to be due to three main reasons,

1 The performance is constantly being improved and this gradual 'inching forward' has meant that up to date information does not remain up to date for long.
2 There is a difference between advanced or improved traction cells incorporating the most recent technological advances, and the standard low-performance golf-cart type traction cells. The latter are not designed for high specific energy since golf carts and milk floats do not generally need long ranges. This distinction is not always made clear.
3 The capacity achieved in advanced laboratory prototypes is bound to be greater than even the most advanced mass produced cells. There is a time lag between technological advances and their commercialisation. Figures quoted for battery performance do not always refer to the same stage of commercialisation.

The range of values quoted for the performance parameters of advanced lead-acid traction cells is given in table 2.3

TABLE 2.3 ADVANCED LEAD-ACID BATTERY PERFORMANCE

	RANGE	CONSENSUS VALUE
SPECIFIC ENERGY (Wh/Kg)	35 - 48	41
SPECIFIC POWER (W/Kg)	90 - 120	105
CYCLE LIFE	500 - 1500	1000

CBS Industrial Batteries claim a cycle life of over 1200 cycles for their traction batteries in accordance with BS 2550 (1983). and Chloride Motive Batteries claim a cycle life of between 1200 and 1500.

2.6.2 POSSIBLE IMPROVEMENTS IN LEAD-ACID TRACTION CELLS

The advancing performance threshold being achieved with the lead-acid electric vehicle battery continues to make it a high probability contender for vehicle propulsion in the short and medium term, and many people within the EV and related industries believe that it may also be the long term power source. (see section 2.8). These gradual but significant improvements make it a continuously moving target against which new systems must be measured.

Any potential improvements in performance must be measured against the factors listed in section 2.5.2 and it should be noted that the relative importance of these factors depends upon the particular duties of the vehicle in question and the environment in which it operates. There is good reason to suggest that each type of vehicle and perhaps each application could legitimately be fitted with a unique battery to suit the demands of the vehicle, just as the golf cart has no need to use the most advanced traction batteries because range and speed are not important.

There are two methods of obtaining more from a traction battery and thus increasing its range of uses. Firstly, effort can be concentrated on improving the inherent characteristics of the cell such as energy stored per unit mass. Secondly, although not exactly a cell improvement, the method in which the battery energy is utilised can be designed and improved to make the most efficient use of the existing energy. It is important to regard these two strategies as interdependent and not as mutually exclusive approaches. They should be developed together so as to optimise the overall system performance.

Although there are no foreseeable fundamental breakthroughs in lead-acid cell technology, there has been a constant incremental improvement in performance over the last 10-15 years. The application of modern technology has led to an improvement in energy per unit mass (specific energy) of nearly 70%, and in specific power (i.e W/Kg) of over 50%. It would be wrong to think that the lead-acid battery has reached full development or that, since there are no foreseeable revolutionary changes in cell technology, there is no room for improvement. Some of the possible developments leading to improved battery parameters are discussed in this section (see also appendix 11).

A. ELECTROLYTE CIRCULATION

When lead-acid batteries are charged concentrated sulphuric acid forms on the surfaces of the electrodes, and this denser acid falls and collects at the bottom of the cells. This leads to what is known as electrolyte stratification, a condition which seriously reduces the cycle life and electrical performance of the battery. To overcome this problem the battery can be overcharged thus inducing gassing, the hydrogen and oxygen bubbles effectively mixing the electrolyte. Unfortunately overcharging also reduces cycle life by accelerating erosion of the positive plates and corrosion of the grids. Also, the greater the gassing, the greater is the risk of explosion due to the hydrogen and oxygen gases reacting. Some form of electrolyte agitation during charging, possibly by pumping pulses of air in the system, would therefore be beneficial and has been found to have the following advantages, [9]

1. Increased cycle life
2. Increased charging efficiency
3. Reduced watering frequency
4. Reduced operating temperature
5. Improved specific energy
6. Improved specific power

Globe Battery Division of Johnson Controls Inc (USA) claim that their electrolyte circulation system has given a fourfold increase in cycle life [8]. Advantages numbers 5 and 6 above relate to the discharge half of the charge/discharge cycle and it is not clear that a circulation system has such obvious advantages during discharge in vehicle use because the agitation caused by a moving vehicle has much the same effect anyway [10]. Tests undertaken by the Aerospace Corporation, Eastern Subdivision USA for the US DOE showed that

> "the benefits of the electrolyte mixing system are: a reduction of water loss during charging, reduced charge time and increased energy efficiency. Taking into account the energy which is needed to operate the pump system, the efficiency is still comparable with that obtained with the unagitated battery. The agitated battery however shows a significant increase in cycle life and should be considered for applications in recharging of deep-cycle lead-acid batteries"

No mention is made regarding the likely cost of such a system.

B. GREATER UTILISATION OF ACTIVE MATERIAL

The poor specific energy and power of lead-acid traction cells is partly due to the poor utilisation of the active electrode material. Typically only 25-30% of active material is used. It is impossible to react all the material in an electrode unless it is impractically thin or the reaction could be made perfectly even throughout the material. Lead-sulphate which is produced during this reaction is an electrical insulator inhibiting the reaction. More material could be reacted but at the expense of cycle life. The Japanese have achieved ranges of up to 500 miles from lead-acid batteries in a lightweight vehicle but the batteries involved only achieved one cycle! Nevertheless, once the nature of the structural changes which occur during battery life are understood more fully, a reduction of at least 20% of the unreacted material has been predicted, with no reduction in durability and hence cycle life [11].

C. ALLOYS, PASTES, PLASTICS, SEPARATORS.

Other measures aimed at improving the energy stored per unit mass concentrate on the other materials involved in the construction of the cells. If the pastes used were more chemically active then the chemical reactions could release more energy. Similarly, attention is also being given to the use of new alloys and there is room for improvements in separator technology [12]. Much of the weight of lead-acid cells is due to packaging and unreactive materials (typically up to 55% of total weight). Ways must be sought to reduce this as far as possible by the use of plastics and other lightweight materials. Active material support grids should be lighter and more corrosion resistant. They could be made of lead-coated aluminium, copper, steel, nickel, titanium or metal coated plastics. For a fuller discussion see reference [11]. In addition, the introduction of carbon fibres into positive electrode grids has resulted not only in a reduction in weight but also in prolonged cycle life and increased power characteristics. During 1985 the Polaroid Corporation became the first company to sell a conducting polymer on the open market. As a result of this research it may be possible to construct a new generation of lightweight batteries [13]. Tubular plate cells offer more scope for reducing the weight of the positive grid while plastics could be used in negative plates.

D. OTHER MEASURES

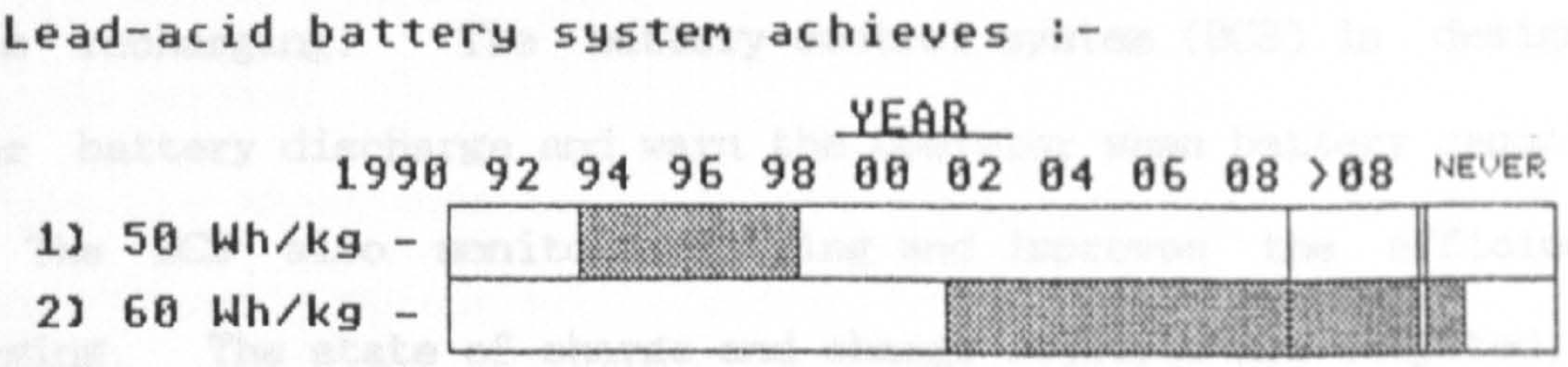
Various other design approaches could lead to possible improvements in battery performance and life. A summary of development areas and research areas is listed in appendix 11.

E. SUMMARY OF BATTERY IMPROVEMENTS

Advanced or improved lead-acid batteries for traction applications are now capable of providing up to about 44Wh/Kg. In the United States however, performance goals for advanced designs were set at 56Wh/Kg by the end of 1986 with projections that 60Wh/Kg would be achieved in practice by then [8]. Like many of the US performance goals, this goal has not been realised. It has been estimated that the probability of developing a low-cost battery capable of 60Wh/Kg and 1000 cycles by 1990 is less than 10% [14]. This estimate was made in 1980 and it is not clear whether or not this goal or estimate has been revised since, but it is evident that it will not be met at this late stage. A Delphi analysis carried out as part of this study (see appendix 5) asked for predictions of future lead-acid battery performance and fig 2.3 shows the results.

Fig 2.3

ESTIMATED TIMESCALE OF VARIOUS BATTERY DEVELOPMENTS FROM RESPONDENTS TO DELPHI ANALYSIS



(shaded areas show the range of estimates)

2.6.3 BATTERY CONTROL SYSTEMS.

The other method of achieving greater performance from the EV power source is to design the system utilising the battery so as to maximise the useable energy, by minimising inefficiencies and incorporating measures to reduce the effects of the limitations and weaknesses of the power source.

For example, the battery will exhibit a greater cycle life if it is maintained and charged properly. Lucas Chloride EV Systems Ltd (LCEVS) began development of a battery management system in 1978, designed to prevent most forms of battery abuse, thus allowing the potential of the battery to be realised more fully and battery costs to be reduced. It was found that the life of traction batteries in service was inferior to that achieved in laboratory tests. To a large extent this was due to abuse or neglect by EV operators, including failure to charge the battery after use, over-discharge of the battery and failure to water the battery at regular intervals. It is also important to design a management system which can handle the heavy demands of in-service use such as variable duty cycles, regenerative braking (section 8.6), the variable depth of discharge to which the battery is subjected and the pulsed voltage discharge which is imposed by most EV control systems [15] (appendix 8).

LCEVS identified an accurate state-of-charge gauge as a key element in managing traction batteries. Such a component could help to prevent the damaging effects of over-discharge of the battery and could facilitate optimum recharging. The battery control system (BCS) is designed to monitor battery discharge and warn the operator when battery capacity is low. The BCS also monitors charging and improves the efficiency of recharging. The state of charge and charge required are computed, as is the time available for charging and the cost of electricity at each time of day, so that an optimum charging strategy can be implemented. During vehicle operation, the BCS continually updates the true battery state of charge to account for the charge accepted during periods of regenerative braking. Allowances are also made for battery self-discharge during idle periods. The benefits expected from the BCS are as follows

a Battery life and hence battery economics will improve by eliminating the various forms of abuse that arise from over-discharge and inaccurate charging.
b Exceptionally accurate battery state-of-charge monitoring will ensure excellent fuel gauge characteristics, which will allow maximum daily EV range without the danger of over-discharge. This will in turn

reinforce driver confidence in the EV when undertaking journeys of widely different lengths (as might be expected of personally owned electric cars).

c Low maintenance charging regimes, scheduled cell equalising and the delaying of charging to coincide with low off-peak electricity tariff periods will further reduce the cost of EV operation.

d Battery pack condition diagnosis and the storage and retrieval of pack data will allow battery history to be logged and examined.

e Battery state of charge will be continually logged during off-charger standing of the EV, which will give a much more accurate estimate of usable capacity after a long stand than is currently possible.

f Ultimately, battery servicing could be scheduled and service request signals generated by the BCS which, if ignored by the driver, could initiate an alarm condition or even vehicle disablement.

Another development aimed at improving the utilisation of traction batteries is an automatic watering system, The cost of watering constitutes a major part of the maintenance and hence the cost associated with EVs. Manual watering can be a difficult and lengthy process in many vehicles and often leads to inaccuracy in topping up. An automatic system would prevent battery abuse and so improve performance and cycle life. LCEVS developed such a system. LCEVS has also developed a battery venting system which safely disperses the gases evolved during the gassing stage of charging. This is not only a safety feature but one which reduces the risk of premature cell failure resulting from the explosion of hydrogen gas in the battery.

Operating experience in the US has shown that batteries generate the most significant problems with electric vehicles [16]. More than 80% of maintenance actions reported by site operators are related to batteries. If this excessive proportion of maintenance actions could be reduced by automatic watering and venting, the economics of EVs would be more favourable. These techniques would also help to safeguard against premature battery failure and its associated costs. It should however be noted that this figure of 80% relates to high performance, traffic compatible vehicles which are a relatively recent development. This emerging technology has undoubtedly proved itself to have considerable potential value but there are still many teething problems to be overcome in practice.

2.7 REVIEW OF ALTERNATIVE BATTERY SYSTEMS FOR EVs

2.7.1 GENERAL CONSIDERATIONS

In this section, the major alternative battery systems will be introduced and discussed briefly. This is not intended to be an exhaustive study of alternative batteries but simply a brief summary of the most important considerations and developments. Further discussion can be found in the articles mentioned in the references and the appropriate sections of the bibliography.

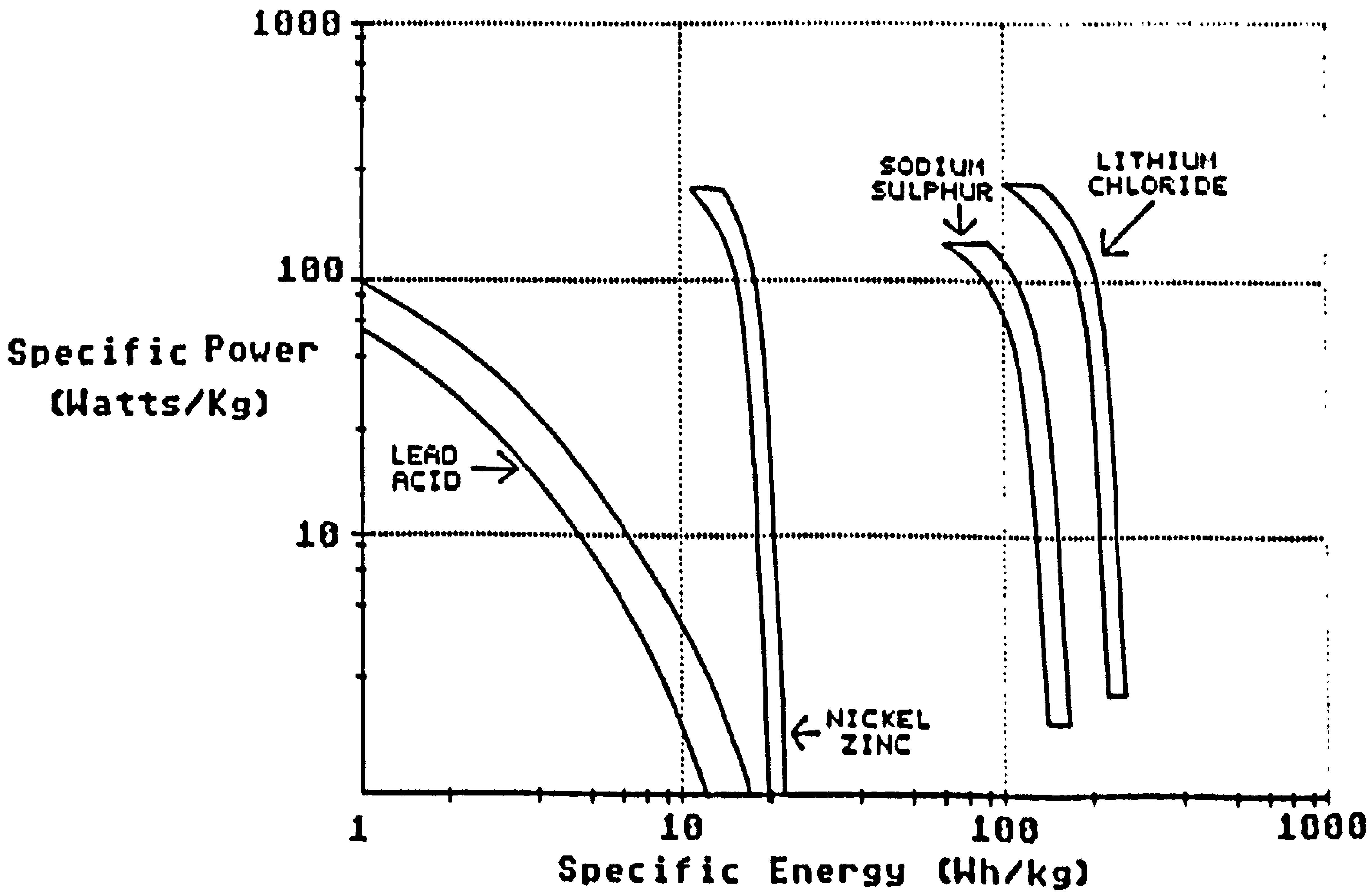
During the last 20 years, there has been considerable international interest and activity in research into suitable battery systems for EVs. Many laboratories in Western Europe, Japan and the US have entered this field. There are more than 30 electrochemical systems which are potential candidates for EV batteries but many can be ruled out because they require large quantities of rare or expensive materials [14]. This leaves about 15 possible alternatives, all of which have their advocates.

A battery energy source must satisfy a number of considerations (see section 2.5.2). It must provide enough power for acceleration and gradient climbing, and it must store enough energy to provide power over a period of time in order to give a satisfactory range. Other factors include safety, cost, ease of charge and use, and so on. There are many trade-offs between these parameters. Hence the optimal system for any particular application must be a compromise solution. Different systems may be appropriate for different applications, so it is not advisable at this stage to rule out possible battery contenders. The optimal choice of power source will depend on the relative merits of the different systems. For example, the lead-acid battery has proved to be a very reliable, rugged and perfectly adequate power source for the milk float and there is no reason to suggest that it will not continue to be the best option for many years to come. The milk float has no need for a battery with a greater specific energy since speed and acceleration are not the most important critera for assessing competing batteries in this situation. The power and energy requirements for a particular vehicle will depend on the vehicle and its mission. Weinstock and Matricardi [18] state that,

> "Even when a mission has been identified and vehicle specifications established, there is no unique acceptable set of performance and cost values for the energy source. Instead, the acceptable parameters form an N-dimensional envelope within which the vehicle designer makes trade-offs among the various parameters in order to arrive at a final selection."

The performance of a battery power source can be described using two major parameters, specific power and specific energy. Ragone [19] attempted to plot the performance of alternative batteries in order to show the relationship between these two measures. This format of presentation has been widely accepted and adopted. Most battery systems exhibit a decrease in energy density with an increase in the power output level, frequently referred to as the Ragone relationship. This is shown in fig 2.4 for various possible battery systems.

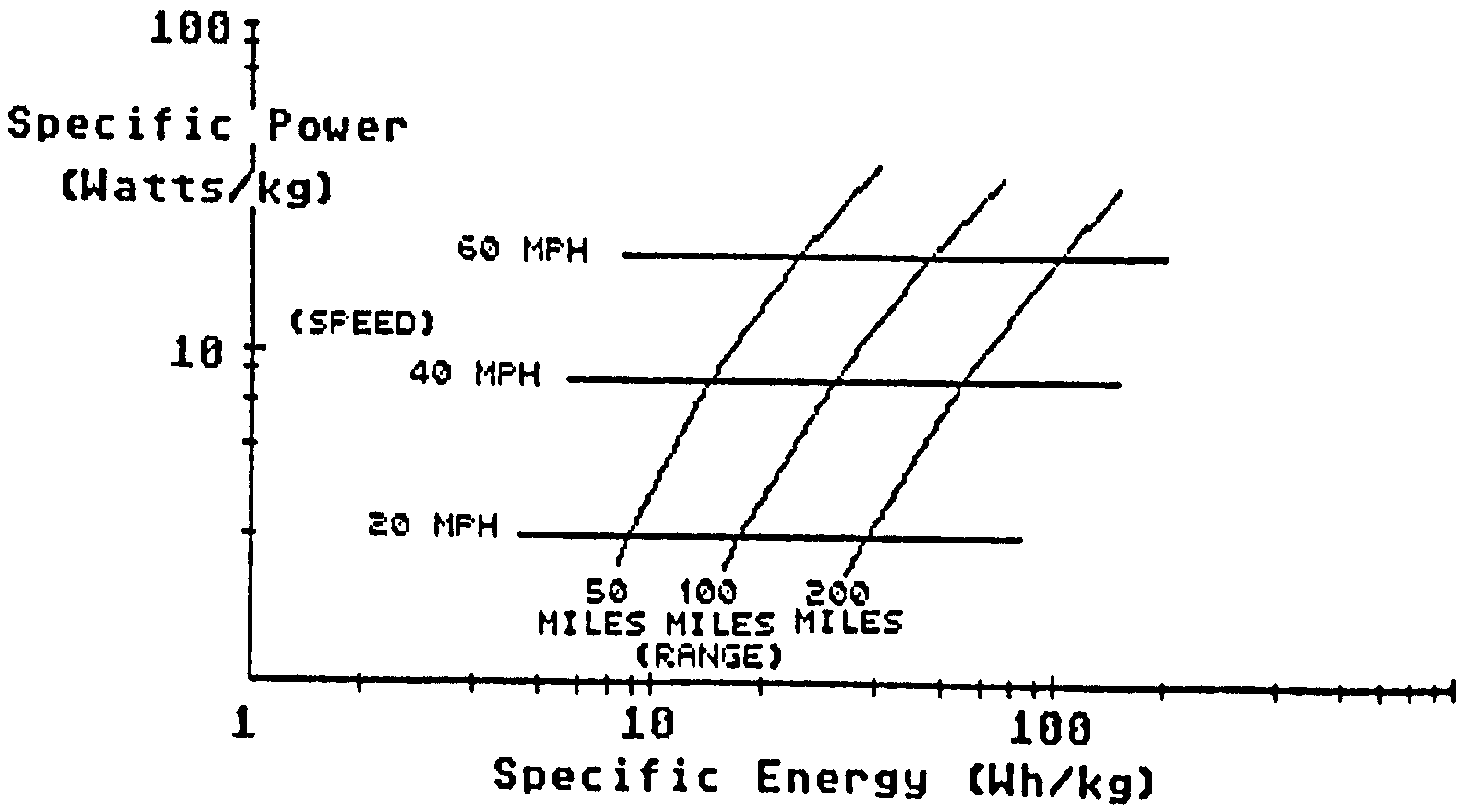
FIG 2.4 RELATIONSHIP BETWEEN SPECIFIC POWER AND SPECIFIC ENERGY
(source - reference 19 - Ragone plots)



The lead-acid battery exhibits the lowest performance in terms of specific energy, and the specific energy is relatively sensitive to power levels. However many other important factors mentioned in section 2.6 have contributed to the lead-acid battery's commercial success. In order to translate the performance characteristics shown in fig 2.4 into terms of vehicle range and speed, a particular vehicle and its associated specifications must be used as the basis of the calculations. This is shown in fig 2.5.

Fig 2.5

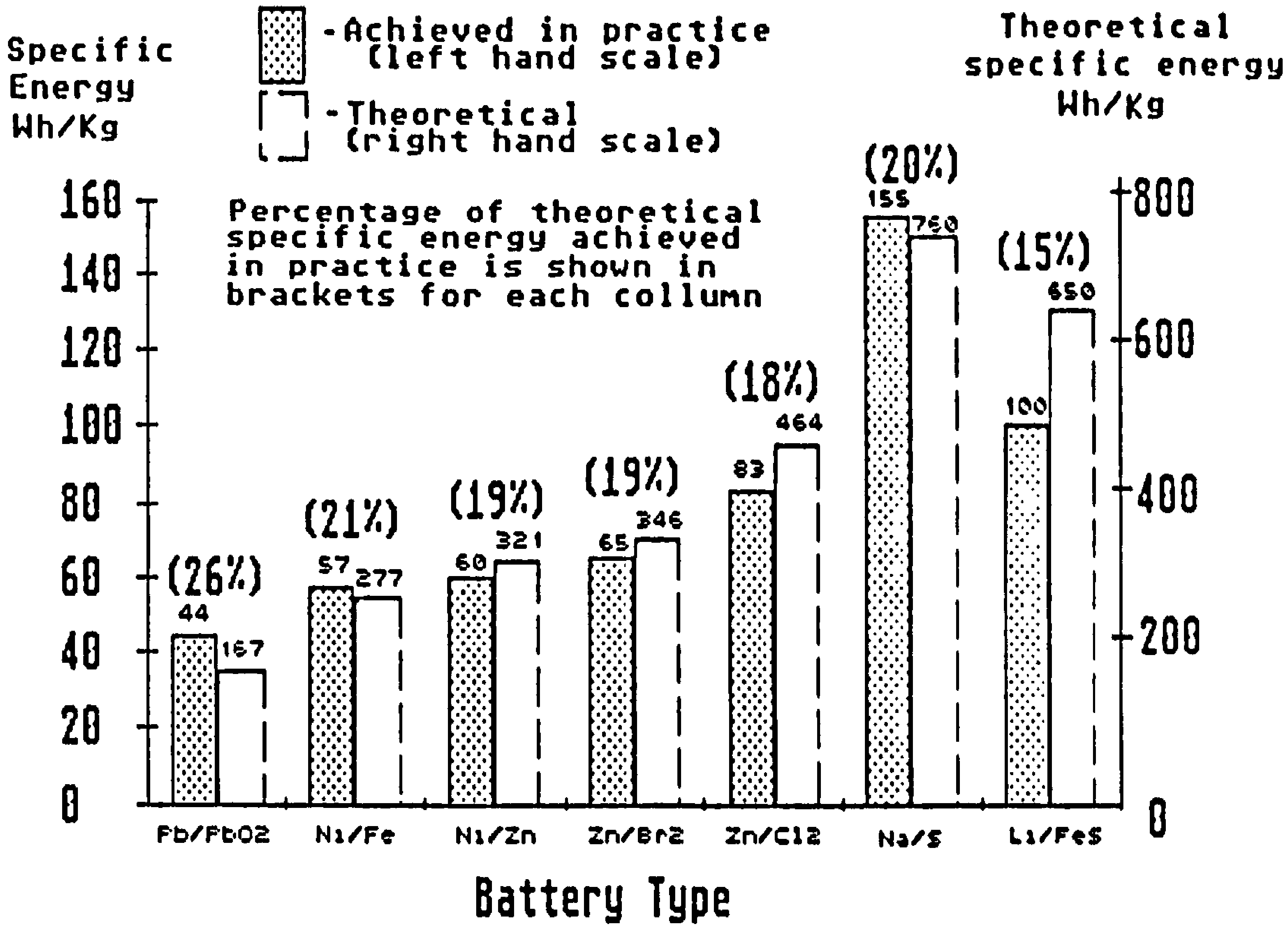
Required specific power and energy for constant speed driving
(source - reference 19 - Ragone plots)



Assumptions :- 1) GVW = 900 Kg, 2) Frontal area = $1.86M^2$
3) Drag factor = 0.6 4) Battery weight = 227Kg.

In addition to the current state-of-the-art of battery types, it is interesting to look at the theoretical limits of performance that could be achieved from any type of battery and to compare this with what has already been achieved. This is shown in fig 2.6.

FIG 2.6 SPECIFIC ENERGY ACHIEVED IN PRACTICE AND THEORETICAL SPECIFIC ENERGY
(scource - reference 21)



Although the theoretical limit of specific energy is not realistically achievable in practice, it does give some indication of how well developed any particular battery type is. It can be seen that the lead-acid battery is more developed in relation to its potential than any of the alternatives. It can also be seen from figs 2.4 and 2.6 that some of the other alternatives offer much greater vehicle performance capabilities than the popular lead-acid battery. Research done by W J Walsh [14] attempted to quantify and scale the number of technical barriers to development and also to quantify the desirability of different batteries. The desirability relates ultimately to performance and cost. The overall costs associated with a particular battery will take account of the cycle life, materials and production cost and safety features, amongst other things. It is very difficult to establish a satisfactory weighting for all the factors which affect battery desirability and Walsh's model cannot be accepted uncritically because of the simplistic system of weightings used. His results are shown in table 2.3 and fig 2.7. In table 2.3 the figures have no meaning except to illustrate the "overall relative desirability" for EV use on a linear scale of 1 to 10. Figures in brackets denote relatively uncertain assessments.

TABLE 2.3

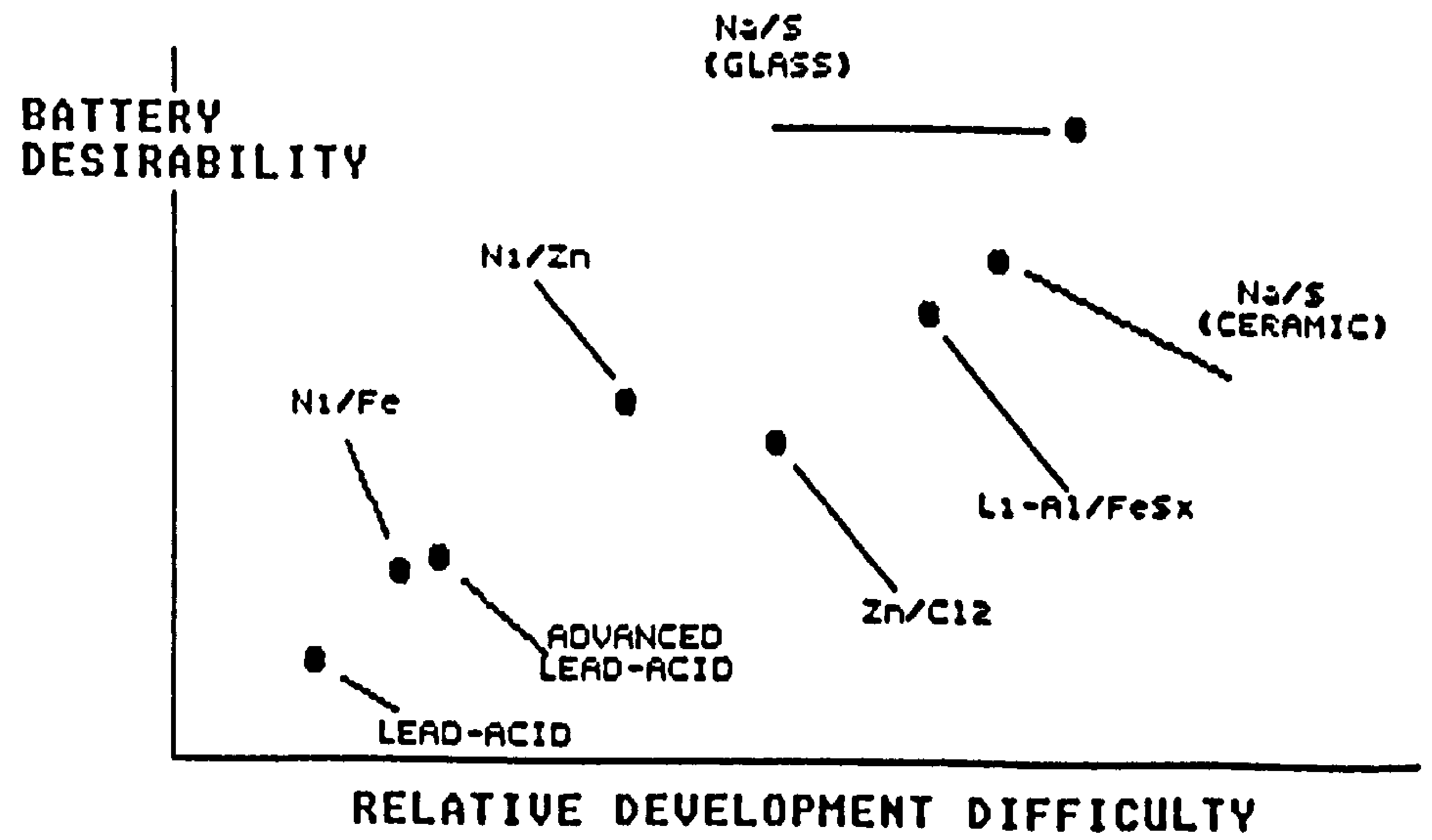
RELATIVE DESIRABILITY OF BATTERY SYSTEMS

	Lead acid	Ni/Zn	Ni/Fe	Zn/Cl	Li-Al/ FeSx	Na/S ceramic	Na/S glass
Specific energy	3	5	4	6	8	8	8
Energy density	3	6	4	4	8	5	5
Peak power	2	8	4	4	5	5	9
Sustained power	3	7	5	8	5	5	9
Cost	7	(5)	3	(5)	(5)	(5)	(8)
Cycle life	(5)	(5)	10	(5)	(5)	(5)	(5)
Safety	7	7	7	2	8	2	3
Resource availability	4	3	3	9	(4)	9	9
OVERALL DESIRABILITY	3.5	7.5	4.5	6.0	8.0	6.0	8.5

Fig 2.7 shows Walsh's estimation of the relationship between the technical barriers to development and battery system desirability. The techniques used to quantify these factors are discussed in reference 14.

FIG 2.7

Relationship between technical barriers to development and system desirability. Measurements were made using a Bayesian interrogation method. (see reference 14 for an explanation of the technique used)



The results show a distinct relationship between battery desirability and development difficulty. However once again this oversimplifies the situation because different batteries may have different relative desirabilities for different applications. Great care needs to be taken to design the vehicle and energy source for each particular application.

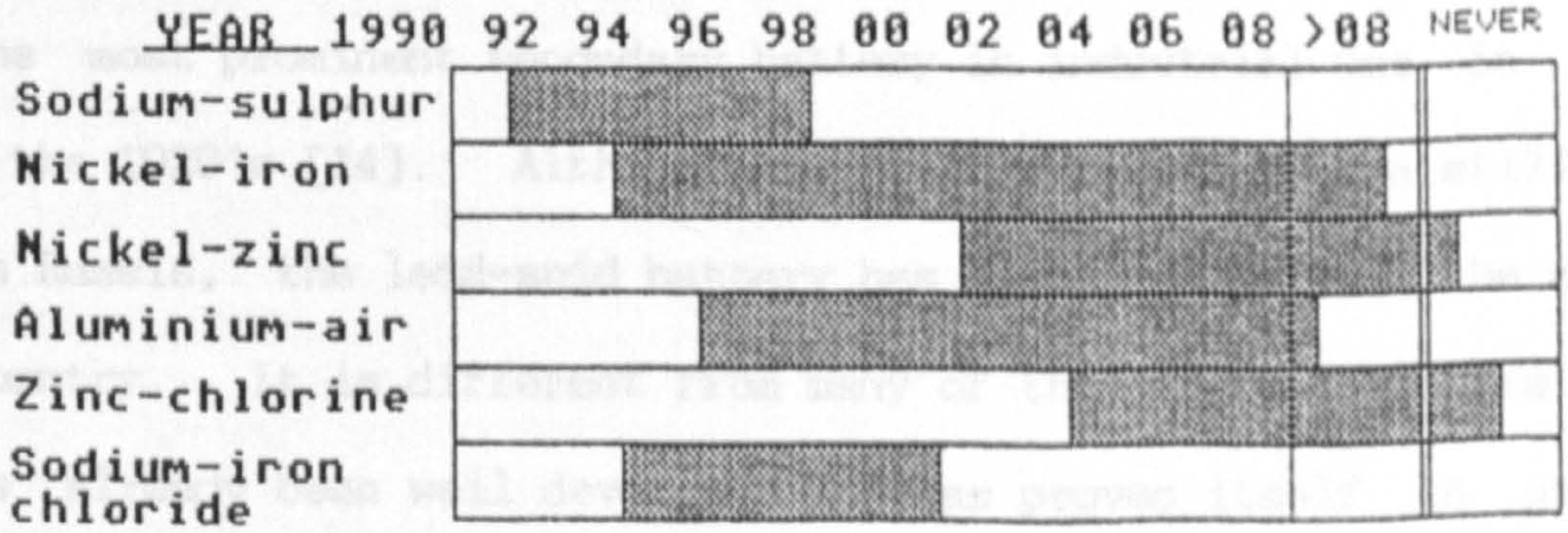
There are many technical barriers to successful development of some of the battery types and it must be remembered that for a battery to be suitable for EV use, it must satisfy many criteria. For this reason, research effort is likely to concentrate on the most attractive options and it will not necessarily be those with the least technical development difficulties that will be successful first. It is necessary to look at the likely time scale surrounding the commercialisation of the various options. As part of a Delphi analysis (see section 5.3.4), respondents who are active in the field were asked to forecast when they thought different battery types would become widely available commercially. Many types of battery may never succeed in the market place for EVs but the responses of those questioned give some indication of the time likely to be involved in development to a marketable state, as shown in fig 2.8.

Fig 2.8

Estimated timescale of various battery developments from respondents to Delphi analysis.

(shaded areas show the range of estimates)

Commercial availability of the following battery systems



It is interesting to note that the sodium-sulphur battery has been one of the most technically difficult systems to develop and yet experts consider that it may be commercially available sooner than some of the other simpler options.

Before moving on to discuss each battery type individually, table 2.4 gives a summary of the main performance and cost characteristics quoted for some of the options to date.

TABLE 2.4

COMPARATIVE COST AND PERFORMANCE ESTIMATES FOR CURRENT STATE-OF-THE-ART BATTERY PACKS

	Lead acid	Ni/Fe	Ni/Zn	Zn/Br	Li-Al/ FeSx	Na/S
Specific energy (Wh/Kg)	30-45	45-55	70	52-58	200	80-160
Energy density (Wh/litre)	-	95-110	100	60-74	250	85-120
Energy efficiency (%)	70-80	60	-	60	-	65-75
Cycle life (cycles)	600-1200	1000-2000	500	500-600	400	1000
Cost estimate (ECU/Kwh)	130-160	200-300	100-180	80-120	80-120	100-200

NOTES
- ECU = European currency unit.
- Cost estimates are based on annual productions of over 100,000 units.
- Figures represent the current state-of-the-art for battery packs; single cells may exhibit significantly better characteristics.

2.7.2 NICKEL-IRON

The nickel-iron battery was developed by Thomas Edison in 1901 and was the most prominent secondary battery in industrial use in the USA until the 1920's [14]. Although nickel-iron batteries are still widely used in Russia, the lead-acid battery has displaced it from the market in this country. It is different from many of the other contenders because it has already been well developed and has proven itself in use. The Peugeot electric 205 used nickel-iron batteries, as have some other test vehicles in Europe and the USA. Today, most of the work on improvement and commercialisation of the nickel-iron battery is taking place in the USA and Sweden, although Russia, France, Japan and Bulgaria also seem to be involved [14]. It is being developed and produced in small quantities by SAFT in France and SAB/NIFE in Sweden [22]. The Swedish National Development Company (SNDC) began development in the seventies as a spin-off from the Swedish iron-air project. A joint programme was established with Eagle Pitcher, the major nickel-iron developer in the USA [23]. SNDC has since pulled out from development work but SAB/NIFE has taken over. In the States, Westinghouse is the other major nickel-iron developer and they are concentrating on the development of a battery with a low initial cost [24]. The advantages associated with the nickel-iron battery include,

- Greater specific energy than lead-acid although the specific energy is still one of the lowest of all battery systems.
- Available energy capacity is less sensitive to power levels than with the lead-acid battery.
- High cycle life
- It can withstand continued deep discharges of up to 100% [18].
- It has a good reputation for ruggedness and tolerance to operator abuse [18].

There are however several disadvantages with this type of battery,

- High initial cost due to the raw material cost of nickel. This type of battery is more sensitive to the costs of nickel than the nickel-zinc battery because the cell voltage is relatively low, so they may require 20-40% more nickel per kilowatt-hour [14]. The long cycle life may however compensate for the materials cost and enable the battery to offer a lower whole life cost. Batteries based on nickel arguably do not have a long term future because it is not a cheap metal, besides having priority use for armour plating steel and jet engine alloys. Also it is mined in politically sensitive areas such as Southern Africa, Russia and the French island colony of New Caledonia.
- Performance is sharply reduced as the temperature drops, especially below zero centigrade [24]. This may limit the battery's usefulness in cold climates unless they can be fitted with a low cost heating system. Such a system would decrease the energy available for tractive effort.
- The system exhibits high rates of self-discharge at high states of charge losing approximately 10-15% of its capacity in the first 48 hours after being removed from charge [18].
- A poor shelf life results from the iron pastes rusting in solution.
- A considerable degree of overcharging is necessary due to the poor charge acceptance of the iron electrode. This limits the energy efficiency to around 60-65% [18].
- Necessary overcharging results in the evolution of hydrogen gas

because the voltages for hydrogen evolution and for iron reduction from $Fe(OH)_2$ are similar. Apart from contributing to the reduced energy efficiency, this necessitates the presence of gas and electrolyte maintenance systems. There are also the safety problems associated with hydrogen management. Measures to limit gassing have so far been successful at the laboratory stage [14].

The nickel-iron battery is one of the most fully developed of all the alternatives and it exhibits superior performance characteristics to the lead-acid system. However, at present it is very costly to produce and its bulky nature suggests that it is better suited for commercial, larger vehicles and not for small cars.

2.7.3 NICKEL-ZINC

Work on the nickel-zinc battery has been undertaken by SAB/NIFE, General Motors, SERGIE of France, Gould, Exide, The Energy Research Corporation and Japan Storage Battery Co Ltd. The nickel-zinc battery is not new however, having been used experimentally in electric shunting locomotives for the Irish Free State Railways in the 1920s, when it was known as the 'Drum' battery. This battery offers the potential for high specific power and a greater specific energy density than lead-acid. In addition it is easily adaptable to a wide variety of vehicle designs. It is capable of delivering its full energy capacity even at high rates of discharge and it maintains the ability to deliver high power throughout its life [25]. Energy output is also less affected by low temperatures than either lead-acid or nickel-iron systems. However, there are several drawbacks,

- High initial cost due to quantities of nickel (see above). Nickel cost should however be substantially less than that of nickel-iron. Zinc is also a relatively rare metal (see table 2.5) and although the battery system may offer twice the specific energy of lead acid it may well cost twice as much [38].
- Low cycle life. This is the major drawback of this system. Cells have serious problems with the zinc electrode in terms of shape change and dendrite formation. This leads to internal short circuiting and cell failure [22]. To a certain extent these problems are being overcome by electrolyte circulation and vibrating nickel electrodes.
- Cycle life suffers when the battery is subjected to deep discharges.

This battery type has always been a strong contender for EV use but there is still no direct proof that traditional nickel-zinc systems have matured into fully reliable long life batteries. It would appear that there is some difficulty in duplicating laboratory and prototype data in the field [26]. General Motors had planned to use their nickel-zinc battery as the power source for their adventurous EV project in which they expected to manufacture and sell 100,000 vehicles by 1984, later postponed till 1985 [27]. These plans were never fulfilled.

2.7.4 ZINC/HALOGEN BATTERIES

Halogens are highly electro-negative, and combined with zinc they give a cell voltage of 2.12 volts for zinc-chlorine and 1.85 volts for zinc-bromine systems.

A. ZINC-CHLORINE

The zinc-chlorine concept was invented by Hooker Chemicals about 20 years ago and since then has been the subject of research within the Gulf+Western group. Although it has been recognised as offering higher energy density and low cost production, it has not been fully commercially exploited because chlorine is hard to manage. Storing chlorine as chlorine hydrate outside the battery however, makes the system marginally more viable. In 1980 it was reported as approaching the engineering stage of development and Gulf+Western reported that it planned to have the battery in production in 1983 or 1984 barring any unforeseen difficulties [27]. Like many other claims surrounding the EV industry, there has been a distinct lack of fruition. Gulf+Western used a prototype Zn-Cl battery in a VW Golf car and achieved encouraging results of 150 mile range at 55 mph [28]. The power system is however extremely complex, incorporating heat exchangers and pumps and pipes (see fig 2.9). The chlorine hydrate must be refrigerated to keep it below 9°C in order to keep it stable. The strong points of the system are,

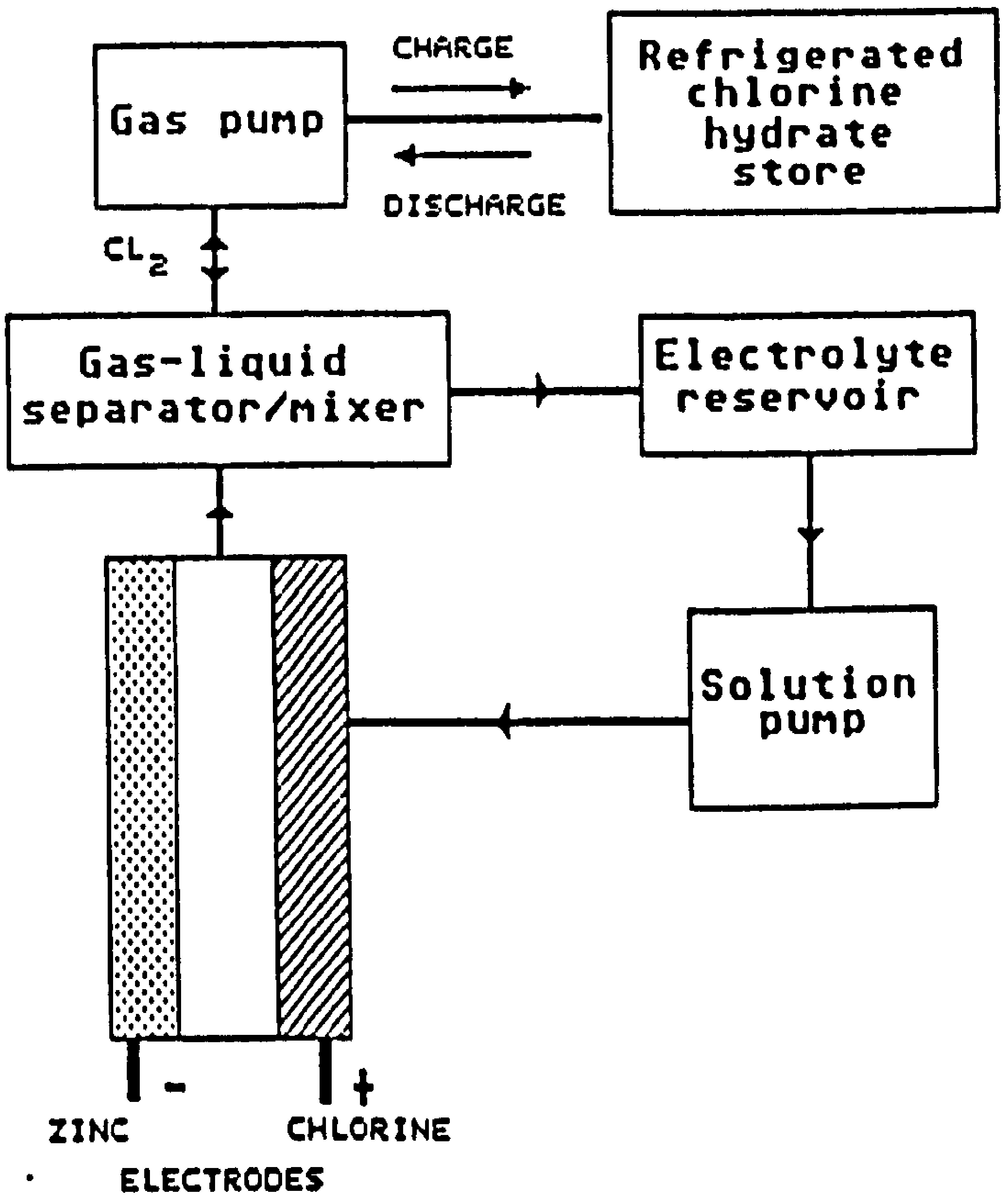
- Good specific energy (70 Wh/Kg).

- Low cost and abundance of chlorine.
- High cycle life. Gulf+Western reported achieving 1400 complete charge/discharge cycles so far without any drop in performance [29] and they hope to achieve 2500 complete cycles in future.

The weaknesses are,

- If the chlorine hydrate rises in temperature above 9°C, lethal chlorine gas can be given off. This presents serious safety and engineering problems [30].
- Very complex and expensive to manufacture.
- Does not scale down well because of the multiple auxiliary systems.
- It is intrinsically bulky and presents serious packaging and safety problems for use in electric vehicles.

FIG 2.9 ZINC-CHLORINE BATTERY SYSTEM



The battery is probably not well suited for EV use due to its bulkiness and the other problems mentioned. It is more likely to be useful as an energy storage and load levelling device. It has been quoted as being "more akin to a chemical engineering plant than a battery" [8]. However it has already been tried in EVs and Gulf+Western have hailed it as "probably the greatest technological development since the turn of the century" [28]. G+W insist on referring to it as the "electric engine".

B. ZINC-BROMINE

In the related zinc-bromine system the bromine is stored as a bromine oil externally to the battery. Development is carried out primarily in the USA by Exxon and under licence in Austria by SEA. The battery does hold some promise for EV use but like the zinc-chlorine system, it has the complication of needing external reservoirs, pumps and pipes. It has the advantages of being very tolerant to complete discharge, easy thermal management and very accurate state of charge control [22]. It also has potential for cheap production. This system would seem to be a better compromise solution than the zinc-chlorine system although its performance is not as great and bromine is another hazardous material.

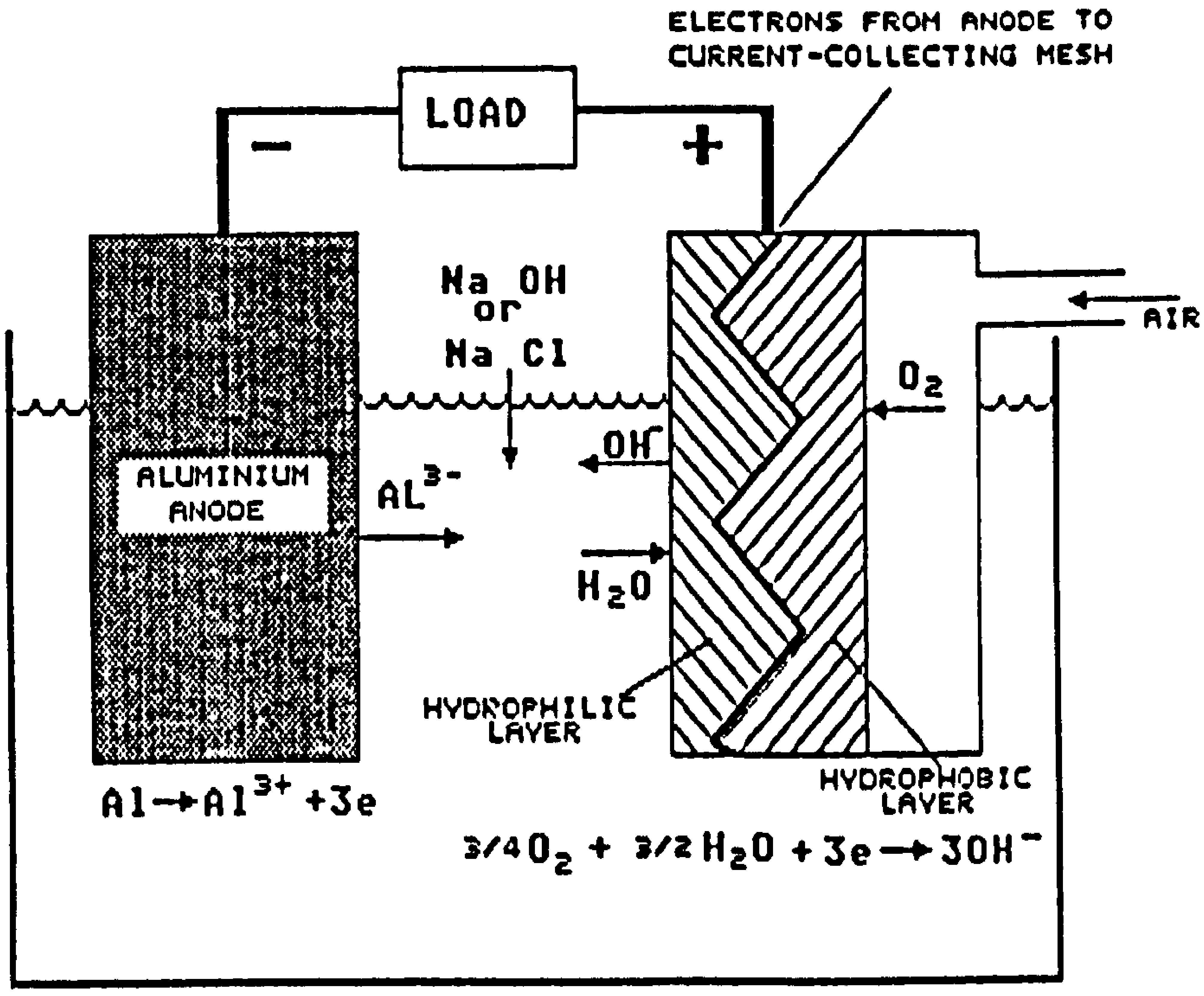
2.7.5 AIR BREATHING SYSTEMS

A metal-air system uses the ambient air to supply the electronegative electrode material (see fig 2.10). The air electrode in alkali solution was the subject of concentrated research in the 1960s in connection with fuel cells [30]. Although considerable experience has been gained, serious problems remain, mainly in connection with water management and cooling, and in protecting the catalyst from oxidation during charging. There are three major types of metal air cells, zinc, iron and aluminium. The first two are electrically rechargeable, but aluminium-air is only a primary battery which may be "recharged" by replacing the exhausted anodes by new aluminium alloy plates. It is a mechanically rechargeable or replatable battery. Zinc and iron systems are under investigation by Lucas, SAB/NIFE, Westinghouse, SNDC in Sweden, Siemens and GCE in France and SAFT. The theoretical specific energy is very high for both the iron-air (756 Wh/Kg) and the zinc-air systems (1054 Wh/Kg). With the iron-air system, start-up in the cold requires heating by external means, power density is relatively low and hydrogen developed during charge has to be taken care of. In addition water and thermal management are necessary. It would appear that, apart from aluminium, air breathing systems are unpromising candidates for traction batteries [8].

ALUMINIUM-AIR

Aluminium has long been recognised as being a candidate for an energy system. The aluminium-air battery has had a long and interesting history and this is clearly summarised in reference [31], but research interest internationally has increased rapidly since the present decline of the aluminium industry which started in the mid 1970s. The price of aluminium in 1983 was \$1600 a tonne but in 1986 it had fallen to \$800 a tonne [31]. This, together with rising petrol prices has stimulated renewed interest in using aluminium as an active component of a battery system. Patents for aluminium anodes and batteries have been issued in the US, Japan, Switzerland, Yugoslavia, Norway, Austria, Canada, France and West Germany as well as Britain. Research is also apparent in Soviet literature. Previously aluminium prices would have made an aluminium-air battery prohibitively expensive to produce but the aluminium industry has made great efforts in the last 7 years to develop a feasible battery (see fig 2.10). Alcan International became involved in 1981 by building up a team of scientists at laboratories in Kingston, Ontario and Banbury in Oxfordshire. By 1983 this team was reported to equal the number of people working on the problem elsewhere, and by 1986 the battery had been developed to the stage where it could be field tested in a golf cart vehicle. The aluminium battery merits special attention not simply because of the remarkable progress in the 1980's but also because of its special characteristics. It has a very high specific energy of around 300 Wh/Kg and a high specific power of around 160 W/Kg. This makes it the only electrochemical system known at present with realistic prospects for achieving a performance equivalent to petrol fuelled vehicles. The battery is more akin to a fuel cell than to a rechargeable battery because it does not require recharging. It operates by submerging aluminium alloy plates in a solution of salt and water or in a caustic solution in water.

FIG 2.10 ALUMINIUM-AIR CELL



NET REACTION :- $AL + 3/2 H_2O + 3/4 O_2 \longrightarrow AL(OH)_3$

The electrochemical oxidation of aluminium releases the 'free energy' which is the source of the cell voltage; the aluminium compound aluminium hydroxide is a by-product which can be recycled to recover the aluminium. The system requires additional water approximately every 250 miles and new plates every 1000 to 2600 miles depending on the plate's thickness [32]. It would be possible to design the battery such that replacement of the plates would only take 15-30 minutes, allowing a vehicle to serve just like a conventional ICE vehicle. However the system is complex, relatively bulky and may require an auxiliary energy source for start up. The electrolyte has to be circulated and an on-board crystalliser is necessary to separate the aluminium hydroxide from the electrolyte stream. Its success in a traction role would seem to be as much a matter of engineering and economics as of basic science. Projected costs are still very high and remain uncompetitive with other systems to date [31], but there is no doubt that its potentially superior performance makes it a very attractive energy source for further development.

2.7.6 HIGH TEMPERATURE BATTERIES

For batteries to have high specific energy, it is desirable for the negative electrode to be selected from among the lightweight reactive alkali and alkaline earth metals, e.g lithium, sodium, magnesium and calcium. The oxides of these metals cannot be reduced in aqueous media, so that secondary batteries employing these materials must use non-aqueous electrolytes and the electrolyte will either have to be solid or molten in state. Two types of high temperature battery have been the object of much research over the past 20 years. Firstly some form of lithium based system, using one of a variety of possible cathode materials, and secondly the much talked about sodium-sulphur battery.

A. SOLID STATE LITHIUM BATTERY

A lithium solid state battery is currently being developed within EEC funded Anglo/Danish/French projects at a variety of locations [33]. The project began in 1978 and is coordinated by the Harwell Laboratories. There is also a current French/Canadian project [22]. These batteries use a polymer electrolyte and the lithium based anode is in the form of a thin film, only 0.1mm thick. Lithium based systems have high potential specific energy and power characteristics, they are light and exhibit good conductivity and high electrochemical equivalence [26]. However, they operate at between 100 and 400°C depending on the materials used, although the new advanced types operate at 100-160°C. The high operating temperature requires the installation of a temperature management system and although the energy losses may be very small in batteries that are used regularly at least twice a week, they may not be suitable for applications where use is irregular because idle sitting will allow the temperature to drop [14]. In addition, neither the lithium battery nor the sodium-sulphur battery contains a mechanism, analogous to the electrolysis of the water in aqueous electrolytes, which permits other battery systems to withstand significant amounts of overcharging without permanent damage [18]. Unlike sodium and sulphur, lithium is quite scarce and supplies are liable to disruption. Some form of lithium battery remains attractive in terms of performance characteristics but it would seem to be a medium to long term possibility. Work on it is reported to have been cut back [28].

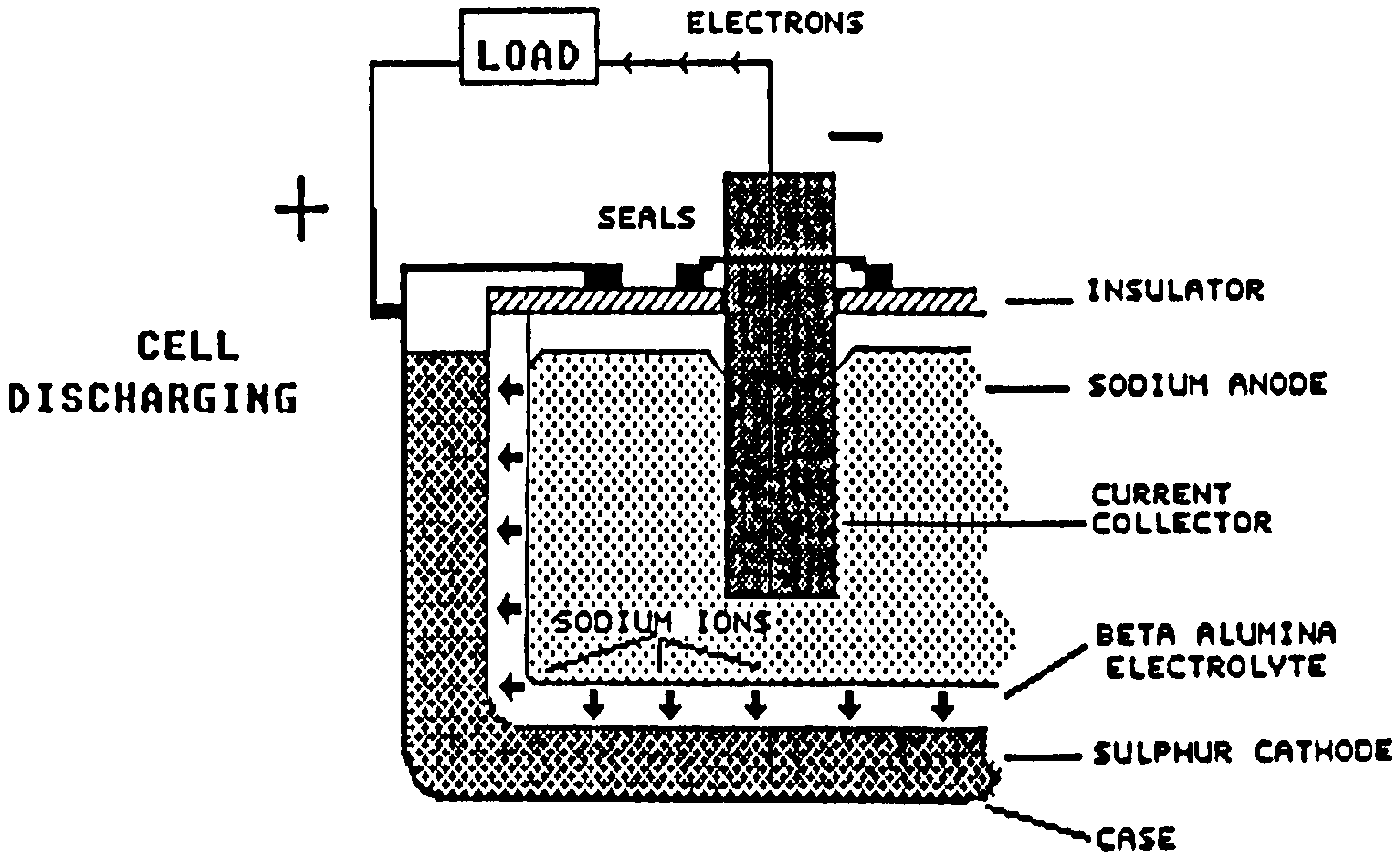
B. SODIUM-SULPHUR

The sodium-sulphur battery has frequently been hailed as the saviour of the EV concept and in recent years there has been much in the way of research and development. Many hopes have been pinned on it because of its potentially high specific energy and power. For example, John Holden the managing director of HIL Electric states that his company is waiting for a secure supply of such batteries and once he has them he believes that he will be able to market a viable electric vehicle. The idea of the sodium-sulphur battery using a solid ceramic electrolyte and molten electrodes was conceived in the early 1960s by J Kummer and N Weber [34], working for the Ford Motor Company in the USA. Fig 2.11 shows the cell design of the Chloride Silent Power Ltd sodium-sulphur cell.

At around the same time as Ford began work on the battery, a related concept in which glass fibres act as a solid electrolyte was conceived by C Levine of the Dow Chemical Company. Since that time significant development efforts have been set up around the world. Participants include Ford Aerospace, Brown Boveri in Germany, General Electric, British Rail, Chloride and the Electricity Council. Work began in the UK at

British Rail and the Electricity Industry Laboratories immediately after Ford announced their development in 1968, and later work at Harwell began. In 1974 the separate programmes were coordinated and a national programme was formed. Chloride Silent Power, jointly owned by Chloride, the Electricity Council and supported by the Department of Industry was formed at that time.

FIG 2.11 CHLORIDE SILENT POWER Ltd. SODIUM-SULPHUR CELL



Work on the sodium-sulphur battery in the States is more concerned with load levelling applications for the battery, while in this country, where the national grid is much more efficient and there is less need for load levelling plants, the incentive to develop is the lure of a high performance EV battery. Characteristics which make the sodium-sulphur system desirable as an EV energy source are,

- Very high potential specific energy, although in practice results have not reached expectations. Single cells with specific energies of over 200Wh/Kg have been constructed but in batteries the figure is generally below 100Wh/Kg. This should lead to a greatly increased vehicle range. A sodium-sulphur powered utility vehicle built by Ford Aerospace achieved a range of approximately 5 times that achieved with lead-acid batteries [18]. The estimates of range increases gathered in the Delphi analysis suggested that a figure of between 2 and 3 times was more reasonable.

- A long cycle life is expected and single cells have survived up to 5000 cycles. Again, batteries exhibit much lower figures of up to 1000 to date [28].
- The raw materials used in the battery are relatively cheap and abundant (see table 2.5) and the overall material costs could be significantly less than for other systems including lead-acid. However the construction costs could well offset this advantage.
- Recharging could take around half of the recommended time for lead-acid systems [35].
- The battery exhibits 100% coulombic efficiency since, unlike the other systems, there are no parasitic side reactions that lead to self discharge [22].

The system however has had, and continues to have, many drawbacks and engineering difficulties,

- Thermal management is necessary to maintain the battery temperature at an operational level of 350°C. This reduces the potential energy efficiency and vehicle range as energy to maintain the temperature must be supplied from the battery itself. Such a system would also add to the weight of the battery.
- The system exhibits little tolerance to overcharging.
- Corrosion of the positive current collector is a serious problem, especially for batteries to be used in vehicles. British researchers have developed an "inside out" design, in which the sulphur is contained within the beta-alumina tube and the sodium contacts the exterior surface of the tube [14]. This approach appears to result in reduced electrical performance but it may have advantages in terms of costs and lifetime.
- Reproducibility in manufacture of beta-alumina tubes and their reliability in use pose problems [8]. The beta-alumina electrolyte tubes are prone to cracking. New designs and better fabrication methods are helping to overcome these problems (see below).
- There are still questions concerning the chemical safety of the system especially in road accident situations. It is difficult to find a way to package the two elements together with a suitable electrolyte. The high temperature and characteristics of the elements give a potentially hazardous system.
- Packaging difficulties, thermal management and complex construction have all lead to inflexibilities in design. In addition, construction requires skilled labour and although the material costs are potentially low, construction costs are liable to be relatively high.

There has been much time and effort devoted to the development of a practical sodium-sulphur battery system over the last 20 years. The work of the electro-chemist and materials scientist is nearing completion but there is still much to be done by the design and production engineers to develop a commercial product. Although the sodium-sulphur system has long been classified as a medium to long term option and the technical problems have set it amongst the more adventurous projects, it is increasingly being looked upon as a near term contender. This is more because of the commitment and will behind its development than the ease of progress. New designs such as the British mini tube system (shown in fig 2.11) and better fabrication methods such as the new beta-alumina processing in France have brought the complete system much closer to commercial viability. In 1985 Chloride Silent Power announced that they had developed the system to a practical stage. They stated "We now feel that we've got a breakthrough in the form of a simplified design" [35]. Chloride Silent Power has developed a sodium-sulphur cell about the size of a conventional torch battery which avoids many of the problems of the traditional long cell tubes. The cells will be hooked together in large numbers to form a battery pack and the developers say that a network of small cells will be far more reliable than a few larger ones. If a cell fails, its resistance will build up but the network of parallel connections will keep the battery functioning almost as normal. The engineers have also managed to reduce the number of components in each cell from 27 to 13 and this should have a favourable affect on construction costs.

In October 1985, Chloride Silent Power signed a contract with the Department of Energy in Washington. Under the contract, the DOE will supply money to back the battery's future development, leading to a production line capable of making 19 million cells a year by the 1990's [35].

C. SODIUM-IRON CHLORIDE AND SODIUM-NICKEL CHLORIDE

The use of an insoluble metal chloride with a basic sodium aluminium chloride melt was first discovered by Coetzer [36] and reported as recently as 1986. Although this battery system has not had the same period of study devoted to it, it already seems to be a promising candidate for EV use. It is currently being developed by Beta Research and Development in Derby, a subsidiary company of the South African Zebra Power Systems. The cells operate over a wide temperature range of between

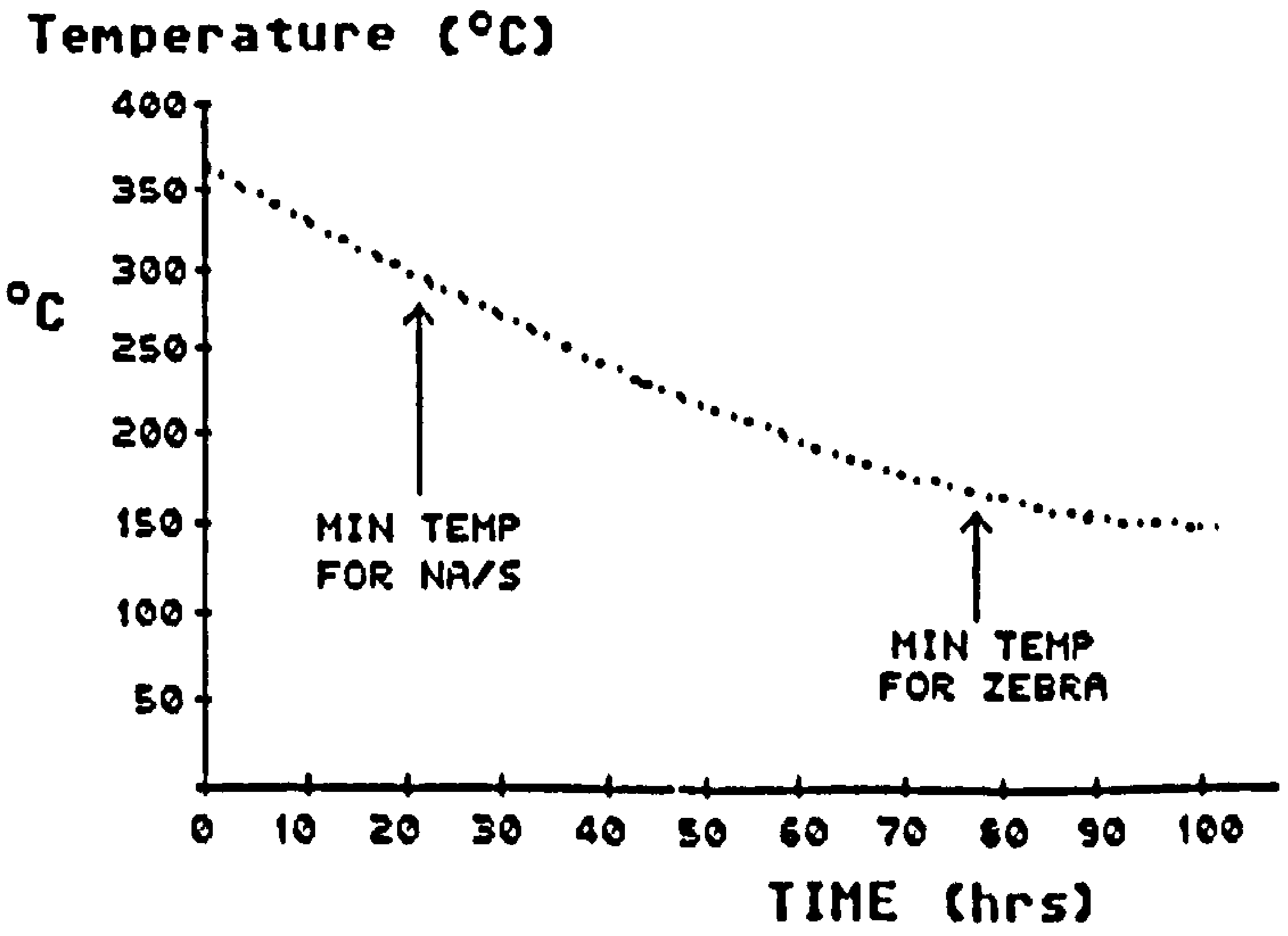
200-500°C.

The Zebra systems exhibit the same advantages as the sodium-sulphur system such as high theoretical energy density (>700 Wh/Kg), a completely maintenance free sealed system and 100% coulombic efficiency. In addition it avoids four of the major disadvantages associated with sodium-sulphur.

1 The system is chemically much safer because any reaction between chemicals that occurs due to fracture of a beta alumina tube is prevented by the formation of the solid products, sodium chloride and aluminium. Whereas sodium-sulphur systems have a sulphur vapour pressure of over 20 bar at 800°C, Zebra cells contain materials with vapour pressure less than 1 bar at the same temperature [37]. The safety of the Zebra system has allowed a freedom of cell design not experienced by the sodium-sulphur developers. This lack of constraints allows 250Ah Zebra cells to be physically crushed and give no undesirable effects, with only a very small temperature rise [38].

2 The Zebra battery, with a lower operating temperature has a far longer cooling down period than sodium-sulphur (over 3 times as long as shown in fig 2.12), and more importantly the power input required at this lower temperature is considerably less. This may be particularly important in connection with electric cars with variable use patterns. It could also lead to reduced costs of thermal management systems. Tolerance to freeze-thaw cycling is essential for battery maintenance and construction and also for surviving any cooldowns in use. Recent work on the thermal cycling of Zebra cells has shown them to be resistant to over 30 thermal cycles [38].

FIG 2.12 Cooling curve for Zebra batteries
(source - reference 37)



3 In the Zebra cells, corrosion of the current collector rod is virtually undetectable [37]. Any corrosion products however that may occur are in any case metal chlorides of which the electrode is

composed, so there is no deleterious effect on performance or life.

4 The Zebra cell has exhibited the ability to withstand a certain amount of overcharge and over-discharge in contrast with the sodium-sulphur system which fails by electrical breakdown on overcharging.

Although these are relatively recent contenders in the race for an EV energy source, progress has been rapid as it has not been constrained by safety and other problems. There has obviously been no time for real-time life cycle testing yet but accelerated tests have shown Zebra cells have shown no loss in capacity or increase in resistance up to 1500 charge/discharge cycles. Length of life at these accelerated rates is reported to be as good as those obtained from sodium-sulphur [37]. Specific energy is around 100 Wh/Kg although there appears to be potential for a much higher figure.

Beta research report that construction is much simpler and safer and hence cheaper than with sodium-sulphur because there is less need for highly skilled construction operators and machinery. In addition, the material costs are less although it must be remembered that material costs are often only a small fraction of the overall system cost. Development work is still required in some areas such as improved hermetic seals, but work is now at the stage where final optimisation for the required applications is needed. Also, the time is ripe for engineering development of production processes and detailed production costing [37].

2.8 SUMMARY AND CONCLUSIONS

It is difficult to predict which battery system will predominate for EV use in the future and it is quite probable that more than one system will be retained as different types of application make different demands on the power source. The lure of high performance, advanced batteries is strong enough to have led to significant effort in their development, and their ultimate success depends as much on the determination to develop as on the inherent characteristics of the systems. On the other hand, the lead-acid battery remains the first choice at present and in the foreseeable short term. Because there is more operating and real time experience with this system, it is likely that it will remain in use in the longer term for those applications for which it is particularly suited.

In the long term, if EVs are to be used in significant numbers, the relative abundance of potential battery materials is of great importance if a sustainable future transport system is required. Table 2.5 shows the relative abundance of the raw materials of many of the possible battery candidates.

TABLE 2.5

NATURAL ABUNDANCE IN THE EARTH'S CRUST OF POSSIBLE FUTURE FUELS

(Sources:- 1) "Mineral Facts and Problems" 1980 edition, Bureau of Mines Bulletin 671. 2)Kaye and Labey "Physical and chemical constants")

	ROCK ABUNDANCE (BY WEIGHT)	SEA WATER ABUNDANCE (BY WEIGHT)
Hydrogen	-	10.8%
Oxygen	60%	85.7%
Silicon	28%	$3x10^{-4}$%
Aluminium	8.3%	$1x10^{-8}$%
Iron	5.0%	$1x10^{-6}$%
Sodium	2.4%	1.05%
Calcium	1.84%	0.04%
Magnesium	2.06%	0.135%
Potassium	1.34%	0.038%
Titanium	0.182%	$1x10^{-7}$%
Carbon: coal,oil,gas, plus present biosphere	0.054%	0.0028%
Sulphur	0.032%	0.089%
Chlorine	0.028%	1.9%
Lithium	0.02%	$1.7x10^{-5}$%
Nickel	0.009%	$2x10^{-7}$%
Copper	0.006%	-
Zinc	0.0024%	$1x10^{-8}$%
Lead	0.0018%	$3x10^{-9}$%

NOTES
It is easy to see why the aluminium-air battery must be a front-runner in the intermediate battery stakes on the basis of materials abundance, though the high cost of extraction from clay in the future may be a severe handicap. Also, the high cost of electricity incurred in the manufacture of aluminium must be weighed against the energy benefits of electrified transport. Indeed the relative costs of extraction of possible materials is obviously a most important factor, and not just their abundance. Note also that Nickel, Zinc and Lead are all relatively scarce metals.

As part of the Delphi analysis, respondents were asked to predict which battery system(s) they considered would eventually predominate for EV use. 51% backed the sodium-sulphur system while a further 26% supported the new Zebra battery. The remaining 23% suggested that either zinc-chlorine, nickel-iron or a lithium based system would predominate. Regardless of which system is ultimately developed and used, the present development of EV technology must not be neglected in a period of waiting for better and better power sources. The technology is already technically viable using currently available lead-acid batteries and in many applications it is also economically viable. In the short term continuing efforts are needed to introduce the technology into those market segments where it can already be successfully used.

CHAPTER 3

A BROAD VIEW OF THE CASE FOR THE INTRODUCTION OF EVs

CHAPTER 3

A BROAD VIEW OF THE CASE FOR THE INTRODUCTION OF EVs

"In fifteen years more, more electricity will be sold for electric vehicles than for light".

Thomas Alva Edison in 1910

The resurgence of interest in the use of electric road vehicles has largely been the response to growing concern about energy supply, environmental problems and trends, pollution control, energy conservation and dependency on foreign oil. These factors have provided new stimuli for the planning, research, organising, development, financing, production and introduction of electric road vehicles. These stimuli will remain as long as the transportation function, both domestic and commercial, continues to face internal and external threats.

In addition, any attempt or decision to make greater use of electric road vehicles will have ramifications beyond the transportation sector. Without consideration of these other areas and a systems approach to EV introduction at a macro level, the full potential of EVs may not be properly exploited. This chapter examines the arguments surrounding the use of such vehicles and the rationale for their introduction.

3.1 THE ENERGY PROBLEM

The availability and use of energy has been a major world concern over the last 15 years. Prior to the oil crisis of 1973 there had been little urgency to think in long term and global terms. Subsequent events and trends however have pushed to the fore the recognition that sharp oil price increases were only a symptom and that the world faces not a temporary crisis but a chronic, pervasive energy problem. The exponential growth in energy use coupled with a similar growth in world population since the 1950's cannot continue indefinitely. Total demand for energy doubles about every ten years [1]. There is also a close link between national economic development and energy consumption (at least in the developing countries) and considering that 71% of the earth's population in developing and undeveloped countries consumed only 5% of the energy used in 1975, it can be seen that for these countries to develop significantly in economic terms a great deal of energy will be needed. If the living standards of the industrialised world are, at the very least, to be maintained, and if the people of the undeveloped developing world are to achieve satisfactory standards of living within a reasonable time, there will have to be economic development and in the least developed nations, rapid economic growth. This development requires energy, especially in the form of liquid fuels for nations in early stages of industrialisation.

The energy problem is a complex set of interconnected problems which all arise from our need for energy. These include social, technological, political, environmental, economic and industrial problems. It spans national boundaries and relates as much to the long term as the short term. Specifically in the short term, growing energy demands must be satisfied in ways that will allow for differing rates of economic development and that will promote the welfare of a rapidly growing global population. The world will have to respond to the potentially explosive aspects of this growth and attempt to maintain a degree of geopolitical stability. At the same time, looking to the longer term, the nations of the world must build sustainable, equitable and resilient energy systems that satisfy the needs of the population in the next century and beyond. In order to establish sustainable systems, resources must be invested in such a way as to ensure future security. Such systems must be able to respond vigorously and flexibly to a wide range of unanticipated global energy needs and difficulties.

3.2 THE OIL PROBLEM

3.2.1 INTRODUCTION

The advent of oil as an energy source has led to the ability to do work that would otherwise be difficult or impossible. Oil has a relative advantage over other forms of energy because of its extremely high energy density and because its liquid nature allows it to be transported easily over large distances. Air travel is a good example of a premium application of oil. The seemingly abundant supply of oil over the last century led to its use in many areas including those in which it had little inherent advantage relative to other fuels. Uses such as electricity generation and space heating are examples. Resource allocation and use has often been based on temporary economic factors instead of taking into consideration the wider issues. In common with other fossil fuels however, resources of oil are finite and are subject to political pressures. The oil crises of 1973 and 1979 have brought this fact into sharp focus and, together with increasing environmental pressures, have heightened the interest in other fuels for transportation including the use of battery powered electric vehicles.

There are several special considerations to bear in mind when considering the use and conservation of oil,

- Oil, or some like substitute, is the only fuel which can be used in the vast majority of present transport vehicles by land, air or water.
- For many of these modes of transport, there are few substitute fuels and the absence of oil would severely restrict these uses. For example, other forms of fuel may not have sufficient energy or power density to be adequate for air travel. Oil has become a unique fuel for many purposes.

- There are other vital premium uses of oil such as lubrication and petrochemicals. Oil is a vital feedstock in the manufacture of numerous products.
- Whole vital industries depend on oil, such as agriculture, fishing, forestry and haulage.
- Oil occurs only in certain areas of the world and some of these may be susceptible to political or military interference.
- Crude oil is separated into different grades which are used for various purposes, but the composition of the crudes varies and shortages may appear in some grades before others.

3.2.2 FUTURE SUPPLY AND PRICE OF OIL

There have been many attempts to forecast world reserves of oil and it is not the intention of this chapter to make predictions. Estimates of the reserves, discovery and consumption rates of oil vary, but reasonably authoritative surveys have been made by Gerald Foley [2] and John Davis of Shell [3]. Their estimates agree with many statements by leaders in the oil industry and are summarised in table 3.1 [4]. A summary of the principal estimates of ultimate world oil resources published since 1940 is given in appendix 10 and table 2.1 is representative of consensus opinion.

TABLE 2.1 ULTIMATE WORLD OIL RESOURCES
(Source - reference 4)

- Total world oil reserves estimated to exist in 1850	274 Bn Tons
- Of this, man has extracted by 1988 about	95 Bn Tons
- Leaving in the earth about	179 Bn Tons

Of this 179 billion tons, about 88 billion are "proved reserves" [5], leaving an assumed 91 billion tons to be found. On average, the proved reserves are being increased each year by finding rather more than 2 billion, and reduced by consumption of nearly 3 billion, so that proved reserves are now falling by nearly one billion tons per year. It is not many years since these reserves were building up and present reserves now include more and more small finds which cannot be exploited economically until the oil price rises considerably. Details of world reserves, production and consumption are given in appendix 10.

Some expert forecasts are based on the belief that new discoveries will decline in line with the total yet to be found. Furthermore, the rate of extraction from a discovery may be only 10% to 30% per annum of the reserves in that area, so the oil industry will find it increasingly difficult to sustain supplies of oil at 3 billion tons p.a. This situation is exacerbated by the lead time of nearly 10 years from discovery to production of many oil wells. Even allowing for significant margins of error in the above figures, it is clear that continued growth in demand for oil cannot be met indefinitely by the oil industry.

> "If present production levels are to be maintained, this is the equivalent of finding new oilfields equivalent to the North Sea every two years for the next 50 years....the task...is beyond the powers of the world's oil industry". (Foley p131) [2]

Oil is a finite resource and sooner or later the excess of world demand for oil over world supply will raise the price of fuel to a level at which it is no longer economic simply to burn it.

> "The problem is not that there will be a complete exhaustion of all energy reserves; it is that...massive new energy supply...will have to be developed. If the start of this transformation is delayed, there will be serious shortages around the turn of the century". (Davis p110) [3]

Whatever any particular government may do, the general laws of supply and demand must operate on a world basis. Oil supply is a world problem and it makes no economic, moral, or military sense for any nation or area to think that local supplies can be used entirely for local demand in the long term.

3.2.3 HOW LONG WILL THE "OIL ERA" LAST?

It is extremely difficult to forecast how long it will be before oil is too precious to burn as fuel. Firstly we do not know exactly how much oil actually does exist and how much of this will eventually be found and recovered. However if current discovery and consumption rates were to remain unchanged, it would take about 80 years for man to deplete all existing proved reserves in addition to those found during this period. After this period there will not be enough oil to meet demand. However, even after the oil crises of 1973 and 1979, world oil consumption has continued to grow substantially. Much of the proved reserves are at present very uneconomic and difficult to develop and there is no guarantee that oil will continue to be discovered at the same rate in the future. In addition much of the world reserves are located in Eastern block and other politically uncertain areas. It is very likely that discovery rates will slow down as reserves are depleted. Given these factors, it may be considerably less than 80 years before demand exceeds known reserves. The commonly quoted reserves/production (R/P) ratio is used to represent the number of years of known reserves remaining. This ratio has remained fairly constant over the last 20 years at around 30 but obviously this figure will drop whenever consumption is greater than discovery. Appendix 10 presents recent estimates of world reserves and consumption rates and how these are distributed around the world.

However, well before the point where reserves are depleted and demand is only partially met by discovery, oil prices can be expected to rise dramatically in the light of impending shortages. Although there will be remaining proved reserves, production rates may not be able to meet consumption rates. It may be many years before this point is reached but there is great uncertainty surrounding the future of oil supply and price, so global diversification away from oil is obviously essential in the long run and desirable in the shorter term.

3.2.4 LIGHT HYDROCARBON OILS

All air and road transport use the light hydrocarbon oils (LHO) which constitute between 3% and 7% of all crude oil. Different sources of oil yield different percentages of LHO but an average of 5% can be taken. This yield could be increased but only at considerable extra expense by further cracking. However, demands are continually being made for more airports and motorways to accommodate increases in traffic. If other users such as the electricity generating industry or industrial users move away from using the other 95% of the oil fuels or economise on their use, the level of increase in demand for LHO which is forecast becomes more and more expensive to supply, and increases the danger of short supply. There would need to be a similar increase in demand for the heavier hydrocarbons to give rise to the necessary LHOs yet it is the heavier fuel oils which are more easily substituted by other fossil fuels, electricity or even renewable energy sources. The situation would seem to be one of rising demand for LHO and stationary or decreasing demand for the bulk of the oil based fuels. The supply of LHO becomes very vulnerable and sensitive to overall demand for oil. The situation can only be eased through economies on the part of the LHO users by increased fuel efficiency, reduced transportational demands or diversification of transport fuels away from oil.

3.2.5 THE NORTH SEA AND OTHER UK RESERVES

The North Sea and other areas around Britain are not a significant proportion of world oil reserves. The Department of Energy report "Development of the oil and gas resources of the United Kingdom 1978" states

> "Total estimated reserves remain in the range 3 to 4.5 billion tonnes. The higher end of the range allows for future discoveries. A formidable effort of exploration, technological advance and investment will be required before the range estimates can be narrowed."

The UK Digest of energy statistics quotes the figure in 1987 to be between 2.095 and 5.465 b. tonnes of which only 1.76 b. tonnes is proven and of which 1.042 b. tonnes has already been extracted [6]. This range of figures seems to be widely accepted [7][8] and it is clear that anything over 3 b. tonnes is likely to be very expensive and not available for some years. The total amount of oil recovered from the North Sea is therefore unlikely to be more than the equivalent of one year's world consumption. These reserves have been and will continue to be a great benefit to the UK in saving foreign currency which would otherwise have to be spent on imported oil, but around half of these reserves have already been sold and much of the remainder will be less economic to extract until prices rise further. It is essential that steps be taken to reduce national dependency on oil even while there are remaining reserves so that the nation is not so vulnerable and so that it is prepared for a not too distant future in which oil is in short supply.

National diversification of energy sources away from oil is extremely important even in the short term since many projects will have long lead times. It is not enough simply to rely on man's resourcefulness to solve the problem once oil becomes scarce enough and the problem is imminent. It may take long periods of time to develop alternative technologies, establish suitable infrastructures, re-educate people, design and set up alternative systems. Resourcefulness should be called upon at at the present time to devise solutions so that future security is ensured.

3.3 THE ADVANTAGES OF ELECTRIC TRANSPORT

3.3.1 INTRODUCTION

The development and use of electric road vehicles and battery systems would be a strategic move in energy terms and would have several advantages.

1 Conservation of oil resources.
2 Diversification of the national energy base of transport.
3 Load levelling for electricity supply.
4 Help national balance of payments.
5 Storage of distributed electricity.
6 Increased primary energy efficiency.
7 Reduced air and noise pollution.
8 Opportunities for British manufacturing industry.

3.3.2 OIL CONSERVATION POTENTIAL OF EVs

Energy use in the transportation sector represents a major part of the total national energy consumption and the growth of the energy consumed by transport has been disproportionately rapid. Transport sector energy demands accounted for half of the total increase in the UK final energy consumption between 1958 and 1976 [9]. For road vehicles alone (mainly cars), the growth was as much as 70% of the total, all in oil-based fuels. In 1987, transport accounted for 28.9% of the total energy supplied to final consumers and 71% of all the oil used. 99.37% of all energy used for transport comes from oil, and road transport accounts for 80% of transport oil usage. The complete breakdown of UK energy flows for 1987 is given in appendix 10.

It is evident that our transport system is almost entirely dependent on oil-based fuels and that it is the largest oil user in the country. If measures are to be taken to conserve oil reserves then the transport sector, and the road vehicle sector in particular, is an obvious place on which to focus attention. Air transport, the other significant contributor to transport oil usage, is more difficult to operate with other fuels. The arguments for moving away from a transportation system which is wholly dependent on oil are,

1 Uncertainties over future supplies of oil.
2 Conservation of oil for other premium uses.
3 To maintain a measure of national independence from oil exporting countries.
4 In the longer term, new transport fuels and systems will be required anyway and if these are not investigated and developed as soon as possible, they may not be ready in time, and consequently there could be a period when we lack sufficient transportation potential. Alternatively, precious remaining premium fuels may have to be burnt needlessly.

Electric road vehicles offer a potential to reduce the amount of oil used in the transportation sector. The level of this saving is obviously related to the extent of EV introduction and the use made of the vehicles once they have been adopted. Although transport is highly fuel specific at present, it offers certain flexibilities that are not so obvious in other sectors of energy use. Whereas buildings have a lifetime of 100 years or more and often retain their heating systems for long periods of time, vehicles need to be replaced every 5-15 years on average. Neglect of energy conservation possibilities in urban planning and industrial developments can impose long-term energy consumption patterns which are often virtually unchangeable. The lead time for new energy saving technologies to be adopted in the vehicle market are potentially much shorter than for other sectors.

The implementation of energy policy on a micro scale however, is ultimately dependent on individuals and their decisions on how and when to use energy. Greater efficiency and savings will only be achieved by measures which encourage changes in attitudes. Although substitution in the transport sector may be potentialy quicker it may also be more difficult than in other sectors. Transport, along with chemical manufacture, represents a premium market for petroleum and oil products. As the price of petroleum rises, it is the other uses of oil such as domestic heating and commercial uses that will find it easiest to change to other fuels, which may be equally as convenient in any case. Also, motorists are shielded from oil price rises to a certain extent because of the cushion of taxation on petrol and diesel. This situation is probably only temporary and should be seen as a breathing space in which to develop new transportation options.

3.3.3 GENERATING CAPACITY AND LOAD LEVELLING

It has been estimated that the existing generating capacity in the UK and EEC would be sufficient to support anticipated levels of EV use until at least the year 2025 [10]. This study assumed a 15% level of EV introduction. Another European study concluded that the current generating plant in Europe could support a population of 7 million EVs [11]. From these studies it is evident that for even substantial EV use, there is sufficient generating capacity in existence provided that charging is largely confined to off-peak hours and other energy demands do not grow at unexpected rates. The point is that EV battery charging could quite easily fit in to the present structure of electricity generation. This issue is studied in more detail for the Islands of Scotland in chapter 7.

In addition, because electrical energy demand is at such a level as to dictate a corresponding installed generating capacity, the consequential off-peak capacity which is the cause of cheap off-peak tariffs would be open to exploitation via electrical storage devices such as EV batteries. For most probable EV applications, battery charging will largely take place at off-peak hours when the vehicle is not in use. Apart from the obvious economic advantage to EV operators, EVs could be very helpful in utilising and storing distributed electricity at off-peak times, thus contributing to load levelling which is desirable for several reasons. Firstly, a more stable daily load allows generating plant to be operated at more constant levels which are more efficient. Secondly, if nuclear power is to play an increasing part in our energy supply for one reason or another, a larger proportion of our electricity will be generated as base load because it is difficult to alter the power output from nuclear stations quickly. There will thus be even greater need for load levelling or energy storage devices. Thirdly, EVs allow greater flexibility in terms of the source used for generation. One of the major problems faced in scheduling generation and in designing the system is the difficulty associated with mixing different types of generating plant to meet a fluctuating demand. This becomes especially difficult when or if renewable energy sources are utilised more. Many such sources are intermittent although they may be predictable, for example tidal or solar power. By contributing to a more stable daily load profile or in utilising power when it becomes available, the EV increases the efficiency of the entire system.

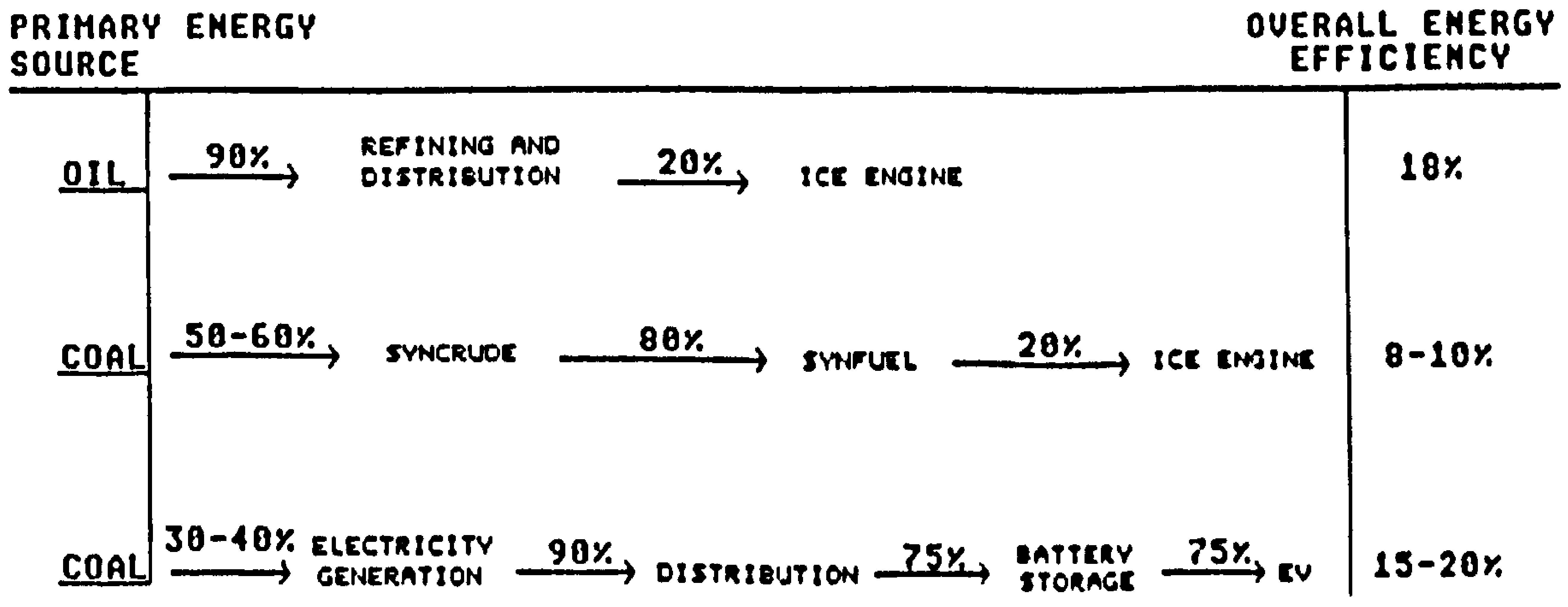
In the USA the national grid is not as efficient and flexible as in the UK, so there has been great incentive to develop load levelling devices. This has lead to US interest in the sodium-sulphur battery and they are currently funding British development of the battery for load-levelling power plants [12].

3.3.4 PRIMARY ENERGY EFFICIENCY OF EVs

Although EVs may diversify the energy base and may save oil, they do so at the expense of some other form or forms of primary energy. This may be coal, nuclear or even renewable sources. The electricity to charge batteries has first to be generated at a power station. The ICE has a very poor efficiency, typically in the region of 20% [13], but the efficiency of getting the fuel from source to vehicle is very high. The EV on the other hand has a much more efficient drive system (typically 75%), but the generation of electricity is only about 30-40% efficient Fig 3.1 compares the primary energy efficiency of the two vehicles and also the option of producing synthetic petrol from coal in the future, hence retaining the existing type of vehicle and energy supply infrastructure.

FIG 3.1 Comparative efficiency calculations for the use of different primary fuels for tractive effort

Sources - Energy World Aug/sept 84 p22
- SAE paper 800109 p2



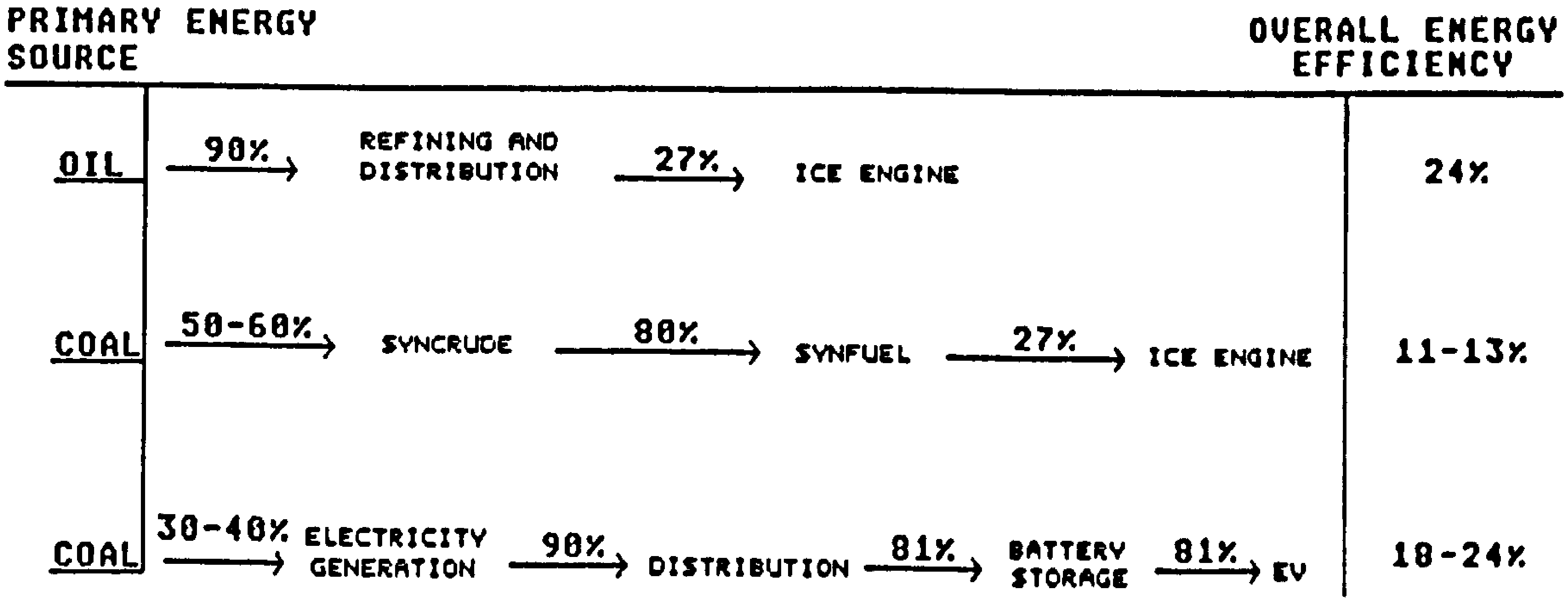
All values in fig 3.1 relate to the present state-of-the-art technology. However, by the time EVs are likely to make a significant impact on energy policy, these efficiencies can be expected to have changed. There is room for improvement in both EV and ICE efficiencies. With regard to ICE vehicles, such modifications as increased compression ratios, better lubricants and controlled cooling fans could lead to overall fuel savings of around 5% in the short run [14]. The present move towards unleaded petrol will of course reduce compression ratios. In the longer term, authorities seem convinced that the engine and transmission could contribute to fuel savings in the region of 30% [15][16][17]. A progressive change in design philosophy, which we are already experiencing, from high performance vehicles to economy vehicles could therefore lead to total reductions in fuel consumption of around 35%. With regard to the EV, possible efficiency improvements to the drive system and motor controller could give a 5-10% rise in efficiency. Battery chargers are already highly efficient but there is probably still room for a 3-4% improvement. It is more important for the traction battery to have an increased energy density and a reduced cost than to have a slightly higher energy efficiency (see section 9.4). Much of the efficiency of the battery is dependent on the way in which it is charged, so it cannot be considered in isolation from charger technology and charging regimes. Much effort has recently been devoted to battery design, and room for improved efficiency is small at around 2-5%. Taking all these figures together the two transport systems can be re-compared. This is shown in fig 3.2.

Although primary energy efficiency is important in light of the global energy problem, it is only one criterion by which to measure the desirability of EVs with respect to energy. As shown in figs. 3.2 and 3.3, under favourable circumstances, the EV is likely to be more efficient in primary energy usage than the ICE burning oil-type fuels which have been synthesised from coal. Efficiency figures, however, disguise the fact that EVs incur a weight penalty of 1.5 to 2 times that of a similar ICE vehicle. There is an associated increase in the energy use per mile.

However, LCEVS and Bedford demonstrated as early as 1979 that their prototype electric delivery van was still more efficient in primary energy use than the petrol version, even allowing for the weight disadvantage [18].

FIG 3.2 Comparative efficiency calculations for the use of different primary fuels for tractive effort

Sources - Energy World Aug/Sept 84 p22
- SAE paper 800109 p2
- Energy World Dec 1982 p2-11



The case for the EV rests more on fuel substitution than on energy efficiency. The EV still presents the opportunity to diversify the fuel base of transport from oil to coal, nuclear or renewable sources. Indeed the natural sources of alternative energy like wind, waves, tides, solar thermo-electric and solar photoelectric collectors all produce mechanical/electrical energy which can be used efficiently in batteries or similar storage devices, but not so efficiently to make synthetic fuels resembling petrol. In remote communities like the islands of Scotland where EVs may be successfully utilised, there is a relative abundance of certain renewable energy sources and these could possibly be used very successfully alongside an EV population. The relative abundance, the cost of production and the opportunity cost of possible transport fuels must be considered in addition to primary energy efficiency. It would not be advisable to base an energy policy simply on efficiency grounds as this lays little importance on the 'premium' attached to certain fuels for specific uses. Even if the EV energy efficiency was poorer than the ICE, a small sacrifice in primary energy usage would release oil from the transportation sector and this must be one of the EV's greatest attractions from a national economic and political point of view.

3.3.5 CENTRALISED GENERATION

In a typical one tonne ICE driven at 30 mph, about 6Kw drives the road wheels and 25Kw heats the atmosphere [14]. By shifting from oil to electricity as a transport fuel there would be an associated shift to centralised generation of electricity. Although there is little possibility of recovering any of the waste heat from ICE vehicles, much of the waste heat can be recovered from central generation plants and a move away from burning fuel in ICEs towards burning fuel in central generating plants allows some of the waste heat to be recovered. Any recovery from power plants increases the overall efficiency of primary energy use and adds weight to the case for EVs. This extra efficiency however would only be achieved nationally if district heating or smaller combined heat and power (CHP) schemes are applied on a large scale. Many of our existing power stations are located remotely from centres of population, which makes heat distribution uneconomical. Small localised CHP schemes are more likely to be an attractive proposition. The need to improve the efficiency of transport energy use and the efficiency of electricity generation can be seen therefore as complementary and interrelated aspects of urban area management and development. The case for CHP in the UK is examined in detail in the Marshal Report [18] which looks at the relative efficiencies of electricity generation, heat production and combined heat and power. The report shows that, with CHP, although there would be a reduction in the efficiency of electricity production of about 10% compared to the present system, there would be a further 53% utilisation of heat which would otherwise be wasted, to give an overall efficiency of

78%. If these figures are extended to the operation of EVs and assuming that the figures for transmission, battery storage and traction are the same as in the previous example, the primary energy efficiency of battery electric vehicles becomes 59%.

However, the use of CHP together with EVs is possibly incompatible with one of the other expected benefits associated with EVs, namely that charging during off-peak periods will help to level load. With CHP stations, the off-peak situation is not so pronounced, especially if there is heat storage available, as some of the power from the steam turbine plant could be switched to heat production at night. Also, although EVs can make use of off-peak electricity both diurnally and seasonally (because of the summer peak in transport), this must be examined in relation to the demand for heat. Unless CHP stations are designed to allow variations in the heat to power ratio, the overall efficiency of operation may be reduced. The optimum conditions for the economic operation of district heating schemes are,

- High density housing. In particular it is less expensive to connect large apartment blocks than individual houses to district heating networks.
- New developments. Pipeline laying is cheaper at this stage of development and causes less inconvenience.
- Large networks, having a high proportion of buildings within the network area connected. This is difficult to achieve without comprehensive planning and restriction of choice.
- Operation for long periods at full load without short severe peaks in demand. The UK climate is ideally suited, with its long but moderate winters.
- Fairly steady demand. In this respect industrial consumers are preferred to housing.

The use of EVs in urban situations, where transport is limited and daily mileages low, could theoretically be developed profitably in conjunction with CHP or district heating schemes. In remoter areas such as the islands however, with a scattered population, the distribution of heat becomes less feasible. This does not however rule out the possibility of locating plants close to densely populated areas and transmitting the electricity to the remoter areas. Indeed this is what happens already in many situations in order to take advantage of the economies associated with large scale production.

3.3.6 OPPORTUNITIES FOR BRITISH INDUSTRY

While there may be no immediate market or need for EVs, and although current UK interest in the technology is mainly related to future transport policy, it is significant that public funding for EVs is primarily being provided by the Department of Industry. The House of Lords Select Committee on Science and Technology stated that it considered EVs to be a major opportunity for British industry [19]. It pointed out that even although the ultimate market in the UK may be relatively small, the export market is likely to be substantial because countries like Japan and the USA are more vulnerable to interruptions in oil supply. The UK has had an acknowledged world lead in EV technology and operating experience because of its history of EV manufacture and use. This lead may be steadily eroded unless efforts are maintained to progress as fast as possible. Moreover, foreign EV industries will probably evolve, capable of competing successfully in the British market if and when it grows. The UK will therefore become dependent on imported technology if our own industry is not competitive.

3.4 POLLUTION AND ENVIRONMENTAL ISSUES

3.4.1 INTRODUCTION

One stimulus to renewed EV research and development has been the increased environmental awareness and pressures in most industrialised countries during the last decade. The substitution of part of the present ICE fleet of vehicles in our country by EVs would have a variety of environmental effects and would result in changes to the levels and types of pollutants emitted. Vehicle exhaust fumes may be reduced but this benefit would have to be weighed against the possible increase in pollution from the power plants where the recharging electricity is generated. In addition, there may be changes in the pollution from production and scrapping of vehicle batteries.

3.4.2 ROAD TRAFFIC EMISSIONS

By employing EVs, the amount of traffic exhaust fumes getting directly into the breathing atmosphere will be reduced. EVs do not emit exhaust fumes and this benefit would have the greatest impact on urban areas where traffic is great and generally slow moving. However, even in forest and rural areas it is now known that heavy traffic can produce sufficient pollutants to destroy vegetation. ICEs are known to emit more carbon monoxide and hydrocarbon pollutants when the engine is not up to running temperature [11]. City driving, with its relatively short distances represents a case where there is a high proportion of 'cold start' motoring and so the levels of emission can be many times higher than under other types of driving. Densely populated areas may benefit most from EVs in this respect. In addition there would be an expected reduction in the amount of pollution from spent lubricating oils and the seepage of this into rivers and seas. As ICE technology advances however, it is probable that the levels of emissions from them will be reduced, thus reducing the advantages of the EV. Toxic exhaust emissions can be reduced by catalysts, exhaust gas recirculation systems, more advanced lean burn engines or by electronic shut-down of the engine during stand still and slow down phases. Whatever the advances, they will be costly to install however and this will help the economic case for EVs. In addition, the ICE will probably never be as pollutant free as the EV, so any substitution would lead to cleaner air, especially in built up areas.

3.4.3 POWER STATION EMISSIONS

By shifting the burning of oil fuels from millions of small localised generators (i.e ICEs) to larger centralised power stations, the problems of pollution control would also be centralised. This could make it easier for emission control measures to be implemented effectively. The impact on the environment is dependent on the type of power station used. if conventional thermal stations are used, there will be increased emission of nitrogen oxides, sulphur oxides, carbon monoxide and dust. The control of centralised emissions from these power stations has also advanced as effort has been specifically directed towards solving some of the problems. Possible control measures include flue gas cleaning, advanced firing techniques and dust separation. These measures could permit significant reductions in toxic emissions. Even without additional control there are still good environmental reasons to move to centralised generation.

- The amount of carbon monoxide is insignificant, especially since it is so rarefied in the atmosphere that it has little toxic effect [11].
- The sulphur and nitrogen oxides are many times more concentrated if they are emitted by vehicles at street level rather than at the higher levels represented by power station chimneys. High level emission reduces the immediate harmful effects to humans and buildings, but unfortunately such emissions will be carried in the atmosphere over long distances and can cause damage to the upper atmosphere and to life elsewhere. Acid rain and destruction of the ozone layer are two such long term effects. Of course it still easier to control emissions from a smaller number of centralised sources.
- Because of the load levelling effect caused by EV battery charging, a larger proportion of electricity generation can be switched to base load generation. This gives greater potential for nuclear and hydro sources to be used. Of course these forms of generation have their own associated environmental costs, but they do not emit the same toxic substances as thermal power stations or ICE vehicles. In the case of coal fired power stations a more even load allows a better

combustion ratio to be achieved, thus reducing emissions, and it has been suggested that a more even daily load would reduce the need to transmit electricity over large distances, thus reducing transmission losses and the ratio of consumption-related emissions [11].

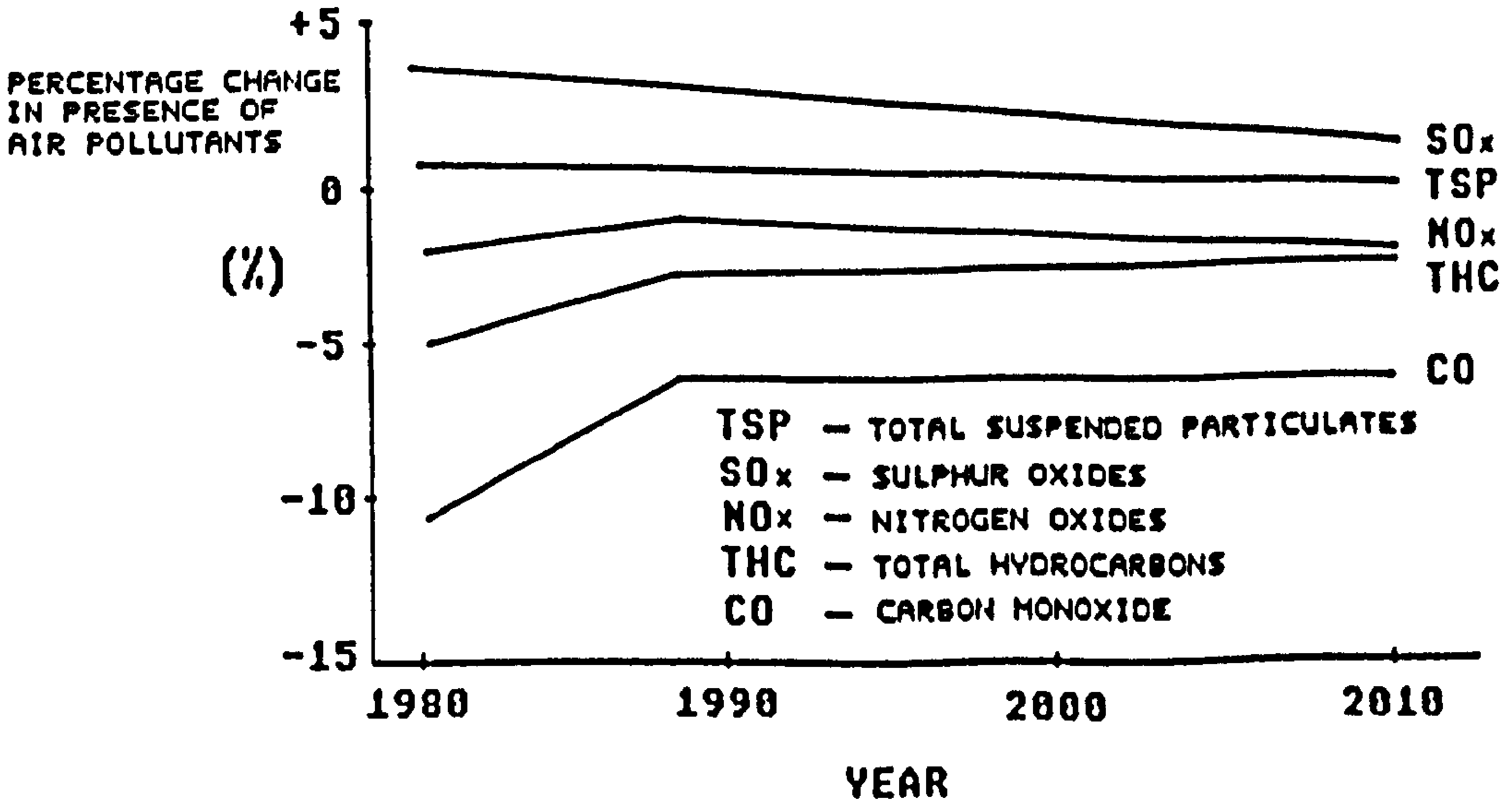
3.4.4 THE BALANCE OF TOXIC EMISSIONS

Any predictions of the changes in air quality as a result of a shift towards EVs are very dependent on the assumptions made concerning the political will to control emissions from either source. The particular pollutants will also vary depending on the fuel burning equipment used. Estimates of future air quality and the changes due to EVs were made by the Regional Emissions Projection System (REPS) - a computer model originally developed by the US Environmental Protection Agency and then improved by the General Research Corporation. Although the figures relate to the 24 most populated air quality control regions in the US and the base year for emissions data was 1975, the general patterns of the changes in air quality that could be expected anywhere are probably quite valid and are shown in fig 3.3 [20].

Fig 3.3

Percentage change in air quality with 20% electrification of light duty vehicular travel from 1980 (USA).

(source - reference 20)

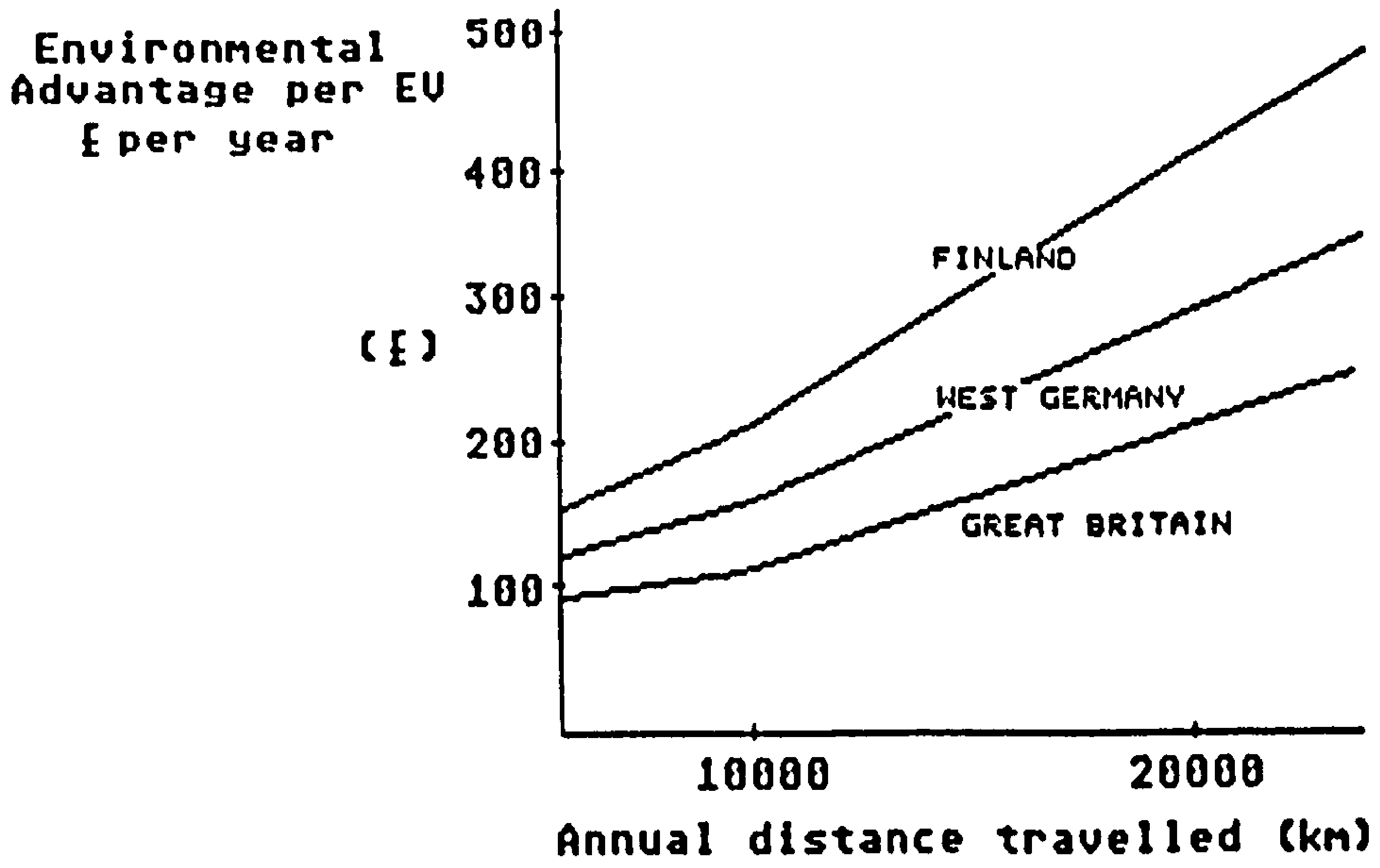


The general trend is one of significant initial impacts, tapering off to modest levels by 2010. This is primarily due to the fact that legal standards for both power plants and conventional ICEs will tend to reduce the potential effect of a changeover to EVs on air quality. A similar study was undertaken by the Commission of European Communities [11] which tried to put a monetary value on the expected environmental benefits of EVs for each of the participating countries. Results are shown in fig 3.4.

Fig 3.4

Environmental advantage of a one-ton electric van in three different European countries

(source - reference 11)



The report pointed out that different expected benefits came about as a result of the differences in mix of power stations, fuel prices and emission controls and that these could be expected to vary over time thus changing the monetary benefits.

3.4.5 POLLUTION FROM OIL REFINERIES

The use of EVs would hopefully bring about a reduction in the consumption of oil. If less mineral oil is produced and distributed, there would be a corresponding reduction in the level of toxic emissions from refineries and in the distribution process.

3.4.6 NOISE POLLUTION

EVs are quieter in operation than conventional vehicles the noise of which predominates in urban locations. It is difficult and expensive to reduce the noise emission of conventional vehicles. However it is the noise from heavy lorries and buses which constitutes the greatest nuisance, so the electrification of cars will not make a great impact until there are fewer ICE lorries and buses in areas with heavy traffic flows. The contribution of electric cars would be more significantly felt in areas where there are fewer heavy vehicles or in areas where they are not permitted. EVs would retain a large noise advantage in city centres, residential areas, rural areas and other areas from which heavy noisy vehicles are barred or into which long-range heavy lorries seldom have occasion to go. Of course it can be argued that such areas are the least affected by noise pollution in any case and therefore effort should be directed to those areas which do suffer from excessive traffic noise. Noise pollution cannot seriously be regarded as a problem in the island communities studied in this report but it is nonetheless a significant factor in favour of national development.

3.4.7 POLLUTION IN PRODUCTION AND DISPOSAL

The vehicle shell for EVs is unlikely to exploit any different technologies from the conventional ICE vehicle in the short run, and long run developments are likely to affect both types of vehicle equally. However, the manufacture of large quantities of lead-acid batteries could give rise to emissions of powdered lead. This would have to be controlled by legally enforced safety measures.

Disposal of EVs and their batteries could give rise to further environmental problems if it is not carefully planned. (This issue is discussed more fully with respect to the Scottish islands in chapter 8). Such problems as the disposal of sulphuric acid and the collection and recycling of lead should be balanced against the reduction in environmental damage from the ICE, e.g water pollution by lubricating oils. The EV is expected to have a longer operating life than the ICE (section 9.2.4) and could therefore be expected to cause less of a problem of disposal in terms of the volume of vehicles needing to be disposed.

3.5 SUMMARY AND CONCLUSIONS

There are clear advantages to be gained in our society by substituting part of the present ICE vehicle fleet with electric vehicles. These advantages lie primarily in the fields of fossil fuel displacement and conservation, in environmental cleanliness and industrial competitiveness. However, from the arguments presented in this chapter, it can be seen that at present these advantages accrue primarily to society at large and not to the individual operator. It would therefore seem to be in the best interests of society as a whole for the Government to transfer some of these benefits to the owners thus sharing the potential advantages between the individual and the community. Such measures could stimulate demand in advance of the day when the options are more restricted due to oil shortages or environmental pressures. Similarly, Government attempts to encourage EV development and manufacture may stimulate international interest in EV usage, and lead to earlier introduction as well as opportunities for UK industry (see summary of House of Lords Select Committee recommendations, paragraph (a) in appendix 9).

The impact and proximity of future impending problems is often underestimated. A sense of urgency with regard to energy, oil and the environment is needed so that the necessary research, development and investment is forthcoming at an early stage. Forecasts of remaining oil resources vary and there is little certainty surrounding the future of oil supply. There may be significant oil resources which remain undiscovered as yet and shortage in supply may still be many years in the future, however, EVs offer the potential to diversify the energy used in the transport sector in the face of uncertainty. The lead times involved in such a major technological and sociological change as that of EVs may be considerable, and action should be taken while there is still a relatively cheap and plentiful energy supply available which will allow a sustainable transport system to be developed.

CHAPTER 4

AN APPROACH TO THE MARKET: MANAGING THE DIFFUSION

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4.1 INTRODUCTION TO "A MARKETING APPROACH"

4.1.1 BACKGROUND

The last two chapters have examined the technology surrounding the electric vehicle and the environmental, industrial and energy related arguments for developing the technology. It has been shown that the high performance EV offers certain advantages and benefits to society as a whole, and that the Government has good reason to be concerned with, and involved in, its development and diffusion. The current position is one in which the technology is already advanced enough to be suitable and cost effective for certain applications, but in which there has been little commercialisation and market introduction. There needs to be a link between the technology and its application, and this requires the management of the innovation diffusion process.

While this study employs a multi-disciplinary approach to the examination of electric vehicle applications, including such approaches as environmental impact analysis and computer modelling and simulation, this chapter is concerned with the role, importance and application of a marketing approach to the diffusion of this particular innovation. Much can be learned from the study of the innovation diffusion process which will help in the establishment of an optimal strategy for the management of the diffusion of EV technology.

4.1.2 A MARKETING APPROACH

There are numerous definitions of marketing, and often a particular definition reflects the interests of the individual. Some definitions take a rather narrow view which reflects the interests of the firm, while others take a broader view incorporating the needs and wants of consumers. When examining a major technological innovation like the electric road vehicle, a narrow view of corporate marketing is not sufficient to describe the activities involved and the nature of the process of diffusion. It would ignore the significance of such wider issues as energy policy, environmental pollution and resource availability which are the important incentives for developing the technology. For the purposes of this study, concepts from both marketing theory and the theories of the diffusion of innovations will be applied. Marketing theory focuses attention on the needs and wants of potential consumers and ways in which these can be adjusted and fulfilled, while diffusion theory gives a framework for examining the way in which an innovation can be expected to be adopted and identifies the factors and groups of people which affect the rate and extent of adoption. The 'marketing mix' is often defined as the action and interaction of the variables - product, price, physical distribution, channel of distribution and promotion [1]. It is this marketing mix which constitutes the total "product proposition" and which provides the basic opportunity to satisfy customer wants and needs. These factors and their interactions are examined in this chapter.

4.1.3 THE IMPORTANCE OF A MARKETING APPROACH

The problems of marketing electric vehicles is often ignored by developers and researchers in the EV and related industries, yet marketing is one of the most important dimensions in the successful introduction of the technology to every day life. Some of the reasons why the relevant industries, Government and researchers should adopt a marketing oriented outlook are,

A. TO RECOGNISE CONSUMER NEEDS

The future of electric road vehicles depends largely on their acceptance by private and industrial consumers. The EV industry must develop a sound understanding of consumer needs for personal or commercial modes of transport. These needs can be seen as falling into two distinct categories; firstly, functional needs which include vehicle performance, initial cost, payload, range, operating costs and so on, and secondly psychological needs, which include status, image, social participation, and so on. EVs can be thought of as having functional and psychological attributes and developers must try to match these attributes to consumers' needs. The combination of both functional and psychological factors in the light of existing energy and environmental pressures and trends point to a number of possible markets for EVs. These markets must be clearly identified and examined to determine the specific characteristics that the EV must have in each of these segments in order to satisfy the functional and psychological factors. The development and specification of the functional attributes and needs can be achieved firstly by examining current use patterns, and secondly by exposing the product to consumers so that they can test the product under those conditions which they consider to be relevant. In the context and limitations of this particular study, collection of data is confined to the direct observation and recording of travel and use patterns. The psychological factors such as perceptions, attitudes and preferences can be evaluated firstly by observing and interpreting current buying habits, and secondly by introducing people to the product and questioning them on their reactions and attitudes. This project attempts to undertake such a study. By carrying out such an analysis the EV industry should be able to identify suitable markets and provide a sufficient set of options for consumers to choose from so that they become comfortable with the new product.

B. TO STIMULATE COMMERCIALISATION

Traditionally the EV industry has concentrated on the functional attributes of the technology and has neglected the psychological needs of potential consumers. This is hardly surprising in the early stages of research and development in such a highly technology led area. The pressure behind EV development is not directly attributable to 'market pull' forces because motorists are not yet looking for anything other than the conventional ICE. The development is largely a case of 'technology push' with encouragement from Government and long sighted organisations in the light of impending energy problems. The industry has been predominantly engineer-oriented, and technical managers may be striving to introduce EVs that represent a much higher level of performance and technical sophistication than the marketing managers are asking for on behalf of the relevant customers. One suspects that in reality even the marketing managers still do not know what the real needs of the potential customers are. This is a relatively common problem in the new product development effort. The resolution of the problem is a function of the orientation of top management and Government. A market orientation will call for the 'freezing' of the product at a particular point in its development process and its introduction onto the market. While this product is on the market, the technology can continue to be developed so that a second generation is prepared for introduction. The EV industry is still in the first phase of development. There is a viable product for certain applications at the present time but there is still a very strong dependency on the technological improvement effort. Everett Rogers identifies six stages in the innovation-development-diffusion process [2],

-Recognising a problem or need
-Basic and applied research
-Development

-Commercialisation
-Diffusion and adoption
-Consequences

The EV industry has certainly reached the development stage but the commercialisation stage has been slow to materialise. Obviously there is little point in commercialisation before a credible product has been developed, but it is argued throughout this thesis that a product does already exist even if it is only suitable for certain applications as yet. In the words of the president of the US Copper Development Association,

> "The industry must move the research and development effort from the shop floor to the street and let the EV customer determine whether or not the vehicle is acceptable .....this will require that the EV change from being engineer-oriented to being mission-dependent. In other words, the mission should determine the future development of specific EVs" [3]

A marketing approach is essential in order to realise the technological capabilities as it is only by offering the potential of commercial or economic success that the research will continue in the long term. There must be an application for the advances. There is another similar danger associated with the neglect of a marketing approach. If the technology is not 'frozen' and developed for sale convincingly, the market will tend to hold back in the expectation of more advanced vehicles in the near future. This is a common problem with any new technology but it is very real and calls for a sensible marketing approach which presents the vehicle with its present capabilities as the answer to the current transportation needs of certain market segments.

C. TO REDUCE RISKS

Plans for the large scale introduction of EVs without a marketing strategy are likely to be unrealistic and high-risk. Experience to date shows that attempts have failed for this reason. Sinclair is reported to have neglected this important element (see section 1.4.4) and the entire USA Government programme resulted in very little in the way of market introduction because of its emphasis on the wrong market segments (section 1.5.2). Developers and Government will both reduce risks if they recognise the fundamental requirement of a marketing approach.

D. TO AVOID PREVIOUS MISTAKES

In an article entitled "Challenges Facing Domestic Car Dealers in EV Markets" [4], the author, a car dealer for General Motors, suggests that a marketing approach is essential for dealers and producers in the future in order to avoid the many pitfalls that have beset the domestic automobile industry in the years since World War II. He points out that the EV industry can benefit from this experience and will now be in a position to use successful time-tested techniques of marketing, distribution, production, consumer relations and dealer development. These are tools, now available to the industry, which will enable it to identify and exploit opportunities and "get it right this time".

E. TO TAKE ACCOUNT OF THE LIKELY PATTERN OF DIFFUSION

It is important that an EV marketing strategy is developed which takes account of the likely pattern of diffusion of the technology. Experience indicates that EV market penetration will be progressive, as users gain experience and confidence. Plans which assume that EVs can be manufactured and marketed on a large scale in a very short time misjudge the nature of the product and the market. A realistic marketing analysis and orientation is important to avoid this type of mistake. A marketing strategy should assume progressive sales growth, and plan for a gradual build up of production and sales volumes. This point is crucial to a realistic understanding of the technology and its potential.

F. TO STIMULATE ACTION IN THE MARKET PLACE

Unless there is direct intervention, disruption or some other unexpected occurrence, people are slow to change their buying habits. It takes a long time to gain confidence in a new product, and when the product is a substitute or replacement technology it has to offer significant advantages in order to be accepted sooner rather than later. Newton's first law states that a body will continue in its state of rest or of uniform motion in a straight line unless acted upon by a force! The same can be claimed for the market place, and the larger the state of momentum or inertia in a market the greater the force will have to be in order to cause change. A marketing approach should be adopted in order to optimise this changing force and to initiate its application in good time.

G. TO NURTURE FAVOURABLE PUBLIC PERCEPTIONS AND OPINIONS

It is commonly claimed that EVs have attracted favourable public opinion in the past but whether this is the case or not, favourable perceptions can be quickly dissipated if the EV industry attempts to market inferior, inadequate, irrelevant or unrealistic vehicles. A sensible and effective marketing approach needs to be adopted in order to prevent such a mistake being made. False or misleading promotion like that which preceded the launch of the Sinclair C5, improper sales techniques at the retail level or weak service facilities can all produce strong negative perceptions for the entire industry. A negative experience with one innovation can also seriously jeopardise the adoption of future innovations. Arensberg and Niehoff referred to this as "innovation negativism", the degree to which an innovation's failure conditions a potential adopter to reject future innovations [5]. When one idea fails, potential adopters are conditioned to view all future innovations with apprehension. As mentioned previously, developers need to determine the needs of consumers and design the vehicle to suit those needs within the limitations imposed by the technology. The technology should then be taken out of the laboratory and into the showroom but only when the time is right and when there will not be masssive negative repercussions. A sensible marketing approach is needed to minimise this risk. For all of the above reasons, a marketing orientation and awareness should permeate the process of research, development and marketing of electric road vehicles and such an approach is adopted in this study.

4.2 MARKET SEGMENTATION

4.2.1 A DEFINITION

Segmentation of a market can be defined as "the process of breaking up large, heterogeneous groups into more homogeneous target audiences" [1]. The aim is to identify specific groups of people who exhibit similar characteristics or needs and who would seem to be suitable candidates for a direct marketing effort.

4.2.2 REASONS FOR SEGMENTATION

There are several important reasons why market segmentation should be attempted,

A. ACCEPTANCE OF THE NATURE OF EV DIFFUSION.

As mentioned previously, any development plan which assumes that EVs will be widely or universally accepted and used overlooks the real nature and potential of the product. It is reasonable to suppose that EV market penetration will be gradual and progressive as users and public gain confidence. Also, as the technology advances and new generations of vehicles are built with greater capabilities, and conventional fossil fuels rise in price, the market for EVs will expand in incremental steps as more and more applications fall within the functional capabilities of the vehicles. To segment the market shows an understanding and acceptance of the nature of the diffusion process in this case.

B. TO STIMULATE AND INITIATE THE DIFFUSION PROCESS

Past research has generally shown that the adoption of an innovation follows a normal, bell-shaped curve when plotted against time. If the cumulative number of adopters is plotted against time, the result is the familiar 'S-shaped' curve [2]. The initial period of adoption exhibits a slow, gradual increase in the rate of adoption. Baker [6] states,

> "The significance of a theory of diffusion lies in the prediction that once initial adoption has occurred diffusion will follow, given the existence of the necessary enabling conditions, and exhibit an S-shaped growth curve. This process may be compared with a chain reaction in which a catalyst is necessary to initiate the process which, once started, will proceed independently in an exponential manner"

By segmenting the market and targeting marketing effort on the most suitable applications, the process described by Baker may be initiated. By finding suitable applications for electric road vehicles, the adoption process can get underway, thus providing a base to work from and develop the technology further. Segmentation will continue to be necessary at future stages in the adoption process but in the short term it will help to provide the initial spark that will allow the industry to gain a successful foothold. In the early stages, EVs will not be suitable for the mass private vehicle market, or perhaps the truth is that they will not be acceptable or desirable at first, and so specialist applications will have to be targeted where the vehicle is most likely to be suited and accepted. It is important for reasons of future international competitiveness that our country maintains its historic lead in the areas of EV technology and user experience. Also, if the industry is not kept functioning in the short term by producing for specialist applications, there will not be a product to improve or a test bed available for future developments when conditions necessitate the diversification of our transport base away from oil. It is very true that many present applications will never be able to use the type of EV that represents the current state-of-the-art and that advanced battery systems will have to be developed before these applications could use EVs. If however there are no EVs being produced and used there will not be a suitable test bed for new battery systems. The House of Lords Select Committee on Science and Technology recognised this need to develop a base and start the adoption process by segmentation. The Committee stated,

> "The country must....lay its plans now for alternative methods of transport in the post oil years....investment is needed now" [7]

The Southern Electricity Board was one of the first major fleet users of high-performance electric vans in this country and a report by the chairman stated,

> "If we do not get proper real-life experience now, there will be nothing to build on when the technology makes a cost-competitive vehicle available" [8]

The author also points out that there will be a tendency to wait for new developments and technological advances before people commit themselves to purchase but he claims that it is a false approach to wait for a "great one day". "The position is urgent enough for us to get on with the job now". We are in a "chicken and egg" situation where manufacturers need orders to justify production and to reduce manufacturing costs but consumers are waiting for these cost reductions and improved performances before purchasing. Government market entry assistance can certainly help (see section 4.5) but so can careful segmentation of the market where suitable applications are sought and cultivated in order to give the technology a foothold in the early stages of adoption.

C. TO IDENTIFY TARGET PEOPLE AS WELL AS TARGET APPLICATIONS

Diffusion theory not only allows us to identify the stages involved in the adoption process but it also attempts to identify the groups of potential customers involved. Not all individuals adopt an innovation at the same time. Rather, they adopt in a time sequence and Rogers [2] suggests that it is possible to categorise individuals on the basis of when they first begin to adopt the idea. He classifies adopter categories on the basis of "innovativeness" - the degree to which an individual is relatively earlier in adopting new ideas than other members of a social system. Rogers points out that innovativeness is a continuous variable, and partitioning it into discrete categories is only a conceptual device, much like "dividing the continuum of social status into upper, middle and lower classes". This type of segmentation is important because it allows the most suitable groups to be targeted, thus once again helping to speed up the entire adoption process. Rogers' commonly accepted categorisation states that the first 2.5% of adopters can be called 'innovators'. They are characterised by their venturesomeness and ability to deal with high levels of uncertainty. Financial resources are also a general prerequisite as is a willingness to accept the occasional setback. The next 13.5% of adopters are the 'early adopters' who are characterised by their 'respectability' and general acceptability in society. They are the most influential category in the diffusion process. Rogers refers to this influential attribute as 'opinion leadership'. Other categories contain the 'early and late majorities' and the 'laggards'. It is the first two categories however that the EV industry should be concerned with at this stage as they represent the people who are most likely to adopt EV technology first and lead the way. The industry should learn to identify them and develop effective means of reaching them. Once again this is the job of marketing. Baker [6] suggests,

> "It is logically defensible to suggest that certain prospective users will have a stronger incentive to adopt early. Hence, if one could identify in advance those potential users so predisposed one could concentrate one's marketing efforts on this most receptive sub-segment, thereby achieving initial sales more

> rapidly than would be the case if a random approach were followed which presumes that all prospective users are equally likely to adopt first."

The first sale is a crucial element in successful commercialisation. It can be the spark that starts the fire and so it is important that maximum benefit is gained by ensuring that the most suitable person or persons are targeted. This could help to accelerate the whole process.

D. TO ENABLE GREATER CONSIDERATION FOR THE NEEDS OF SPECIFIC SEGMENTS

By paying particular attention to suitable target segments in the early stages it should be possible to give greater attention to user requirements. This should result in increased overall benefits of EV operation to users and stimulate a more rapid growth in EV population (see sections 4.3.1 and 4.3.2)

4.2.3 LOGICAL TARGET SEGMENTS

The reasons for applying a marketing approach and the necessity for market segmentation have been discussed, so this section asks the question - which segments should the EV industry be aiming at?

A. COMMERCIAL VEHICLES AND DELIVERY VANS

In the motor industry, big production lies in the private car; commercial van production is not as large. This has led to a difference in approach to development in different countries. The USA demonstration programme aimed to develop vehicles suitable for private transport uses. Understandably, the administration was lured by the huge size of the potential market but it turned out to be an unwise strategy in terms of the initiation of the innovation adoption process. This strategy was in keeping with history, in that individual developers of the ICE vehicle concentrated on personal transport. Vans and trucks came later.

In this country the serious development effort has been directed largely towards the commercial market as a short to medium term strategy.

The relative size of the passenger car market, and its greater ultimate volume are fully recognised, but electric commercial vehicles are regarded as a logical necessary starting-point for the following reasons,

1 The type of duty cycle common to urban delivery vans and trucks is generally more compatible with the capabilities of present EV technology than the passenger car. Daily mileages tend to be more regular and less variable in length. Domestic cars are subject to a great variety of uses. The same car may be used for shopping, commuting, holidays and other leisure activities. There is also great variety in use patterns from one vehicle to another. On the other hand, a large number of commercial vehicles operate on a daily duty-cycle within the range of an EV. Department of Transport statistics show that over 90% of the daily use of light goods vehicles requires a range of less than 60 miles [9]. However this says nothing about the range requirements of the individual van.

2 The vehicle is normally used in an urban environment with frequent stop-start applications. EVs are commonly accepted as being operationally suited to this type of use; they consume no energy while stationary at traffic lights or road junctions and so on and average speeds are relatively low. The EV's greatest relative advantage can therefore be exploited.

3 It is still difficult to package the mass of lead-acid batteries and EV drivetrain into a small passenger car without structural modifications to an existing ICE vehicle, or by employing a "ground-up" design where the vehicle is purpose built. This implies costly manual assembly or significant capital investment. On the other hand, a light van or truck is large enough for the electric drive system to be packaged in an existing shell.

4 Commercial vehicles are normally operated from a fixed location in a clearly defined area, permitting their operation to be easily monitored

and supervised.

5 The typical higher first cost associated with EVs is more likely to be a barrier to private purchase, whereas a commercial organisation is more likely to be influenced by whole-life ownership costs.

6 The risks involved in EV development and commercialisation are likely to be less in smaller, more specialised production runs. In this country there is already a viable electric truck industry which is progressing in its own sphere, and a move towards commercial road vehicles builds on this experience and market.

7 There are several distinct reasons for aiming at fleet users,

- With a fleet of vehicles there is more possibility of reorganising duty cycles and reserving some duties for limited range electric vans.
- Size and purchasing power is greater and several EVs could be sold to one operator. Greater sales can be expected for the same level of promotion.
- There is a heavy emphasis on efficiency and economy.
- Fleet users are likely to act as leaders in using innovative transport alternatives, thus creating an example to follow.
- Service arrangements can be tailored to suit fleet locations, for maximum effectiveness and minimum cost.
- New service and maintenance procedures are easier to implement and control within a transport organisation than within the private car sector.

8 Lucas Batteries Ltd reported in the early stages of their development programme, before they joined forces with Chloride, that they had noticed that fleet operators were prepared to accept a portion of the additional financial cost in order to participate in the development programme [10]. Lucas argue that this premium which has been accepted in the early stages of development demonstrates the support for electric vehicles within the commercial sector in the UK.

9 Although the number of commercial vans in the UK is a tiny fraction of the domestic car market, a larger proportion of delivery vans and commercial vehicles make suitable candidates for replacement by electric vehicles. The Southern Electricity Board estimates that there could be a total market for up to 750,000 commercial vans in the UK [8], while

LCEVS, using a much more conservative basis of estimation, claimed that the annual demand could reach 13,000 vehicles per year. This market segment is therefore significant and could greatly assist in the initiation of the adoption process and further commercialisation.

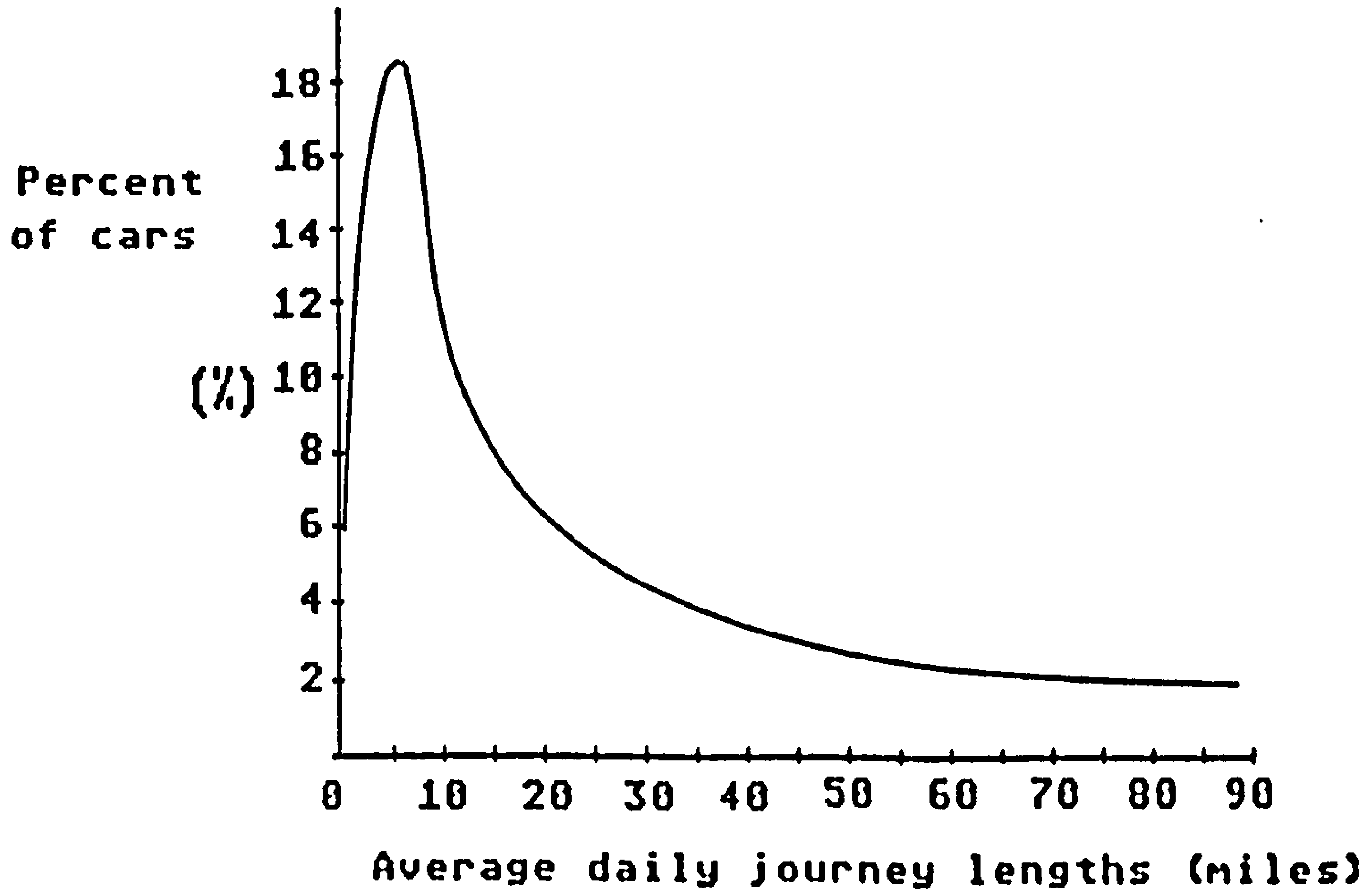
It is clear that electric delivery vans and trucks cannot by themselves significantly reduce national road fuel consumption or environmental pollution because of the relatively small numbers involved. To achieve these ends and to demonstrate that electric vehicles are a sensible strategic option, electric passenger cars must eventually be commercialised. However the UK Government has recognised that the development of practical electric vans is a logical first step towards the future introduction of electric cars on a large scale [7].

It was for the reasons listed here that LCEVS decided to pursue the development of electric drivetrains for commercial vehicles. Their objective was to place an increasing number of vehicles in service, so as to establish an effective manufacturing and service base. They adopted the philosophy that small-scale production was necessary in the short term to create the right conditions for rapid sales growth when a cost-competitive vehicle becomes available. The UK Government agreed to support LCEVS by subsidy during the period 1981 to 1986 after which LCEVS expected to reach cost parity with their electric versions. Unfortunately their major participant, Bedford, had to pull out in early 1986 and so plans have been significantly disrupted. However it is argued here that the approach was sound and that it still remains the most suitable strategy for the future.

B. URBAN DOMESTIC VEHICLES

It has often been suggested that the ideal market for electric vehicles is the urban passenger car, and sometimes this has been narrowed down to mean the second or third car in a household. The reasoning behind this assertion hinges on the typical daily mileages covered by such vehicles. The Department of Transport claims that 93% of all cars travel less than 60 miles in any given day [9]. (These statistics are misleading however because they say noting of the range requirements of the individual car over a longer period of time). Fig 4.1 shows the distribution of average daily mileages for passenger cars in the London area.

FIG 4.1 DISTRIBUTION OF AVERAGE DAILY JOURNEY LENGTHS FOR VEHICLES IN LONDON



It can be seen that few vehicles have average daily mileages outwith the current range of an electric car. This argument however fails to take account of the variability in daily mileages of each vehicle. A particular car may only travel 20 miles per day for 6 days a week but on the seventh might travel several hundred miles. This largely limits the electric car to the second car market. In 1978 there were about 2.4 million households owning more than one car, representing about 5 million cars. On this basis the potential market for electric second or third cars would be around 3 million vehicles [9].

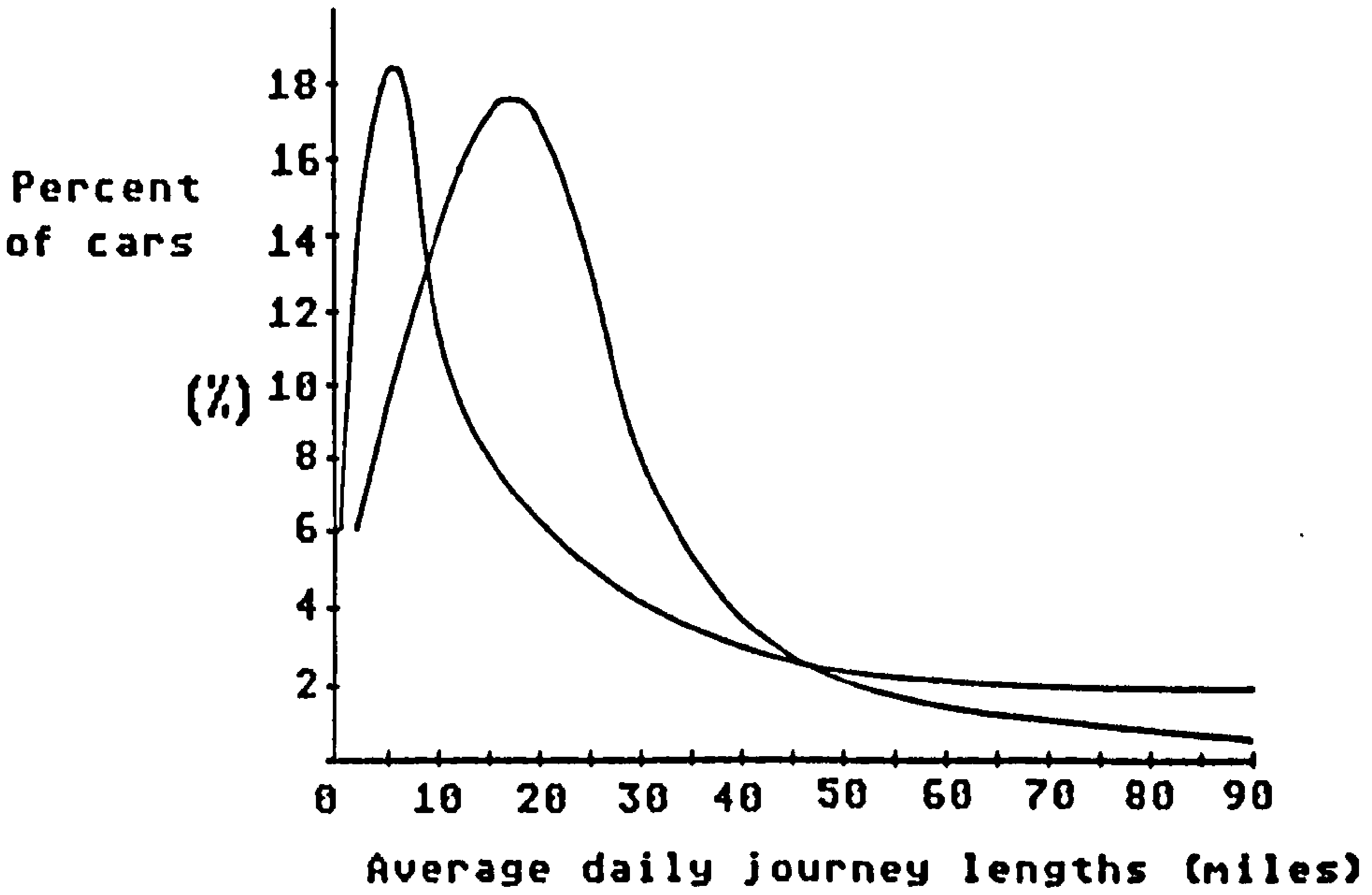
In the USA, multi vehicle households tend to use their vehicle for different functions and hence they have markedly different use patterns. In this country however there seems to be less segregation of duties between vehicles and so even the second car market is more limited. It is sometimes argued that an electric car could be bought as a second car by households who presently own only one car. The electric car is cheaper to run and so by using the EV in place of the ICE car for suitable journeys the running costs associated with operating the ICE vehicle would be reduced. This argument however overlooks the fact that the difference in running costs would also have to pay back the capital cost of the EV which is likely to be quite substantial and will probably be greater than the capital cost of an 'equivalent' ICE. It is unlikely that enough use would be made of the EV to recoup all these costs if they were an addition to the present fixed costs of an ICE. The economic case for the EV is based on the assumption that it is a replacement for the ICE vehicle and not an addition to it. The whole life costs of the EV may be less than those of the ICE but this saving is certainly not large enough to justify running an additional vehicle (chapter 9 looks more closely at the economic case for EVs). The electric car therefore has to be seen as a replacement for an existing or planned car. This being the case, it is also essential that potential purchasers should be receptive to the idea of owning an EV instead of a conventional vehicle. It is doubtful that this level of acceptance is widely present. The American experience together with that gained from the other attempts at the commercialisation of domestic electric cars would indicate that the market is still not ready for this type of product. Sinclair tried to follow a policy whereby he sought to lower consumer expectations to a level that EV technology could confidently deliver. He tried to sell a new form of transport and a fresh perception of how far and fast people actually need to travel. Fundamentally, consumers did not accept it. Greater confidence and acceptability must be nurtured in advance of such an introduction. This acceptance might be stimulated by economic conditions such as rises in oil prices, or it might be brought about by legislative measures, or it may have to be instilled through increased exposure of the technology together with the provision of adequate information and education. Once again, the argument seems to be in favour of introducing the technology in applications where there is already adequate acceptance, giving exposure to the product and demonstrating its capabilities.

C. ISLAND COMMUNITIES

This study is concerned with examining the potential of electric road vehicles for island communities. It is argued that this application offers some scope for the early introduction of EVs. It should be pointed out that while this particular study examines the case of some particular Scottish islands, the definition of 'island applications' need not be confined to geographical areas which are surrounded by water. It has been mentioned previously that the West German Government was very interested in the possible use of electric cars in West Berlin. This city is to all intents and purposes an 'island'. An island can be thought of as any location where movement in or out of the immediate vicinity is restricted for one reason or another. This may be because of water, terrain, political or legal restrictions or even cultural factors. This restriction of mobility leads to particular use patterns which are more compatible with the capabilities of current EV technology. Obviously, the smaller the 'island', the smaller will be the average daily mileages. For example, in the US, Commuter Vehicles Inc. established a small market in two very small 'island' situations - firstly as patrol vehicles in prisons and correction centres and secondly as recreational vehicles in holiday resorts. The Italian island of Capri is populated entirely by electric vehicles as there are strict regulation prohibiting the use of ICE vehicles. Similarly, in the Alpine town of Zermatt in Switzerland, only EVs and horse drawn vehicles are permitted. Zermatt is a popular holiday town and this measure is intended to reduce noise and air pollution. Tourists have to leave their cars several miles away. The taxis, commercial vehicles, private vehicles and even police vehicles are all electric. Because such 'islands' are very small, there is no need for vehicles to have very high performance characteristics. All the above applications use fairly low speed and low range vehicles. If the island is larger, as in the case of the Hebrides, the necessary range increases. The ease of 'escape' from the island is also of relevance when examining the potential for EVs. In very remote islands where few vehicles ever leave, there is more chance that a motorist will be prepared to replace an ICE with a vehicle that would not be very useful outside of the island home. There are many Scottish islands, all of which have different characteristics in terms of size, population, ease of accessibility, cultural characteristics and so on. Two islands in particular were chosen for close examination - the Island of Lewis and Harris in the outer Hebrides and the mainland island in the Orkneys. These islands along with others possess some advantageous characteristics for the use of electric vehicles which would indicate that they represent a market segment which is worthy of further investigation for the following reasons.

1 Average daily mileages are low and high mileages are rare (see section 6.7). Mileages are high enough to offer substantial cost savings to operators (section 9.3). Fig 4.2 shows the distribution of average daily mileages for island vehicles in comparison with those for London (shown in fig 4.1.) Although the average daily mileage is greater on the islands, fewer vehicles exceed the range limitations of an electric vehicle.

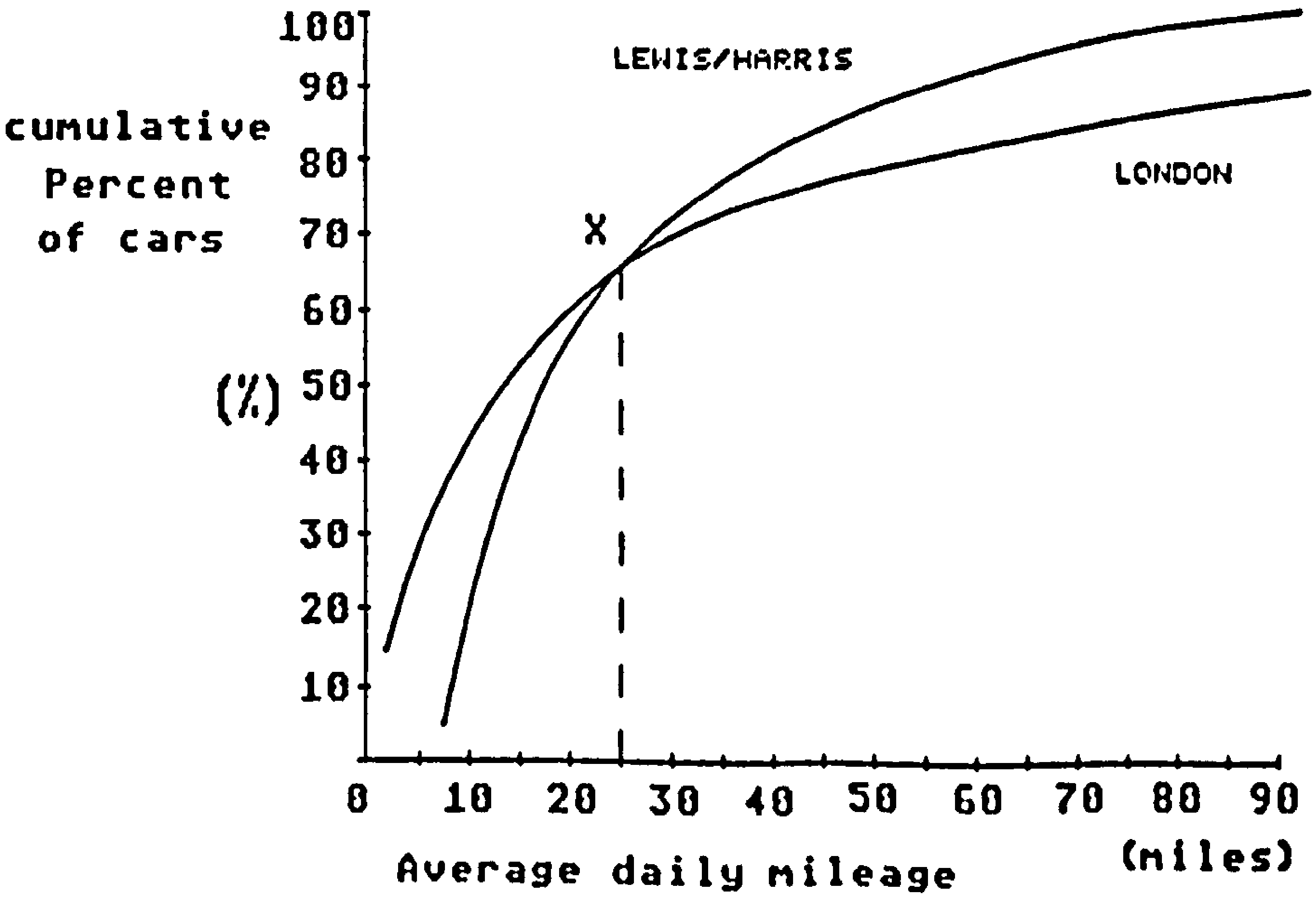
FIG 4.2 DISTRIBUTION OF AVERAGE DAILY JOURNEY LENGTHS FOR VEHICLES IN LEWIS/HARRIS AND LONDON



Rearranging this data it is possible to produce the following cululative graph,

FIG 4.3

CUMULATIVE PERCENTAGE OF CARS FALLING WITHIN AVERAGE DAILY MILEAGE LIMITS



Provided the range of the substitute EV is greater than X miles (25 miles in this comparison), there are more vehicles on the islands which are suitable for substitution by EVs on the basis of average daily mileage.

2 Transportation of vehicles to the mainland where longer mileages are generally undertaken is limited. Many vehicles never leave the islands (see section 9.4.4). This is partly accounted for by high ferry fares and partly by the cultural background. Many islanders have never left the islands and many more only leave on very rare occasions. There is not such a dependency on long distance travel and there is less of an assumption that modern life and a higher standard of living go hand in hand with increased flexibility in travel. The islands are populated largely by scattered crofting communities, and islanders can be very parochial in nature. This is an attitude which may become more widely spread as fossil fuels are depleted and transport options are restricted.

3 On the whole the islands are relatively flat although there are one or two steep hills in Harris, the steepest being around 16%. This is within the capabilities of most electric vehicles. The general flat nature of the terrain is suitable for EVs because hilly terrain necessitates the expenditure of large amounts of tractive energy, which reduces the operating range.

4 The price of petrol and diesel fuel on the islands is higher than on the mainland, largely because of transportation costs. The average price of 4 star petrol in Lewis in August 1988 was 10% greater than in Central Scotland. It is not uncommon for this differential to be even greater and this makes the economics of operating an EV more favourable (ceteris paribus) on the islands.

5 Island roads are largely single track and are very tortuous. Although there is a local authority programme of road improvements,

roads will continue to be smaller than is common in more populated areas. Island roads in Lewis and Harris all fall below national engineering standards. Driving involves much stopping and starting, accelerating and decelerating - conditions which reduce the efficiency of both types of vehicle. EVs however, consume no energy while stationary or during decelerations. Driving speed also tends to be lower as there is less opportunity for high speed cruising. Similarly there is less need for high performance vehicles with impressive acceleration capabilities. Under these conditions EVs compete well, as is evidenced by the experience of the milk float.

6 The Orkney islands are connected to the national electricity grid and plans are going ahead to link the Outer Hebrides as well (see section 7.4.3). There is therefore a ready supply of electricity at national grid prices available for charging EV batteries. Many of the smaller islands and the Shetland islands do not have this facility and electricity is generated via diesel generators. This can be very costly and diminishes the economic argument for introducing EVs. The Orkneys are also the site of experiments with aerogenerators and the islands now have several installations, some of which contribute to the national grid system. Island communities are very often rich in alternative sources of energy such as wind power and wave power and perhaps in the future these will play an increasingly important role in island energy provision. Alternative energy sources are ideally suited to use by EVs, since energy continues to be produced even when it is not needed, so storing energy which is surplus to requirements in EV batteries is effectively capitalising on a 'free' source of energy.

7 Lead-acid traction batteries perform less efficiently at low temperatures, especially sub-zero temperatures. The islands, and in particular the Hebrides, have less severe winters than most of the

mainland. Average winter temperatures do not fall so far because of the closeness of the sea and the warming effect of the Gulf stream.

The second part of this study examines many of these factors in greater detail to establish the market potential present in this particular market segment. Although it may appear that islands represent a relatively small market segment, it must be remembered that there are many 'island communities' all over the world which together could represent a considerable market area for EVs. To take two particular examples, the Greek islands were the intended application area for the Enfield electric car (section 1.4.3) and remote islands such as Hawaii and other Pacific islands are heavily dependent on expensive imports of oil for transport. Hawaii has recently installed the World's largest aerogenerator and similar developments could work hand in hand with battery powered vehicles. In addition to offering a potential market for EVs, islands communities could be important as an early application of the technology which could initiate and stimulate the larger diffusion process.

D. SUMMARY OF MARKET SEGMENTATION

Market segmentation is an essential stage in the successful commercialisation of EV technology. Not only does the nature of the technology and the diffusion process require this approach and understanding but it is important to recognise the different stages in the diffusion process and the different people involved. By segmenting the market and focusing attention on the most suitable people and segments, the adoption process can be initiated sooner and can be accelerated once it has started. This will allow a credible EV industry to become established sooner in advance of mass penetration. In addition, an emphasis on the customer will lead to an increased understanding of customer needs leading to operator benefits and greater acceptability.

The commercial vehicle market would seem to be a logical starting point but there may be other market segments or applications which hold potential for early adoption of the current technology. One such application may be island vehicles.

4.3 PRODUCT DESIGN, DEVELOPMENT AND MANUFACTURE.

4.3.1 DESIGN FOR FUNCTIONAL NEEDS

The product is perhaps the most important element in the marketing mix, since it holds together the other factors of promotion, distribution and price. A sensible marketing approach to the development, design and manufacture of the product forms an essential element in the success of any innovation.

The EV can be designed to meet many of the functional requirements of a particular application. It is possible to build an EV with similar acceleration or top speed to an ICE vehicle but only by sacrificing some range and battery cycle life. Similarly it would be quite possible to build an EV with a much greater range than is presently quoted as being typical, but this would only be gained at the expense of top speed, acceleration, and perhaps battery life as well. A larger battery increases range but decreases space and payload. It can be seen that there are many performance and functional trade-offs which give designers the flexibility to match an EV as far as possible to the needs of the application. Because there are such large and controllable trade-offs with regard to EV performance, it is all the more important that potential operators should be able to specify what characteristics they require. With an ICE vehicle, the individual requirements of purchasers revolve largely around performance and appearance. Functional needs are expressed in terms of speed, acceleration and fuel consumption. With the EV it is also necessary to consider the range. Range is largely determined by the battery system used, so customers should be allowed to choose a suitable system for their needs, bearing in mind that increased range will be won at the expense of other functional capabilities. The designers, developers and retailers of EVs should ensure that there is a choice available (see section 11.4.3). ICE vehicles are available in huge numbers of model varieties, many of which have only minor or superficial variations from the other models. With EV technology however it is more important to provide functional differences between vehicles because of the sensitivity of vehicle usefulness and economics to individual use patterns. By developing an EV without providing adequate variety and without taking account of differing needs, the EV industry might fail to gain the confidence of potential customers. One basic vehicle chassis and body could support numerous variants at minimal extra cost, all with different capabilites.

4.3.2 DESIGN FOR PSYCHOLOGICAL NEEDS AND ATTITUDES.

All innovations are different and have different characteristics. Rogers argues that these differences as perceived by individuals account for differences in their respective rates of adoption [2]. It is the perception of these differences that is important. With EVs, developers should examine these characteristics, designing and promoting their vehicles in order to meet psychological needs and encouraging accurate and beneficial perceptions. Rogers claims that,

> "In general, innovations that are perceived by receivers as having greater relative advantage, compatibility, trialability, observability and less complexity will be adopted more rapidly than other innovations. These are not the only qualities that affect adoption rates, but past research indicates that they are the most important characteristics of innovations in explaining rate of adoption"

These characteristics are now discussed in turn as they relate to EVs, in order to highlight the areas to which the industry must pay particular attention in the design and promotion of EVs.

1 RELATIVE ADVANTAGE is the degree to which an innovation is perceived as better than the idea that it supersedes. This may be measured in a number of ways. With EV technology, the relative advantage is largely economic and environmental. These advantages will have to compensate for the many areas in which the EV represents a relative disadvantage, for example in terms of range, speed, acceleration, status, convenience and so on. With highly visible products like a car, status related advantages are likely to be very important.

The EV has the advantage that the variable costs associated with operating it are much lower than the running costs of the ICE (chapter 9). This element of cost advantage is also easily communicated to potential purchasers. Environmental advantages will probably be more important to Governments than to the individual although it is arguably the case that individuals are becoming more aware and concerned about such considerations. Perhaps environmentally acceptable products will gain added acceptance and maybe even a certain prestige. The Government could also try to ensure that innovations such as the EV which are advantageous to society as a whole are also beneficial to individuals. The most obvious way to do this is by financial incentives (see section 4.5.2)

Of course, because it is the perception of relative advantage that is important, it does not matter as far as adoption is concerned if the EV has a great deal of real advantage. What does matter is that it is seen to offer advantages to the operator. This again is a function of design and promotion.

2 COMPATIBILITY is the degree to which an innovation is perceived as being consistent with existing values, past experiences and current and future needs of potential users. Unfortunately, the EV may well be incompatible with many motorists' perceptions of what a personal mode of transport should be, given current lifestyles. The adoption of an

innovation may require the prior adoption of a new value system. In the case of EVs, attitudes towards the function and capabilities of vehicles will necessarily change as fossil fuels become scarcer and more expensive. A move towards more accommodating attitudes has already taken place since the oil crises, as is evidenced by the move towards smaller, more efficient vehicles. In order to create a market for the EV before economic conditions dictate it, developers should try to design the EV to meet current preferences as far as possible. This may mean using the designs and shells of existing vehicles or using conventional materials in order to give the appearance of a vehicle with which the customers will be comfortable and confident. A "ground-up" design using new materials, while offering the potential for more efficiency, may be less acceptable because it is unfamiliar and may be regarded with suspicion. Compatibility also refers to compatibility with consumer needs.

3 COMPLEXITY is the degree to which an innovation is perceived as relatively difficult to understand and use. It is very important therefore that the EV should be designed for ease of use. The modern EV is in fact a very complex piece of machinery although in principle it is quite straightforward. There are fewer mechanical parts in the drive-train and it is probably easier to understand than the ICE engine. However, the traction battery is a complex item and its effectiveness and efficiency are dependent on a multitude of features. The electronic control unit is also an extremely complex piece of electronics. For these reasons, it may be wise to design the EV and the battery charger so that they can be treated like a 'black box'. It should be made easy to drive and charge without a deep level of technical understanding. It should be packaged in such a way as to leave little room for operator errors and abuse and it should not require the adopter to develop new skills. In section 2.6.3, a battery management system being developed

by Lucas Chloride was discussed which aims at achieving this 'user friendly' characteristic. The operator should not feel scared of the vehicle and should not be encouraged to view it as substantially different from the ICE. Developers should establish guidelines for operation that are easy to follow even if this could result in less than ideal performance in some cases. It is more important to gain confidence in the technology and its realistic abilities than to squeeze out every last mile of potential range while discouraging people with the complexities of how to achieve this.

4 TRIALABILITY is the degree to which an innovation may be experimented with on a limited basis. Those who are inclined to adopt will do so more readily if their anxieties and questions have been answered by "hands-on" experience and experimentation. EV developers should therefore make it possible for potential customers to experiment with the vehicle. This will probably involve more than simple test drives in the early stages of adoption (see section 4.4).

5 OBSERVABILITY is the degree to which the results of an innovation are visible to others. There is little that EV designers and developers can do to increase the observability of the benefits of EVs except to ensure that the relative advantage is as great as possible and that promotion is as good as possible.

4.3.3 THE PRODUCTION OF EVs

The question of who should manufacture electric road vehicles is a very important one since the vehicle design, price, performance, customer confidence and ultimately the rate of adoption will all be influenced by it. The major volume manufacturers have all experimented to varying degrees with electric cars and vans, and specialist manufacturers have to date failed to produce and market a successful electric car. There are perhaps three categories of manufacturers who could conceivably establish the market for electric road vehicles,

1 The existing large volume vehicle manufacturers like Ford, General Motors, Peugeot, Volkswagen and so on
2 Specialist electric vehicle and component manufacturers who already have experience with low performance vehicles like the milk float. New companies may also be tempted to enter the field as specialist producers. For example, the Danish company, Hope, which is a computer manufacturer, and HIL electric which was established with the sole objective of marketing electric vehicles.
3 Some combination of of the above two categories. Cooperation may be needed such that the specialists could manufacture components unique to the EV while the volume manufacturers could provide the shell, standard components like wheels, seats and so on, and the assembly facilities. This approach was taken by LCEVS Ltd and it appeared to be achieving some success before the main volume manufacturer pulled out.

The answer to the above question may vary with the time span being considered. In the short term it is conceivable that specialists will persist in attempts to establish the market, while volume manufacturers will be content to step in later once a larger market has been established and the initial risks have been taken. In the long run it may well be the volume manufacturers who take on the role of EV producers while specialists continue to produce special purpose vehicles with smaller markets. To a certain extent, a 'chicken and egg' situation exists in that without a large market, volume manufacturers may not be prepared to get involved, and on the other hand, without the financial resources, manufacturing capabilities, promotion, price and service facilities of the existing volume manufacturer, potential customers will be very slow to gain confidence in the product.

4.3.4 VOLUME MANUFACTURERS Vs SPECIALIST PRODUCERS

There are many good reasons why the volume manufacturers should become involved at an early stage,

1 CREDIBILITY

The public are more likely to have confidence in the large manufacturers because they are well established names and people will not so quickly associate them with 'risky' investments. It is unlikely that consumers would have enough confidence to buy from specialist manufacturers in a big way because this would represent a complete change in their buying habits. Additionally, if the large manufacturers were to build their EVs using the shells of existing ICE vehicles, the concept of the EV would be easier to accept and reconcile with present vehicle concepts. It would not represent such a major change if it looks the same as the ICE version. People would require less 'innovativeness' to buy an EV of this type. This credibility may have been partly responsible for the successful introduction of the diesel car.

2 DISTRIBUTION AND MARKETING

Electric vehicles could be marketed directly by the manufacturers, as an integral part of their model range, and distributed through their normal dealer network - as happened with the Lucas Chloride/Bedford venture. This would obviously greatly increase the level of nationwide exposure and selling resources for EVs and would make purchase that much easier. The large vehicle manufacturers also have more ability to advertise and promote the product.

3 SERVICE BACK-UP

By integrating sales and distribution into existing dealer networks, the volume manufacturers also have the advantage of being able to offer an efficient nationwide service capability and infrastructure. Consumers are unlikely to buy a new vehicle if they do not have the confidence and assurance of an efficient and effective after-sales service. Vehicle retailers sell more than just a machine, they sell an 'ability to travel', and customers are aware that they are purchasing expertise, advice and service back-up as well as the basic vehicle. By buying from established networks, the customer reduces the risks associated with his personal transportation. EVs are unlikely to sell unless there is a strong national infrastructure to support the vehicle. For this reason, the existing vehicle manufacturers and their associated dealer networks are better suited to support a population of EVs and they are likely to achieve this in a shorter period of time than small specialist manufacturers. The alternative would be to train a nationwide team of service personnel but this would be very costly, especially in the early stages of EV introduction where EV population is likely to be small and scattered.

4 FINANCIAL RESOURCES

The large producers have more financial resources to allow them to invest in plant and machinery, promotion, design, distribution and after-sales service. They are more likely to be able to make a serious and successful attempt at establishing a market. As mentioned previously, an attempt to market an inferior product package could damage public perceptions of EVs and stimulate hostile attitudes.

5 MANUFACTURING CAPABILITIES AND COSTS

Huge investment in assembly lines and machinery would be avoided if existing facilities were used. The volume vehicle manufacturers have the necessary equipment to produce EVs at the lowest possible cost, and other specialists would probably not be able to compete on cost grounds. This strategy takes maximum advantage of modern engineering and production methods, and the cost benefits associated with standardisation of chassis/body components. In conventional vehicle manufacture the main area of investment is in design, development, styling, marketing and production of the vehicle shell rather than the propulsion system. If EVs are to compete head on with ICEs and attract public confidence, huge investment would continue to be necessary in these areas and the existing manufacturers are best placed to meet this requirement. Investment would be minimised by merging production of ICEs and EVs so that it was spread over a larger output.

6 PRICING

Large manufacturers and their related distribution outlets are more likely to be able to offer attractive financing agreements to customers. In the LCEVS/Bedford programme a lease scheme was developed whereby operators could lease the batteries or the entire vehicle from the manufacturers thus spreading the capital costs out and shortening the payback period. Operating cost savings could be directly set against lease charges from the outset.

There are however several reasons why the large volume manufacturers may not wish to establish the market.

1 COMPETITION WITH EXISTING PRODUCTS

The EV is unlikely to be bought only as an addition to ICE vehicles. It would displace a certain number of ICEs and they would therefore be competing against each other. Until economic, political, sociological or legal considerations are heavily in favour of EVs, the volume manufacturers may be unwilling to move away from the ICE. In addition, they have huge investments in plant and machinery and research and development effort which is directed towards sales of ICE vehicles for many years to come. The lead time associated with developing new generations of vehicles is considerable and current plans for improved

ICE vehicles will be relevant for many years yet. EVs are expected to have longer useful lives than their ICE counterparts (see section 9.2.4) so their widespread use would lead to a reduced level of new vehicle sales. Because of this, ICE manufacturers will probably not want to get involved at too early a stage.

2 RISKS

Whilst the major vehicle manufacturers keep abreast of EV technology in their R&D departments, occasionally making one-off prototypes for publicity reasons, they may prefer to see a specialist manufacturer take all the initial commercial risks of EV launch. If this is successful they could step in later with their own design in much larger quantities at a lower unit selling price. They would thus avoid the risk of not only a product failure but also the adverse affects on their corporate image.

3 MARKET SIZE

In the early stages of EV adoption, it is unlikely that the size of the demand would be large enough to tempt the major manufacturers to participate. They have traditionally adhered to the view that it is not worth making a new model unless they can expect to sell substantial numbers. One author and management consultant to the motor industry estimates that because of the huge investment in new production lines and specialist machinery, it is not worth introducing new model of ICEs for sale of less than 200,000 vehicles [11]

The establishment of a product and market for electric road vehicles presents problems for both the specialist manufacturers and the existing major vehicle manufacturers. The short term and long term solutions may be different but it becomes increasingly evident that both have a part to play. The optimal solution in the short term may be some combination of forces such that the risks and expertise are distributed. The small specialists may be prepared to accept more risks but they need the support of the existing distribution and after-sales services of the volume manufacturers and their assembly line production techniques, not to mention the credibility which surrounds their present ICE designs. Without this cooperation, the early introduction of electric road vehicles and cars in particular is likely to be more difficult. The Lucas Chloride strategy is the best example to date of a rational and logical attempt to achieve this cooperation and credibility. When considering this problem the House of Lords Select Committee on Science and Technology came to the conclusion that,

> "It is highly unlikely that future traffic-compatible EVs will emerge from this sector (specialist manufacturers) - the specialist builders are too small and lack the substantial resources which will be required. Most of the development of EVs is going to come from companies prepared to invest heavily in R&D and linked with the volume car manufacturers. Government support should reflect the manufacturer's investment" [12].

The report suggests that there could be useful cooperation between volume vehicle manufacturers and large component companies like Lucas Industries or the Chloride Group.

4.4 PROMOTION AND EXPOSURE OF ELECTRIC ROAD VEHICLES

4.4.1 STAGES IN THE INNOVATION-DECISION PROCESS

In order to establish a market for electric road vehicles, developers will not only have to develop a suitable product and identify suitable market segments but they will also have to expose and promote the product within the segments. Diffusion scholars have identified several stages in the 'innovation decision' process which are likely to affect the success of the innovation. These stages are defined by Rogers as knowledge, persuasion, decision, implementation, and confirmation [2]. In the case of an innovation like the EV where widespread acceptance still has to be established, the first two stages in this process must be regarded as priorities.

1 KNOWLEDGE STAGE

It is debatable whether individuals play a passive or active role in gaining awareness of an innovation, and whether it is the need or the presence of the innovation that leads to the awareness. Undoubtedly the nature of the innovation will determine which of these is the primary factor, as some needs lead to the development of a solution which is already called for by individuals. On the other hand, it is possible that the awareness of a product may lead individuals to feel a need for it. In the case of the EV, the need for the innovation is still felt by Government and society as a whole because of its potential to save oil reserves, and because of its environmental advantages. The individual on the other hand will not regard his ownership of an EV in these terms because of his miniscule contribution to these problems. The need for EVs may arise for financial reasons or because of the need for transportation once fossil fuels become scarce. In order to develop awareness therefore, developers will have to present the vehicle as the answer to these needs.

Several kinds of knowledge concerning innovations can be identified, the first being awareness knowledge. Individuals will need to know that the product exists but further knowledge will be necessary before they can develop informed attitudes. They will have to have an understanding of how to operate the product properly and they may also wish to understand the principles underlying how the innovation works. With electric road vehicles, potential operators will need to have the confidence that they know how to use the vehicle. The amount of knowledge that they will need can largely be minimised by designers if efforts are made to ensure that the EV is as similar to the ICE as possible. This would probably mean leaving as many controls and instruments as possible unchanged and using standard components. It is important therefore to raise the level of public awareness of EVs and section 4.4.3 examines effective methods of doing this. It has been suggested that early knowers of an innovation tend to have various identifiable characteristics. According to Rogers' research, they tend to have more education, higher social status, more exposure to mass media communication channels, and are generally more cosmopolitan than late knowers. This unfortunately does not lend support to the argument that islanders in Scotland are well suited for EV introduction. However, the islanders seem to exhibit lower levels of conformity to fashion and common thought, and show higher levels of independence that the majority of mainland and city inhabitants. (Although this statement is based largely on subjective opinion, the results of a questionnaire presented in section 9.4 seem to support it). This may be an advantage when it comes to the formation of opinions and decisions to adopt or otherwise.

2 PERSUASION STAGE

The persuasion stage is where the person who has gained knowledge about the innovation forms a favourable or unfavourable attitude towards it. More information about the EV should be supplied in order to allow potential buyers to evaluate how well the EV would fulfil their particular needs. The type of information needed at this stage is more experimental and experiential. At this stage a person will not go as far as to decide whether or not to buy an EV but will try to evaluate what the expected consequences of owning an EV are and what are its advantages and disadvantages for him. Probably the most persuasive factor at this stage is the observation of EVs being used by other individuals, especially friends and neighbours.

Information sought by individuals is essentially directed towards reducing the uncertainty which inevitably surrounds a new innovation and therefore developers need to foresee the questions that are likely to be asked and provide this information.

4.4.2 INFORMATION REQUIREMENTS OF A PROMOTION POLICY

From the arguments presented so far in this chapter it becomes increasingly evident what information should be supplied to potential operators in order to stimulate early adoption of EVs.

1 Once developers have established the functional and psychological needs of a particular market segment, the EV should be designed as far as possible to meet these needs and demonstrate them observably.

2 Motorists should be encouraged to define and evaluate realistically what their motoring needs are. As fossil fuels increase in price, it will become increasingly necessary for them to establish priorities and restrict their motoring. If motorists can be brought to appreciate this, they may be more receptive to the idea of operating an EV as it will not represent such a long term limitation. Attitudes towards unlimited personal transport and flexibility will have to change over time unless a plentiful liquid substitute for oil is developed. Similarly, the ability of the EV to undertake the majority of motoring requirements needs to be pointed out so that the EV is not seen as a poor second but as an adequate primary vehicle. In a two vehicle household, the EV would be capable of fulfilling most of the travel requirements and only on longer journeys would the ICE need to be used.

3 Information about the attributes of the innovation needs to be highlighted. The EV should be promoted as offering a relative advantage over conventional vehicles. The predominant relative advantage in this case are financial savings, reduced maintenance time and increased environmental cleanliness. This last advantage will cause more interest if individuals can be encouraged to have a greater concern for the environment. EVs also need to be promoted as

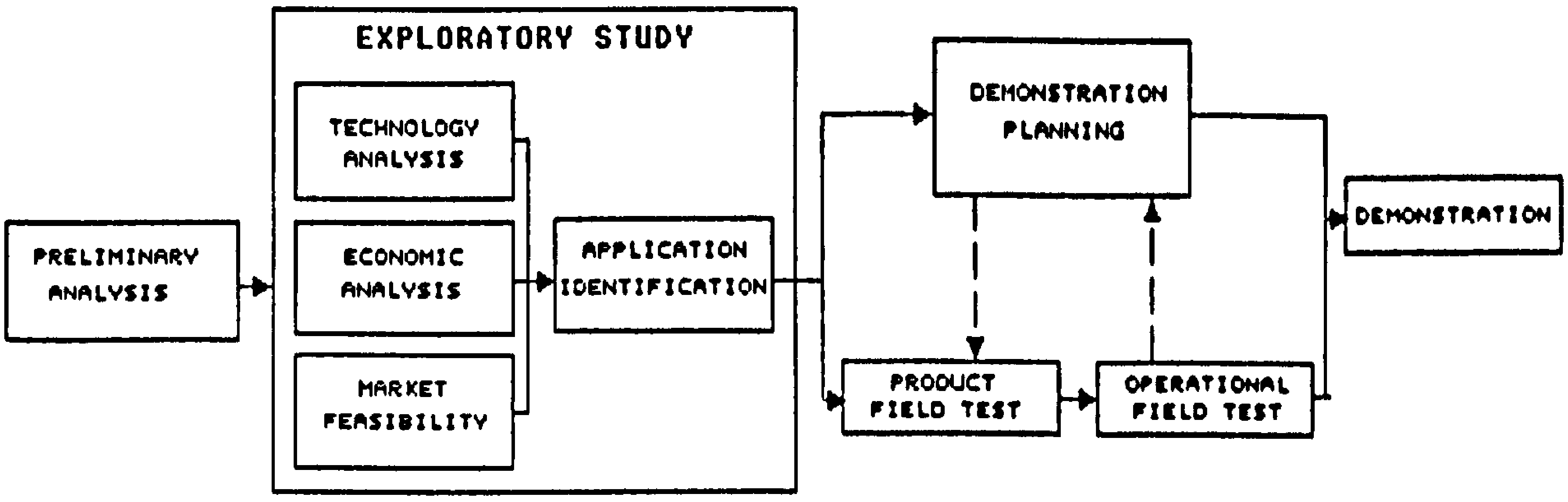
offering simplicity of use and maintenance and they need to be presented as being compatible with the skills involved in driving and operating a normal ICE vehicle. As well as the EV's compatibility in many areas it should be presented as representing as little fundamental change to the user as possible.

The aim of supplying relevant information is to speed up the innovation-decision process and, in addition to determining the optimal informational inputs, it is essential to identify the optimal communication channels through which to disseminate this information. Different market segments and adopter categories will respond to different means of communication and will need to be approached through different strategies.

4.4.3 DEMONSTRATION PROGRAMMES FOR ELECTRIC ROAD VEHICLES

Demonstration means showing how something operates in the real world, and a sensible demonstration programme would help to achieve the diffusion of the informational needs mentioned in the previous section. The main goal of a demonstration programme is to speed up the commercialisation of an innovation. This goal can be pursued through three specific objectives: firstly to produce information to aid decision making; secondly to show the technology in an applied setting; and thirdly to encourage acceptance. In the USA, the need for an EV demonstration programme was recognised and formed the basis of the 1976 Act of Congress discussed in section 1.5.3. Unfortunately there was not a suitable product to demonstrate, so success was very limited. If it can be shown that the technology is adequate for its intended application then a demonstration programme could help to stimulate acceptance. Demonstration is distinct from, and follows, adequate field testing, and figure 4.4 shows where it fits in to the development of a market for EVs.

FIG 4.4 THE CONTEXT OF EV DEMONSTRATION



This project is concerned more with the initial steps in the process outlined in fig 4.4 but it is argued that a viable product and suitable applications do already exist, so some consideration must be given to demonstration of the EVs. The EV must be placed in real life use so that potential users can observe it in operation. So far in this country, many of the regional electricity boards have started to use electric vans in many of their operations (see appendix 6), and several Electricity Council staff have been using Enfield electric cars for their own personal use for a number of years. Public bodies, especially those with a vested interest in the success of the EV, like the electricity industry, are obvious targets for participation in a demonstration programme. Similarly, if a particular market segment such as the islands of Scotland can be encouraged to use EVs, other segments will be exposed to their use. Even within the island segment applications should be sought for the initial demonstrations; applications where the EV can be positioned for visibility. Chapter 10 presents two particular applications (school mini-buses and grocery vans in the islands) which could feasibly represent their initial use. Bear et al. suggest that there are several factors which affect the success of a demonstration programme [13]. Many of these are discussed in this study and the appropriate chapter numbers are shown here,

- User orientation (chapter 4)
- Technology well-in-hand (chapter 1,2 & 11)
- Commercially feasible application (part 2)
- Well developed institutional environments (chapter 7)
- Use of an exploratory study (part 2)
- Absence of tight time constraints

4.5 GOVERNMENT ASSISTANCE IN THE INTRODUCTION OF EVs

4.5.1 INTRODUCTION

In chapter 3 it was shown that the introduction and use of electric road vehicles offers certain advantages, but that these advantages accrue mostly to society at large while the disadvantages are borne largely by the vehicle owners. It is true that there are some attractions for the owner but, by and large, there is yet little incentive for people to purchase EVs when ICEs are available. This situation is changing as the technology advances and energy costs rise but the economic use of EVs is still restricted to certain special applications. Even within these applications, the cost benefits associated with EVs is probably not persuasive enough to entice large numbers of individuals to adopt the innovation. However it has also been suggested that the early introduction and use of EVs is important for future success. There is a real need to maintain a viable EV industry in advance of the day when large scale adoption will be likely so that the technology, expertise and manufacturing capabilities are established. In addition, the longer the EV is kept in the laboratory, the longer it will be before the EV can make a realistic contribution and the advantages outlined can be reaped. It is obvious that a long term view of the EV and its potential is necessary. The gap between the demonstrable capabilities of EVs and commercially viable production can be sufficient to discourage active progress and the result has often been the stagnation of development programmes at the field testing stage. It is likely that EV penetration will be a progressive process as users and potential users gain confidence, so plans which assume that EVs can be manufactured and sold in large quantities in the short term are unrealistic. EV market strategy should assume progressive sales growth, and plan for gradual scaling-up of production volumes. While full commercial viability is and must remain the long term objective, in the short term it may be necessary to transfer some of the benefits to the user in order to maximise the benefits to society as a whole. The current tax concessions on lead-free petrol is an example of how national interest can be translated into personal incentives. A similar approach is needed to encourage users to purchase EVs in place of ICEs. Central and local government can play a key role in narrowing the gap in the short term but it must do so in a way that will enable the industry to find its own feet. Measures should be taken to provide both "industry push" and "market pull" stimuli. Although manufacturers are unlikely to be persuaded to enter the EV field simply because of Government incentives which may be short lived, Government has two major weapons which it can use to assist; 1) financial aid and 2) legislative measures.

4.5.2 FINANCIAL MEASURES

The steps already taken by the UK Government were outlined in section 1.5.2 and the House of Lords Select Committee report lists various Government contributions to EV development along with its recommendations for future support. Support has concentrated in areas which are regarded as being most likely to succeed, and structured so as to support rather than control private enterprise. However, both the Electric Vehicle Association and the Electricity Council have stated their concern over the apparently diminishing role being taken by the DTI. Measures which may be appropriate in the future would include,

1 MARKET ENTRY ASSISTANCE

Funding could be made available to competent EV manufacturers to enable them to offer the finished vehicle for sale at a temporarily reduced price. This was the approach taken with LCEVS who received a Government subsidy on every EV drivetrain that was sold to the cooperating vehicle manufacturers. This subsidy was given on a declining basis allied to rising production volumes over an agreed period of time, with the aim of creating a commercially viable industrial base within a fixed timescale. LCEVS and Bedford had estimated that after the 5-year subsidy, they would be able to produce and sell the vehicle at a competitive price, but unfortunately Bedford pulled out just prior to this achievement. This "product launch" type of Government support would seem to be the most appropriate and advisable in the future because it recognises the nature of the problem faced by the EV industry. This was recognised by the House of Lords Select Committee which examined the case of EVs (see appendix 9)

2 RESEARCH AND DEVELOPMENT

Continued support for basic and applied research programmes is needed to help to ensure that the technology continues to advance and is well placed to meet the demands that will be placed upon it. The Government has supported several programmes in the past such as the sodium-sulphur research programme carried out by Chloride Silent Power Ltd. Areas which should be funded include drivetrains, lead-acid batteries, other advanced batteries, traction motors and electronic control systems. The benefits of such support will probably be reaped in the medium to long term but it is still essential for the establishment of a viable industry.

3 DEMONSTRATION PROGRAMMES

Once the technology has been developed to a commercially viable stage, central or local government support will be valuable in field testing and demonstration programmes. In the past, schemes such as the London-Goes-Electric scheme, run by the GLC, have been assisted by Government contributions. Perhaps one of the most valuable measures that could be taken by local government would be the purchase and use of EVs by the authority itself (see appendix 9).

4 TAXATION

Various taxation measures could be taken and indeed some already have. Electric road vehicles are exempt from annual road tax charges and MOT testing but further steps could be taken in the short term. One EV manufacturer suggests that even a minimal additional tax on petrol in this country would provide substantial funds for investment in EV development. Operators too may be given taxation incentives of some form or another.

5 FLEET PURCHASING POLICY

Selected fleet users, chosen on the basis of their size, operational characteristics and long term potential, should be helped to purchase trial fleets of EVs, in representative numbers, and become the nucleus of a broader future market. In particular, public authorities could be encouraged to buy EVs. The House of Lords Select Committee recommended bulk orders for EVs by public authorities (appendix 9)

6 LEASING SCHEMES

The high initial cost of EVs, which are produced in small quantities, and the initial uncertainty surrounding their successful application are disincentives to purchase. A national or targeted leasing scheme could help to spread the costs of ownership over a more reasonable time period. Operators could then partially offset the lease payments by the substantial fuel and maintenance cost savings. If batteries were leased over a fixed period of time it would enable the battery cost to be predicted accurately and would avoid the need to make provision for premature battery failure. To provide the maximum advantage, leasing schemes could be designed to suit the individual and his expected use of the vehicle.

4.5.3 LEGISLATIVE ASSISTANCE

Measures already taken by the Government include the abolition of MOT testing and National Type Approval for commercial electric vehicles. There are a number of other possible measures which could be taken,

1 Creation of designated areas, which are reserved for the exclusive use of EVs together with public transport and bicycles.

2 Issue of parking permits for EVs in areas where the use of conventional vehicles is limited and the parking is severely restricted.

3 Stricter legislation regarding pollution and noise and emission control for ICE vehicles. This may help to increase any economic advantage of EVs by requiring additional investment in ICE production.

4 Introduction of Corporate Average Fuel Economy (CAFE) regulations. In the USA such regulations oblige each corporate vehicle manufacturer to ensure that the average fuel efficiency for the entire annual production exceeds a certain figure: 20 miles/gal in 1981 rising to 27.5 miles/gal in 1986. EVs are more energy efficient than ICE vehicles if the efficiency of electricity distribution is not included so manufacturers could reach this figure by producing a number of EVs.

5 Standardisation of legislation concerning EVs could help to eliminate any hidden penalties in the present legislation which is built upon the ICE vehicle. Differences in the vehicles such as their braking systems and necessary safety measures need to be recognised, otherwise present legislation could act unwittingly as a disincentive to produce

or own EVs (see also section 8.4). Developers have pointed to some instances where outdated or inappropriate legislation has caused difficulties [8]. Examples include Vehicle (Construction and Use) Regulations and tachograph regulations.

6 Establishment of parking lots in the outskirts of cities and operation of electrified public transport, electric taxis and perhaps even private electric rental cars for connection with the city centre.

7 Provision of public recharge points (see section 7.3.3)

4.5.4 OTHER NON-LEGISLATIVE MEASURES

Although financial and legislative assistance is the most obvious form of help, there are other measures which Government could take to assist in the introduction of EVs,

1 ADVICE of both a technical and administrative nature could be provided by Government departments such as the DOI. To a certain extent this is already given but a means whereby the channels of communication are clearly defined would help to disseminate information on legislation and regulations, EEC regulations, available methods of support and the procedure for claiming it, technical information and up to date information on Government policy and involvement.

2 CROSS FERTILISATION of ideas and information between parties. The Electric Vehicle Association in the UK is a trade association which tries to achieve this by compiling data and information for the use of its members. The DOI or the Department of Energy could provide a complementary service.

3 TRAINING of skilled electric vehicle mechanics could be provided or coordinated by Government. The Electric Vehicle Development Group (EVDG) in the UK stated in 1980 that they were working with the Road Transport Training Board to establish apprenticeship schemes for EV

mechanics [15]. However the outcome of this move was never reported on and it could be criticised for being premature. Once EVs are being produced in larger numbers, such a scheme may be worthwhile.

4 REPRESENTATION in the EEC and worldwide would be valuable for the EV industry. Government departments could ensure that any aspects which might give rise to possible difficulties are brought to their notice as early as possible so that they may protect the interests of developers.

4.6 SUMMARY AND CONCLUSIONS

With any major technological innovation there is a need to manage the development and diffusion processes in order to optimise the benefits and avoid possible dangers. As the technology develops it must be moved out of the basic and applied research stage and be developed for commercialisation. EV development is still largely confined to technological improvement efforts although it is suggested that a viable and useful product already exists. There is a real need for a marketing approach of the diffusion. It is important to ensure that an EV industry remains and is developed in preparation for increasing market penetration. Market segmentation can highlight potential markets where EVs could be introduced successfully at an early stage. Attention has already focused on the light commercial vehicle and the 'second car' in multi vehicle households. However, island communities are the application under examination in this study because there are many characteristics of such communities which would appear to be suitable for the utilisation of EVs. In addition, successful introduction in such an application would serve as an impressive demonstration of EV capabilities to society as a whole.

Government has a vital role in the management of new technologies, in reflecting the needs and aspirations of society, and as steward for protecting the environment. In cases like that of the EV the Government may need to redistribute some of the benefits of the technology through financial incentives and legislative measures so as to stimulate interest in manufacture and purchase, leading to maximised national benefit.

SECTION TWO

THE ISLANDS ASSESSMENT

CHAPTER 5

THE SCOPE AND STRUCTURE OF THE ISLANDS STUDY

CHAPTER 5

THE SCOPE AND STRUCTURE OF THE ISLANDS STUDY

> "It is pointless to cultivate a sense of urgency when (island) life is governed by time and tide, season and weather, and by communication and transport".
>
> Finlay J. MacDonald

In this second section of the study, the particular case of some of the island communities of Scotland is examined. The islands which are used as the basis of the study are the island of Lewis/Harris (all one island) in the outer Hebrides and to a lesser extent the island of mainland Orkney.

5.1 OBJECTIVES

The objective of the study is to examine and measure the potential for high performance electric road vehicle introduction in the island communities of Scotland. Although this may ultimately be measured in terms of the number of EVs that could feasibly be introduced now or at some future time, it is equally important to identify, examine and understand the various factors which affect the potential for introduction. By highlighting and examining these factors at an early stage it is hoped that it will assist in the development of realistic and useful alternatives for future transport systems.

A second objective of the study is to develop a systematic and practical methodology for assessing EV usefulness in a given application.

This includes the identification, collection and analysis of relevant data.

5.2 THE METHODOLOGY

5.2.1 INTRODUCTION TO THE METHODOLOGY

A methodology is essential in such a study in order to provide a logical framework, progression and consistency in the work. Most studies relating to EVs have concentrated on specific, often narrow, aspects of the technology. Few have focused on a well defined area of application and at the same time adopted a holistic approach to the exposition and examination of the problems involved at the micro-level under consideration. The methodology which has been developed to provide a logical framework for this study is therefore the product of a systematic approach. The main features of this methodology are outlined prior to elaboration in later chapters

5.2.2 STRUCTURE AND APPROACH TO ASSESSMENT

The study assesses the potential usefulness of EVs in the islands by examining the various requirements of a personal means of transportation. There are several basic qualities which vehicles must have in order to perform their intended function. These attributes can also form the basis of assessment. They can be summarised as follows,

1 VEHICLE PERFORMANCE. The vehicle must be capable of use in the intended application. The vehicle performance in terms of range, speed, energy consumption and gradeability must be known before its usefulness can be determined. These measures are dependent on the particular application of the vehicle and so it has to be tested for duty cycles which are typical of those that it will encounter. Similarly, once the technical performance is known, the success of the vehicle in terms of its ability to perform its intended function

must be estimated. The 'application potential' is a measure of how much of the intended application can theoretically be fulfilled by the EV, i.e given vehicle range and gradeability on island roads, how many islanders could feasibly use an EV in place of their ICE?

2 REALISABILITY OF VEHICLE POTENTIAL. It is one thing to know the technical and theoretical abilities of the vehicle but it is also important to know how well the vehicle will live up to its potential and how much of this potential will be realised. Once again, this can only be evaluated in light of the intended application and it includes factors which go beyond those relating to the vehicle itself and its technical reliability. With regard to EV technology, the ability to refuel easily and as quickly as possible is central to the realisation of its potential. A suitable refuelling infrastructure and electricity distribution network is of prime importance.

3 SAFETY is important to most operators and doubts surrounding the safety of a new technology will undoubtedly create a substantial barrier to adoption. Safety must be seen in wider terms than simply crashworthiness or technical safety; it must also be evaluated in terms of safety of decommission and ultimate disposal.

4 DESIRABILITY AND ACCEPTABILITY. Ultimately, a new technology will not be adopted unless it offers some advantages over the technology it is replacing. The advantage could be in terms of performance, utility or safety but one of the strongest incentives to adopt a new technology is the economic case surrounding it. In the case of the EV there are certain operating disadvantages as compared to the ICE but the desirability in terms of the ownership costs may adequately compensate for these. An economic analysis is therefore central to an assessment of vehicle desirability. In addition, the

'acceptability' of the technology and its various attributes, as expressed by motorists attitudes and preferences, is examined in order to evaluate the market potential for EVs in the islands.

5.2.3 COMPUTER MODELLING AND SIMULATION

Throughout the island assessment, computer models and simulations are used to analyse the data collected, and to simulate what actually happens in real life situations as closely as possible. The use of computer facilities allows the analysis of large amounts of data and can provide a much more comprehensive examination of the data. This has enabled the adoption of the second strategy associated with the methodology, namely the concentration on a large number of individual assessments (see section 5.2.4).

A. COMPUTER MODELLING AND SIMULATION IN EV R&D

Computer simulation involves experimentation on a computer-based model of some system. The model is usually a mathematical or logical representation of a real life system with its related variables. The mode of experimentation is one which uses a 'trial and error' way to demonstrate the likely effects of various policies. Those policies, (ie. combination of variables) which produce the best results in the model may then, as far as possible, be implemented in the real system. Alternatively, the model and resulting simulation may be used simply to gain an understanding of the system and to establish its likely performance in real life. Computer modelling has become an important tool in many areas of research and development. This is certainly true in almost every area of the modern automobile industry where analytical modelling-assisted studies and assessments have been carried out to provide information for management planning and research decisions.

B. KEY STAGES IN COMPUTER SIMULATION

Once the problem to be addressed has been defined there are some key phases which together make up a 'simulation approach'. Obviously, no two simulation projects will be identical but some generalisations can be made. In particular, three main stages can be identified, although in practice there may be a certain amount of overlap between these stages.

MODELLING is the stage at which the basic mathematical, logical or algebraic representations of the system are established. The relationships may be established from direct observations of the system or may be constructed from existing knowledge. Ultimately, all these relationships must themselves originate from experimentation just as the recognised laws of physics and dynamics have been established as the result of observation and experimentation, and lead in turn to the evolution of explanatory theories.

PROGRAMMING is the next stage in computer simulation and this is when the model is translated into a clear, unambiguous set of instructions or algorithms that can be understood by the computer. A suitable programming language must be chosen which will allow the particular model to be translated as easily and simply as possible. To a large extent the nature of the model and the required results will determine the language to be used. FORTRAN was used as the programming language for this study

EXPERIMENTATION is the ultimate aim of any simulation project as this is the stage at which results can be generated and the full benefits of imitating a real life system can be reaped. The model is basically a vehicle for experimentation to demonstrate the likely effects of various policies. There are several cost and time saving advantages resulting from experimentation on computer models,

a) A rapid response time permits the evaluation of a large number of alternative test conditions in a greatly reduced period of time. In some cases, real-time tests would take an unacceptable period of time. In the case of traction batteries where real-time tests on cycle lives would take years to complete, the use of simulations allows conclusions to be reached very quickly.

b) A rapid response time permits processing of large amounts of data thus allowing more accurate representation of the system than would be possible without a computer model.

c) Experimentation can be carried out on a system before it has to be implemented, or at an early stage of its development. Changes and improvements resulting from insights gained during simulation can be made during development, bringing consequent savings. For example, with vehicle drivetrain modelling, it obviates the need to build the vehicle, test it and then modify it whenever a possible improvement is found.

d) The results of simulations are reproducable, as are the test conditions. In real life testing, there are many conditions which could probably never be repeated. For example, in vehicle operating performance tests, environmental conditions such as wind speed and air temperature cannot be controlled. Similarly, battery performance depends on many factors including the charge and discharge history. With the use of modelling and simulation techniques, the effect of such variables can be identified, isolated and measured.

C. HISTORICAL DEVELOPMENT OF EV MODELLING

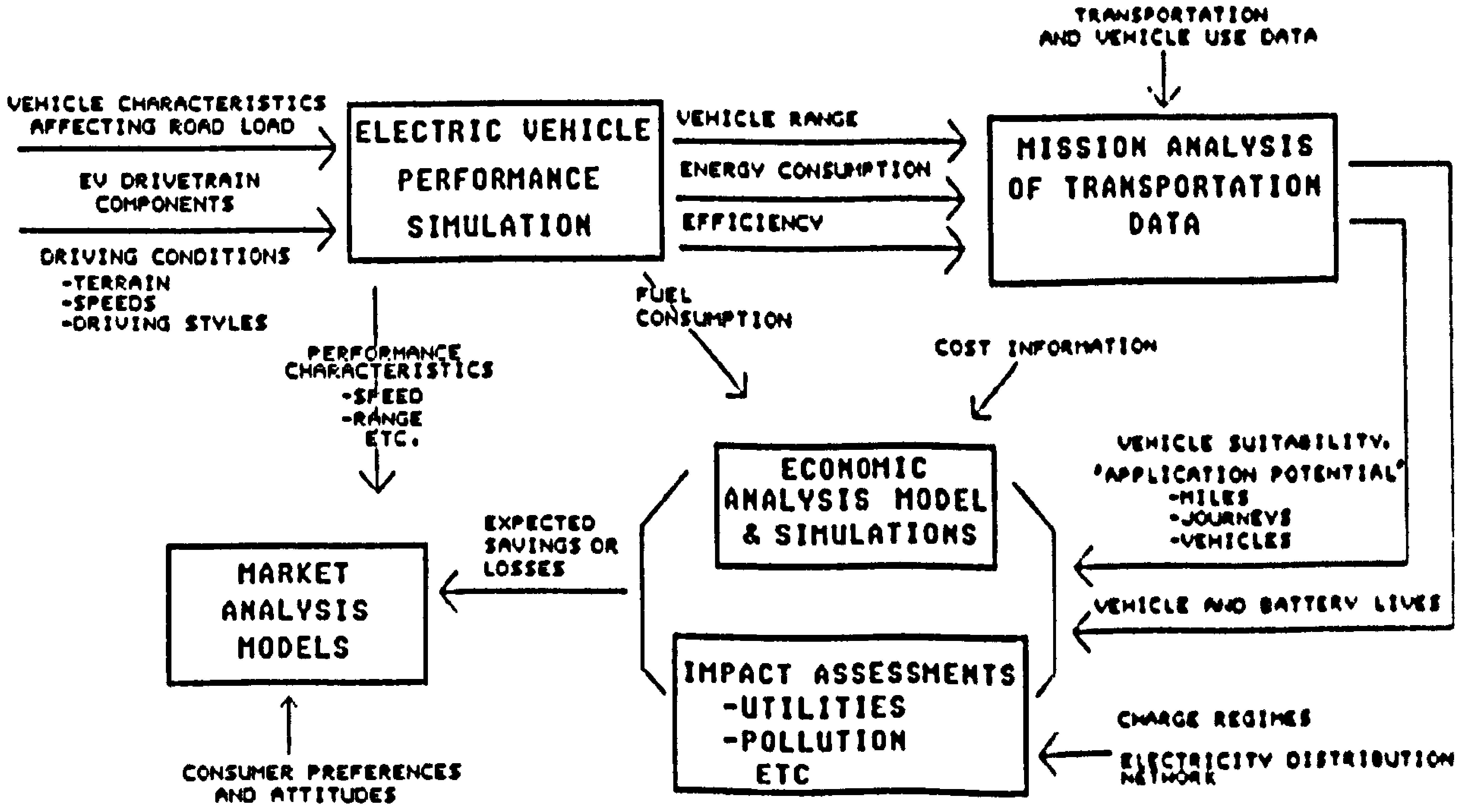
Electric vehicle modelling with the aid of computers is a technique which has been used for almost 20 years. In 1969 the US Army developed a programme [1] to examine and evaluate the design of electric vehicle systems, and two years later the Aerospace Corporation undertook a study for the US Environmental Protection Agency [2] to evaluate exhaust emission levels and the overall feasibility of hybrid electric vehicles. Another computer model was developed in 1976 by Hamilton and Hagey [3], to examine EV suitability for urban use and EV impacts on energy consumption, resource consumption and travel costs.

By 1977, a study at the Jet Propulsion Laboratory [4] showed that at least 111 computer models existed for EV research. The US Department of Energy, the Lawrence Livermore Laboratory, Ford, Nasa, Boeing Computer Services Coy, Exxon enterprises and the General Research Corp are but a few of the larger organisations who were, or still are, involved in this area.

D. USES OF ELECTRIC VEHICLE MODELS IN THIS STUDY

There is a wide range of uses made of computer models for EV work, the end use being to give a better understanding of the operational requirements and handling of the systems involved, which in turn provides information for R&D planning and decision making. Fig 5.1 summarises the major uses made of computer models in this study together with the informational requirements of each model. Fig 5.1 helps to highlight the wide range of applications for computer based models in EV research and development.

FIG 5.1 COMPUTER MODELS RELATING TO THIS STUDY



The first stage shown in fig 5.1 is the simulation of an EV's operating performance as it undertakes the duty cycle assigned to it. The effects of using different drivetrain components or vehicle designs and configurations can be observed and measured as an aid to preliminary and final design optimisation. It is possible to examine the effects of different duty cycles, road surfaces, environmental factors and so on, on the performance of EVs in terms of energy use, range, acceleration, speed, gradeability and so on.

Once the technical performance of a particular vehicle has been defined, it is possible to assess how far such a vehicle would meet the requirements of any particular application or use. This would require analysis of vehicle use data in light of the vehicle's capabilities. The results of a mission analysis would be useful when evaluating the economic case for EVs because it is important to evaluate the economic case in light of the particular application for which the vehicle is used. Models can also be constructed to examine the impact that EVs would have on the environment, resource usage, the electricity supply network and the local and national infrastructure.

One of the primary aims of any technology assessment is to gauge the likely market desirability and success of the technology. The information gathered from all other stages in the assessment through modelling and simulation will be relevant to a market analysis model.

The above description is a general outline of the kind of uses that can be made of computer models in EV research and development and the uses made of computer modelling in this study. In practice, models will be very different and will be designed to use the information that is available and to yield the required information. In any technology assessment a systems view is necessary to ensure a balanced appraisal. By using computer models and simulations a wider, more detailed and more balanced picture can be established.

5.2.4 CONCENTRATION ON INDIVIDUAL MOTORISTS

The data which relates to island driving characteristics has been predominantly gathered from island motorists themselves and relates to individual driving habits and characteristics (section 5.3.3). At all stages in the analysis, an attempt has been made to retain the detail associated with this individualistic data. Each motorist's case is analysed separately and constitutes a small part of the whole picture rather than using generalised or averaged figures which lose detail. Other data used in the analysis, such as the driving data, which forms the input to the performance simulation model described in sections 5.3.2 and 6.4, is similarly treated. Summary statistics can be calculated for the island as a whole from all the individual cases. This approach was taken for several reasons.

1 It allows the analysis to be as realistic and as close to the real life situation as possible. The detail of actual operating characteristics or driving patterns or road profiles or motorist attitudes is retained. There are so many factors which are of interest and which are relevant to the analysis that if data is summarised or condensed too early, there is a risk of losing information or detail. This becomes clearer as the various analyses are discussed in turn.

2 Consistency was required throughout the study and by adopting this approach, a logical progression was possible from one particular analysis to the next. Furthermore, the results and outputs from each analysis and its associated models could then be used as input material for subsequent models along with the original data, provided that there is a consistency in form and approach.

3 This strategy yields information and insight into the overall island situation by examining a large number of individual cases. The uniqueness of the modelling approach developed in this study is that

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island characteristics which emerge result from an aggregation of profiles of individual users and not from summary statistics of each of a large number of parameters relating to individual users.

5.3 DATA USED AND ITS COLLECTION

5.3.1 TYPES OF DATA AND RESEARCH TECHNIQUES

For the purposes of this study, large quantities of data are required and so it is important that due consideration be given to the sources and types of data used. Much effort and needless data collection can be avoided if the data collection process is adequately designed with the end use and informational requirements in mind. This section gives an introduction to the data collection process, highlighting the different types of data and their major sources.

There are two broad categories of data gathered in the course of this study. Firstly, there is 'primary' data which has had to be collected by direct measurement, observation and questioning. Data in this category has not been collected or compiled before and must be sought at source. It was necessary to design measurement and collection techniques to yield appropriate data.

Secondly, there is 'secondary' data which can be collected by reference to other works such as statistical reviews, studies or publications or, in the case of this work, local government studies.

When it comes to the research techniques used to collect data, there are two main categories which can be identified - REACTIVE AND NORMATIVE. The former relates to survey situations where data originate from interaction between investigators and respondents as in interviews or questionnaires. Normative techniques, also known as non-reactive measures, relate to research where information does not depend on respondents but is measured objectively. Such techniques are more familiar in science or engineering oriented research than in marketing research but calls have been made in other contexts for more non-reactive measures to be adopted by marketing researchers as well [5].

5.3.2 DIRECT MEASUREMENT WITH APPROPRIATE INSTRUMENTATION

The first step in the study of the islands is to see how the vehicle will perform given typical island driving conditions and duty cycles (see chapter 6). As a part of this work it was necessary to define and measure typical island driving conditions and duty cycles as accurately as possible. This was done by designing and building a purpose made portable data logger which could be used to measure and record the required raw data. For reasons which are explained in chapter 6, it was decided to simulate a vehicle driving on the island roads with a computer model rather than test out a real vehicle in the real location. The raw data from the data logger formed the basic input to the computer vehicle performance simulation.

This raw primary data measurement and collection, by normative techniques is seen as fundamental enough to the project to merit fuller discussion in a separate chapter. A fundamental point associated with this type of data collection and modelling is that modelling is a technique which is justified when it is clearly connected with practical issues. Validation of the model takes place when it can be demonstrated that it can accommodate 'real' data.

5.3.3 DATA COLLECTION WITH QUESTIONNAIRES AND LOGBOOKS

Much of the information concerning driving habits, attitudes and preferences was collected directly from island motorists themselves. This data was used to evaluate the application potential for EVs in the islands (see section 6.7) and the market potential (see section 9.4), as well as providing the basis on which an individual's expected economic benefits could be calculated (see section 9.2).

A. THE SAMPLE

A sample of motorists was selected to participate in the data gathering process. As far as was possible, the sample from each island was chosen to reflect the geographical spread of the population over the islands as a whole. This was done by using population statistics to determine the required number of respondents from each geographical area. This was considered necessary because each area could have slightly different mileage characteristics, the predominant feature of vehicle use being the return journey to the capital town. (Population statistics are show in appendix 5). Within each area, houses for visitation were selected as far as possible at random while driving through.

B. THE QUESTIONNAIRE

The questionnaire was designed for use as an interview with motorists. It was designed to gather information on driving habits, vehicle ownership characteristics, attitudes and preferences. Difficulty was encountered in designing the questionnaire because of the nature of the subject area and the required data. Electric vehicle technology, while not new, is unfamiliar to most of the target population. Most of the islanders have some knowledge of the general idea of low performance electric industrial vehicles or milk float type vehicles, but an awareness of the newer high-performance, traffic-compatible electric car is quite rare. It is generally outside the respondents sphere of knowledge and therefore opinions on the subject, if they exist, are either very weakly held or in some cases misguided. This makes designing questions which are intended to elicit attitudes towards the area very difficult indeed.

Two approaches were considered. Firstly, it might be possible to conceal the true subject of enquiry and avoid direct reference to electric vehicles. In an attempt to avoid biasing responses with any false preconceptions, questions would be designed to draw out the respondents general attitudes to personal transport vehicles. Inferences could then be made about the suitability of an EV for the particular respondent and his likely attitude towards them. His willingness to adopt the technology would be assessed from a knowledge of his preferences and stated needs. On the other hand, the respondent could be informed as fully as possible of the nature of the research, he could be given information about the technology upon which to base his answers and opinions and he could be invited to comment from this base of knowledge. Of course, respondents may have existing knowledge and awareness of the area and may be competent to comment and form realistic opinions, but in reality only 42% of islanders questioned claimed to be aware that vehicles of the type being studied actually existed.

The questionnaire was designed to incorporate both of the above approaches. Initial questions were asked which aimed at drawing a picture of the participants' general needs and preferences without any reference to the new technology. Then information was supplied about the nature of current electric vehicle technology and its status. Participants were then invited to give their general impressions and response. In addition they were invited to present any particular misgivings or doubts and to express how suitable the vehicle would be for them personally. By employing this two pronged investigation it was possible to pinpoint inconsistencies in the responses and hence gain even further insight into the likely acceptance or rejection of the technology. Check questions were also employed in the questionnaire (sample questionnaire in appendix 5).

Another important consideration in employing questionnaires in this type of research is the way in which they are administered. An interview style was used for various reasons,

1 Greater returns were expected using this method than if forms were

simply distributed for islanders to read, complete and return on their own. Even although fewer households would be reached, results could be guaranteed.

2 The questionnaire was of a considerable length and might not have attracted a very charitable response. The presence and attention of an interviewer might help to generate interest and hold attention.

3 By using an interview style, it was possible to provide more information on electric vehicle technology than would otherwise be the case. The respondent could ask questions about the information he would like to know before giving his reactions and responses. Also many of the questions had to be very subjective in nature and might have been difficult to understand without an explanation. All interviews were conducted by the same person so that consistent information could be supplied.

4 It was felt that greater accuracy would result not only because respondents would get a truer understanding of the questions but also because the interviewer would more easily be able to understand the responses given and the true opinions of the respondents. It would be possible to question participants more fully and gain a clearer insight into their answers. Responses could then more easily be classified against consistent scales. Interpretation of written answers is more difficult and may result in biases of interpretation.

C. LOGBOOKS

In addition to completing an interview style questionnaire, participating motorists were requested to record details of every journey they made in their vehicle over a period of time. They were issued with a logbook, an example of which is given in appendix 5. The logbook recorded data on the date, time of day in hours and minutes when the journey started, vehicle mileage at the start of each journey and whether or not the journey ended at the owner's premises. This data was considered to be fundamental to a detailed analsis of application potential (section 8.7) as well as being useful in other stages of the island assessment. The period over which journey data was recorded varied from driver to driver depending on the frequency of journeys. The shortest record was four days and the longest was nearly two months.

D. RELIABILITY OF DATA AND POSSIBLE SOURCES OF BIAS

In any phase of data collection there are potential sources of bias or error which can make the data less than 100% reliable. From the initial stages of designing sensible and meaningful questions, to the presentation of these questions and their understanding, and in the accurate recording and interpretation of responses, there is always the danger that errors will arise. Each stage in the above sequence is filtered through the conditional perception of the human mind. An interview style should help to minimise certain sources of potential bias. Both the understanding of questions by participants and the interpretation of responses should be more accurate.

Obviously the reliability of the data depends on the honesty and reliability of the participating motorists. Ultimately there was no way of knowing how accurate respondents had been in recording their driving profiles. However, the records of vehicle mileometer readings showed that very few journeys were omitted and the dates recorded invariably coincided with the dates of distribution and retrieval of logbooks. There were however possible biases in the data received.

1. While every care was taken to select houses at random, it is possible that biases were introduced here. Houses close to the road were more visible. To enable a large sample to be collected, houses with cars parked outside were preferred in order to save time.
2. Sampling was done during a 10 hour period each day, so much of it was done during normal working hours when many employed vehicle owners

would not be at home.

3 The field work period was undertaken in July when some people would be on holiday and those who were at home may not have had a typical travelling profile. The schools were on holiday so trips to and from school or the nearest school bus stop were not recorded.

4 Logbooks were left with participants for them to complete. They were asked to record 40 journeys. The length of time to complete the logbook is therefore related to the vehicle use and those returned soonest were therefore generally from high mileage or regular vehicle users. Only 63% of respondents returned the logbook and it is possible that those who failed to return represent lower mileage users. Forgetfulness or impatience are likely to be greater in these cases. Any bias resulting from this is likely to result in a conservative or pessimistic estimate of application potential, since lower mileage vehicles will generally be more easily replaced by EVs, yet they may not be adequately represented in the sample returns.

5.3.4 INFORMATION GATHERING USING DELPHI TECHNIQUES

The opinion of experts can give important insights into the future state of a technology or industry, particularly in the identification of potential innovations or developments likely to lead the path of progress away from the extrapolated trend. Traditionally, expert opinion has been brought to bear through the medium of committee meetings. The Delphi technique was developed to overcome some of the weaknesses of the committee, by using the individual judgements of a panel of experts which is divorced from any distorting effects of a committee, and simultaneously overcoming the problem of geographical dispersion and the full diaries of participants. Proponents of the technique would argue that the technique arrives at a more accurate picture of the future than the traditional committee meeting because of the minimisation of bias. Delphi attempts to eliminate distortion by using a questionnaire, circulated to a panel whose members are not aware of the identity of their fellow members. Questions are normally framed in specific, quantifiable and unambiguous terms and respondents are asked to supply quantified answers. Delphi techniques have usually been associated with the estimation of the timescale of future developments but, for the purposes of this study, a development of the technique was attempted. Questions relating to future costs and performance characteristics were also asked. In addition, the questionnaires were not simply restricted to quantifiable answers as is common with Delphi techniques but additional discursive questions were asked in order to shed light on broader issues. The questionnaires and quantifiable results are shown in appendix 5.

The procedure normally involves three rounds of questioning,

ROUND 1 Circulate the questionnaire by post to the panel.

ROUND 2 After analysis of round 1 replies, recirculate, stating the median and the interquartile range of replies and the major issues which have been pinpointed. Respondents are asked to reconsider their answers in the light of the replies and those whose estimates fall outside the interquartile range are invited to state any reasons, as they may represent some insights or specialist knowledge. At this stage some additional questions can be asked as a result of the issues arising from round 1 replies.

ROUND 3 If an additional round is thought necessary for clarification, another iteration can be undertaken. For the purposes of this study, it was felt that another iteration would be unnecessary as most participants were confident of their estimates. Round 3 took the form of individualised questions to each of the panel members on points which had arisen from their replies.

The panel members were selected from those known to be associated with the EV industry and supporting component industries. The Delphi technique is well suited to this kind of research, and to this particular research subject, because of the uncertainty surrounding so many aspects of EV technology and its development. Expert opinion and reasoning is of the utmost importance and value because, as yet, there is little certainty surrounding future developments, costs and performance achievements. High performance EV technology and introduction is still in a relatively embryonic state.

5.3.5 OTHER SOURCES OF SECONDARY DATA

Pre-existing data which had already been collected and compiled was used at several points in the study as inputs to the computer simulations.

1 Traffic flow statistics for the island roads were obtained from surveys conducted by the local authorities.
2 Population statistics were collected from electoral registers and local authority statistics.
3 Data on the electricity distribution network and the production and consumption of electrical energy was obtained from the North of Scotland Hydro Electric Board.
4 Data on battery discharge and lifetime characteristics was taken from reports of test programmes and manufacturers' specifications.
5 Data on vehicle component efficiencies was taken from published test results.

Data which did not form part of the simulation programmes but which was required for other purposes was collected largely from published Government statistics and local authority records.

5.4 SUMMARY

In attempting to assess the potential for EV introduction in the islands, a methodology was established which was based on the evaluation of how well the EV fulfils the requirements of a personal mode of transport. Computer simulation is used throughout the study to model the effects of EV use in the islands as this permits the processing of large amounts of data relating to many individual motorists and driving conditions. It also facilitates a study of the effect of varying the parameters involved. There is strong justification for the technique of modelling when it is clearly connected with practical issues. In addition, validation of the model takes place when it can be demonstrated that it can accommodate 'real' data.

Much of the data which was required for the modelling process was unique to the islands and had to be collected at source by specially designed equipment and questionnaires. Data on the characteristics of the island roads was collected during field work by purpose-built data logging equipment and data on the driving patterns and attitudes of island motorists was collected by appropriate questionnaires and logbooks. In addition, the opinions, estimates and predictions of experts in the EV field were gathered using a Delphi analysis.

CHAPTER 6

EV PERFORMANCE IN THE ISLANDS

CHAPTER 6

EV PERFORMANCE IN THE ISLANDS

6.1 INTRODUCTION

The aim of this study is to examine the suitability of electric vehicle technology for a specific application.

The first step in this assessment is to examine how the technology will behave and perform when assigned to the specific application under examination. In this particular case we need to know to what extent EVs will be capable of undertaking a proportion of the transportation function on the islands. There are two stages in the assessment of EV performance and usefulness,

a) determination of the technical operating characteristics of the vehicle such as range and energy consumption, given the terrain and driving styles encountered in the islands,

b) examination of how far such a vehicle with its particular operating parameters will meet the needs of islanders with their particular use patterns.

6.2 PERFORMANCE SIMULATION OF ELECTRIC VEHICLES

6.2.1 THE NEED FOR PERFORMANCE SIMULATION

Although the concept of the EV is inherently simpler than that of the ICE, the control and battery systems are extremely complex and the operating performance of the EV is affected by numerous factors. Since the early EV development work at the beginning of the century, there have been many technological advances in the various drivetrain components used in the vehicle. The cumulative advances have meant that present-day EV research is dealing with more complex and less easily achieved advances. In addition, there are many kinds of EV since many different component configurations are possible. Computer modelling and simulation has enabled extensive performance testing which would be very expensive in real-life tests in terms of time and costs.

In 1976 the UK Department of Industry commissioned the International Research and Development Company Ltd. to produce a worldwide survey of hybrid electric vehicles [1]. It was evident from the report that there was a wide range of hybrid vehicle designs and operating objectives. It was difficult however to match the designs and the operating objectives and to choose the best design for a particular use. The report suggested therefore that the performance potential of hybrid vehicle designs should be examined using computer simulations. Although this report dealt specifically with hybrid vehicles, the same approach can be used for evaluating EVs and their designs. EV performance simulation models have several functions,

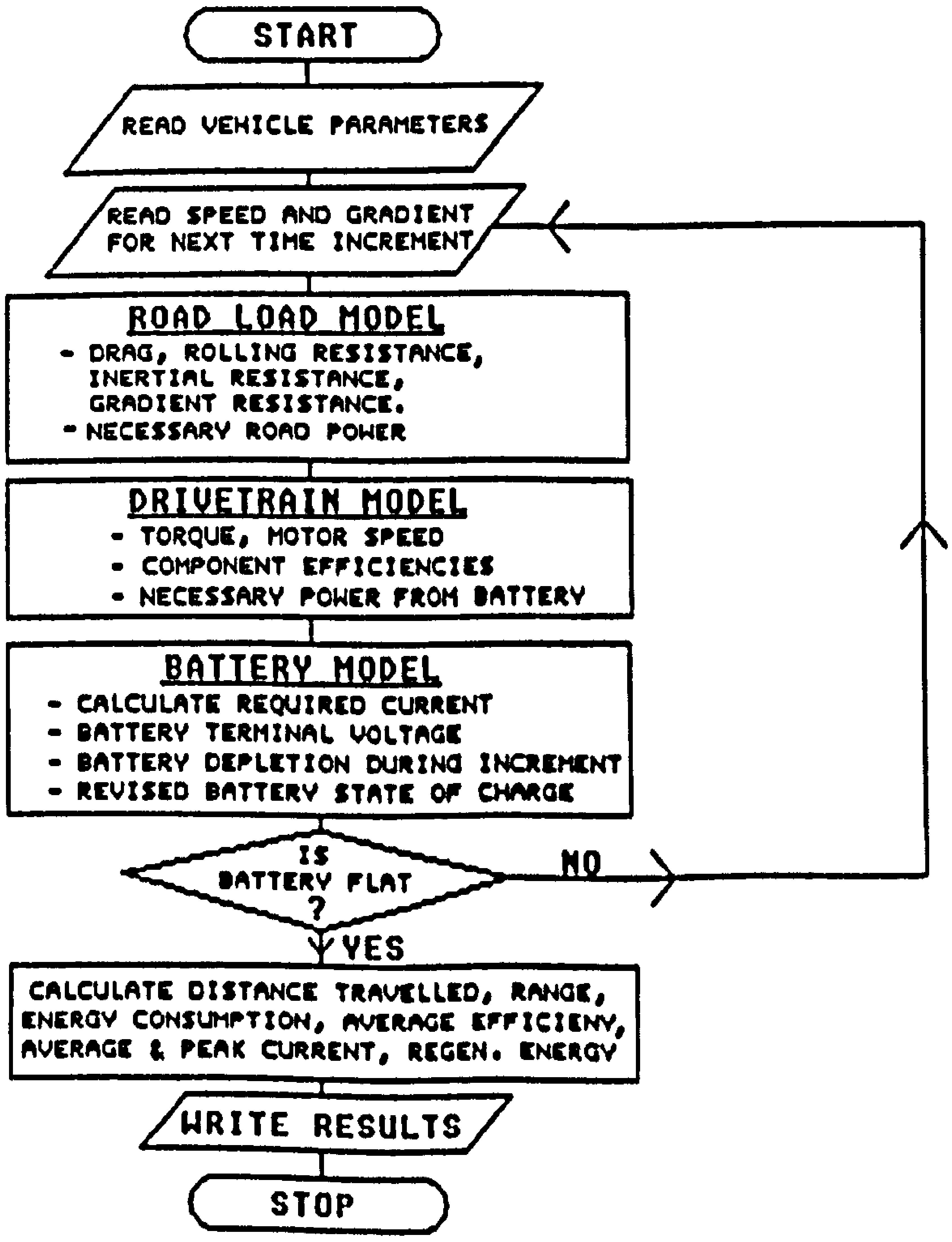
a) to examine the operating performance of a particular EV with given specifications in given conditions. Performance can be measured in terms of such variables as range, energy consumption, gradeability, speed, acceleration and payload.
b) to determine the energy and power requirements of the EV drivetrain components which are necessary to achieve certain operating performance levels.
c) to compare operating performance as a function of such parameters as aerodynamic drag, battery voltage and current, gross vehicle weight, driving style and so on.
d) to compare one vehicle with another and to compare EVs with other types of vehicle.

Such a model is generally based on simulation of the activity of each of the drivetrain components according to predetermined relationships, over time, as the vehicle undertakes the duties assigned to it. This is called a time-incremental or piecewise-linear model and generally requires the use of a computer because of the complexity of the relationships and the volume of calculations involved.

6.2.2 TIME-INCREMENTAL MODELS

With time-incremental EV performance models the vehicle is tested over a pre-specified 'driving cycle' (discussed in section 6.4) which is defined in terms of vehicle speed over a period of time. The model developed in this study also attempts to incorporate the gradient of the road because vehicle performance is greatly affected by the gradients that have to be traversed. Values for vehicle speed and gradient are provided for every time interval (usually of one or two second intervals) and, along with information on vehicle and component characteristics, the tractive effort which is required to provide the combination of vehicle motions can be calculated. Fig 6.1 outlines the major steps in the process and the structure of the model developed for this study.

FIG 6.1 FLOW CHART OF PERFORMANCE SIMULATION MODEL



Models of each of the drivetrain components are used to calculate component efficiencies and modify the gross measure of tractive effort to calculate the demands on the battery. A suitable battery model is then used to describe the changes in the stored energy as time progresses. The simulation continues until there is no remaining stored energy or until there is insufficient power to meet the tractive effort required.

6.3 THE EV PERFORMANCE SIMULATION MODEL

6.3.1 RATIONALE FOR CONSTRUCTING A PURPOSE-BUILT MODEL

There are many electric vehicle models and simulations in existence but for several reasons it was considered necessary to construct a purpose-built model to satisfy the objectives of this study

a) For ease of access and use.

b) All models are built with a specific objective in mind and are tailored to answer particular questions. By building the model envisaged it should be possible to design it to answer the questions of particular interest in this case and simultaneously avoid tackling problems that are of little or no real relevance. Hence the model was designed to examine vehicle range and performance given typical island duty cycles. It concentrated on varying the driving cycles and not primarily the vehicle design.

c) Many existing models require data inputs that are either not available or are difficult to obtain. In addition, their relevance was often questionable. By building a model, it was possible to ensure that the relevant data required for construction and use was available and in a convenient form.

d) The exercise of constructing the model and gathering the appropriate information was a useful process, providing deeper insights into the areas of EV modelling, EV drivetrains, traction batteries and their performance, factors affecting EV performance, EV design and many other factors connected with EV operation. Problem areas were also highlighted and areas where there is inadequate literature and research were pinpointed. For example there is still a lack of information on the life cycle performance of traction batteries under typical EV driving conditions. This is of course due to the long periods of time that such tests require.

e) Well designed experiments allow the analyst to infer the causes of system behaviour. Acquiring meaningful insights depends more upon good experimental design than on the subtleties of statistical analysis. The effort put into modelling and programming helps to achieve these end results.

6.3.2 THE BASIS OF THE MODEL

The model was based on observations and relationships which have been observed and recorded during tests and which have been reported in the relevant literature. Component operating characteristics were simulated using relationships established during tests and not on any fundamental laws of dynamics. There are however two unavoidable dangers inherent in this approach

a) Extrapolation beyond the scope of the data always presents problems in modelling. Simulation results will only be valid over the range of values for which components were tested and for which a relationship has been established. In this model however, the aim is not to predict component performance under any new or untested conditions but simply to examine performance under specific and unique sequences of driving conditions which are normally within the range of tested conditions. Care must be taken to ensure that these restrictions are observed.

b) As increased accuracy is sought, the model will have to become more and more specific to one particular vehicle or battery or component due to the lack of generally established theories to describe component behaviour. If an attempt is made to build a model which is general enough to represent a variety of configurations and components, a sacrifice will have to be made in terms of the model's precision. The level of flexibility inherent in the model has to be chosen along with the level of detail and sophistication. Not every component in the drivetrain necessarily needs to be modelled exactly as it would behave in real life. Indeed this would be extremely difficult, especially in the case of the battery. Frequently the level of sophistication of a model is largely dictated by the availability and form of data. Every effort was made to keep the model constructed for this particular study as versatile as possible so that extensive sensitivity analysis would be possible. It was considered more important to arrive at acceptably useful estimates of vehicle performance and have a flexible model than to achieve extremely precise but limited answers. The simulation model was built as a time-incremental or piecewise linear model as described previously. The overall model is clearly structured in three parts, the road load model, the drivetrain model and the battery model (see fig 6.1). The vehicle and component operating characteristics and specifications are largely those of a particular vehicle which was used to build the model upon. The chosen vehicle is the General Electric Electric Test Vehicle No. 1 (ETV-1) which was built as an advanced state-of-the-art electric car for testing purposes. By building the model on the basis of this vehicle it is possible to evaluate how close the predictions of the model are to real life operating tests on the actual vehicle itself. The vehicle is described in appendix 7 and references [2][3] and [4].

6.3.3 ROAD LOAD MODEL

This sub-model was based upon fundamental physical relationships, unlike the other two sub-models. There are four major elements of tractive effort. The vehicle propulsion system has to provide sufficient effort to overcome these elements of resistance, and this force is known as the 'road load'.

A. AERODYNAMIC DRAG

This is due to friction as the vehicle pushes its way through the air. It is a function of vehicle shape, frontal area, speed and many other factors such as air pressure and wind speed. Most of the vehicle related factors are taken into account when measuring a vehicle's drag coefficient. This is a dimensionless measure concerned with the aerodynamics of the vehicle. In general, EV's present greater potential for reduced drag coefficients than conventional vehicles because there are fewer restrictions on the locations of drivetrain components. For further discussion see [5]. The tractive effort necessary to overcome aerodynamic drag can be calculated using the Tenniswood-Graetzel equation,

$$TEa = 0.5 \times Z \times Cd \times A \times V \text{ (newtons)} \qquad [5][6][7][8][9][10]$$

where Z = The density of air = 1.226Kg/m^3 (at 15°C and 10Pa (1 bar) ambient conditions.)
Cd = Drag coefficient.
A = Vehicle frontal area, (m^2)
V = Vehicle velocity, m/s. (This velocity should be measured relative to the wind speed rather than the road. By assuming calm conditions or that wind speed and direction is variable enough to cancel out in the long run, we can ignore wind altogether, allowing more general use of the model)

B. ROLLING RESISTANCE

This component is due to the friction between the vehicle tyres and the road. It is probably the most difficult component to quantify precisely as it is dependent on many variables such as tyre type and pressure, road gradient, road surface and tyre and road temperature. It is extremely difficult to model accurately or meaningfully all these factors during a vehicle simulation over a defined variable driving cycle. Obtaining data would be almost impossible and results from different simulations would be very difficult to compare. The effects of these minor variables on the measure of rolling resistance are minimal and the total measure of rolling resistance accounts for only a small fraction of total road load. Some authors have defined a quadratic velocity dependent equation, [8],[9],[10], while others have assumed rolling resistance to be constant for any given vehicle, [6],[7]. In practice, velocity is not observed to affect rolling resistance significantly at speeds of less than 60mph and tests on the ETV-1 vehicle in the USA actually showed a slight decrease in resistance at increased speeds, possibly due to tyre temperature, [11]. A more detailed discussion of rolling resistance and speed, tyre type, pressure and temperature is given in [12]. The equation used in this model is,

$$TEr = Cr \times W \times G \quad \text{(newtons)} \qquad [8][7]$$

where TEr = Tractive Effort required to overcome rolling resistance.
Cr = Coefficient of rolling resistance (dimensionless)
W = Vehicle mass (GVW) (Kg)
G = Acceleration due to gravity (9.81 m/s/s)

C. ACCELERATION RESISTANCE (Inertial effort)

This element of road load tractive effort is dependent on the linear acceleration and deceleration of the vehicle and can therefore be positive or negative. The rotational inertia of all the rotating components adds to the basic measure of vehicle inertia. In order to be perfectly accurate, all the moments of inertia of the rotational masses would have to be known. Obviously this calls for large amounts of data and simultaneously limits any model to one specific drivetrain. These rotational inertias constitute a small but reasonably constant proportion of total inertial resistance at realistic speeds, [5],[8]. It is reasonable therefore to aggregate these inertias into one measure which may be approximated as 10% of the basic vehicle GVW load, [6].. The equation which has been used to calculate acceleration resistance is,

$$TEi = 1.1 \times W \times a \quad \text{(newtons)} \qquad [6][7][8][9]$$

where TEi = Tractive effort to overcome inertial resistance
W = Gross Vehicle Weight (GVW) (Kg)
a = Vehicle linear acceleration, (m/s/s)
(1.1 is the factor by which the basic GVW load is increased to account for all the rotational inertias.)

D. GRADIENT RESISTANCE

Whenever a vehicle encounters a gradient, kinetic energy will be converted into potential energy or vice-versa. To maintain a constant speed, the measure of tractive effort exerted by the power source will have to change. This represents a change in road load and can be expressed by the formula,

$$TEg = W \times G \times \text{Sin}X \quad \text{(newtons)} \qquad [6][7][8][9]$$

where TEg = Tractive effort to overcome gradient resistance.
W = GVW (Kg)
G = Acceleration due to gravity
X = The angle of inclination

ADDITIONAL CONSIDERATIONS

While it is true that additional energy is required to start a vehicle rolling from rest and for cornering, these components were considered to be small enough to ignore [13].

The inclusion of these elements would make it very difficult to use the model for arbitrary driving cycles and the detailed data necessary would be very difficult to collect accurately. Allowances for the above is better made after simulation as an adjustment for the type of road or driving pattern.

TOTAL TRACTIVE EFFORT

Total tractive effort is simply the sum of all the individual components.

$$TEtot = TEa + TEr + TEi + TEg \quad \text{(newtons)}$$

This is the measure of total force that the drivetrain will have to be capable of developing in order to maintain the desired speed on the given gradient.

ROAD ENERGY

The energy necessary to undertake the given driving cycle can now be calculated for each time increment of the cycle,

$$\underset{\text{(joules)}}{\text{ENERGY}} = \underset{\text{(newtons)}}{\text{TEtot}} \times \underset{\text{(metres)}}{\text{DISTANCE during } \Delta t}$$

where Δt = Delta Time (i.e one time increment)

ROAD POWER

Power is the rate of expenditure of energy and in this case is given by

$$\underset{\text{(watts)}}{\text{ROAD POWER}} = \frac{\text{ENERGY}}{\text{TIME INCREMENT}} \quad \frac{\text{(joules)}}{\text{(seconds)}}$$

6.3.4 DRIVETRAIN MODEL

Now that the measures of tractive effort and road power can be calculated in the road load model for each time increment of the duty cycle, the next step is to refer this measure back through each component of the drivetrain, from the wheels to the battery, adjusting it to allow for all the individual inefficiencies. The object is to arrive at an accurate measure of the power, (and ultimately the current) required at the battery terminals.

A. TRANSMISSION EFFICIENCY

During constant speed driving, transmission efficiency can easily and accurately be modelled as a function of vehicle speed. In variable speed driving however it is not only dependent on the speed but also on the torque. During variable speed or arbitrary cycles, the combination of torque and speed vary greatly, and different transmission systems will have different resultant efficiencies under the same conditions. The gearing ratio also affects the efficiency. It was necessary therefore to base the model on the characteristics of a single, typical system [7]. (See fig 6.2). The torque and speed can be calculated simply by multiplying the total force at the road wheel interface by the rolling radius of the wheel,

$$\underset{(Nm)}{\text{ROAD TORQUE}} = \underset{(N)}{\text{TEtot}} \times \underset{(m)}{\text{Rolling Radius}}$$

The torque delivered to the transmission is given by

$$\text{TORQUE (trans)} = \frac{\text{ROAD TORQUE}}{\text{GEAR RATIO}}$$

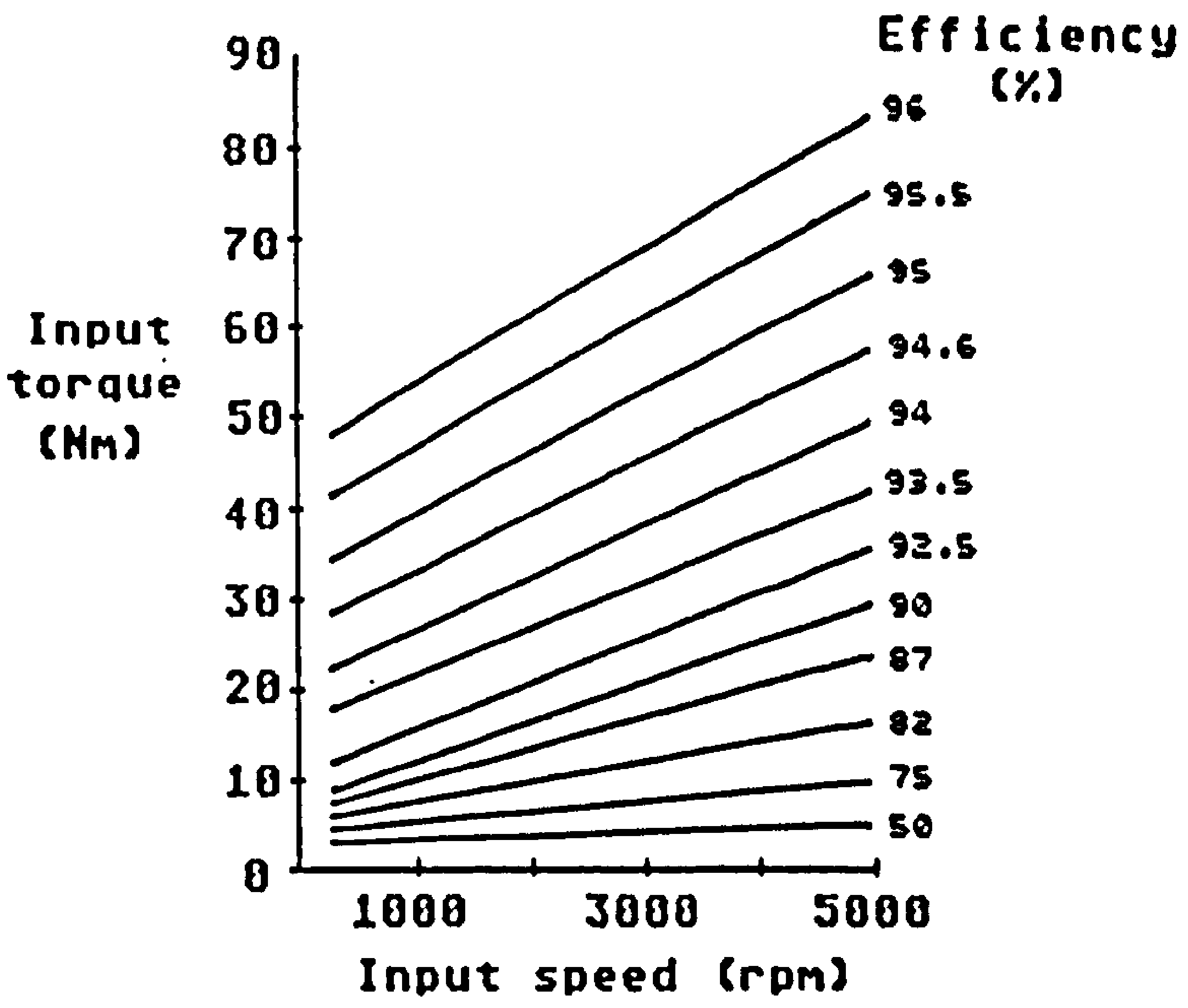
The speed of the motor can be calculated thus

$$\text{MOTOR RPM} = (V / Wc) \times Gr \times 60$$

where V = Average velocity in time increment (m/s)
Wc = Wheel circumference (m)
Gr = Gear ratio

An equation describing the transmission system (fig 6.2), dependent on torque and speed can be obtained by surface fit techniques. In this case a multiple linear regression technique was used in which the independent variables were various combinations of speed and torque. (When using such a technique, the form of the equation has to be stipulated before the regression can be calculated.) An efficiency map of the transmission system is shown in fig 6.2

FIG 6.2 TRANSMISSION EFFICIENCY MAP



The equation which was arrived at to describe the figure above was,

If Torque is less than 10 Nm,

$$\text{Efficiency} = -279-(14x(S/MS))-(1.61xT)+(8.49x(S/MS)^{0.425})+ (305xT^{0.1})-(63.7x((S/MS)^{0.425}/T^{1.15})))/100$$

If Torque is greater than 10 Nm,

$$\text{Efficiency} = 28.4-(7.47x(S/MS))-(0.119xT)+(7.28x(S/MS)^{0.425})+ (49.5xT^{0.1})-(154x((S/MS)^{0.425}/T^{1.15})))/100$$

where S = Speed (rpm)
MS = Maximum speed (rpm)
T = Torque (Nm)

B. MOTOR EFFICIENCY

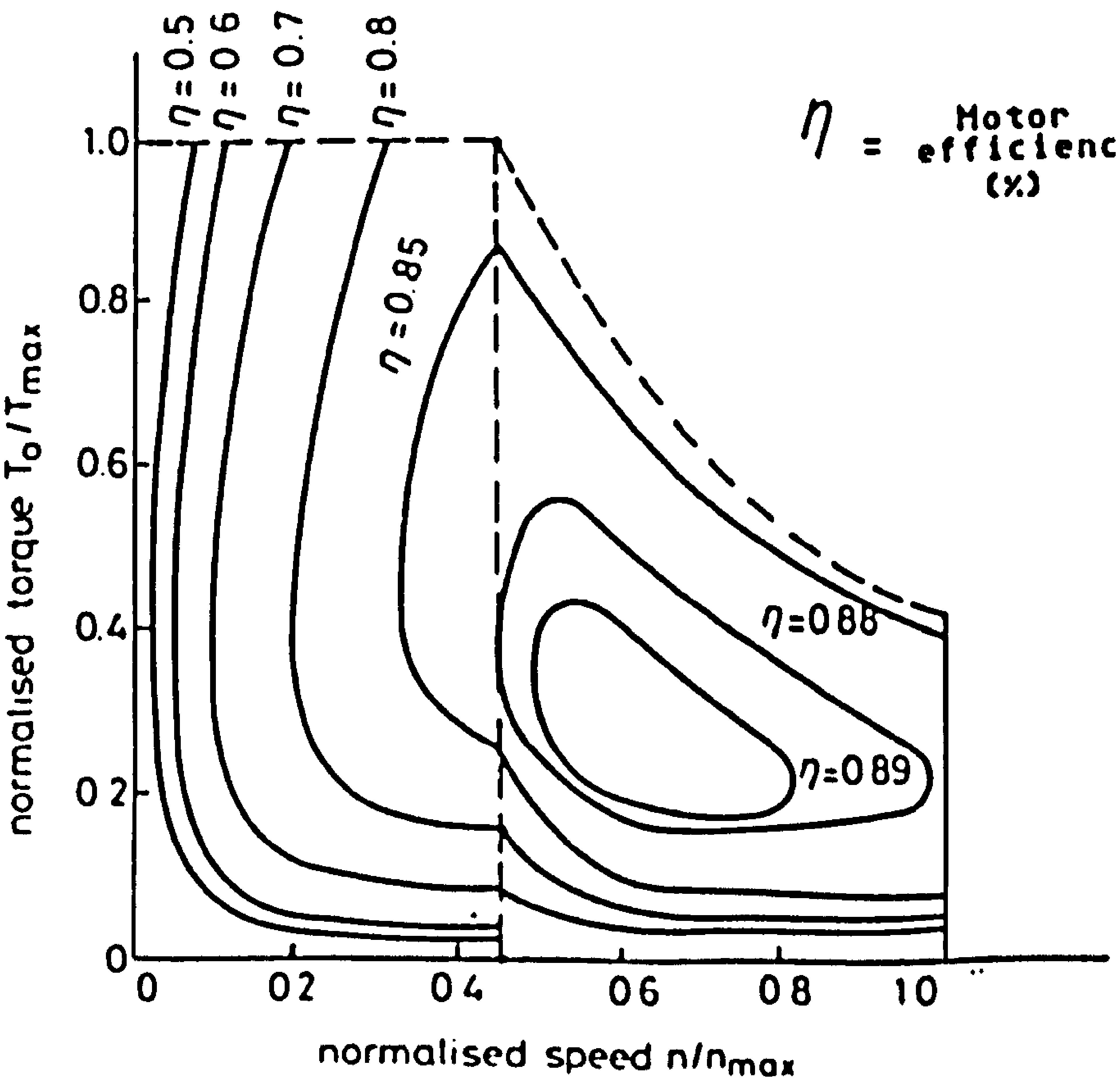
Once again, motor efficiency is dependent on speed and torque. The output torque of the motor can now be calculated by adjusting the road torque for the transmission efficiency. Electric motors of the same type have very similar efficiency characteristics over a certain range of power ratings so it is possible to represent many different sizes of motors by the one set of efficiency data. For DC motors, the most commonly used type of motor for EV applications, it is possible to represent motors in the range 10-40hp and 1200-5000 rpm base speed ratings by the same data [7]. Most EVs would use a motor within this range. In such cases it is useful to measure speed and torque as a fraction of the maximum motor speed and torque, so that it becomes possible to represent any motor without changing the model. The motor from which the efficiency data for this model was taken was that of the General Electric ETV-1 test vehicle which was designed to perform well under urban driving conditions with heavy motor demands [7].

The motor specifications are,

Max Speed - 5000 rpm
Max Torque - 140 Nm
Max Power - 30 Kw

Again multiple linear regression techniques were used to find an equation which fitted the efficiency characteristics represented in fig 6.3. The equation is given below, and can be found in the simulation programme in appendix 1.

FIG 6.3 Motor Efficiency Map



If motor speed is less than 2800 rpm,

$$\begin{aligned}\text{Efficiency} = {} & 0.39+(1.1\times(S/MS))+(0.986\times(T/TM))-(0.42\times(S/MS)^2)- \\ & (0.4\times(T/TM)^2)-(1.3\times(S/MS)\times(T/TM)- \\ & (0.01\times(S/MS)/(T/TM))\end{aligned}$$

If motor speed is greater than 2800 rpm,

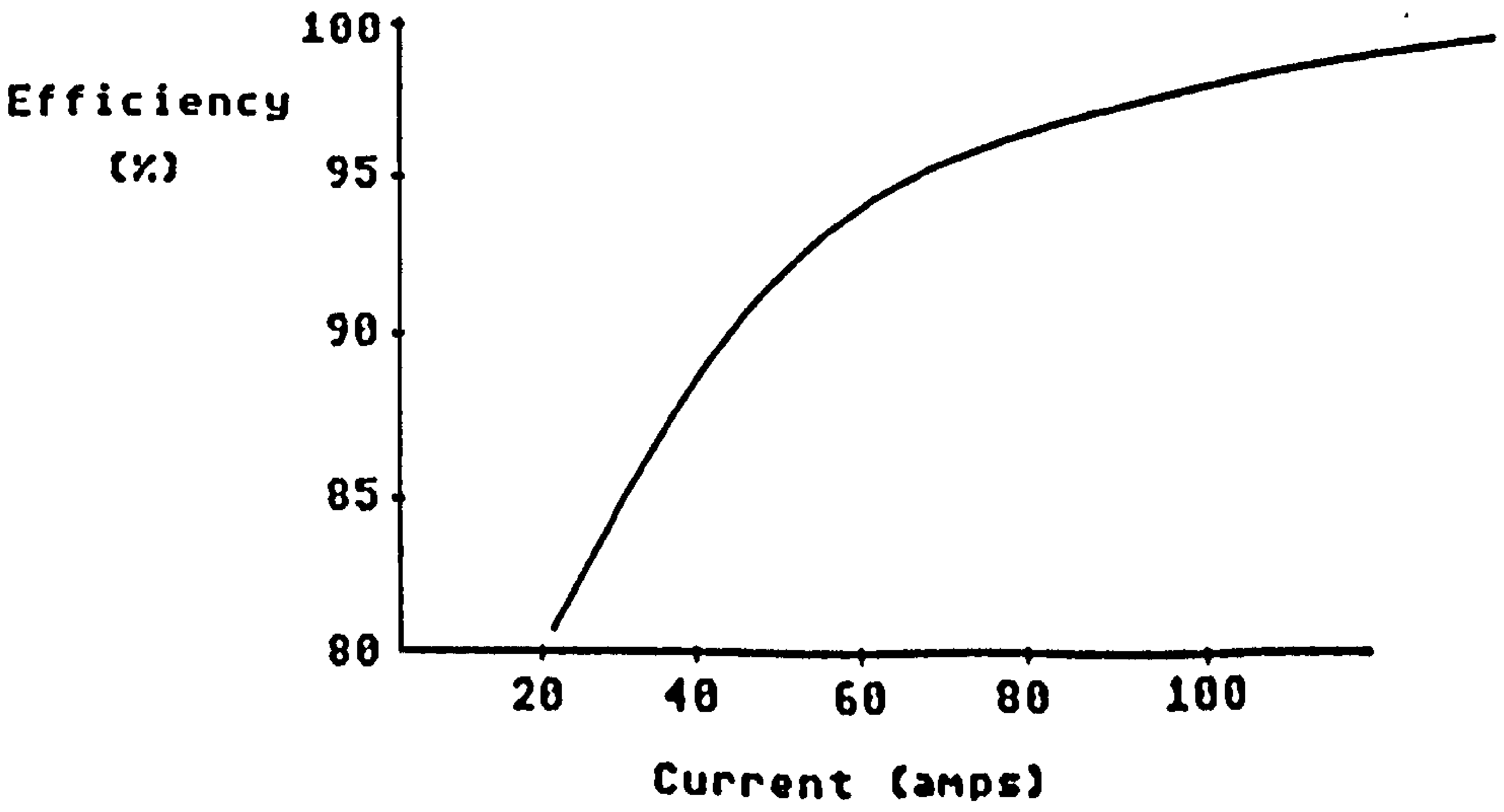
$$\begin{aligned}\text{Efficiency} = {} & 0.679+(0.442\times(S/MS))+(0.712\times(T/TM))-(S/MS)^2)- \\ & (0.218\times(T/TM)^2)-(1.09\times(S/MS)\times(T/TM)- \\ & (0.0136\times(S/MS)/(T/TM)\end{aligned}$$

where S = Speed (rpm)
MS = Maximum speed (rpm)
T = Torque (Nm)
TM = Maximum Torque (Nm)

C. CONTROLLER EFFICIENCY

The efficiency of the control unit depends primarily upon the current that it has to handle regardless of vehicle speed. Efficiency increases with greater currents as shown in fig 6.4 [6]. This relationship is approximated by three straight line segments in the model (details in appendix 1).

FIG 6.4 CONTROLLER EFFICIENCY AS A FUNCTION OF CURRRENT



D. SYSTEM EFFICIENCY

This is simply the product of all the individual component efficiencies, transmission, motor and controller,

$$EFFtot = EFFt \times EFFm \times EFFc$$

E. POWER REQUIREMENTS AT THE BATTERY TERMINALS

By increasing the road power for the system losses we arrive at a measure of the power required at the battery terminals.

$$\underset{(watts)}{\text{BATTERY POWER}} = \frac{\text{ROAD POWER}}{\text{EFFtot}} \quad \begin{matrix}\text{(watts)}\\ (\%)\end{matrix}$$

F. ENERGY CONSUMPTION

A running total of the aggregate energy used during a simulation run can now be made by calculating the energy consumption in each time increment and summing. The energy used in any particular time increment is given by,

$$\underset{(Whrs)}{\text{ENERGY USED}} = \underset{(watts)}{\text{BATTERY POWER}} \times \underset{(seconds)}{\text{TIME INTERVAL}} / 3600$$

Energy consumption per unit distance is calculated by recording the cumulative energy used and dividing by the cumulative distance travelled.

6.3.5 BATTERY MODEL

Undoubtedly, the major problems of EV simulation lie with the battery and its associated models. Battery modelling is used to predict the performance of the battery over a given period of time with a given set of environmental conditions and demand variables. It is the energy delivered by the battery that determines the range and energy consumption of an EV. The energy delivered varies according to the way in which the battery is discharged and the battery model attempts to simulate the discharge process so as to determine the vehicle range and energy consumption for any particular journey.

Range and performance predictions are very difficult because it is not easy to model accurately the characteristics of a battery as a source of tractive effort - there are so many variables which affect performance. It would be extremely difficult to incorporate them all into the model. Fortunately, many of these factors are minimal in their effects on overall battery performance or they tend to cancel each other out. Attempting to incorporate too many relatively unimportant minor factors and dubious relationships into the model leaves more room for errors and cumulative errors to arise. In an ICE system there is an absolute amount of fuel and an absolute amount of energy contained on board the vehicle. Whereas petrol has exactly the same amount of energy stored in every drop or litre or tankfull, the quantity of energy available from a battery varies according to how the energy is used. In an EV, both the energy consumption and the energy available are variable quantities which are affected by the duty cycle. The other components which together form the electric vehicle drivetrain are well understood and can be relatively easily and accurately modelled. This is partly due to the fact that they have been used over a long period of time for many other applications. Also, their behaviour can be predicted over a wide range of operating states and they can be represented in deterministic models. Not so with the battery however which, using electrochemical reaction as the basis of its performance, cannot be described as a purely mechanical system. Models are based on the results of extensive battery tests and on observations of actual terminal performance and not on theoretical internal reactions. This has often required vast amounts of testing and test data for each battery type modelled, and in turn this detracts from the generality and universality of the model making it more specific and less flexible.

Battery modelling has suffered from lack of general applicability and generally accepted principles, for several reasons,

a) Most of the non-EV applications of batteries have required little or nothing in the way of analytical models to describe battery behaviour.

b) The traction battery, which relies on electrochemical reactions and internal phenomena, is more complex and harder to represent analytically than the other mechanical components. Although equations have been developed to describe internal phenomena, it is still very difficult to relate these equations to external battery terminal characteristics.

c) There are many different types of batteries using different elements and hence different electrochemical reactions. Even within the same basic coupling, there are differences of plate thickness, internal physical configuration and so on. Indeed, two apparently identical batteries are very likely to behave somewhat differently.

d) The performance of a battery is influenced by how it has been used in the past, so a model would have to have a record of the individual charge and discharge history for each battery.

e) There are many extremely complex interactions between the huge number of factors influencing battery performance, not all of which are completely or adequately described as yet. This has hindered attempts at analytical modelling.

There are two different approaches to battery modelling; generic models and specific models. The former use power and energy concepts, ie. they describe the battery in terms of its specific power and specific energy. Specific models on the other hand incorporate current and voltage concepts as a function of time. During the driving cycle the battery voltage will gradually decrease, necessitating a corresponding increase in current to achieve the same power (or driving profile). Both types of model have advantages and disadvantages but due to the relative availability of battery data, the second approach was used in this study.

PRINCIPAL ELEMENTS OF THE BATTERY MODEL

The major important battery relationships which were isolated for examination and inclusion in the model were,

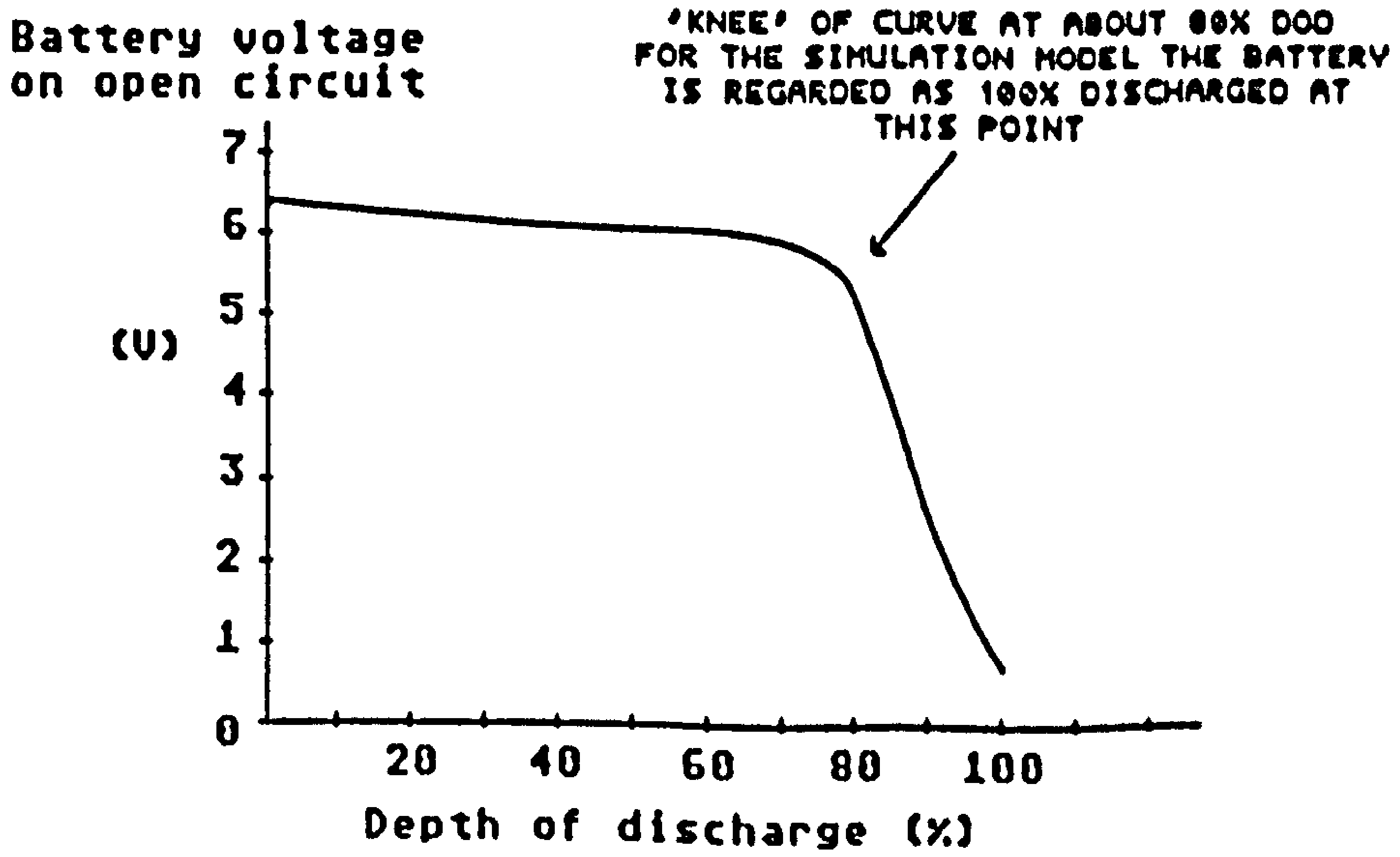
1. Battery voltage on open circuit v state of charge (SOC)
2. Battery terminal voltage v instantaneous current
3. Battery capacity and SOC v instantaneous current

Using these three basic relationships it is possible to determine the battery current and voltage and the amount of battery depletion during each time increment and the resulting state of charge at any time. It is then a case of monitoring the SOC as the simulation progresses until there is no remaining energy available. The range of the vehicle can then be calculated for that particular driving cycle.

A. BATTERY VOLTAGE ON OPEN CIRCUIT V SOC

The voltage of a cell drops as the state of charge reduces. We need to be able to determine the voltage at any state of charge in order to calculate the current, the depletion factor and the new SOC. Fig 6.5 shows a typical voltage curve for a lead-acid 6V battery (3 cells).

FIG 6.5 BATTERY OPEN CIRCUIT VOLTAGE AGAINST SOC (Lead-acid)



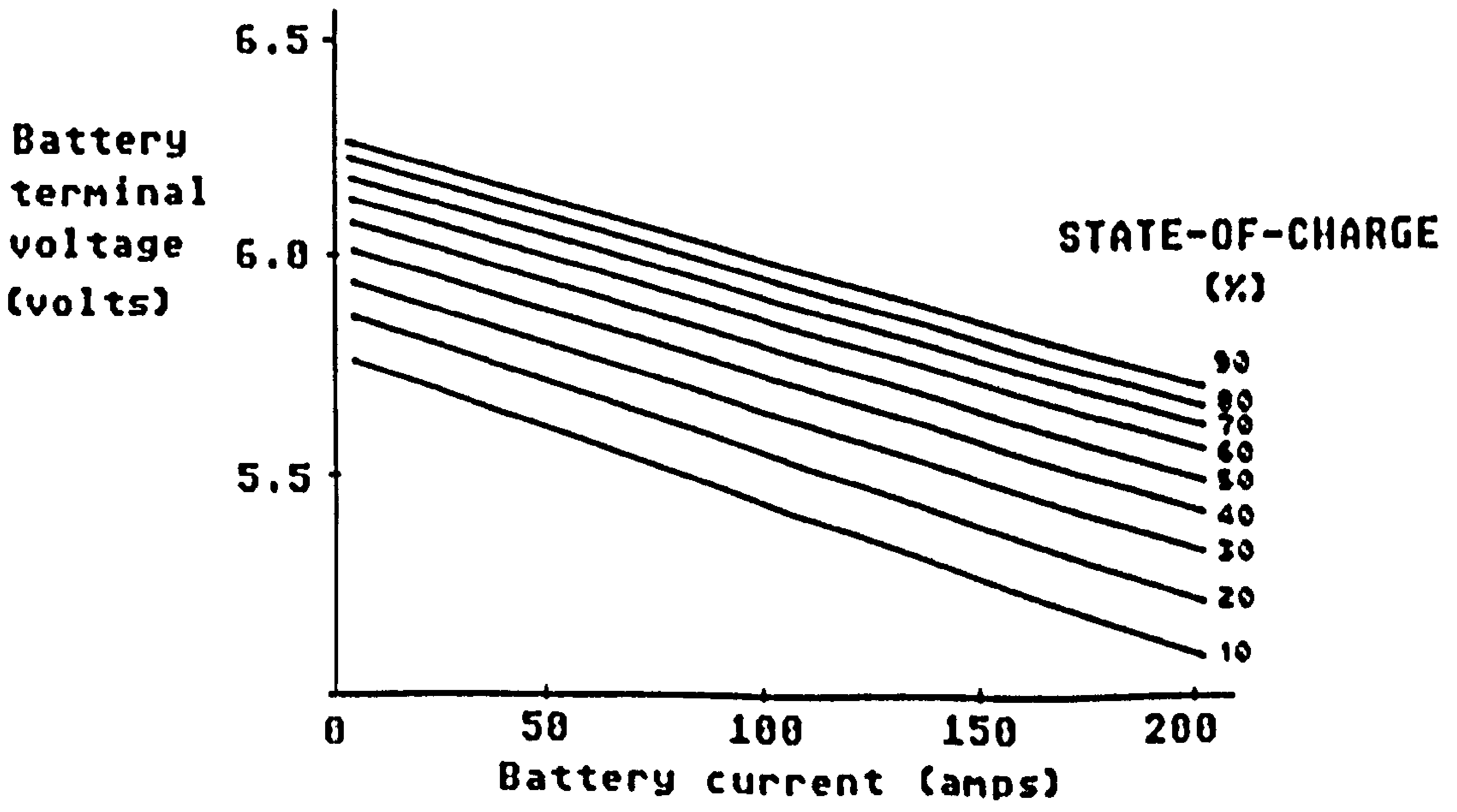
There is a very sharp decrease in voltage after the knee of the curve and for the purposes of this model the battery is regarded as flat (zero SOC) when this knee is reached, although In reality, there is still a certain amount of energy available even after this point, but in the interests of battery life, it is unadvisable to discharge too deeply. The knee of the curve is reached after approximately 80% of the potential battery energy has been expended. In the case of the particular cell shown above this happens at 5.7 Volts.

The curve can be approximated by fitting straight line segments, and the Ford motor Company, in their model, used three line segments which were found to be adequate. Two segments were used for this model, the equations of which are found in appendix 1.

B. BATTERY TERMINAL VOLTAGE V INSTANTANEOUS CURRENT

Battery voltage is also reduced when a current is drawn. The magnitude of this instantaneous current dictates the extent to which battery terminal voltage will drop. This is shown in figure 6.6.

FIG 6.6 BATTERY TERMINAL VOLTAGE AGAINST CURRENT AND SOC



The following equation can be used to describe the relationship,

$$Vt = Vo - (\text{CURRENT} \times 0.003)$$

where Vt = Battery terminal voltage while current is being drawn
Vo = Battery voltage on open circuit

There is a 'chicken and egg' situation inherent in the calculation of terminal voltage and instantaneous current because one cannot be calculated without the other. Some battery models have attempted to arrive directly at a measure of terminal voltage but this however would necessitate calculating the current without reference to the voltage. A unique procedure was developed to get round this problem. This model uses the calculated measure of power, calculated in the drivetrain model, and open circuit voltage to calculate current and terminal voltage. As we cannot know the terminal voltage until we know the current and vice-versa, the solution is to use the measure of power arrived at in the vehicle model and the voltage on open circuit (which is independent of current) to give an initial estimate of the required current.

$$\underset{(\text{amps})}{\text{CURRENT}} = \frac{\text{POWER}}{\text{VOLTAGE}} \; \begin{matrix}(\text{watts})\\(\text{volts})\end{matrix}$$

This measure of current will be an underestimate, because the voltage used in its calculation is too high since it takes no account of the drop due to instantaneous current. However we now have an approximation to the true current and we can get closer and closer to the actual current by an iterative process whereby the calculated current at each step is used to obtain a new measure of voltage according to the relationship depicted in fig 6.6. This in turn is used as the basis of the next calculation of the current. Hence,

$$Vt1 = Voc - [\,\text{POWER} / Voc\,] \times 0.003 \quad \ldots\ldots\ldots \text{a.}$$

$$Vt2 = Voc - [\,\text{POWER} / Vt1\,] \times 0.003 \quad \ldots\ldots\ldots \text{b.}$$

$$Vt3 = Voc - [\,\text{POWER} / Vt2\,] \times 0.003 \quad \ldots\ldots\ldots \text{c.}$$

It was found that three iterations were sufficient to arrive at a satisfactory measure of current and voltage for all reasonable levels of power. Obviously the more iterations used, the closer the answer will be to the real current but there are decreasing marginal improvements in the accuracy of the answer for each iteration and after three iterations there is very little change in the calculated measure of terminal voltage.

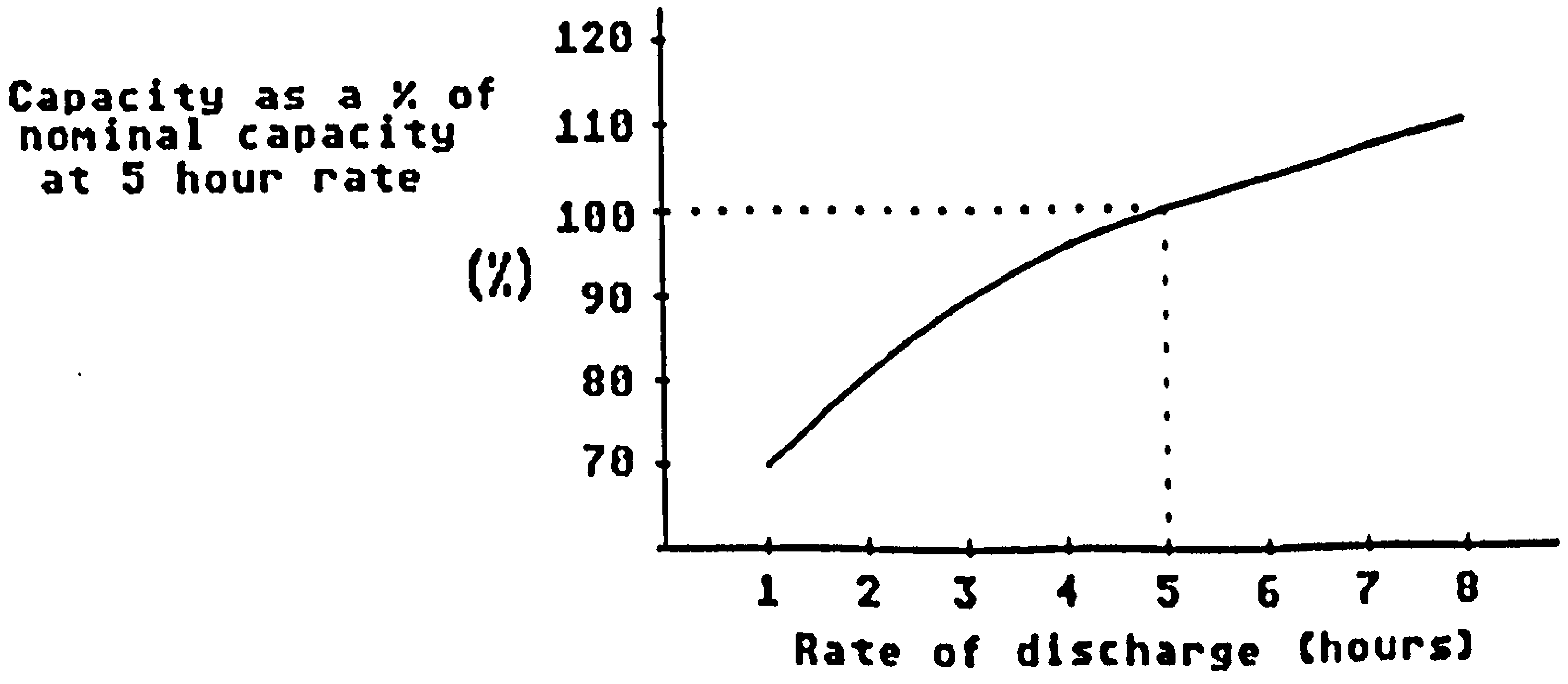
C. BATTERY CAPACITY AND SOC V RATE OF DISCHARGE

It is a well known phenomenon of battery systems that the energy available on discharge is a function of the rate of discharge. In order to compare batteries it is necessary therefore to measure the capacity under specified conditions. British Standard BS 2550 states that,

> "The rated capacity, C^5, shall be stated by the manufacturer for a temperature of 30°C, a discharge time of 5 hours and a cut-off voltage of 1.70 Volts per cell"

This capacity, measured in amp hours, is normally referred to as the capacity at the five hour discharge rate. During constant speed driving, it is a simple matter to determine how long it will take to deplete the battery, or alternatively how much energy is available. This relationship is shown diagramatically in fig 6.7.

FIG 6.7 BATTERY AMP-HOUR CAPACITY AS A FUNCTION OF DISCHARGE RATE



During arbitrary variable speed driving cycles, where complex current loads are experienced, it is not quite so easy to calculate battery capacity. The current drawn during each time interval is assumed to be constant and the amount of battery depletion is calculated on the basis of this constant current discharge for each time increment. In effect, the theoretical amount of energy that would be available if any particular current was sustained is calculated according to the relationship in fig 6.7, and then the fraction of that total capacity which is used during that particular time interval is easily calculated. A cumulative total of the energy used allows us to tell when the battery has no remaining charge. This implicitly makes the assumption that the same capacity versus discharge rate shown earlier still holds true for varying discharge rates. The equation that describes the relationship in fig 6.7 can be used to calculate the percentage of available battery capacity used during each time increment,

$$\Delta SOC = \frac{-Ib \times T}{3600} \times \frac{100}{[Ib / Ib^5] \times C^5} \qquad [6].$$

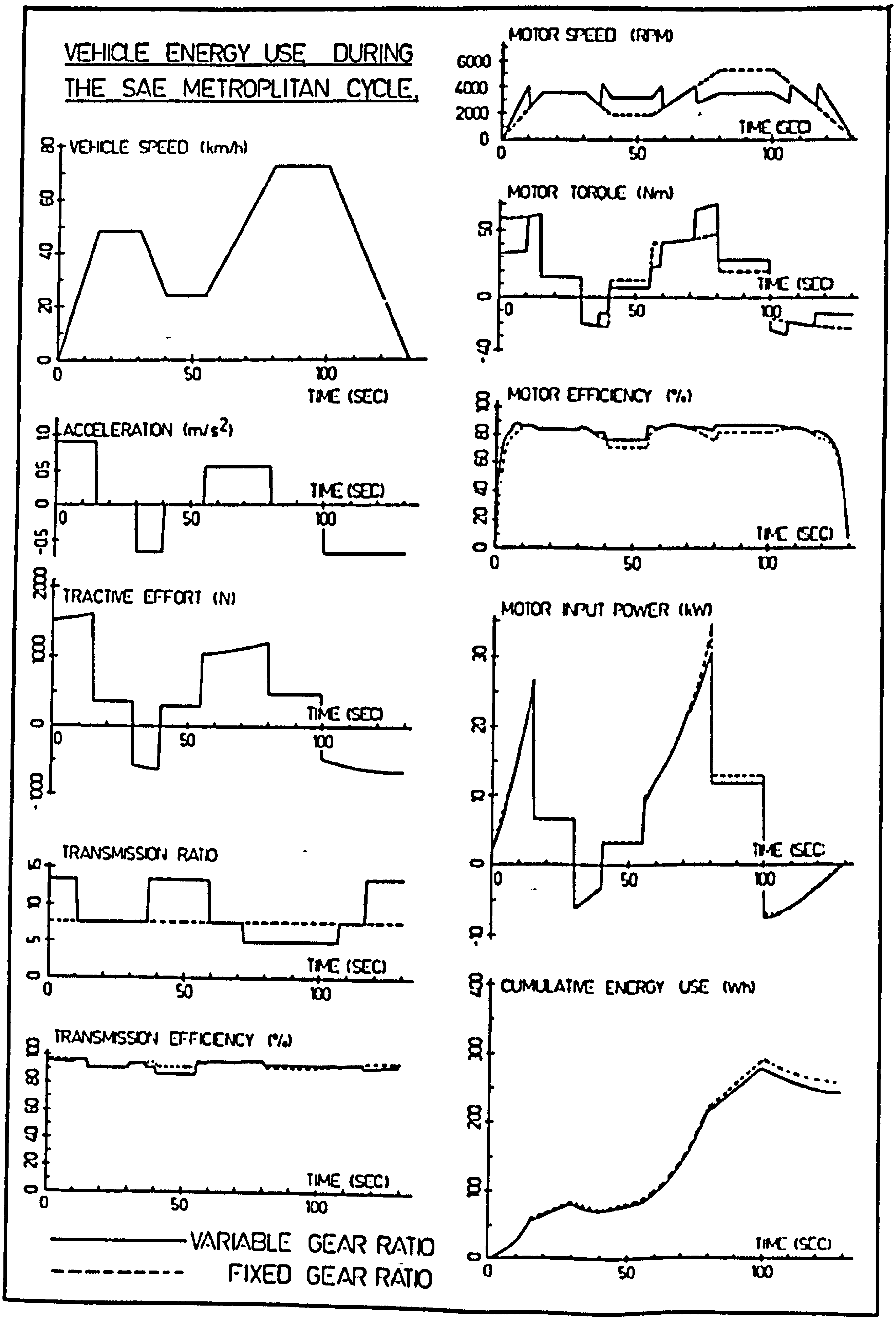
where ΔSOC = Delta SOC% (ie. the percentage of SOC used during the time increment)
Ib = Battery discharge current (amps)
T = Time increment duration (seconds)
Ib^5 = 5 hour discharge rate current (amps)
C^5 = Battery capacity at 5 hour discharge rate (amp hours)

The above equation agrees with actual battery tests except for very low rates of discharge corresponding to discharge times of greater than 20 hours. During normal EV use, an extremely small fraction of battery discharge occurs at such low levels of current so there is little error introduced into the vehicle simulation. The new SOC is calculated thus,

$$SOC_n = SOC_{(n-1)} - \Delta SOC$$

This measure is then used to calculate battery open circuit voltage in the next time increment and the whole process is repeated until there is no useful energy remaining in the battery. Final calculations can then be made for range, energy consumption, average component and system efficiency and so on. Fig 6.8 shows typical results from a similar time incremental model which was developed at Eindhoven University of Technology. The figure shows how several of the key variables change as time progresses in the simulation.

FIG 6.8 Example to illustrate how time incremental models work
(From a model developed by Eindhoven University)



The results obtained from the model which was developed at Stirling University for the island situation are discussed in section 6.5.

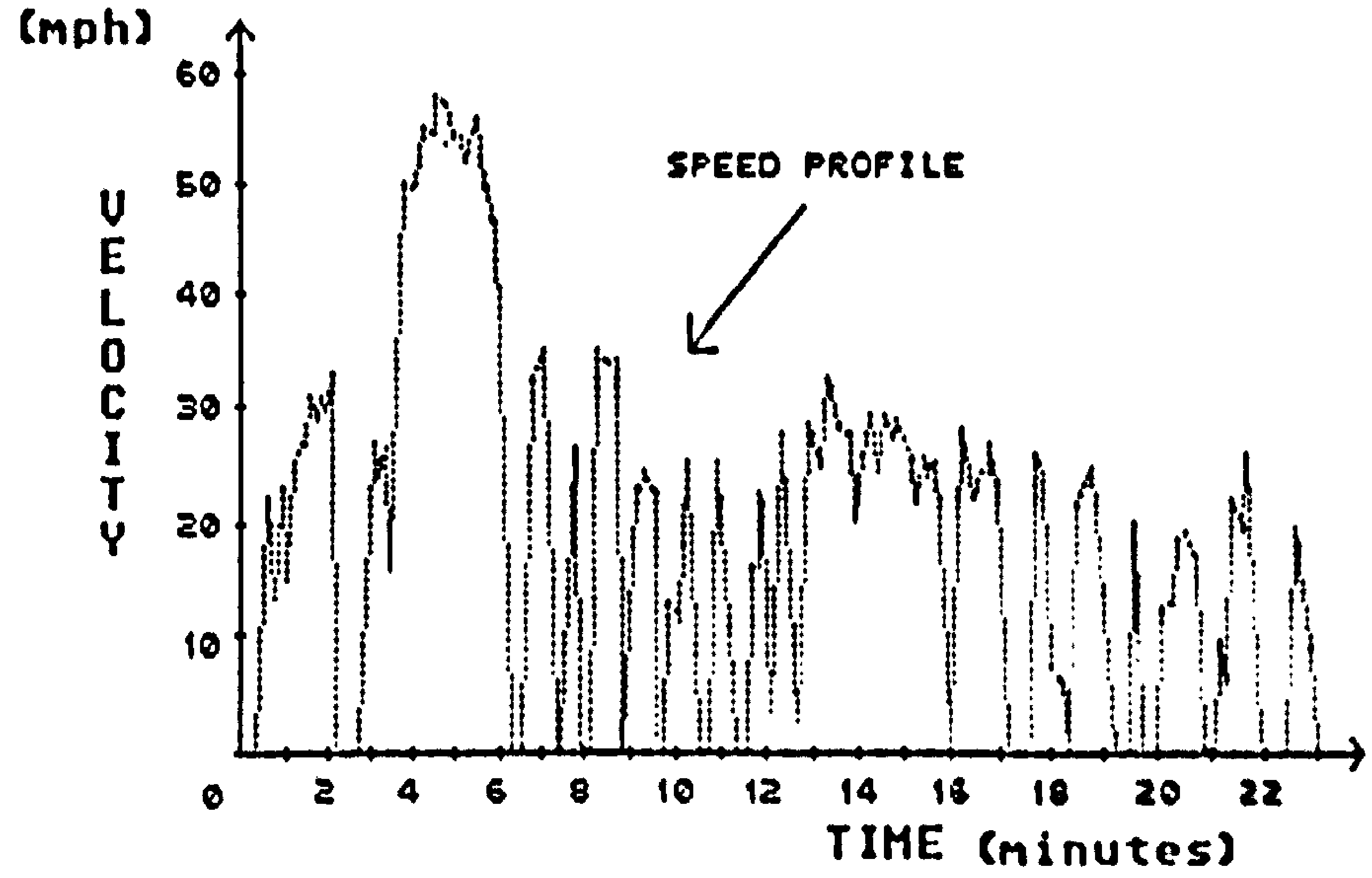
6.4 DRIVING CYCLE DATA COLLECTION

6.4.1 STANDARD DRIVING CYCLES

The vehicle simulation model requires as its inputs the speed of the vehicle and the gradient of the road being traversed at regular time intervals or increments. From these two measures all the elements of tractive effort can be calculated. The speed and gradient are assumed to be constant for the duration of the time interval and are taken to be the average of the measurements at the beginning and end of the interval. Obviously the smaller the time increment, the more accurately will this linear approximation represent the true speed and gradient. If these quantities could be expressed as algebraic functions it would be possible to calculate continuous power and current functions and so achieve even greater accuracy. However, due to the arbitrary nature of speed and gradient and the problems associated with gathering and storing the huge amount of resulting data, it is necessary to approximate the curve with short straight line segments (time intervals of 2.3 seconds were used).

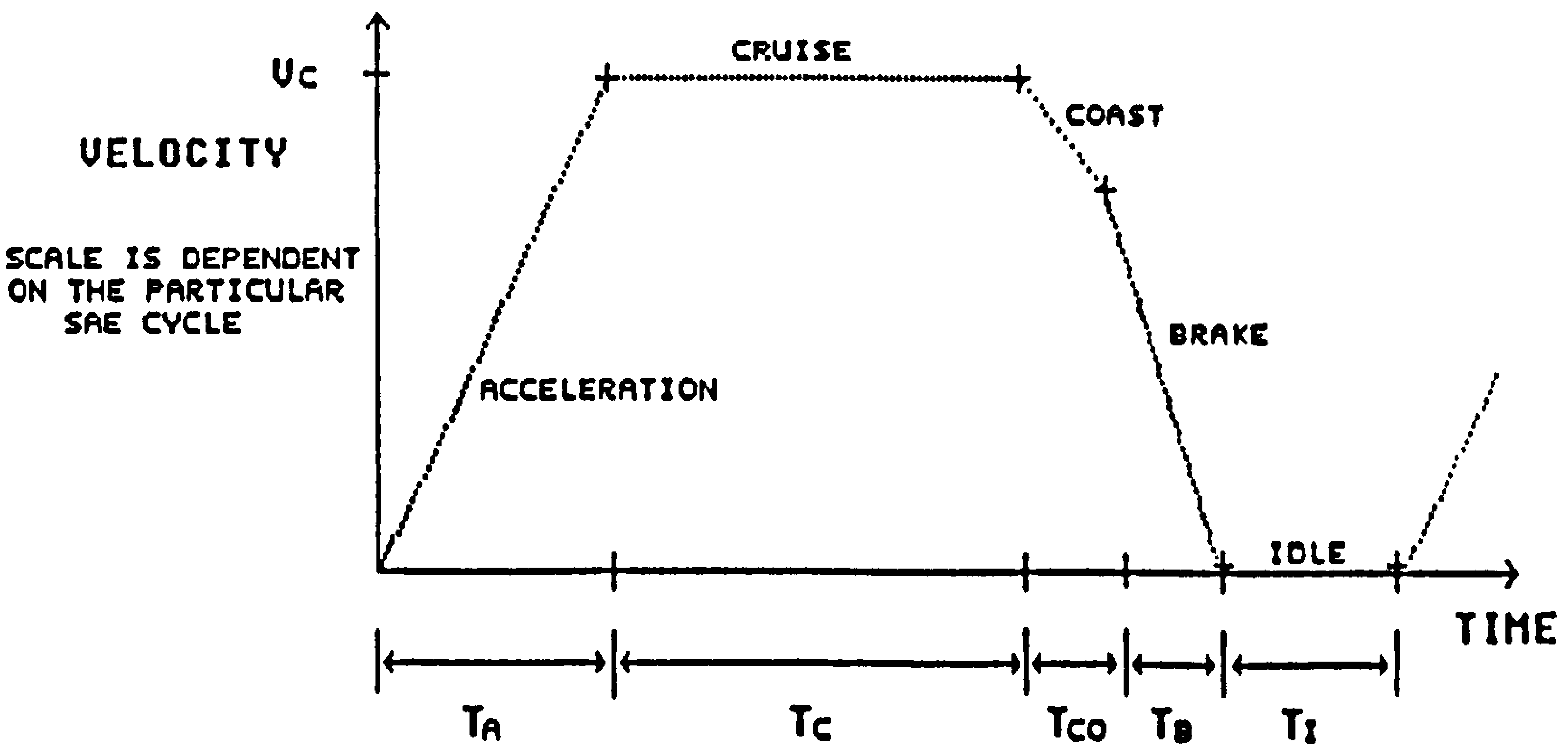
A "driving cycle" is the term given to describe a particular series of driving operations in terms of vehicle speed at regular intervals over a period of time. Several standardised driving cycles have been developed in recent years to characterise various types of driving modes or a sequence of operations, such as "city" or "rural" driving, or "European" or "taxi" driving. These cycles are used for vehicle testing and an example of such a driving cycle is shown below in fig 6.9

FIG 6.9 Vehicle speed over the Federal Urban Driving Cycle



These standardised cycles were established by direct observation of certain types of driving applications and then modified by statistical techniques to arrive at standardised driving cycles. The most common cycles in the United States are known as the Federal Urban Cycle (also called the CVS cycle) and the Federal Highway Cycle (HWY). The CVS cycle was developed originally to evaluate the noxious emissions of ICEs and is based on a cycle derived from statistical flow of traffic patterns in Los Angeles. The HWY Cycle was developed to typify rural or cross-country driving in the States. A composite of these two driving modes is used in Europe to evaluate fuel economy and emissions and is known as the EEC Cycle. A number of other cycles have been developed or derived statistically from actual driving situations to describe other types of driving modes; for example, the TAXI Cycle typifies taxi cab driving in congested urban areas, and UPS describes delivery truck operation in a large urban area. In the early 1970s, efforts were made to develop standard driving cycles for EVs. The first EV cycle, developed by the Society of Automotive Engineers and known as SAE J227 was designed to give approximately the same road load energy per mile as the CVS Cycle but lower peak road load power. Since it is a hypothetical cycle, rather than a cycle based on actual driving patterns, it is specified more simply than the cycles discussed in the previous paragraph. The J227 cycle was re-issued soon after it was adopted as a US SAE standard because the implicit power demands were too high for many of the EVs being developed in the States. It was replaced by four simplified cycles, designated SAE J227a-A,-B,-C,-D. These are widely used in EV testing and are shown below in fig 6.10.

FIG 6.10 SAE J277 schedule 'a' series of driving cycles
(see section 6.4.1 for explanation)



Values for V_C, T_A, T_C, T_{CO}, T_B and T_I vary with the specific cycle :- SAE-A,B,C or D

Although EV technology has been advancing rapidly and has been the subject of much recent interest, there is no doubt that EVs are at present best suited to specialised applications. Because of this it is important to assess their potential and suitability for each specific duty and so the driving cycle should represent the type of driving that the vehicle would be expected to encounter under each application. Although the previously mentioned EV cycles attempted to do this, it was felt that they were not specific enough to individual duties to give a realistic representation of the tasks involved. This is certainly true of the Island situation, where there is no known pre-specified duty cycle. It can also be maintained that different islands would require unique driving cycles. The type of roads, the geographical dispersion of the population, the terrain and the driving habits of the islanders all add weight to the argument for 'application-specific' driving cycles. In addition, none of the existing cycles takes the gradient of the road into account and this component of road load along with inertial effort constitutes the largest part of the total road load power and energy use. It is difficult to incorporate a measure of road gradient into a standardised cycle because it is essential to schedule the speed and gradient in such a way that the interdependence between these two measures is recognised. When discharging a traction battery the sequence and magnitude of the discharge currents are important in determining the energy available for traction. It is impossible therefore to separate the velocity function from the gradient profile in the duty cycle. For these reasons it was considered necessary to establish purpose-built duty cycles for the particular islands and applications in question. This meant defining particular roads in terms of their gradients and of the vehicle's speed as it traversed these gradients. No attempt was made to build standardised or generalised duty cycles from such "real-life" road-driving profiles, for the following reasons,

a) In road load measures the gradient factor could not be included adequately, dissociated from velocity, in a standardised form of model.

b) Although standardised duty cycles have been developed for EV testing, there is no reason in the context of this study why such a cycle should be used. Standardised cycles such as the SAE cycles were developed for comparison purposes, whereas in this study, the primary objective of performance simulation was to obtain an estimate of vehicle performance in the islands which is as realistic and accurate as possible. There is no need to limit the amount of driving data which forms the input to the model and so, in the interests of accuracy, it was considered preferable to use many real-life road profiles rather than a single standardised cycle. Using this approach, it is still possible to generate summary figures for vehicle performance by weighting the results of simulations of different island road profiles (see section 8.5).

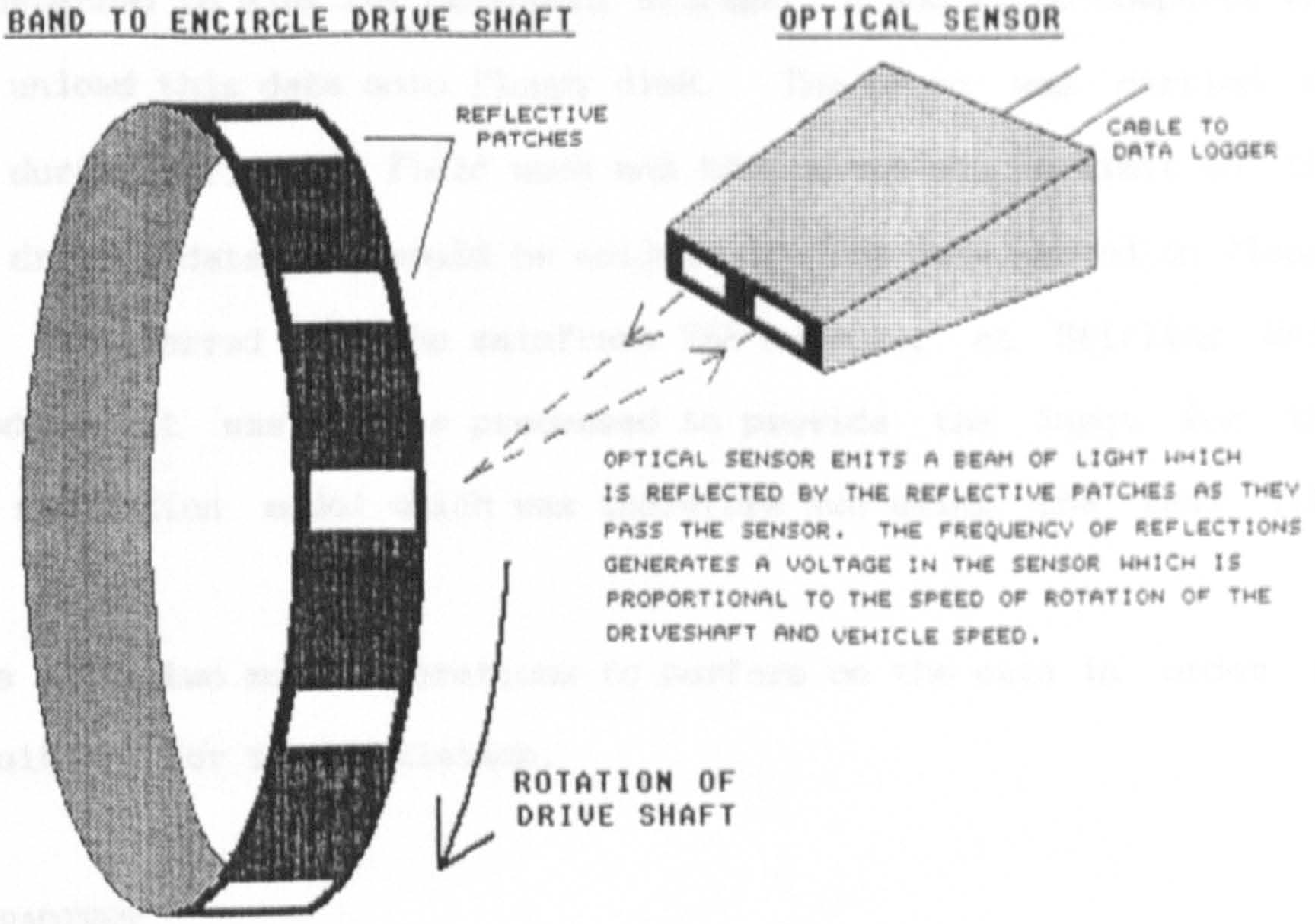
6.4.2 RECORDING THE TRIP PROFILES

In order to establish island duty cycles, it was necessary to collect primary data relating to island roads by direct measurement with appropriately designed instrumentation. To obtain the trip data (speed of vehicle and road gradient) which is needed as the input to the computer simulation model, a purpose built portable data logger was designed and built at Stirling University and a normal ICE car was fitted with appropriate sensory devices. The aim of this project was to record at regular time increments, via special sensors, the vehicle velocity and road gradient as the road was being traversed by the vehicle which was fitted with the equipment.

THE VELOCITY SENSOR

The speed of the vehicle was measured by a small optical sensor which measured the frequency of rotation of the drive shaft of the vehicle. The drive shaft was encircled with a thin band attached to which were several evenly spaced reflective patches. The optical device shone a beam of light onto the driveshaft and whenever a reflective patch passed this beam the reflection was registered by the sensor, (see fig 6.11 and appendix 12). The frequency of these reflections generated a voltage, via the sensor, which was linearly proportional to the speed of the drive shaft and vehicle wheel. Vehicle speed could be calculated once the rolling circumference of the tyre was known.

FIG 6.11 OPTICAL/MECHANICAL VELOCITY SENSING SYSTEM.



GRADIENT SENSOR

The gradient of the road was detected by an electronic inclinometer which generated a voltage in proportion to the angle of inclination. Details and specifications are given in appendix 12.

THE DATA LOGGER

The data logger was powered by two rechargeable lead-acid batteries which were capable of providing enough energy to power the logger for over an hour of data recording per recharge. A description of the hardware used and photographs of it are given in appendix 12.

6.4.3 DATA PREPARATION

The raw data output of the data logger required a certain amount of preparation before being suitable as input to the computer simulation. The logger stored a measure of speed and gradient every 2.3 seconds of the journey in its RAM, memory and after the recording session this data had to be transferred to disk for permanent storage. A BBC micro computer was used to unload this data onto floppy disk. The micro was carried on location during periods of field work and thus there was no limit to the amount of driving data that could be collected. The data stored on floppy disk was transferred onto the mainframe VAX computer at Stirling University where it was further processed to provide the input for the computer simulation model which was therefore run using the real life data.

There were two major operations to perform on the data in order to make it suitable for the simulation.

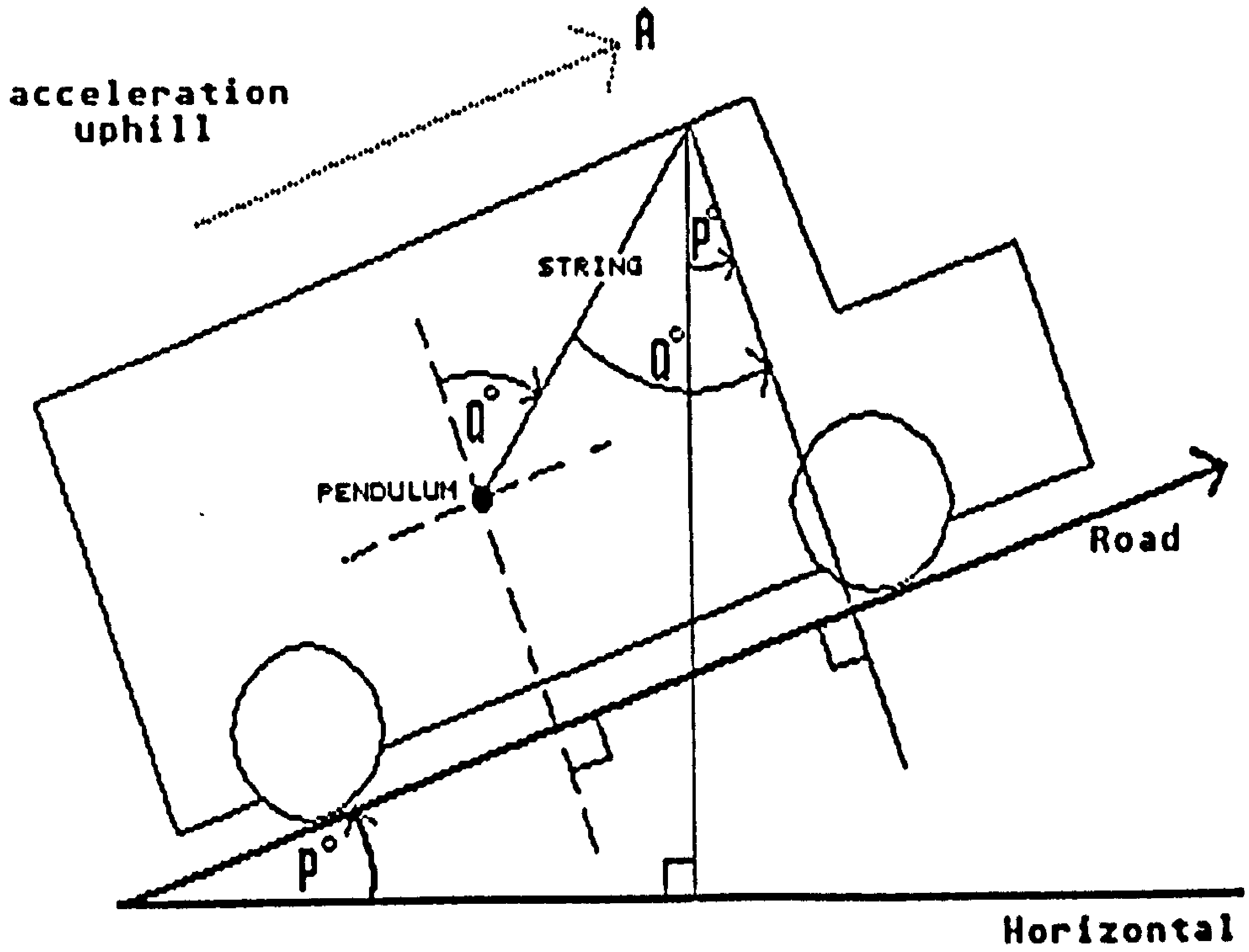
A. TRUE GRADIENT

The readings recorded by the inclinometer were not true measures of road gradient because accelerations and decelerations of the vehicle affect the reading of the inclinometer. Accelerations will record as a positive (uphill) gradient and decelerations will record as a negative (downhill) gradient. This is of course due to the gravity sensing nature of the inclinometer. It is necessary therefore to correct for this acceleration-dependent element contained within the gross "gradient" figure that is recorded during driving. A trigonometrical expression had to be constructed to differentiate between the true gradient and the inertial element. This is explained below.

If the gravity sensing component of the inclinometer is thought of as a small pendulum with mass m, and the tension on the connecting string as T, then calculate all the forces exerted on the mass of the pendulum can be calculated. Taking the case of an acceleration uphill, the pendulum will swing backwards causing the inclinometer to record a larger angle than the actual angle of inclination of the road (see fig 6.12)

LET A = Vehicle acceleration (+ve) or deceleration (-ve) (m/s/s)
P = The angle of the slope, uphill (+ve) or downhill (-ve)
Q = The angle recorded by the inclinometer, (+ve) or (-ve).
g = Acceleration due to gravity, (9.81 m/s/s)

FIG 6.12 CALCULATION OF TRUE GRADIENT



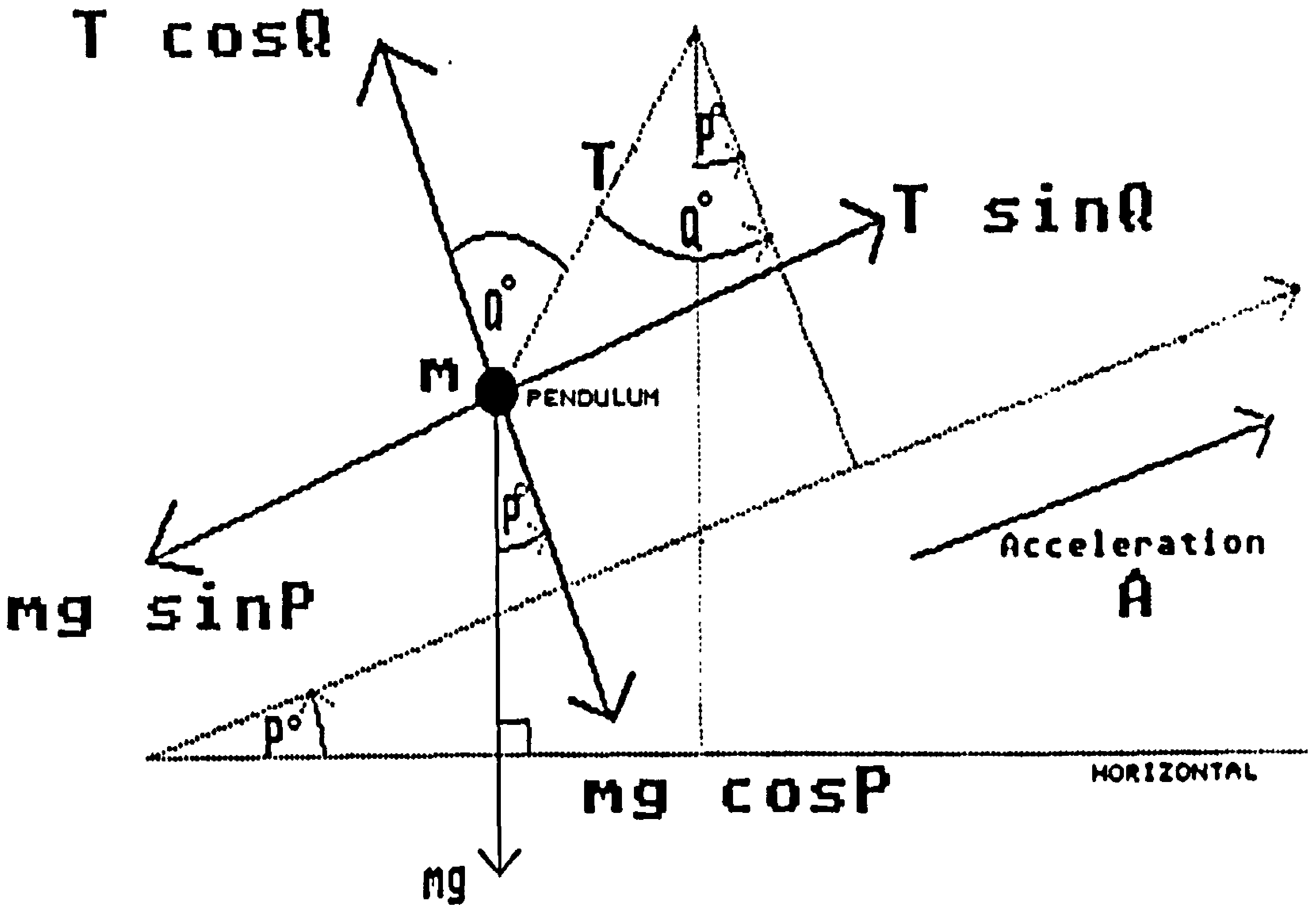
The forces acting on the bob of the pendulum can be resolved into their components perpendicular and parallel to the road (fig 6.13).

Summing these forces,

Parallel to the plane : $T \sin Q - mg \sin P = mA$ 1
Perpendicular " " " : $T \cos Q - mg \cos P = 0$ 2

These two basic equations are true algebraically, i.e the variables P,Q,and A can be positive or negative. In practice this means that the equation can represent an acceleration up or downhill, or a deceleration up or downhill.

FIG 6.13 FORCES ACTING ON THE PENDULUM



Rearranging equations 1 and 2,

$$\Leftrightarrow \quad T.\sin Q = mA + mg.\sin P \quad \ldots\ldots\ldots \; 3$$

$$\Leftrightarrow \quad T.\cos Q = mg.\cos P \quad \ldots\ldots\ldots \; 4$$

Divide 3 by 4

$$\Rightarrow \quad \tan Q = \frac{A + g.\sin P}{g.\cos P}$$

$$\Rightarrow \quad g.\tan Q.\cos P - g.\sin P = A$$

$$\Rightarrow \quad \tan Q.\cos P - \sin P = \frac{A}{g}$$

Multiplying through by cosQ,

$$\Rightarrow \quad \sin Q.\cos P - \cos Q.\sin P = \frac{A.\cos Q}{g}$$

$$\Rightarrow \quad \sin(Q-P) = \frac{A.\cos Q}{g}$$

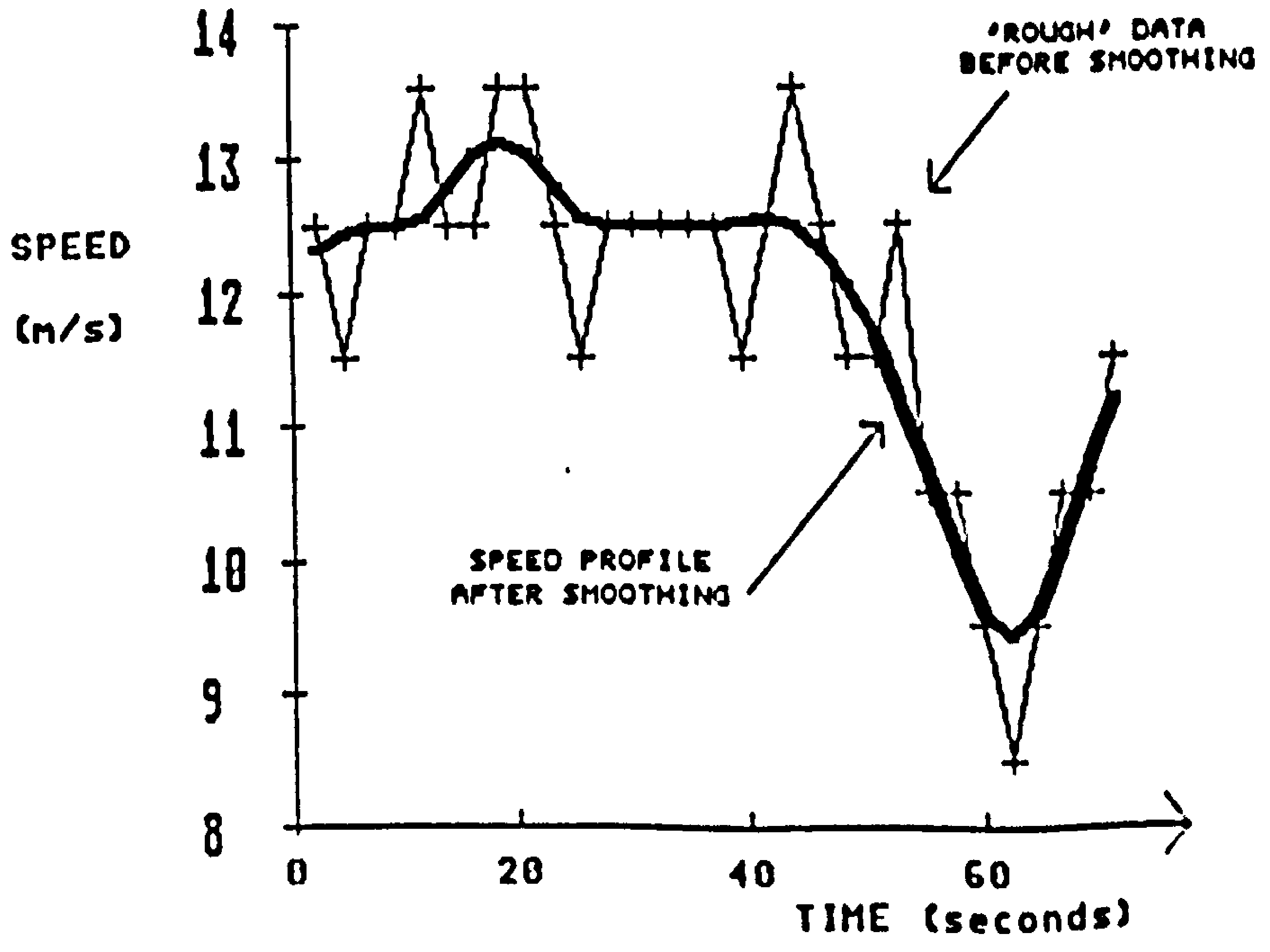
$$\Rightarrow \quad Q - P = \arcsin\left(\frac{A.\cos Q}{g}\right)$$

$$\Rightarrow \quad P = Q - \arcsin\left(\frac{A.\cos Q}{g}\right)$$

B. DATA SMOOTHING.

The logger recorded the measures of speed and gradient in integer form so each figure was truncated before it is stored. This has two major implications. Firstly, each stored figure will be smaller than the true measure by between 0 and 1 unit of measurement. Secondly, the graph of recorded speed or gradient over time will be quite jagged, as recorded values cannot vary continuously but by one whole unit steps only, even though the real difference might be minute. In addition to these limitations, because data was recorded using a conventional ICE vehicle and not an electric vehicle, it was not possible to mimic exactly the characteristic movement of an EV. This is largely overcome by the measures taken in the previous section but the problem of gear changing remains. Shifting up gear in an ICE is normally characterised by a temporary reduction in velocity which is then regained before the original speed profile is resumed. In an EV with no gears the overall increase in velocity follows a smooth curve with no such dip in it. If the rough data was used in the simulation model, vehicle range and energy consumption would be calculated for an unrealistic situation, characterised by continual short term accelerations and decelerations (see fig 6.14).

FIG 6.14 Velocity profile before and after smoothing
(an illustrative example)



As inertial effort is one of the major elements of tractive effort and optimal vehicle performance is achieved by constant speed driving, this would lead to an underestimate of vehicle performance. It was necessary therefore to rectify these limitations of the data and this was done by data 'smoothing'.

A Minitab command file (appendix 1) was written which took the raw data recorded by the data logger and performed various modifications on it. To begin with, the truncation of the data was rectified by adding 0.5 to every data record of speed, as this was the average amount by which the truncation has reduced the true measure of velocity. The speed profile was then smoothed using the Minitab programme. Next the vehicle acceleration or deceleration was calculated from the velocity figures. This was then used to calculate the true gradient, by adjusting for the effect in inclinometer readings introduced by accelerations and decelerations. The resulting gradient figures were then smoothed as well.

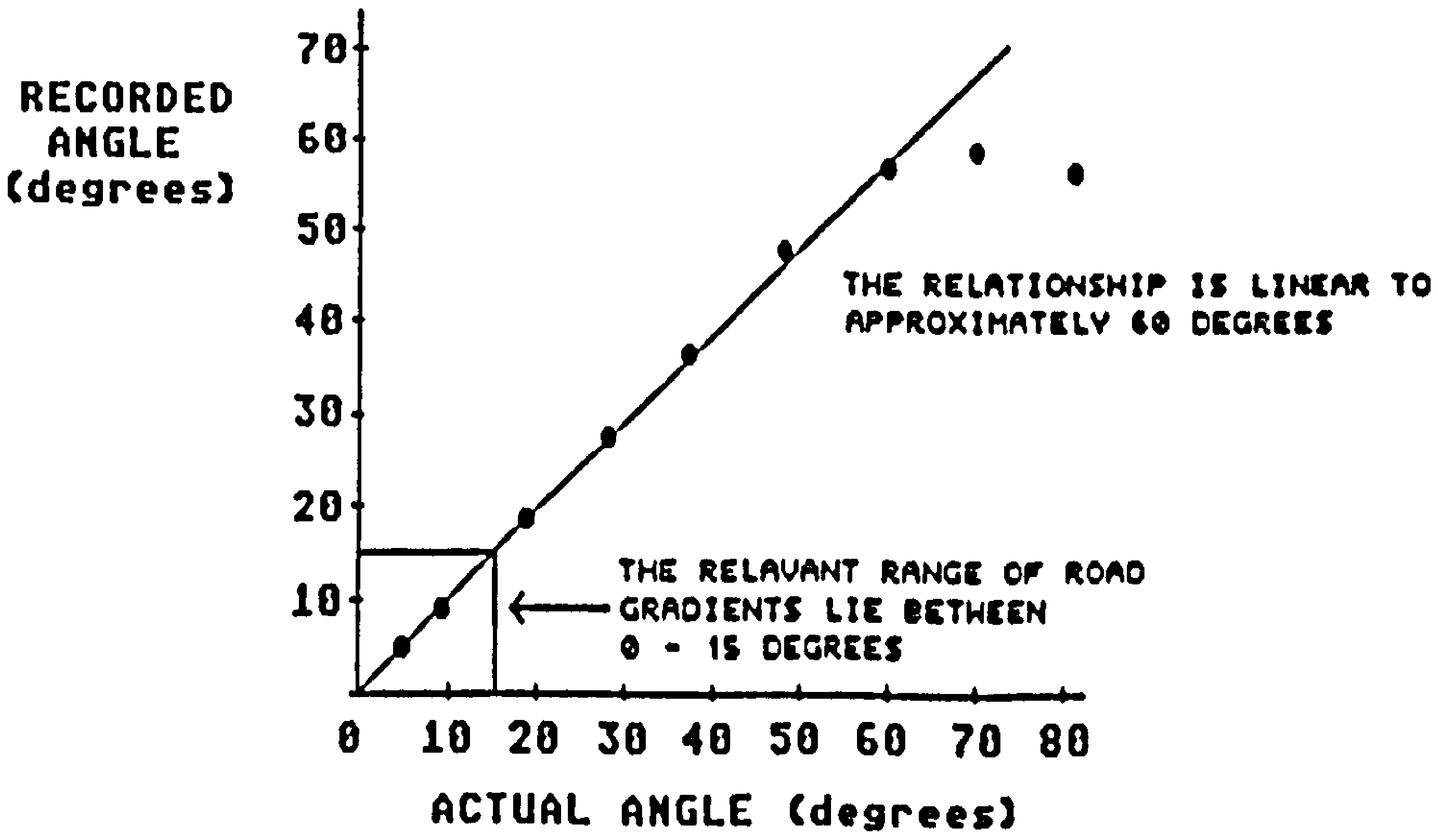
6.4.4 DATA VALIDATION.

It was of vital importance that the data used for the simulation model was as accurate as possible and that checks were done to determine how closely the recorded data reflected the real speeds and gradients being measured. The following methods were used to check the validity of the recorded data.

A) VELOCITY was measured using an optical/mechanical system as described in section 6.4.2. The optical sensor measures the speed of rotation of the driveshaft and because of the simplicity of the system and because there were no unforeseen influencing factors associated with the application of the system when attached to the vehicle, it was decided to test the system in the laboratory where controlled tests were easier. The reflective strap which was normally attached to the vehicle driveshaft was attached instead to a drill bit in the laboratory so that it could be rotated at known speeds. Different rotational speeds were measured via the optical sensor over the range of speeds that could be expected in a car (i.e the equivalent of 0-70 mph). Once properly calibrated, the system proved to be accurate to within 1% over the entire operating range.

B) GRADIENT was measured using an electronic inclinometer which was also tested in the laboratory over a range of known angles and the accuracy was found to be consistent with the manufacturer's specifications. Results of the laboratry tests are shoen in fig 6.15.

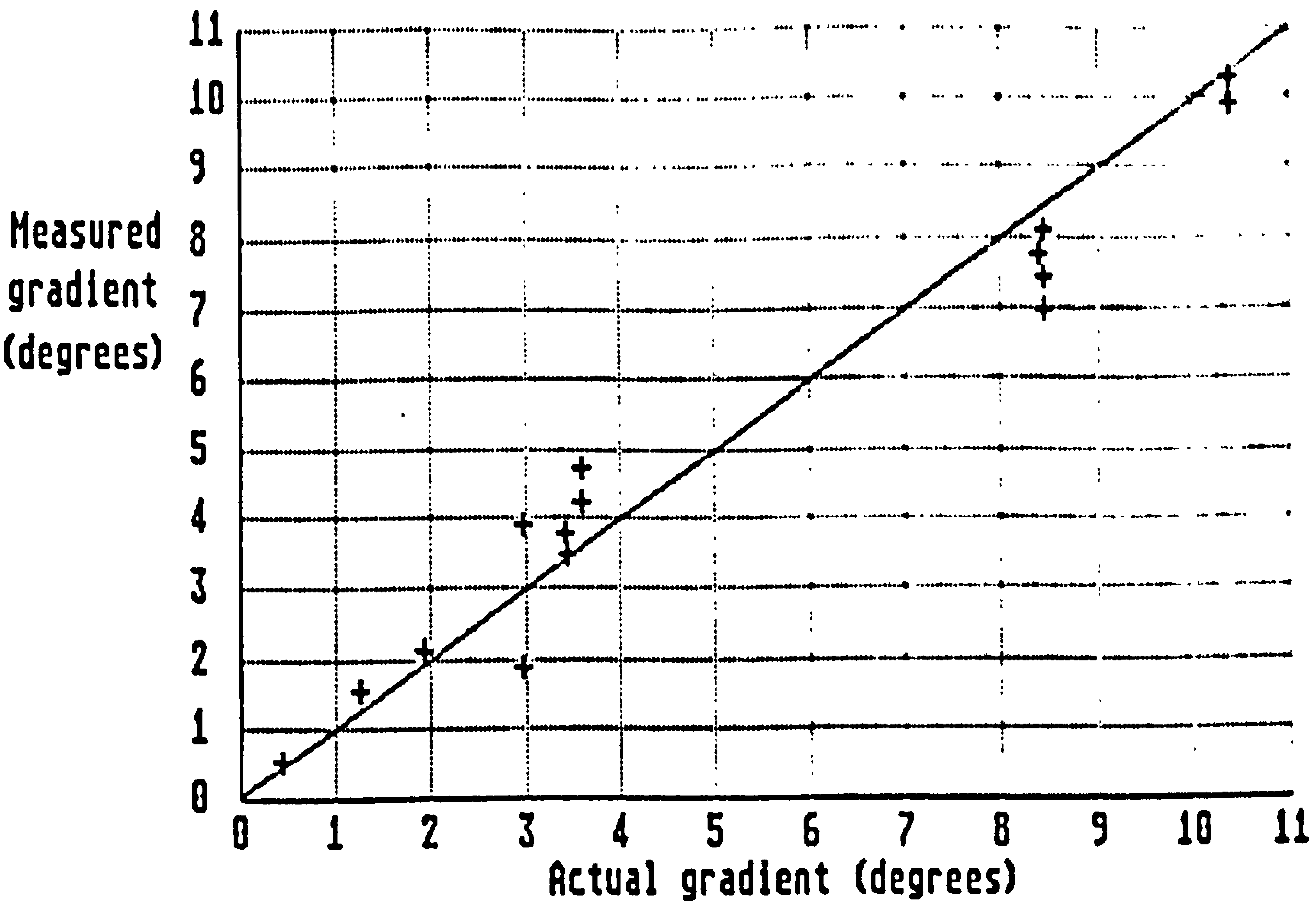
FIG 6.15 GRADIENT CALIBRATION CURVE FOR INCLINOMETER



Two factors however were suspected of causing complications once the system was in operation in the vehicle - the movement of the vehicle and the changes in velocity. Two tests were undertaken to asscertain the validity of the collected data.

1) The entire data logging system was used in the vehicle to record gradients on several road sections where the inclination had already been measured using surveying equipment (results shown in fig 6.16).

FIG 6.16 GRADIENTS MEASURED BY INCLINOMETER AGAINST TRUE ROAD GRADIENTS



These few point estimates however tell us nothing about the consistency of the estimates on repeated application. A second check was used to test for consistent errors.

2) During the recording of road profiles, the vehicle normally started and stopped a recording session at the same location so that the cumulative rise or fall during the session was zero. If there had been a consistent error in the measurement of road gradient, the data would show that the vehicle had either risen or fallen in height by the end of the run. This enabled a check to be made to see whether or not the inclinometer was consistently over or under estimating the true inclination. This was done by calculating the distance travelled in each time increment, multiplying this distance by the Sine of the angle of inclination to give the height change in each time increment and summing the height change for the entire run. Results of such validity checks showed that recorded gradients were never consistently over or underestimated by more than 0.2 degrees. Any consistent over

or underestimate was rectified before the data was fed into the simulation programme. Although the second test tells us nothing about the accuracy of any particular recorded data point, when taken in conjunction with test 1 it does demonstrate that the inclinometer gave a 'reasonable' measure of road gradient. No other EV performance simulation model is known which includes a measure of road gradient, even although the tractive effort required to climb gradients is such a large component of total tractive effort. Although the instrumentation did not give a perfect estimate of inclination, road gradient was considered important enough to include in this study.

6.4.5 THE FIELD WORK

After building and testing the data recording and processing system, the next stage in the analysis was to collect real-life driving data for the application in question which in this case was for the roads of the Outer Hebrides and the Orkney islands. This meant driving on the islands with the data logging system installed in a car. It was important during data recording to undertake a realistic imitation of the type of driving and duty cycles that island vehicles are expected to undertake. The whole idea of the simulation and the application potential assessment was to see how well and to what extent EVs could perform the tasks currently carried out by ICE vehicles. The EV is being regarded as a direct substitute and therefore has to be assessed on the basis of current use patterns. Fortunately the island roads rarely permit high speeds and most island drivers have driving styles that would quite suit the limitations of a high performance electric vehicle. The car that was used in the field work was a Peugeot 305 diesel estate. This vehicle has an acceleration profile not dissimilar from the ETV-1 test vehicle which was used as the basis of the performance simulation, and while it does provide more power and a higher top speed, driving speeds were kept below 60mph and every effort was made to avoid excessive and unnecessary accelerations. It was not possible during driving to determine when more power was being demanded than could have been supplied by the EV but the results of the performance simulation showed that this very rarely happened (see section 6.5). As far as possible, data was recorded while following island cars along different stretches of road, thus imitating typical driving patterns even further.

6.4.6 ISLAND DUTY CYCLES

All the major roads and most of the minor roads on the two different islands were driven and the journeys recorded. The maps in appendix 2 shows these roads. In Lewis and Harris a total of 6.3 hours of driving were recorded, representing 182.6 miles and in Orkney, 3.2 hours of driving were recorded, representing 95.5 miles. Traffic flow figures were available for the various road sections shown in the maps so each of these road sections was recorded separately. When running the performance simulation, vehicle range and performance were simulated separately for each of the sections so that a weighted average of range and energy consumption could be calculated by taking into account the traffic flows and section lengths. The aim was to arrive at a single figure for vehicle range and energy consumption which could be seen as representative of what an EV could be expected to achieve on the islands. This meant allowing for a certain proportion of journeys on single-track roads, double-track roads, town driving, hill climbing and so on. Although some vehicles may rarely leave the town and some may rarely drive on hilly, single-track roads, the composite figure was calculated using a weighted proportion of each type of terrain. The traffic flows and road section lengths are given in appendix 2. The weighting factor is the product of the traffic flow and the section length in miles. This is calculated as a percentage of the total product of flow and length, and represents the proportion of island traffic miles that are completed on each section of road.

6.5 SIMULATION RESULTS

6.5.1 SPECIMEN RESULTS

Once the driving data from the islands had been logged and prepared it could be fed into the vehicle simulation programme in order to predict vehicle performance in terms of its range, energy consumption and system efficiency for each road section. The specimen results shown below are for one particular stretch of road in Lewis (section 8-12 :- see map in appendix 2). This stretch of road was run through the simulation again and again until the vehicle battery was depleted. The performance calculations could then be made.

```
RANGE IN MILES                             -    55.727
   RANGE IN KILOMETRES                     -    89.685
Wh USED PER MILE                           -   225.342
   Wh USED PER KILOMETRE                   -   140.051
TOTAL AMP HOURS USED                       -    53.989
POTENTIAL AMP HOURS REMAINING              -   136.011
TOTAL DRIVING TIME (minutes)               -    97.231
AVERAGE BATTERY CURRENT (amps)             -   111.702
MAXIMUM BATTERY CURRENT (amps)             -   369.747
AVERAGE MOTOR EFFICIENCY                   -     0.860
AVERAGE TRANSMISSION EFFICIENCY            -     0.857
AVERAGE CONTROLLER EFFICIENCY              -     0.900
AVERAGE SYSTEM EFFICIENCY                  -     0.667
MAXIMUM BATTERY POWER  (Kw)                -     31.43
POWER LIMIT EXCEEDED (time increments)     -         3
POTENTIAL REGENERATIVE ENERGY (Wh/mile)    -    41.607
```

6.5.2 EXPLANATION OF OUTPUT

The range figures represent the range that could be expected from the vehicle if it were to be driven over that particular road section again and again without any rest periods or additional battery charging until there was no available energy left. As described in section 6.3, the battery model used regards the battery as 'flat' when only 80% of the available energy has been used. In other words the range calculations will be within prudent bounds. Depletion beyond the point where there is a sharp decrease in battery voltage is likely to result in damage to the battery and so should be avoided. It is prudent therefore not to rely on any extra energy except in difficult situations. Also, as the battery life progresses there is a decrease in the amount of energy it can store. Battery failure is usually defined as the point in the life cycle when the battery can no longer store 80% of its rated capacity. Although in the early stages of battery life the vehicle may well achieve a range of 30% to 40% more than at the end of the battery life, or than the simulation results presented in this chapter, it is again prudent to base calculations on the guaranteeable amount of energy available. The total amp-hours used in each simulation is dependent on the type of driving and the terrain, as the energy available on discharge is a function of the rate of discharge. The higher the rate of discharge, the less energy is available. The total amp-hours available from the battery pack used in this simulation was 190 Ah at the 5 hour rate of discharge. As a considerably larger current is drawn than the 5 hour current, only a fraction of the 190 Ah are obtained from the battery. The amp hours which are not exploited are also shown in the results.

The total driving time shows the number of minutes that the vehicle could be driven on this stretch of road within the bounds of prudence before running out of energy.

The average and maximum battery current during the simulation are simply calculated from an analysis of the current drawn in each time increment. Average component efficiencies are calculated in the same manner and the system efficiency in each time increment is the product of all the component efficiencies. The average of this system efficiency over the duration of the run can then be calculated.

The battery power is monitored as time goes on and the peak power requirement of the duty cycle is recorded. This is an important measure as it is impossible during data logging with an ICE vehicle to tell if more power is being demanded than would be available from the EV that is being evaluated. The maximum power that the ETV-1 drivetrain can deliver is 30 Kw so it can be seen that this limit has been exceeded by 1.4 Kw on this particular section of road. It is perhaps more important to see what proportion of the driving time has been undertaken at excess power levels so that we can assess how much weight and credibility can be given to the simulation results. This would also gives an indication of how well an EV could meet the power demands of a 'normal' island driving routine. The "power limit exceeded" figure in the simulation results represents the number of time increments during the simulation in which more that 30 Kw was required. Each time increment is 2.3 seconds long so in the above simulation a total of 6.9 seconds of driving time were outwith the limits. This represents a mere 0.1% of driving time.

The potential regenerative energy figure is the sum of all the watt-hours that are potentially recoverable during deceleration and downhill driving. This is dealt with in detail in section 6.6 which looks at the area of regenerative braking. The figure shown is an upper limit or theoretical amount of energy and has to be modified for inefficiencies before it can give a true indication of the potential increase in range or value of regenerative braking.

6.5.3 MODEL VALIDATION

There is obviously no point in using the performance simulation model to predict EV performance in the islands if it is not known how accurate the results are. Model validation is therefore essential in order to indicate what level of confidence can be placed in the model and its results. Because the model had been based on a particular vehicle, the General Electric ETV-1 test vehicle, it was possible to compare simulation predictions with real-life operating data. In addition, there have been several other attempts to simulate the performance of this vehicle using computer models. The results from the model devised for the present study (referred to hereafter as the Stirling University model) were compared with the results of other simulations and real-life tests for a range of different driving speeds and on the SAE-D cycle. The comparison is shown in figs 6.17 and 6.18.

FIG 6.17 Range achieved versus speed for constant speed driving

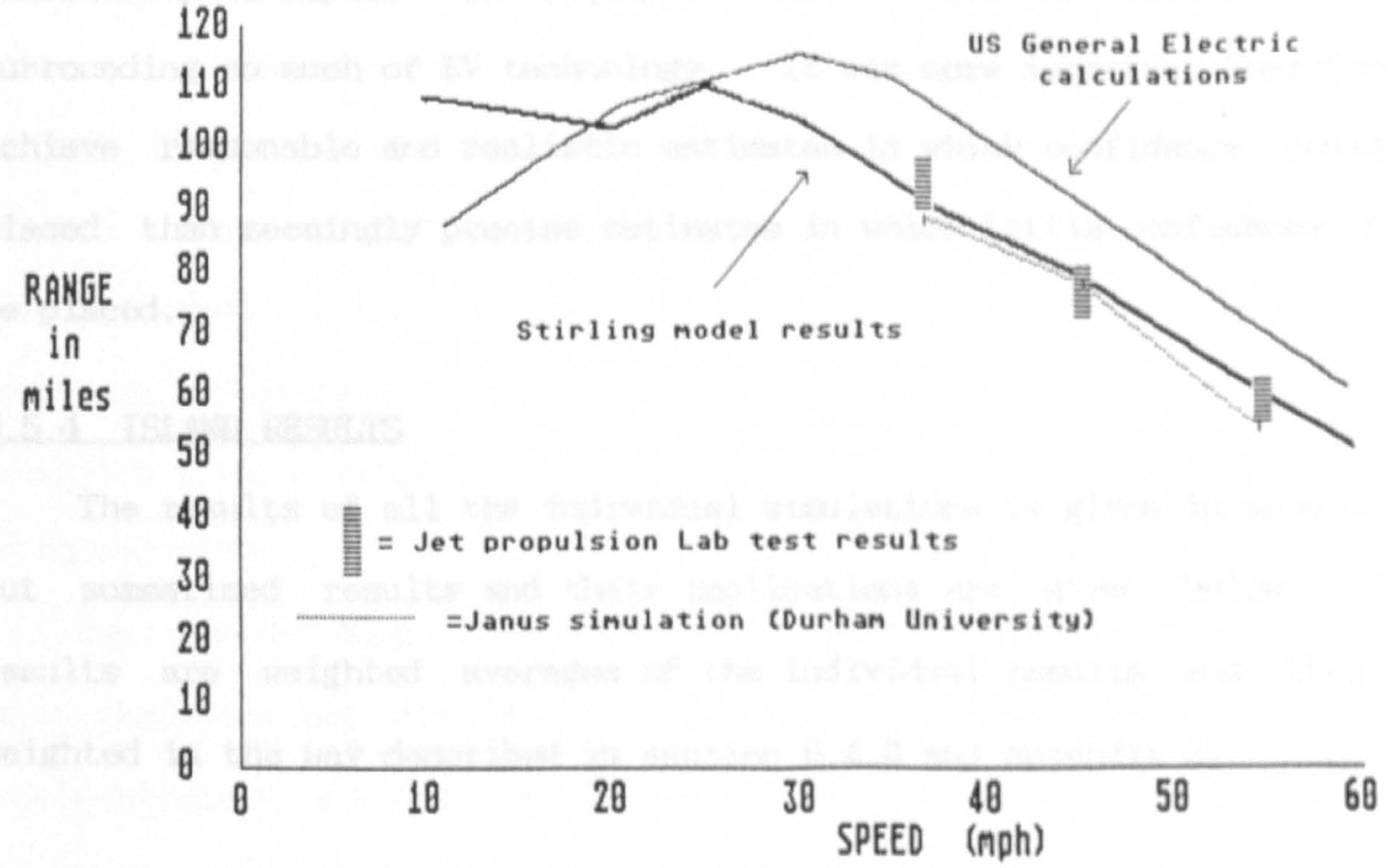
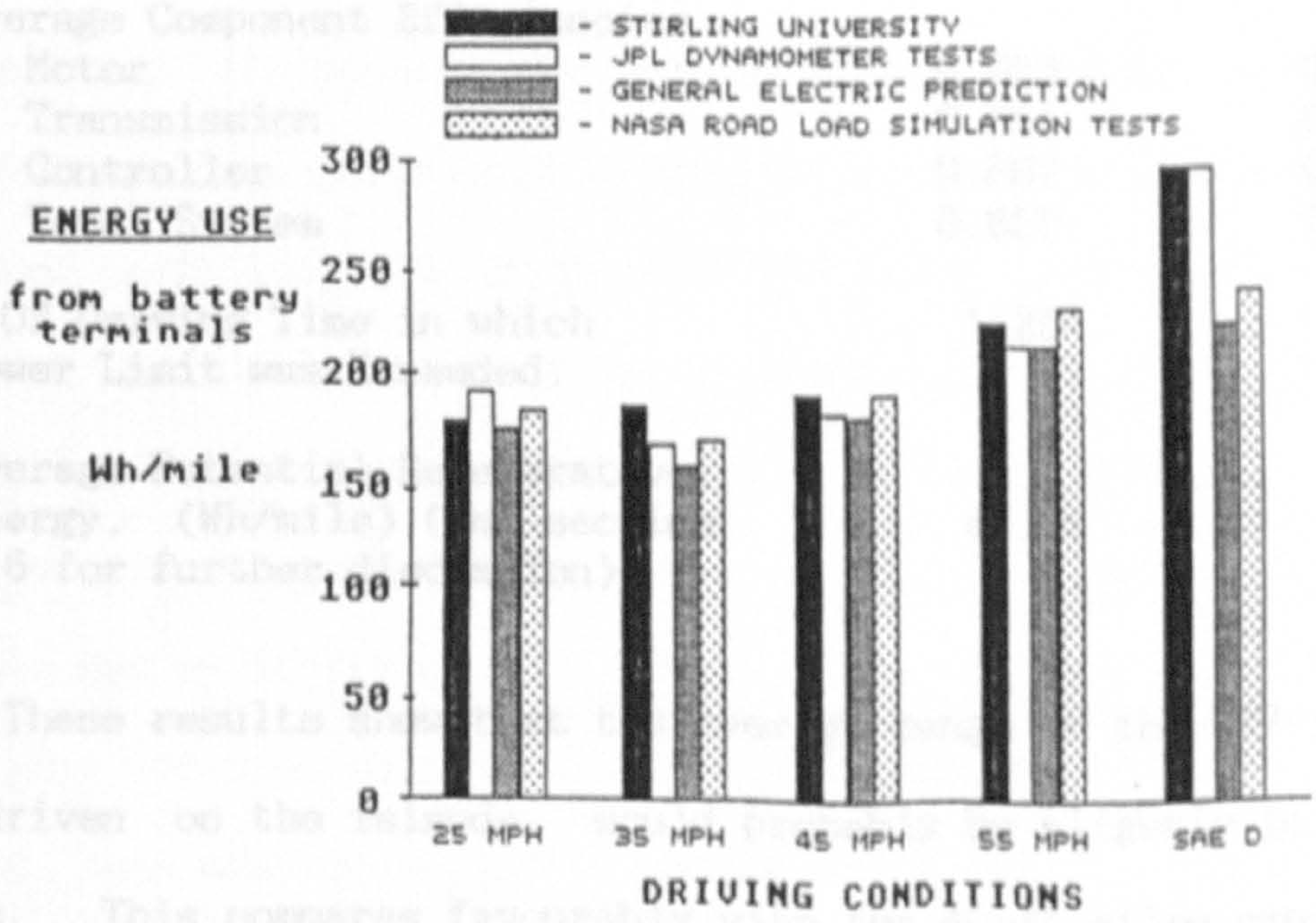


FIG 6.18

COMPARISON OF ENERGY CONSUMPTION PREDICTIONS AND TESTS FOR DIFFERENT DRIVING CONDITIONS



The Stirling University model gives satisfactory results which fit the real-life tests well. In fact, the fit is better than that of some of the other computer simulations in existence. It was therefore considered that confidence could be placed in the model results as far as they were used for the remainder of this study. Throughout the study considerable sensitivity analysis was required because there is little certainty surrounding so much of EV technology. It was more important therefore to achieve reasonable and realistic estimates in which confidence could be placed than seemingly precise estimates in which little confidence could be placed.

6.5.4 ISLAND RESULTS

The results of all the individual simulations is given in appendix 2 but summarised results and their implications are given below. These results are weighted averages of the individual results and they are weighted in the way described in section 6.4.6 and appendix 2.

	LEWIS/HARRIS	ORKNEY
Weighted Average Range (miles)	51.98	54.88
Energy Consumption (Wh/mile) (as provided by battery)	241.24	228.40
Average amp-hours used	53.03	53.05
Average Battery Current (amps)	115.23	114.70
Average Component Efficiencies		
Motor	0.853	0.854
Transmission	0.854	0.850
Controller	0.897	0.921
Total System	0.657	0.674
% Of Driving Time in which Power Limit was Exceeded.	1.25	1.52
Average Potential Regenerative Energy. (Wh/mile) (See section 6.6 for further discussion)	41.35	37.52

These results show that the average range of the ETV-1 test vehicle, if driven on the islands, would probably be slightly in excess of 50 miles. This compares favourably with the 40-45 miles expected under the

SAE-D cycle. The ETV-1 vehicle drive system was specifically designed to maximise the vehicle range under the SAE-D cycle. The design of the motor and electronic system was focused on this goal, and the performance of these components under other driving conditions was considered of secondary importance by the designers. Had the drive system been optimised to maximise the vehicle range under different duty cycles, a different design may have resulted with a different vehicle range. Work on the ETV-1 vehicle began in 1978 and most of the above tests were carried out between 1980 and 1981. Although the vehicle represented the most advanced technology when it was first built, the advances in component and battery technology since then would probably give a similar vehicle a greater range today, hence the range estimates can be regarded as conservative.

The greater range achieved on the islands may be due in part to the fact that driving speeds are generally more constant, with fewer accelerations than under the SAE-D schedule. The data logging equipment constructed for this research was also used to collect driving data in several towns and cities. The range and performance predictions resulting from this data showed that vehicle range under these conditions was very similar to that achieved in the islands (details in appendix 2). Although the style of driving imposed by urban roads and traffic is different from the islands, the average end result was very similar. However, whereas the various urban simulations resulted in very consistent figures, the standard deviation of range predictions being 1.34 miles, the island road sections produced a wider range of predictions with a standard deviation of 10.95 miles in the Hebrides and 10.8 miles in Orkney. One particular road section resulted in a predicted vehicle range of 71.3 miles while another was as little as 31.2 miles. The difference was probably due to the type of road section, the former being a very flat, straight and double lane section while the latter was a small, single track section which had many bends and hills. The roads in Orkney are generally flatter, straighter and wider than those in Lewis and Harris and this would appear to be reflected in the predicted vehicle ranges. Energy consumption is also very similar between islands and it is slightly lower than in urban situations. It would be wrong to place too much significance on the precision of the figures but we can say that this particular electric vehicle can be expected to perform similarly on the islands and in urban situations and should be capable of an average range of at least 50 miles on the islands, on the basis of the technology as it was in 1980.

The results of the performance simulation model are not only informative in their own right, they are utilised throughout the remainder of this study for a variety of uses. Range estimates, along with data on vehicle use patterns, form the basis of assessment of vehicle usefulness on the islands (section 6.7). The energy consumption figures are used in an economic analysis of EVs for the islands in chapter 9, and in an analysis of the adequacy of the electricity distribution network on the islands for battery charging in chapter 7. The acceptability of EVs is also dependent on their performance, so the performance figures are used in the market analysis in chapter 9. The model is used to examine the effect of improvements in EV technology on vehicle performance and hence on the overall potential for EV introduction in the islands (chapter 11). The potential for regenerative braking is discussed in the next section.

6.6 REGENERATIVE BRAKING

6.6.1 BACKGROUND

One of the greatest limitations of EV's is their limited range between recharges. The possibility of recovering a portion of the vehicle's kinetic energy during periods of deceleration presents an opportunity to extend vehicle range. When a vehicle decelerates using normal mechanical friction brakes, kinetic energy is converted into heat and dissipated at the brake shoes. Regenerative braking in EVs refers to the technique of catching and storing this energy for further tractive use, by using the traction motor as a generator during periods when there is a surplus of kinetic energy. This energy can be stored in a variety of storage mediums such as flywheels, elastic devices, hydraulic or pneumatic devices or various thermal systems. In a simple EV it is normally the battery which is used for energy storage. The relative merits and demerits of regenerative braking have been debated for a long time in connection with its justification, and there is still a wide variety of opinion as to whether it is a worthwhile addition to an EV. In this section the 'potential' advantages and disadvantages of a regenerative braking system will be discussed, and in the case of the island vehicle will be evaluated.

6.6.2 THE POTENTIAL BENEFITS

A. INCREASED RANGE

By recycling energy which would otherwise be wasted as heat and wear on the brakes, the energy source can deliver more energy per discharge, which in effect gives the battery a higher energy density. This should allow a greater range, or conversely a smaller battery could be used to achieve the same range as a vehicle without regenerative braking, allowing also greater space in the vehicle, reduced weight, increased payload and greater flexibility of design. Various tests have been undertaken to examine the increase in vehicle range attributable to regenerative braking [14],[15],[16], and the results have varied considerably. Many of these studies have considered only the case of urban stop-go type driving where available regenerative energy is greater than under other types of cycle.

The theoretical or ideal amount of energy available for recycling will not all be available for use, for two main reasons. Firstly, the efficiencies of all the components in the regenerative system have to be allowed for. The transaxle, the motor and the electronic controller all exhibit inefficiencies as described earlier. The battery also has to be taken into account, and while some authors have assumed that the battery efficiency during short duration pulses of regenerative energy is the same as the efficiency during normal charging (70-80%), it has been suggested that the charge acceptance by the lead-acid battery of the regenerative braking pulse current is particularly good and approximates 100%, [15]. In addition, little or no additional thermal burden on the battery was experienced and in some cases cooling was even slightly enhanced. Experiments showed that the results applied also to nickel-iron and nickel-zinc batteries. However, even given the above findings, overall system efficiency can only at best be around 70% (typical average drivetrain efficiency). The second loss of energy is due to the overall braking system. During a large proportion of decelerations, the braking effect of regenerative braking is not sufficient to achieve the required slowing effect and a supplementary mechanical friction braking system must be available. Similarly, regenerative braking is motor speed dependent and, at some minimum motor speed, disappears completely as a practical method of stopping the vehicle. Therefore the regenerative system and the mechanical system must be blended together. The proportion of the energy available for regeneration is dependent on the severity of the deceleration and hence on the extent of the mechanical braking. It should be noted that EVs incur a weight penalty over conventional ICE vehicles of between 1.5 and 2 times and this necessitates a more powerful and efficient braking system due to the greater momentum involved.

The above factors reduce the theoretical contribution of regenerative braking to vehicle range, but this is not to say that it would not be a very useful addition to an EV under certain circumstances. On the other hand, the absolute amount of energy actually available for recycling is dependent on the nature of the particular driving cycle. If there is little or no theoretical energy available in the first place then there is little or no benefit to be had by trying to recycle it. At the extreme, constant speed driving of long durations would offer no potential energy savings using regenerative braking systems. It is therefore essential to discuss the practical usefulness of regenerative braking in terms of the particular application to be made of the vehicle. Table 1 below lists the results of computer studies of the effectiveness of regenerative braking on range calculations under various driving cycles [17],

TABLE 6.1

STUDIES OF THE EFFECTS OF REGENERATIVE BRAKING ON THE RANGE CALCULATIONS FOR TWO EVS (Lead-acid batteries)

CYCLE	RANGE (MILES) NO REGEN.	RANGE (MILES) WITH REGEN	INCREASE (%)
	Vehicle 1 - 1134 Kg Passenger Car		
SAE	114.5	128.2	11.9
CVS	112.7	127.4	13.1
HWY	109.2	111.5	2.1
TAXI	90.4	112.8	24.7
UPS	108.6	128.5	18.3
	Vehicle 2 - 2041 Kg Delivery Van		
SAE	117.5	132.6	11.3
CVS	115.5	132.3	11.5
HWY	99.2	101.7	2.5
TAXI	93.6	118.5	26.5
UPS	113.3	136.1	20.1

The figures in table 6.1 relate to computer simulations of vehicle ranges for vehicles with relatively high drivetrain efficiencies, and the results shown are probably the maximum gains that could be expected in practical EVs. Other studies and real life tests have shown smaller range increases. The figures do however show how the energy recovered by regenerative braking systems varies according to the duty cycle. Under the highway (HWY) cycle the gains are very small and this is because of the relatively constant speed at which the vehicle is driven, with fewer accelerations and decelerations. The limitation of recoverable energy is also set by the type of battery used. Lead-acid batteries will not stand recharging with too high a current, whereas nickel-iron will. Sodium-sulphur is expected to be capable of accepting higher charge currents but it cannot stand much overcharging (see section 2.7.6).

B. REDUCED ENERGY COSTS

Successful regenerative braking results in an increase in energy output for a given energy input to the vehicle. The amount of energy supplied from the electricity supply socket in order to undertake any specific journey is therefore reduced and as this is the energy that is paid for and on which economic analyses are based, the energy cost per mile is correspondingly less. However, as mentioned above, the savings will vary with the application in question. Also, the value of reduced energy costs are examined in section 9.3 where it is shown that they constitute only a very small part of vehicle ownership costs and that even substantial reductions will have only small effects on the overall economic case.

C. PROLONGED BATTERY LIFE

It has been suggested that because battery life is related to the depth of discharge of the battery, regenerative braking should result in an increased battery life and so reduce battery replacement cost because the depth of discharge implied by a particular journey is reduced [15]. It must be stated however that this assertion is not based on actual measurements and it would seem to be a rather simplified argument. The relationship between battery cycle life and depth of discharge is discussed in sections 6.3.5 and 9.2.7 where it is shown that the relevant measure for battery cost is not necessarily cycle life but total energy throughput. This measure is related to depth of discharge, but not linearly, and shallow discharges can be harmful to optimal battery life. It is evident that the capacity of a vehicle's battery should be chosen to match the vehicle's daily demands, and that regenerative braking would only reduce battery costs if wider consideration were given to the actual daily depth of discharge. The same savings could be achieved by a sensible choice of battery capacity for a particular duty cycle. In some cases regenerative braking could actually increase battery costs by shifting the average depth of discharge away from the optimal. Furthermore, it is uncertain what affect the intermittent, short duration, variable magnitude, high current pulses resulting from regenerative braking would have on the battery life. Continual recharging of a battery at very shallow levels leads to a decrease in lifetime energy delivered, but there is no evidence available to prove that regenerative braking is similar in its effect. This would require further research.

D. PROLONGED BRAKE LIFE

Providing a braking action without the use of friction brakes would obviously prolong the useful life of the brake linings of the mechanical braking system because of the reduced usage and wear.

6.6.3 DISADVANTAGES OF REGENERATIVE BRAKING

The benefits of regenerative braking listed must not only be examined in the light of the intended vehicle application but also balanced against the disadvantages and the true cost associated with achieving these benefits.

A. ADDITIONAL INERTIAL WEIGHT

The inclusion of a regenerative braking system necessitates imposing additional weight on the vehicle. EV energy consumption is extremely sensitive to inertial weight (see section 11.2.5). Part of the energy recovered using such a system would be required in order to transport the additional weight of the system.

B. VEHICLE CONTROL COMPLEXITY

There is no doubt that regenerative braking requires the installation of a complex system. The motor controller has to accommodate reverse flows of current and the mechanical braking system has to be blended with the regenerative one. By including it, an inherently simple drivetrain concept is made more complex and arguably less reliable. With two braking systems, it is even arguable that the safety in terms of driveability is jeopardised; potential problems include the performance under icy road conditions.

C. COST

By far the greatest disadvantage associated with regenerative braking is the high cost of the system. The vehicle must be fitted with a bilateral controller and this effectively doubles the cost of the controller. The easiest regenerative electrical circuits are achieved with permanent magnet motors, which have no separately wound fields. These motors however tend to be more expensive than most commonly used series-wound motors on a horse power for horse power basis. Also permanent magnet motors are limited to about 5 hp even with the latest neodymium-boron-iron magnets. There will also be additional costs involved in blending the two braking systems together.

6.6.4 OPERATING EXPERIENCE

The Electricity Council fitted one of their Enfield cars with regenerative braking. They found, quantitatively, that it was of little benefit in terms of vehicle range; the impression being that the energy gained by regeneration was wiped out by energy losses in the controller which had to be fitted with a cooling fan. HIL Electric, who hope to begin pilot production of their electric utility vehicle in March 1989, state that regeneration would only increase range by between 2.5 and 7% depending on the duty cycle. They consider that this is not economically worthwhile as it would double the cost of a reliable controller.

Mr F Wykes, the Chairman of the Battery Vehicle Society, suggests that regenerative braking is, on balance, not economically worthwhile except in special modes of operation, where, for example, a routine journey involves continuously climbing a long hill, returning downhill by the same route.

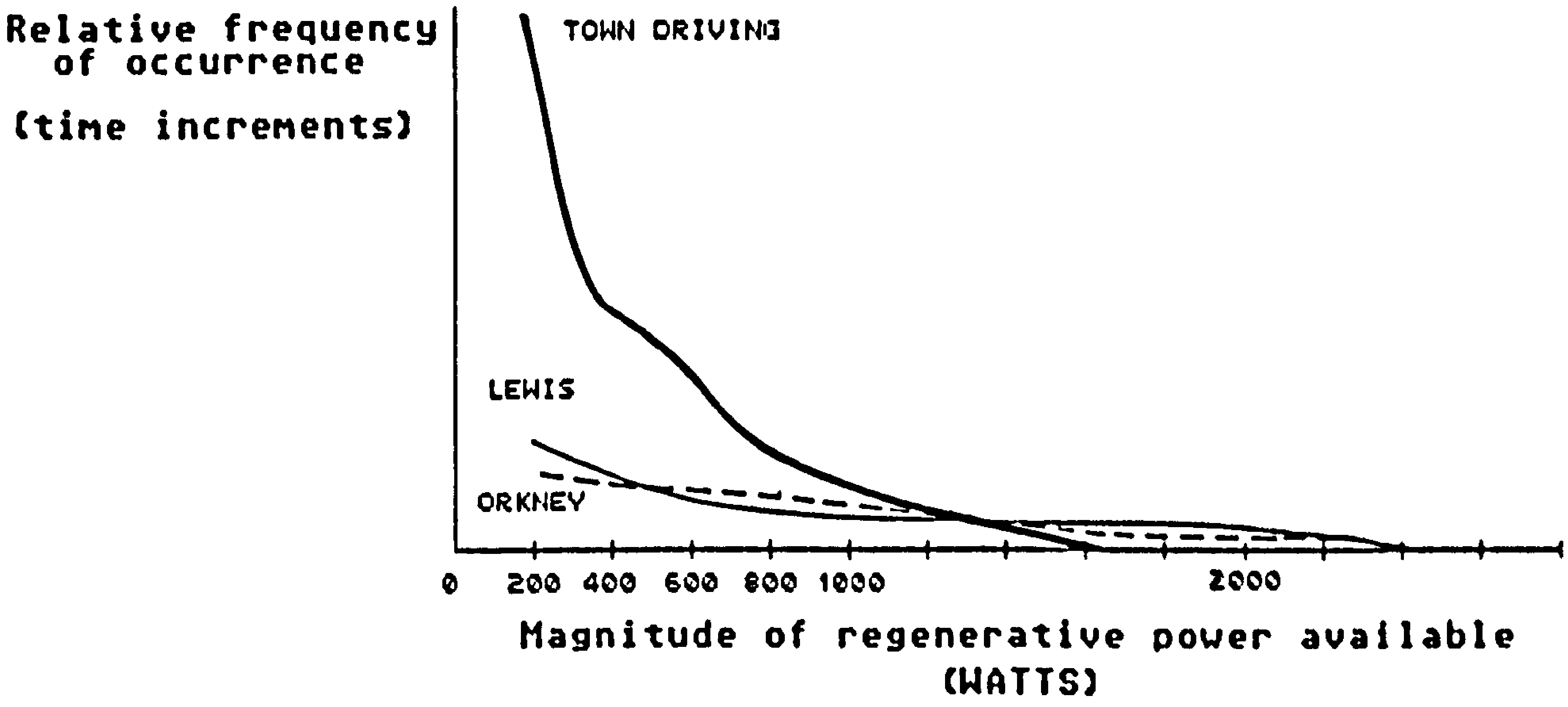
Lucas Chloride EV Systems built their electric delivery van drive-train to include a regenerative braking system which was commonly liked by drivers. It could be switched on or off at will. It is not known what difference it made to vehicle range.

6.6.5 THE VALUE OF REGENERATIVE BRAKING IN THE ISLANDS

It has frequently been stated above that regenerative braking should be assessed in terms of the application or duty cycle of the vehicle involved. With this in mind, the performance simulation programme described in section 6.3 was developed to enable the potential regenerative energy associated with different duty cycles to be calculated. During many time increments the momentum of the vehicle will be greater than that required and there will be a surplus of kinetic energy. This will happen at times when the vehicle is going down hills and the gravitational pull is greater than the force required to overcome aerodynamic drag and rolling resistance. The same will be the case when the vehicle is slowing down. The model measures the magnitude of the excess force in any time period that it occurs. The easiest way to see the difference caused by different types of driving is to plot a frequency chart of the different levels of potentially recoverable kinetic energy. Fig 6.19 shows the difference between typical town driving and driving in the islands. All curves are weighted average figures showing the result of many hours of driving in all parts of the islands and in several cities.

FIG 6.19

Relative frequency of regenerative power pulses of differing magnitudes for different types of driving



The relatively steady speed and long periods of continuous driving on the islands means that there is a much smaller amount of regeneration energy available for recycling than under town driving duty cycles. However because of the higher speeds that are common on the open road, there are several occasions when the level of regeneration energy present is greater than in the town.

The simulation model also sums the total amount of regenerative energy that is potentially recoverable.

DUTY CYCLE	POTENTIALLY RECOVERABLE REGENERATIVE ENERGY (Wh/mile)
Town	75.67
Lewis/Harris	41.35
Orkney	37.52

There is about twice as much energy available for recycling under town driving situations. These figures show the theoretical amount of energy and it must be remembered that if regenerative braking were employed, much of this energy would be lost due to drivetrain inefficiencies and because much of it occurs at levels which are too low to recover only a very small fraction would be realised.

It is also clear that the installation of regenerative braking for island vehicles would be of less use than under urban situations. There is much debate over the economic worth of regenerative braking even under more favourable duty cycles like urban driving, so for the remainder of this study it will be assumed that it is not cost effective for island vehicles at present.

6.7 APPLICATION POTENTIAL ANALYSIS

6.7.1 INTRODUCTION

Now that the performance of the test EV has been predicted for island duties, the amount of the transportation function that it could feasibly undertake can be analysed. The 'application potential' is defined here as the proportion of the existing transportation function that could be completed by electric vehicles as substitutes for existing ICE vehicles at a given point in time. This may be measured as the ratio of miles or journeys or days completed or in terms of the number of vehicles which could be substituted. The most appropriate measure is discussed in a later section but it is reasonable to say that they all yield useful insights. Such an analysis would allow for the technical limitations of battery powered vehicles on the one hand (examined in the last section) and the way in which the vehicle would be used on the other. A further measure of application potential could be calculated which takes into account any scope vehicle owners would have for reorganisation of their vehicle usage, in such a way as to permit an EV to fulfil a larger part of their existing needs. This second approach is extremely difficult to carry out analytically, and is difficult to quantify results, but an attempt is made to include some of these additional factors when undertaking a market analysis (section 9.4).

Application potential is an optimistic measure of vehicle usefulness because it is simply concerned with the theoretical upper limit of possible EV use in a specific application. Other aspects such as consumer acceptance and confidence, or the effects of vehicle costs on the decision to buy, are not relevant at this stage. They will be taken into account in later chapters concerned with market potential and the economic case for EVs.

6.7.2 DATA COLLECTION

The basic data used for this analysis was collected from island drivers themselves. A sample of motorists were issued with a logbook in which they were requested to record details of every journey they made in their vehicles over a period of time. A specimen logbook is shown in appendix 5 and the sample selection procedure and the reliability of the data was discussed in section 5.3.3.

6.7.3 LOGBOOK ANALYSIS

A computer simulation (appendix 1) was built to analyse the data from the logbooks and determine application potential. Each motorist's case was analysed separately and such measures as his expected annual mileage, days in which the distance travelled was outwith the capabilities of the EV (infeasible days), infeasible miles, infeasible journeys and so on could be calculated. Summary statistics for the islands as a whole could also be calculated.

This approach was taken because it was considered necessary to be as true to real life as possible. By using actual journey data and by assessing each vehicle in turn, it was felt that a more useful picture of application potential could be achieved than by using generalised or averaged data. There are so many factors of interest contained in the logbook data that to establish general patterns and to use average data would lead to a loss of information and detail. The spread of journey mileages and the periods during which charging can be done are important for vehicle assessment and it is difficult to incorporate these fully in a model without actually examining real life data for each driver in turn. Previous studies have undertaken application analyses but these have usually taken a less detailed approach. Horrowitz and Hummon [18] used a Monte Carlo type simulation which generated daily journey data from known distributions of journey mileages and frequencies. Although their results are interesting, they do not take enough account of the differences between individual drivers. Also they only examined the case of the least used vehicle in multiple vehicle households. Their assumptions on battery life and charging characteristics may be considered over simplistic. The research carried out by the German Federal Ministry of Transport [19] took a much less journey oriented approach altogether and based its analysis on the answers given to a questionnaire. Respondents were simply asked to estimate their mileage characteristics and a screening method was applied to eliminate unsuitable motorists from the analysis.

6.7.4 THE APPLICATION POTENTIAL SIMULATION MODEL

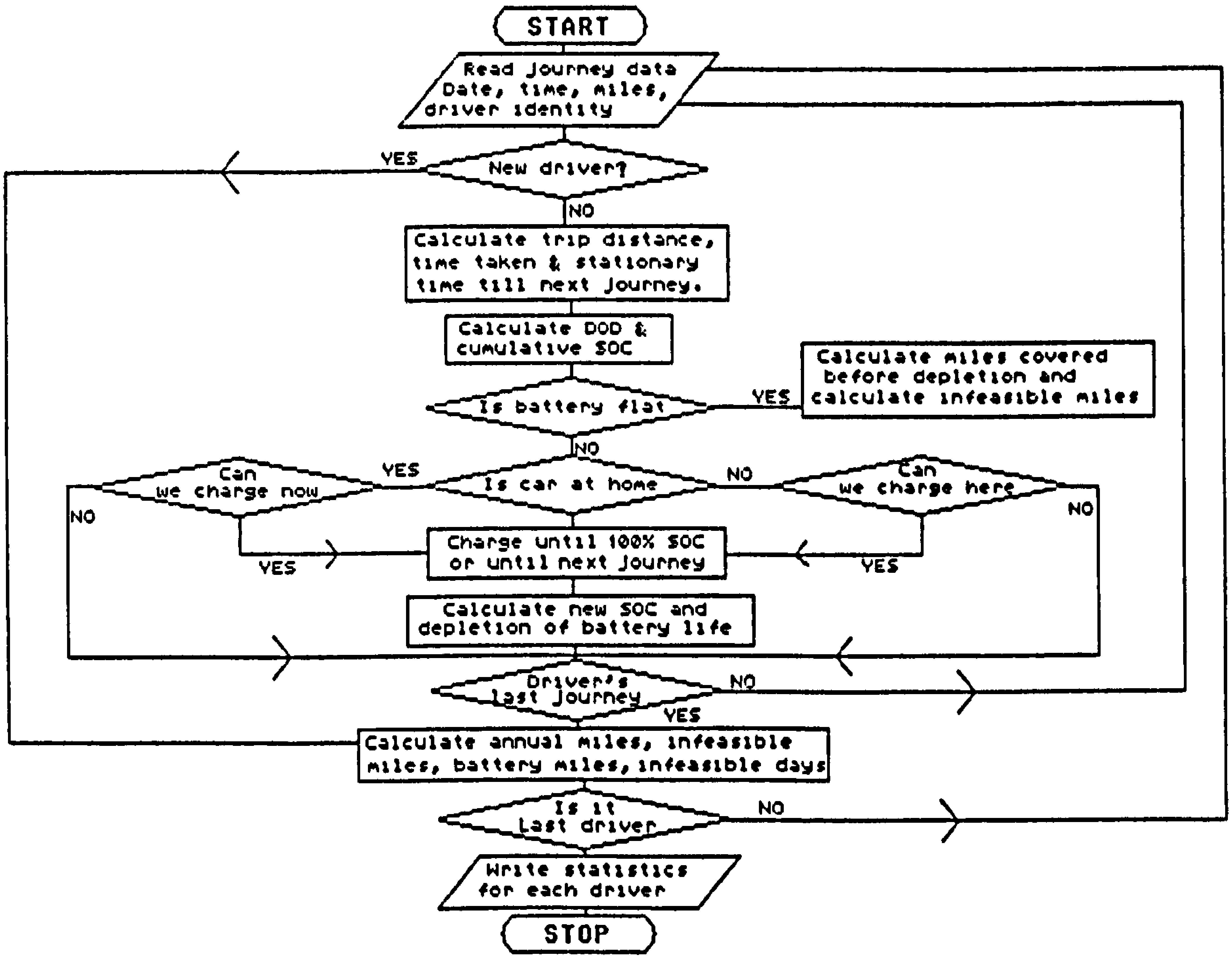
A FORTRAN programme was developed to simulate the use of each vehicle as it was used each day according to its recorded journey patterns. A flow chart of the model is shown in fig 6.20. There were two aims in developing this model,

1 To determine the application potential in the islands at the present time, given present driving patterns and with presently available technologies. Examination of the effects of different charging regimes and charging infrastructures was also possible.

2 To build relationships between future states of the technology and its performance and the resulting application potential. As the state-of-the-art improves, the range of the EV can be expected to increase and it is important to determine the resulting increases in application potential. Such an analysis requires building a great amount of

flexibility into the model so that the effects of such things as alternative battery systems with their implications for increased range and reduced charging times can be examined.

FIG 6.28 FLOW CHART OF APPLICATION POTENTIAL MODEL



6.7.5 A SUITABLE MEASURE OF APPLICATION POTENTIAL

If a motorist were to substitute a limited range vehicle such as an EV for his usual vehicle, it is highly probable that he would experience a certain amount of inconvenience. That is to say he may not be able to undertake all the journeys he might otherwise wish to unless he reorganises his vehicle use. Even allowing for all reasonable reorganisation he may still experience inconvenience or disruption to his desired journey pattern. When measuring the application potential of this technology in the islands, it is first necessary to define exactly what is meant by disruption or inconvenience. In this analysis, it has been taken to occur on any occasion on which the EV is incapable of performing the same duties as the ICE. We could define and measure it as the number or fraction of miles that the EV would be incapable of completing. Alternatively it might be the number of journeys that are outwith the range of the EV, or the number of days on which the cumulative mileage is greater than the range. One research study chose as its indices firstly the proportion of total vehicle trip time disrupted, and secondly 'delay' as a proportion of total vehicle trip time, where delay is defined as extra charging time necessary (either before or during a trip) to maintain existing trip destination. [20] The first of these indices is almost identical to measuring the proportion of infeasible miles, the only difference being that the speed of driving is important when measuring trip times and it is argued here that this is an almost irrelevant consideration. It is the ability to travel distances that the motorist pays for and he will be more concerned with how far he can or can not drive rather than for how long. The second of the above measures (delay) is also inadequate to describe disruption realistically. The delay due to necessary charging could amount to a very long time in certain cases. This would seriously bias any aggregate measure of application potential and result in very misleading or confusing results. In fact it is quite possible that there simply would not be adequate time between or during journeys to permit enough charge to be put into the battery. An 8 hour charge for present lead-acid batteries will be used up in about 1 to 2 hours, and because it takes longer to replenish the energy than to use it, many high mileage vehicles cannot realistically be analysed by using this measure of disruption.

The application potential will be the converse measure to that used for disruption. It is frequently stated that electric vehicles could undertake a very large proportion of the vehicle miles travelled in this country.[19][20] This argument, and the figures quoted to support it, is particularly impressive in the case of urban applications. For example it is reported [19] that over 80% of journeys are less than 10 miles in length and that 95% of required miles in London could be completed by a population of EVs which had a range of 75 miles [21]. This however is a misleading statement and overestimates the real application potential of the technology. Although it is useful to have such a measurement, it fails to take account of the fact that a much smaller proportion of motorists will never experience inconvenience at some point. A more realistic measure of application potential therefore is the number of vehicles which could be replaced by an electric equivalent without experiencing any trip or mileage disruption. Although a motorist may be able to undertake most of his desired miles with an EV, it is the few occasions where he would not that will dissuade him from using an EV. His ability to reorganise his travel, or his possession of another vehicle, would of course ease the situation and may allow him to cover all the miles he wants to, thus increasing the application potential.

This study is concerned with the actual potential for substituting EVs for ICEs in the islands, and the measure used for application potential in the first instance is therefore the number of vehicles that could be exchanged without causing mileage disruption.

The level of disruption that will be 'tolerable' will depend upon the individual and the financial incentives that he has to change to an EV. It might be possible to hire an ICE vehicle for those occasions where an EV is inadequate, and the acceptability of this will depend on the savings expected from running an EV and the hire charges of an ICE. These issues are discussed in the section on market potential.

6.7.6 MODELLING THE BATTERY STATE OF CHARGE AND LIFETIME

In this model a running total is kept on the energy remaining in the battery. This acts like a fuel gauge where the amount of energy on board the vehicle at any time is always known. Each time the vehicle is used the depth of the journey discharge is calculated and the battery state of charge is updated. Depending upon the charging regime being used (see below), the battery is then charged for the period of time available and again the battery state of charge is updated. A typical 8 hour charging profile is shown in fig 7.2 in chapter 7. The amount of charge replenished is a function of both the time available and the battery state of charge at commencement of charging. A multiple linear regression model was used to describe this relationship and the resulting equation is shown below. The rest of the simulation model is given in appendix 1.

$$\begin{aligned}\text{CHARGE} = {} & 1.26-(0.014\times\text{SOC})+(18.2\times(\text{Time}/60))-(0.0923\times((\text{Time}/60)^{3}))+\\ & (0.415\times(60/\text{Time}))-(0.104\times\text{SOC}\times(\text{Time}/60)))\end{aligned}$$

where SOC = battery state of charge (%)
Time = The time available for charging (minutes)

A battery has a finite cycle life which is dependent upon the way in which it is charged during its life. This is discussed in section 9.2.7. In the application potential simulation model the effect that individual use patterns have on battery life is examined for each motorist. Every time the battery is charged the depleting factor that this charge has on the overall life of the battery is calculated according to the equations presented in section 9.2.7.

8.7.7 THE CHARGING REGIMES SIMULATED

There were three basic charging regimes considered in the model. Variations on these regimes were also simulated.

1 The vehicle can only be charged at the owner's premises, and charging is limited to one overnight charge per 24 hour period during off-peak tariff times. If the vehicle is not used in any particular day then no

charging takes place. This regime results in relatively large charges being given to the battery.

2 The vehicle can be charged only at the owner's premises but charging is done whenever the vehicle is stationary. No priority is give to utilising off-peak rates, so much of the charging is done during the day. It is not possible to make any realistic allowances for future knowledge of journey patterns in the model, so it is assumed that the vehicle will be plugged in for charging as soon as it comes to rest even if there would be no need in retrospect for such opportunity charges. This will of course result in many unnecessary charges but it is argued that this situation may not be very far removed from reality. The motorist may well have some idea of his motoring needs for the rest of the day but there will always be uncertainty surrounding unexpected needs. Because the vehicle mileage is so limited in comparison to his present vehicle, the EV will represent a risk of failure to complete desired journeys, so it is anticipated that the average motorist will tend to attempt to alleviate this problem by ensuring that the vehicle is as ready as possible for unexpected demands. This policy will of course result in higher energy costs if the operator has a white-meter electricity tariff available to him during off-peak hours, but the magnitude of this cost is examined in section 9.3 and appears to be very small.

3 The third simulated charging regime is similar to the second except that it assumes that it is possible to charge the vehicle anywhere when it is stationary. Whenever the vehicle is not being driven it is plugged in. This assumes that there will be widespread public charging facilities throughout the islands. This charging regime will represent the maximum amount of charge that it is possible to give to the vehicle with present technology and will hence lead to the maximum estimate of application potential. It may be unrealistic owing to the fact that

vehicles may frequently be parked in places where there is no access to electricity supply points. It does however give us an upper limit of usefulness of EVs. It will also allow us to assess the likely advantage of having a public recharging infrastructure available.

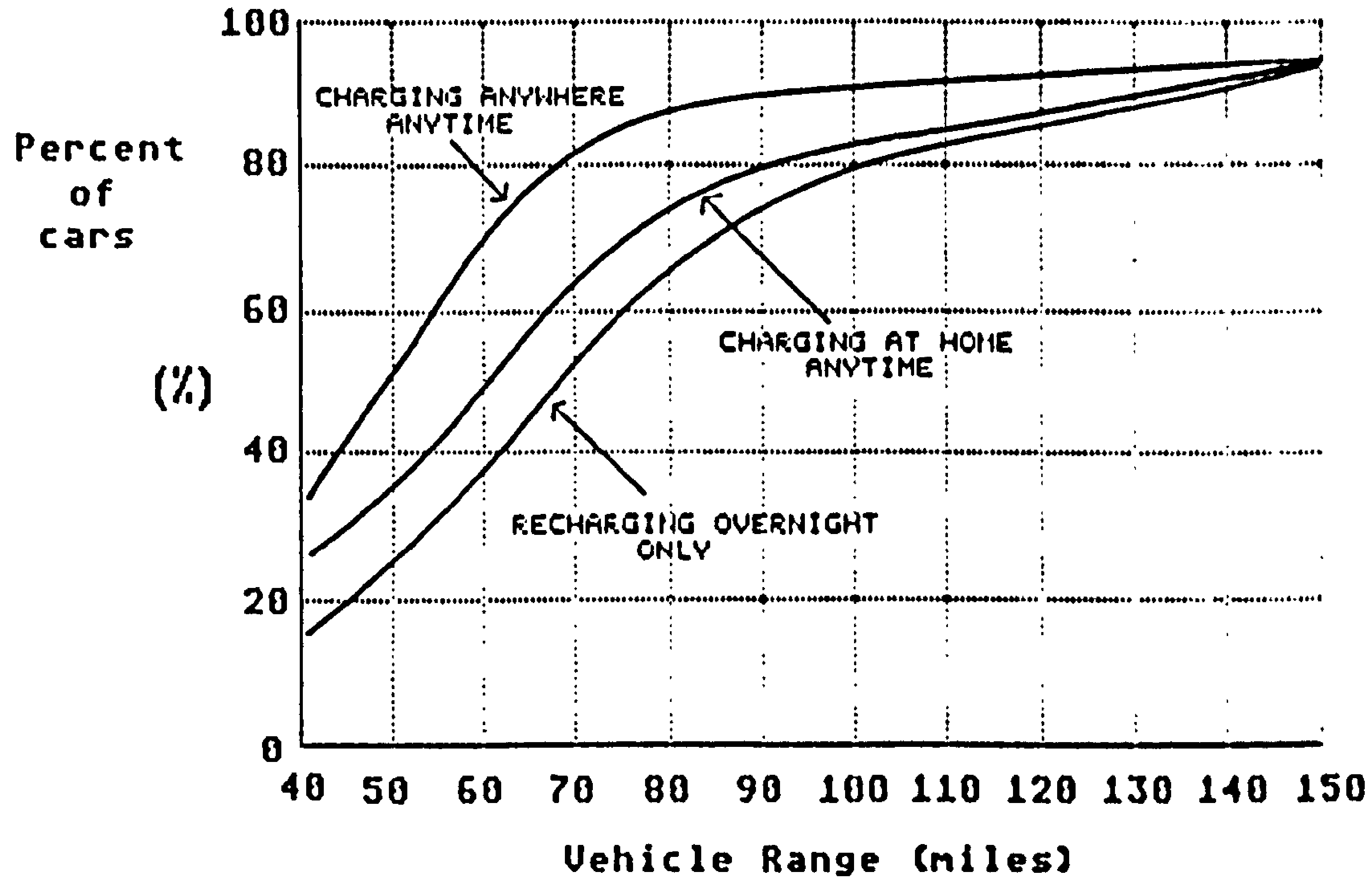
The above three strategies will represent increasing levels of application potential but there will be costs associated with this increased usefulness. The cost of electricity is greater if opportunity charging is employed and the expected life of the batteries may be detrimentally affected. In addition to the basic regimes above, the effect of postponing recharge of the battery until it has reached a prespecified depth of discharge is examined. This further restriction is simulated for each of the above regimes. Although this will result in a lower application potential, it may increase the life of the battery. These issues are explored in the economic analysis (section 9.3.4) Publicly available charging points will also have associated costs (see section 7.3 on recharging infrastructures).

6.7.8 SIMULATION RESULTS

Figure 6.21 shows how the number of vehicles which could be electric without causing any inconvenience varies with the assumed range of the electric replacement. All three charging regimes are shown. The calculation was based on the assumption that the battery requires 8 hours for a full recharge according to the data shown in fig 7.3. (figures for Orkney are given in appendix 3).

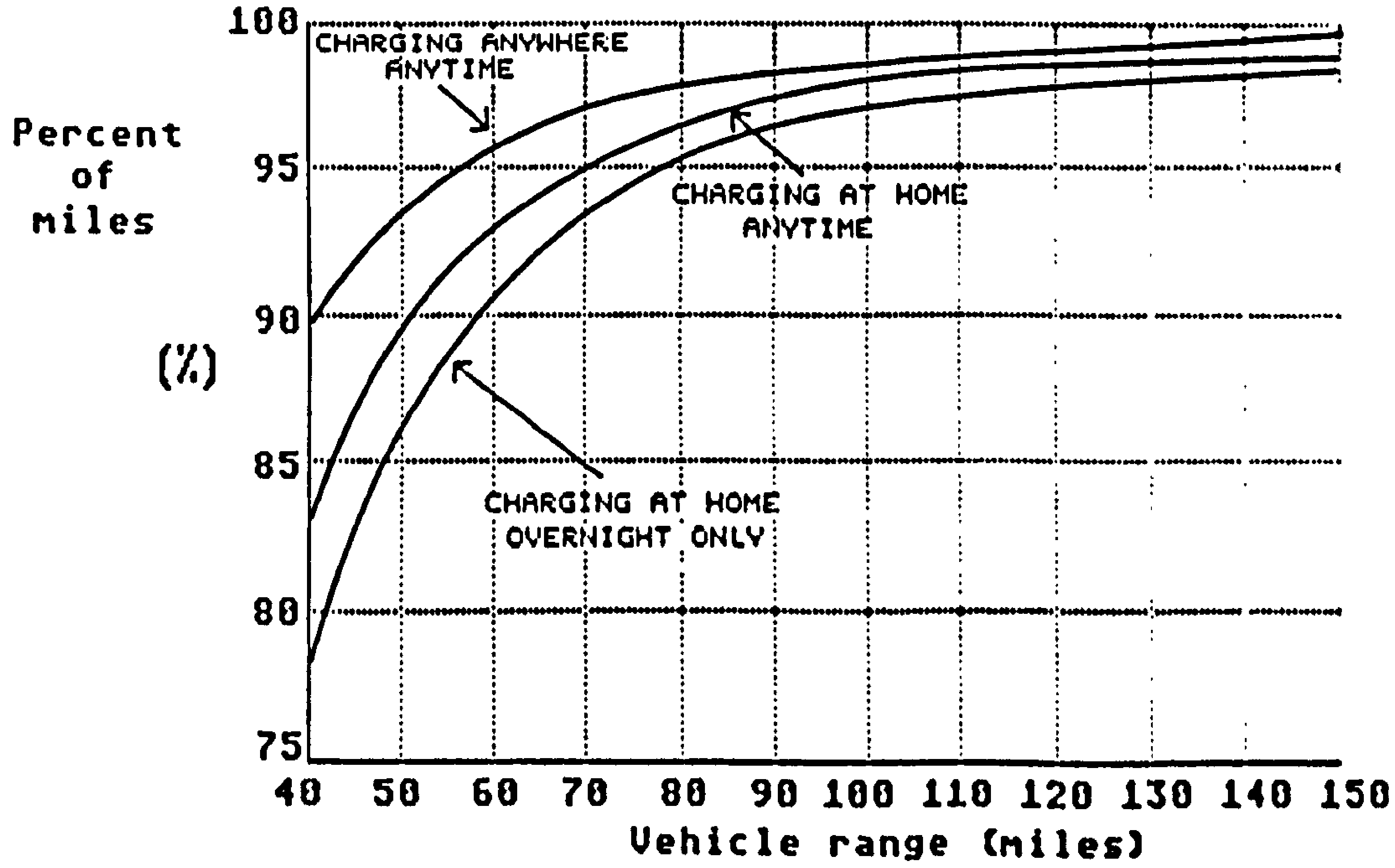
It can be seen that there is a significant percentage of vehicles which could legitimately be electric if range limitation was the only consideration. Under a policy of charging at home whenever vehicles are not being used, around 37% of cars could feasibly be electric without causing any inconvenience.

FIG 6.21 Percentage of island cars experiencing no inconvenience, versus vehicle range (Lewis/Harris



The application potential increases as the assumed range increases but after a range of around 60 miles the addition to application potential per mile of increased range begins to tail off and after a range of about 80 miles any increases in application potential are very small indeed as most cars fall within the application potential. Also, the difference in usefulness that is experienced by using different charging regimes is at a maximum around a range of 55 miles and after this it becomes of increasingly less importance which regime is used. In Orkney it was found that after a range of 150 miles was assumed, there were no vehicles experiencing inconvenience, regardless of the charging regime used. This is because there were no daily mileages in excess of this recorded during the data collection. Another important point to note is that the upper line (representing charging anywhere at anytime) will in reality be closer to the middle line (representing charging at home anytime). This is because vehicles parked away from home will not always be sufficiently close to a public charging point and will not therefore be able to charge whenever they are stationary. The advantage offered by a public recharging infrastructure must therefore be called into question because of the relatively small impact that it makes on application potential. This is increasingly the case as the range given by the vehicle technology increases. The costs of such an infrastructure have to be balanced against these possibly small advantages (see section 7.3). Fig 6.22 shows how the percentage of miles which are currently travelled but which become infeasible using EVs varies with vehicle range and charging regime.

FIG 6.22 Percentage of achievable island miles versus vehicle range



The application potential simulation was also used to show how the number of infeasible journeys and infeasible days varies with assumed vehicle mileage (figures 6.23 and 6.24) although for the reasons already discussed this is not such a useful measure as the number of cars which do not experience disruption or the proportion of miles which are infeasible.

FIG 6.23 Percentage of achievable island days versus vehicle range

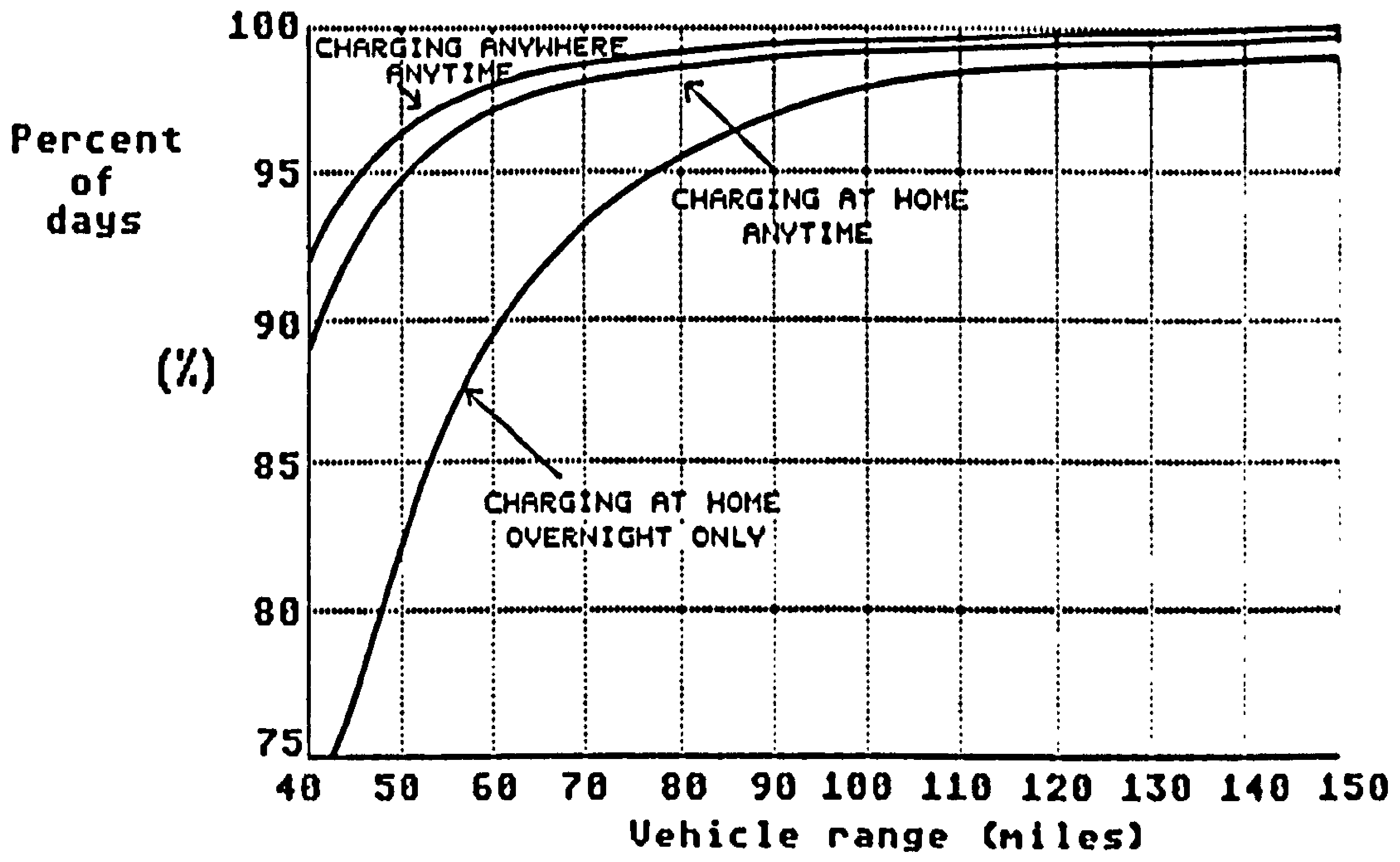
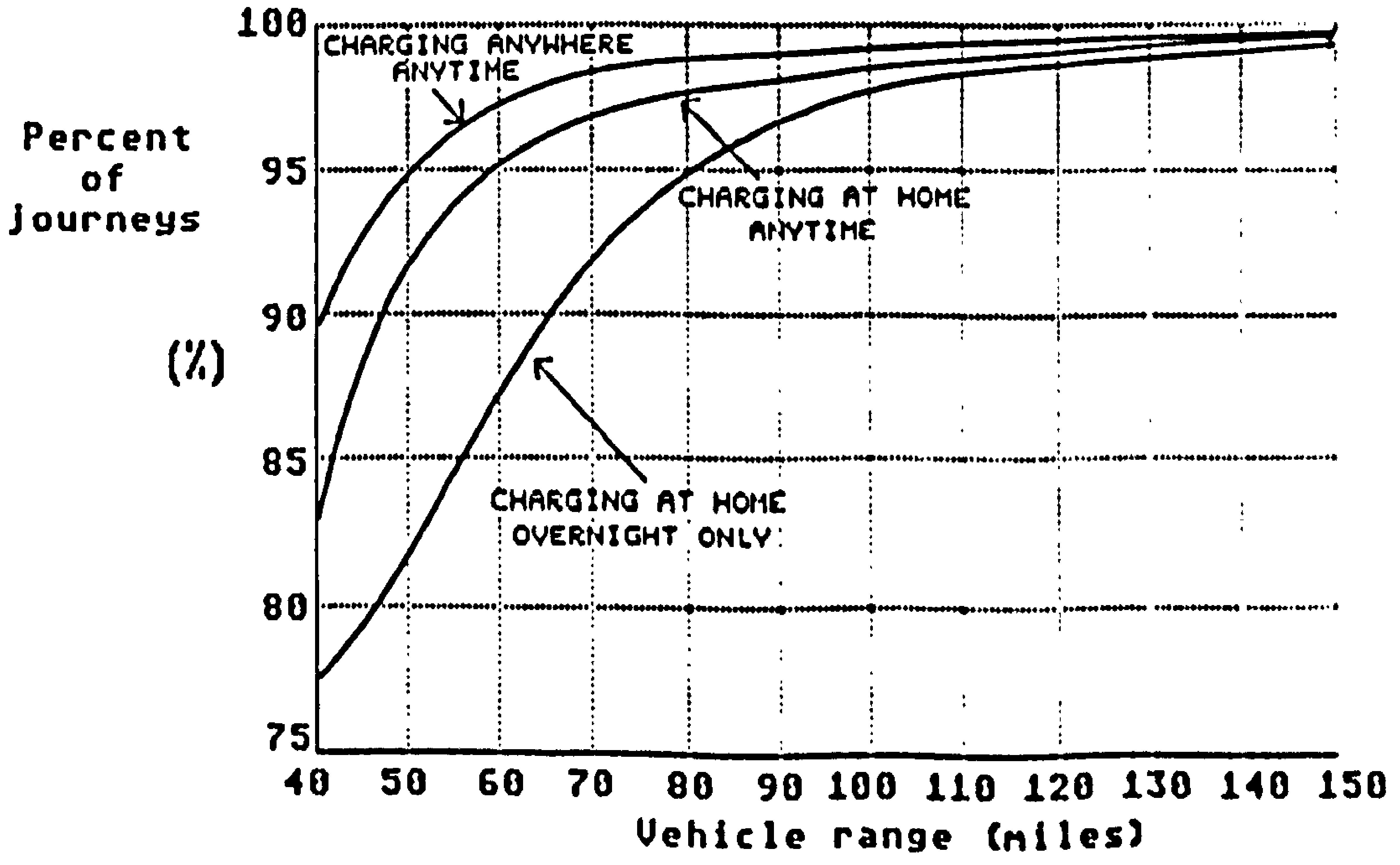


FIG 6.24 Percentage of achievable island journeys versus vehicle range



6.8 SUMMARY AND CONCLUSIONS

The aim of the research outlined in this chapter was to study the performance of EVs in the island situation and the extent to which they could replace ICEs. A time-incremental simulation model was constructed to estimate vehicle performance measures such as vehicle range and energy consumption. The model was based on the characteristics of the General Electric ETV-1 test vehicle which uses a 190 amp hour lead-acid battery system. The road load section of the model calculates the principal elements of road load - aerodynamic drag, rolling resistance, inertial effort and gradient resistance. The drivetrain section of the model takes account of the torque and speed of the motor and transmission systems, in order to calculate the component efficiencies and the measure of power required from the battery. Finally the battery section of the model takes account of the relationships between battery voltage, current, capacity and state of charge in order to calculate the energy consumption and range of the vehicle.

A study of the island roads had to be carried out to establish real-life road-driving cycles, measuring speed and gradient in a time-incremental way using a specially devised speed sensor and inclinometer. A purpose-built portable data logger was designed and built to record the measurement of the sensors. From this raw data calculations were made of road gradient, vehicle speed and vehicle acceleration throughout each journey - covering all the major roads and most of the minor roads on the islands.

The EV simulation model was then used to calculate the energy consumption from the battery on many different types of duty cycle on the island roads, hence the range, maximum current required, component efficiencies and so on, were calculated. The simulation model was also designed to provide an answer to the debated question regarding the potential value of regenerative braking as a means of increasing vehicle range. This was examined in some detail, the conclusion being that it would be of little operational benefit to island EVs, although the addition to range would be substantially greater in urban situations.

To investigate the application potential, data on island motorists' driving patterns was obtained from logbooks completed by a sample of motorists, recording details of every journey made over a period of time. This data was analysed by a further computer simulation model in order to assess how much disruption, if any, each motorist would experience through operating an EV instead of an ICE. The effects on application potential of different charging regimes was also examined in order to assess their relative values. Application potential would not be increased significantly by charging the vehicle whenever it was stationary although the additional range may be very useful on some occasions. The difference made to application potential by different charging regimes becomes even less significant as the vehicle's basic range is extended.

Using the performance measures established from the EV performance simulation model, it was found that a significant proportion of the transportation function on the islands could be undertaken by EVs. The most realistic measure of application potential is the number of island cars which could be replaced by EVs without causing any travel disruption to the operator. Approximately 37% of island cars currently fall within this category in Lewis and Harris although this estimate rises significantly as assumed vehicle range is increased, even moderately. With a doubling of vehicle range, over 80% of cars fall within the application potential. Although the current application potential is limited, a doubling of EV range and the consequential increase in application potential is within the bounds of foreseeable technological advances. This is discussed more fully in chapter 11.

The results of the simulations showed that the EV could be expected to climb any gradient on the islands and achieve an operating range of around 50 to 60 miles. A similar range could be expected from the same vehicle in urban driving conditions. These results are used throughout the remainder of this study for a variety of uses including an economic analysis, a study of the adequacy of the electricity distribution network, a market potential analysis and an examination of the likely effects of future technological developments.

CHAPTER 7

FACTORS IN REALISABILITY OF EV POTENTIAL - RELIABILITY AND REFUELLING

CHAPTER 7

FACTORS IN REALISABILITY OF EV POTENTIAL - RELIABILITY AND REFUELLING

7.1 INTRODUCTION

In the last chapter the performance and theoretical usefulness of EVs was assessed for the island application but not only must the vehicle prove its theoretical ability, it must also be possible for it to realise this potential in practice before it will attract public acceptance. When questioning island motorists, 52.1% stated that vehicle reliability was the most important factor when choosing a new vehicle and 93% stated that it was one of the most important characteristics. Overall, this was the single most important factor for islanders. In this chapter EV reliability is examined, but a wider view of the subject is also taken to examination of refuelling infrastructures and the impact of EVs on the electricity distribution network, factors which also affect the realisability of EV potential.

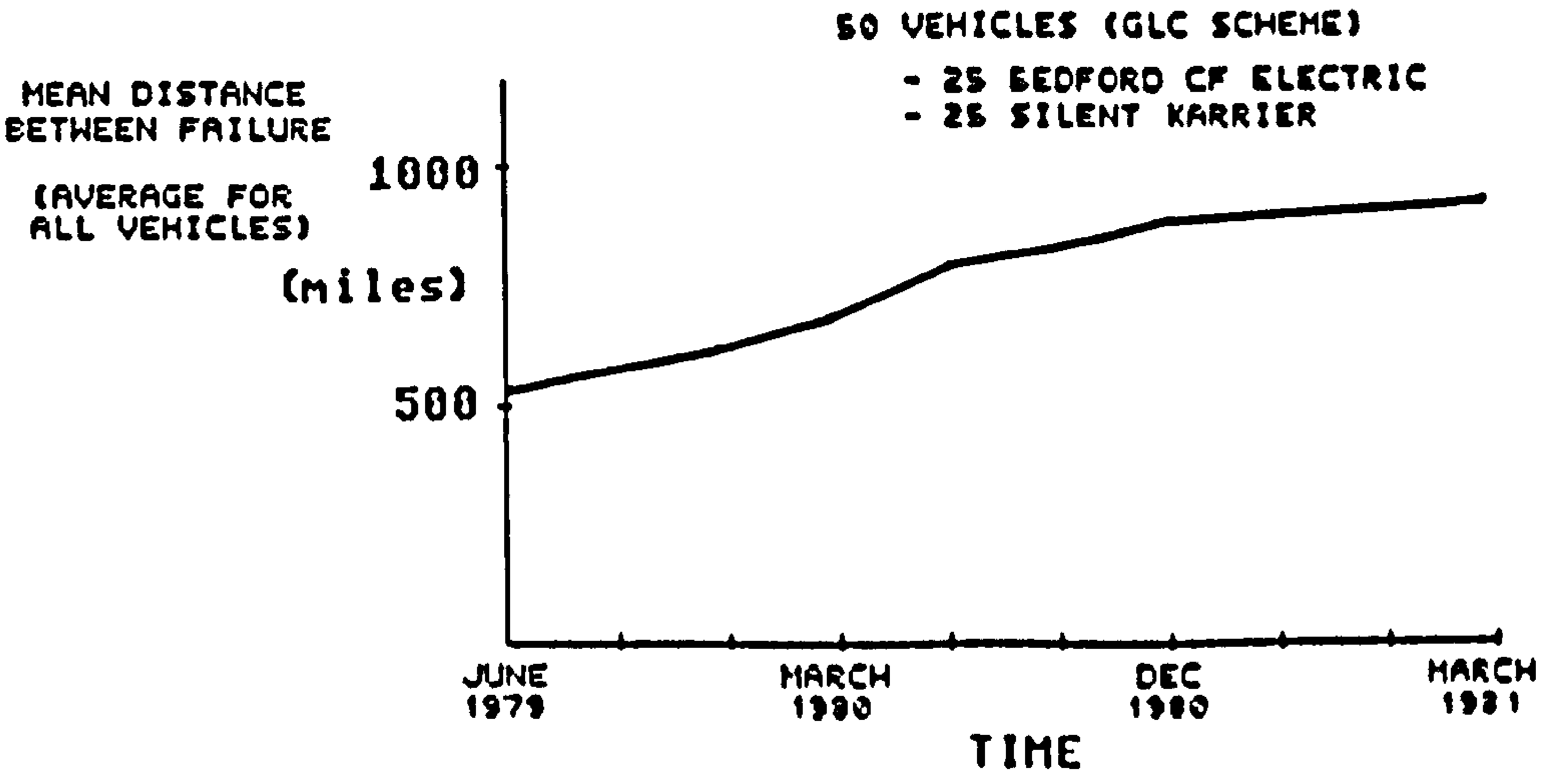
7.2 TECHNICAL RELIABILITY OF EVs

There is no inherent reason why EVs should not be as reliable as, or even more reliable than, their ICE counterparts. There are fewer mechanical components in the EV such as gearbox, exhaust, carburettor, cooling system, ignition system and so on, so the increased mechanical simplicity could lead to increased system reliability and reduced down-time. Prototype high-performance EVs have tended to be less reliable than ICEs but that can be attributed to the user's lack of familiarity with

EVs, inadequate servicing networks and some design faults, all of which could be remedied [1]. The high-performance EV is still at a relatively early stage in its development so it is difficult to estimate how reliable it could be with further development and volume production. The limited operating experience which has been accumulated would suggest that technical reliability should eventually exceed that of the ICE counterpart. It is valuable to examine this operating experience.

Lucas Chloride Electric Vehicle Systems Ltd reported as early as 1981 that the reliability of their drivetrains had steadily improved to the point where downtime was, in most cases, less than than for equivalent ICE vehicles [2]. The reliability trend for 50 prototype vehicles taking part in an assessment scheme (established in 1978) is shown in fig 7.1.

FIG 7.1 RELIABILITY TREND FOR ELECTRIC TEST VEHICLES



LCEVS reported that the overall trend was even more encouraging, since a later batch of Bedford electric vans fitted with improved control systems, which entered service in 1980, proved to be at least twice as reliable as the earlier vehicles evaluated in fig 7.1 and have been virtually trouble free. They stated in 1980 that current reliability problems were confined to a small number of recurrent faults to which solutions had mostly been found [3]. Fleet Advisory Management Services operated 3 electric Bedfords in part of an assessment scheme and reported that downtime during the evaluation period was minimal [4]. The Electricity Council reported that although their Enfield test vehicles were found to be unreliable during initial tests, once it had been 'de-bugged' and modifications were made, it proved to be a very reliable car (see section 1.4.3). The inherent technology was proved to be sound although there was an evolutionary process involved in achieving this reliability. Experience with the milk float and its excellent performance record of technical reliability and low operating costs adds evidence to the claim that EV technology could be inherently more reliable than ICE technology once it is adequately developed. National Carriers Ltd reported that their experience with 5 electric trucks was very satisfactory [5]. The trucks were electric conversions of Dodge KC8055 1.75 tonne payload vehicles, the drivetrains for which were manufactured by LCEVS. The vehicles offered substantially reduced maintenance commitments and operating costs in comparison to the ICE versions. Routine inspection and servicing time and content were nearly halved and breakdowns were "a very rare occurrence". If the inherently simpler mechanical system of the EV is suitably designed and adequately developed, there would seem to be no reason why its technical reliability would be a barrier to the successful introduction of EVs.

7.3 A PRACTICAL RECHARGING INFRASTRUCTURE FOR EVs AND THEIR INTRODUCTION

7.3.1 INTRODUCTION

Even if the EV has a high degree of technical reliability, one of the greatest concerns for the prospective EV operator will be the ability to refuel his vehicle adequately when desired so that he can undertake the desired trips and realise the potential utility of the EV. At present it is extremely easy to refuel an ICE vehicle at almost any time, and motorists are likely to be concerned about possible reductions in this flexibility with EVs.

While the ability to produce high-performance EVs is a major problem, an equally important problem exists in regard to the ability to service a population of EVs. Since these vehicles are designed to use an alternative fuel, an effective system for refuelling must be established. This infrastructure must be able to provide fuel at convenient locations, in a reasonable time and at an affordable cost before potential customers will have enough confidence to purchase. The study of electric road vehicles has attracted much attention, and research has been carried out in the areas of vehicle design, battery technology and vehicle costs. There has however been relatively little research devoted to the question of the most suitable type of refuelling infrastructure for this type of vehicle. It is argued here that much of the work that has been done has perhaps been based on a misconception of the nature of electric road vehicles, their uses and their introduction into modern society. This section discusses the work already done, highlights the above mentioned misconceptions and draws conclusions concerning the various refuelling infrastructure mechanisms discussed, thus allowing a more realistic and practical EV infrastructure to be presented and discussed.

Refuelling infrastructures fall broadly into three categories which will be examined in turn. The first is the 'battery exchange' type of system where discharged electric vehicle battery packs are exchanged for fully charged ones at battery exchange stations which are similar in nature to present day petrol filling stations. This is more akin in nature to changing petrol tanks than to filling up with petrol. The second category is the 'rapid recharging point' where EVs can be "plugged in" at strategic locations during periods when the vehicle is not in use so that the available energy in the battery can be increased and hence the range extended. There is of course a third option which, although it is arguably the most obvious, practical and simplest one, is generally not explored adequately. It is for all or most charging to take place at home or wherever the vehicle is normally kept.

7.3.2 BATTERY EXCHANGE STATIONS

In 1978 the Department of Transport published a report [6] which examined the implications of setting up a network of battery exchange stations for a population of electric cars. Many limiting assumptions were made in order to carry out this piece of research and, as in many other fields of inquiry associated with electric vehicles, it was undertaken without taking a holistic or adequate 'systems' view of the overall electric vehicle technology. Narrowing down on one aspect of the technology frequently necessitates making unrealistic assumptions and frequently leads to unrealistic conclusions. There were many unrealistic assumptions contained in the DOT report which seriously detract from the value of the conclusions drawn and indicate that the emphasis of the work was in the wrong area,

a) ALL cars were to be electric. The approach taken by the DOT was based on the understanding that private electric cars would be universally acceptable and would be owned by all motorists, i.e that they would completely replace the internal combustion engined vehicle. Indeed if there were not a large electric car population, an extensive battery exchange network could not exist on economic grounds. There would not be enough demand, and a small exchange station network would not fulfil any function satisfactorily. It was suggested in chapter 4 that this level of electric vehicle acceptability and application is unlikely to be attained, due to the very nature of and limitations of the vehicle. Even if it were, it would probably be such a gradual process that a different type of refuelling infrastructure would be more appropriate, at least as an intermediate step. The battery exchange system is a long term solution for a long term outlook, but it is not a scenario that will ever occur unless a shorter term view is taken that will provide for the introductory and adoption stages of the EV innovation.

b) "Battery exchange stations would be set up IN PLACE OF the existing petrol supply network."

c) "Car users would not be allowed to charge their batteries at home because home charging would upset the economics of the infrastructure which would be under-utilised."

d) There would be no change in driving habits, i.e motorists would still demand the same total amount of energy in order to undertake the same total mileage. This is clearly unlikely as EVs will not be suitable for long mileage uses in the foreseeable future even if there were numerous battery exchange stations.

e) "Each battery would be returned for charging with 5% if its available energy remaining on average." If this were not the case, queues would become longer because exchanges would take place more frequently and also the economics would again be upset. Furthermore, it is unrealistic to expect drivers to be able consistently to refuel after a fixed mileage unless there is an equally unrealistic number of exchange stations.

All of the above assumptions have the effect of biasing the results of the research in favour of a battery exchange network. It should also be noted that if the restrictions implicit in these assumptions were imposed on motorists, it is doubtful if many motorists would ever be prepared to purchase an electric vehicle unless there were no other options. Even if a network of exchange stations were established, it is unlikely that any of these assumptions would hold true, so the conclusions in this study must be regarded as being unrealistically optimistic. Even under these restrictive conditions however the study came to the conclusion that an exchange of battery would cost, for an equivalent amount of energy, about two and a half times as much as petrol, and only in the most favourable conditions considered could it approach the cost of synthetic petrol manufactured from coal. See tables 7.1 and 7.2.

TABLE 7.1

ANNUAL RUNNING COSTS OF VARIOUS REFUELLING STATIONS. (1975)

	Lead-acid Batteries £(000s)	Petrol £(000s)	Synthetic Petrol £(000s)
Repayment of capital and interest			
Battery Stock	167 [1]	-	-
Station/equipment	85	15	15
Labour	131	17	17
Energy	73	156	250
Insurance	8	4	4
Rates	4	2	2
Other costs	4	2	2
TOTAL	472	196	290

TABLE 7.2

TOTAL COSTS EXPRESSED IN PENCE PER GALLON-EQUIVALENT

	Lead-acid Batteries	Petrol	Synthetic Petrol
Station operators cost (p/gal-equivalent) [2]	73	30	45
Relative cost (Petrol = 100)	243	100	150

NOTES

[1] The study showed that in addition to the batteries attached to vehicles, exchange stations would need to hold an extra one battery pack for every two on the road.

[2] These costs do not include any profit, excise duty or VAT on the selling price. These items made the retail price of petrol in 1975 about 73p per gallon.

The high battery exchange costs are due mainly to the high capital cost of the stations and battery stocks, and the high labour costs necessary to operate an exchange station. The actual cost of the energy involved is less than half that of the petrol but the other cost factors associated with a battery exchange network more than cancel out this advantage. Although the above cost figures were calculated in 1975, it can be argued that they are still indicative of the cost differential involved for battery exchange. Firstly, the major cost items involved in exchange stations have increased in real terms since 1975, and since these already represent a larger proportion of the costs than they do for a petrol station, the differential will have increased. Also the cost of electricity has risen more than petrol in real terms since 1975. Secondly, these costs must be seen as extremely unrealistic and optimistic given the assumptions on which they were based, in which case battery exchange stations would be even less economically acceptable. Thirdly, it should be noted that the electric road vehicle is at present struggling to prove itself in economic terms (see Chapter 9). By using the vehicle in appropriate and specialised applications, the electric vehicle can prove to be cheaper to operate, but the case is by no means overwhelming and in many situations it cannot compete with the ICE. Any possibility of being more economical, and thus more acceptable, would be totally negated by the costliness of a battery exchange system. It would be cheaper to use synthetic petrol which would have the added advantage of retaining the motorist's flexibility of travel and also the existing fuel supply infrastructure.

The arguments in favour of battery exchange stations are few and centre around the vehicle's increased potential range. The arguments against such a system are summarised below.

1 The costs involved would negate any existing or potential economic advantage of electric road vehicles.

2 Motorists who were forced for one reason or another to deposit their used batteries while they still retained a significant amount of energy would lose out. Unless credit was give on partially used batteries, in which case there would be a problem of gauging the energy content

remaining, motorists would end up paying more per mile for their fuel. It is difficult to determine accurately how much energy remains in a battery. In addition, as the battery gets older, it stores less and less energy. An equitable system of battery exchange and payment for energy used would be complicated and difficult.

3 Similarly, it would be impossible to "top up" with energy in order to complete the last leg of a journey or for a long journey ahead or to last over a period when the exchange station was closed or inaccessible or when there were no suitably positioned exchange stations. Exchanging batteries is, in effect, changing the whole fuel tank for a full fuel tank, irrespective of the fuel remaining in the old tank, and this is not ideal from the consumer's point of view.

4 The figures in table 7.1 and 7.2 are based on the assumption that the exchange station owners are also the owners of the battery packs. If this were the case, there would be little incentive for motorists to treat the batteries with utmost care and attention, and this would have detrimental effects on the overall economics of the system. Traction batteries are very sensitive to operator abuse such as over-discharging and discharging at high currents, which can significantly shorten the battery cycle life and lifetime energy throughput (see section 9.2.7). If on the other hand, the vehicle owners were the owners of the batteries, it would be impossible to ensure that motorists were not given old batteries to replace new ones or damaged ones to replace good ones. Once again the incentive to look after batteries is greatly reduced. There would also be a reluctance on the part of the motorist to exchange a piece of equipment which would cost upwards of £1000 (costs given in section 9.2.6).

5 With a small population of electric road vehicles, battery exchange stations would probably be widely spaced and so they would not fulfil their purpose properly. Hence there is a 'chicken and egg' situation

where battery exchange stations depend upon the existence of a large population of electric cars and, according to the DOT report, extensive introduction of electric cars will not take place unless there is an extensive network of exchange stations which is large enough to provide adequate refuelling for these vehicles. This would require massive initial investment which would not be fully utilised unless there was a very sudden conversion to electric cars leading to a large EV population. However, the extent of market penetration of electric vehicles will depend upon increasing range, so their introduction will be a gradual process as EVs manage to compete in a widening variety of specialised applications. The probable nature of this introduction does not lend itself to the approach exemplified by the battery exchange type of infrastructure. The argument has been raised that someone must have built the first petrol station and that a refuelling infrastructure for the ICE vehicle grew up gradually. However, it must be understood that the nature of petrol as a fuel is very different from electrochemical energy. Because of the extremely high energy density of petrol, an ICE vehicle with a full petrol tank has a range of up to ten times that of an EV with fully charged battery and thus needs correspondingly fewer refuelling stops. Hence correspondingly fewer refuelling stations are required. Also, petrol can easily be carried on board the vehicle to extend the range even further, without incurring a serious weight penalty, and in addition a fuel reserve can be stored by the vehicle owner at home. Petrol outlets can be small concerns and can be attached to other types of business. These factors meant that a refuelling infrastructure grew up gradually around the ICE with a minimal number of stations in the early stages of vehicle introduction. Battery exchange stations on the other hand would have to be very large and numerous before people would begin to use electric vehicles.

6 Unless actively prevented from doing so, the operator of an EV could plug into his domestic electricity supply for most of his energy needs, thereby incurring only the cost of the raw energy. The bulk of the cost of a battery exchange would be attributable to costs other than that of the energy. By utilising off-peak tariffs, the motorist would pay less than a fifth of the price of petrol for an equivalent amount of energy and less than a tenth of the cost of a battery exchange. A battery exchange scheme would not therefore be highly utilised and would become even less viable.

In summary we can say that the concept of refuelling stations fits in more readily with the demands of the ICE vehicle and with the nature of petrol as a fuel than with the electric vehicle and its battery.

7.3.3 ON-BOARD BATTERY RECHARGING AT RECHARGE POINTS.

It is not possible at present, because of the nature of the ICE refuelling infrastructure, to "top up" with petrol at home, in a car park, at work or anywhere else other than recognised and registered petrol stations. With an EV however it becomes possible to refuel by charging the batteries at a large number of locations.

Under this system the battery pack remains attached to the vehicle, ('on-board') thus avoiding some of the disadvantages of the previous system. The whole vehicle is required to remain stationary as the batteries are charged. One option to consider briefly when considering on-board charging is the possibility of rapid recharging where large currents are used to charge the batteries very quickly, thus saving time, increasing daily range and causing less travel inconvenience. The problem with this type of charging is that the faster a battery is charged, the more detrimental is the effect on battery cycle life. This of course increases battery costs. However it has been stated in a study carried out by the European Electric Road Vehicle Association (AVERE) [7], that, although frequent charging within 90 minutes caused some battery deterioration, the additional cost for batteries was less than that needed for battery exchange. A major problem with fast charging is the size of the currents that would be required and the cost of the equipment to handle these. Charging within 90 minutes would require starting currents of up to 300 Amps and these increase as the charging time is reduced. Also the higher the starting current, the more expensive is the charger to make and buy.

Returning now to examine on-board battery charging as a possible refuelling infrastructure, the main advantages are,

1 There would be no need for a large battery stock to be made available, in contrast to a battery exchange station system where it represents a substantial proportion of the cost of the latter.

2 If chargers were located at public recharge points they may be more intensively used, serving many customers instead of just one vehicle operator. Greater efficiency and economy might result. If used privately for the exclusive use of one operator a charger should last the lifetime of at least two vehicles. Many motorists might therefore not need it for its whole life, or might not want to pay the initial cost of a charger.

3 On-board recharging at public supply points would be substantially cheaper than battery exchange because of the inherently simpler nature of the system.

4 There would be less need for a complete refuelling infrastructure to be established in advance of EV introduction because recharging points can more easily be introduced as the proportion of EVs increases. It is true that there would be a certain critical level of public charging points necessary but it would be a small capital outlay in comparison with the battery stations. This type of infrastructure is therefore more compatible with the nature of EV introduction. It is more

'demand-led'.

5 The daily range of EVs can be extended within limits, and, as this range increases, so the uses to which they can be put would be increased and the amount of inconvenience caused by limitations of range would be reduced.

Although the above advantages indicate that this system would be cheaper than the battery exchange system, it is still not necessarily cheap enough to be realistically desirable. Similarly, although range is increased it is done so at a cost. The reasons for this and some of the disadvantages of the system are,

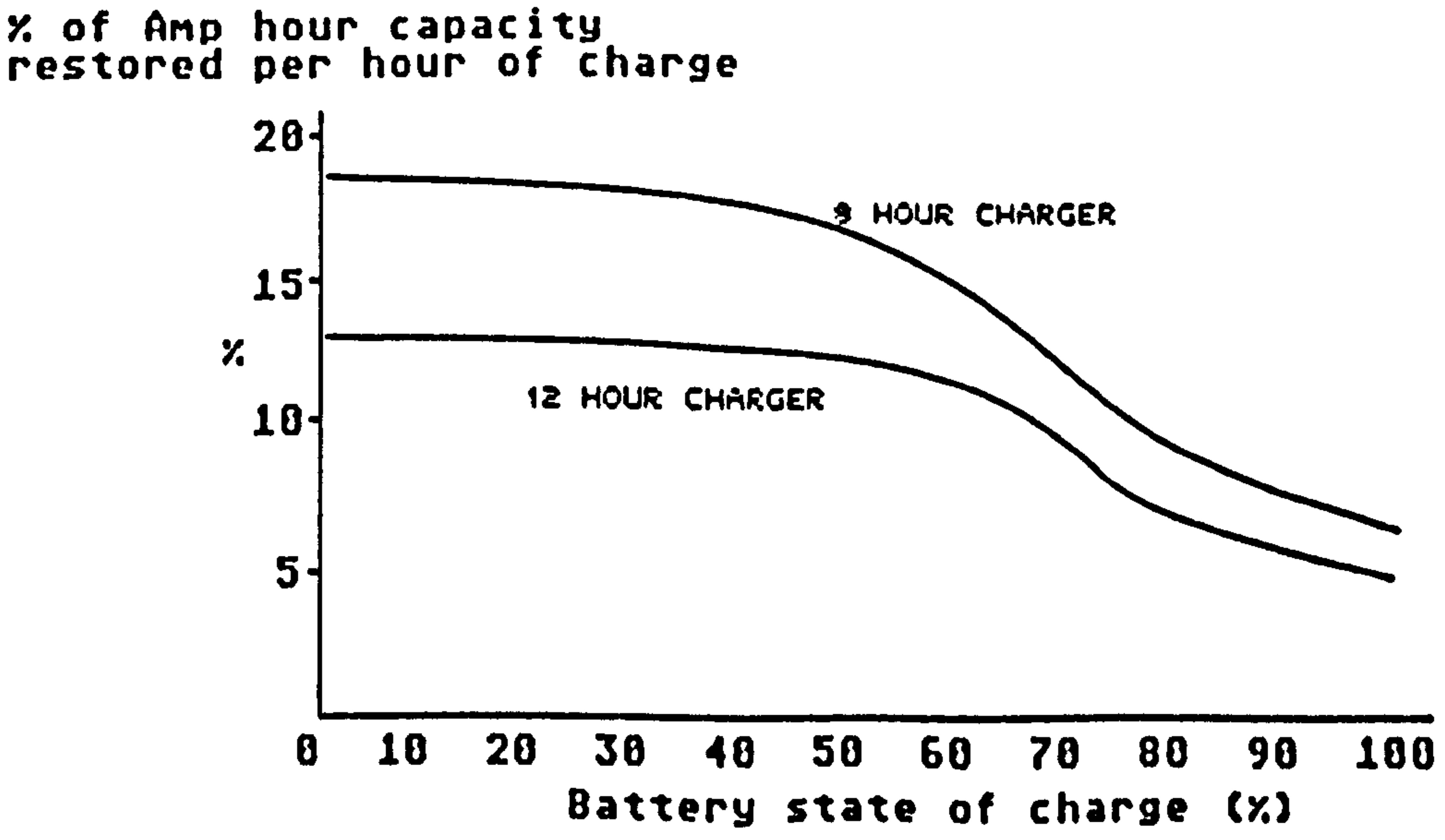
1 Energy costs would be higher than the basic cost of energy for several reasons,

- Recharge points would have to incorporate methods of protection against vandalism, abuse and weather. They would require substantial amounts of wiring and electric cable laying and would have to be capable of delivering large currents. A payment system would also have to be installed and all these refinements would add to the cost to the consumer. The TRRL [8] made some estimates of the likely capital costs of providing publicly available supply points and showed that such points would cost over 100 times as much as providing a suitable domestic supply point. It would still cost over 20 times as much as a high rate power supply at home (i.e 26 Amp outlet) Not only is this capital cost greater, but the utilisation factor is likely to be lower, thus pushing up the necessary charge for energy even further.
- Because each different type of battery pack requires a different charging profile i.e starting current, charge time, capacity, number of cells, battery age and condition and so on, the chargers involved would have to be much more sophisticated and costly than those used at present, in order to be able to cope with the inevitable variety of

demands. The complexity of the system would add to the cost of each recharge.

- Most "opportunity charging" would take place during the day when off-peak tariffs cannot be exploited.
- The more charge there is remaining in a battery when it is connected up for recharging, the less energy the battery will be able to accept over a given period of time,. i.e towards the end of a charge cycle, the charge acceptance process gets slower and slower. If therefore a battery is plugged into a charger to be topped up at a recharge point when there is a substantial amount of energy remaining in it, the energy returned by the opportunity charge is minimal and is not cost effective. Fig 7.2 shows the amount of charge that a battery will accept depending on its initial state of charge.

FIG 7.2 APPROXIMATE % OF AMP HOUR CAPACITY RESTORED PER HOUR, AGAINST BATTERY STATE OF CHARGE



It can be seen that there is little benefit in opportunity charging when the battery is already 70% charged or above, unless the little extra in terms of range is more important than the time taken or the cost.

2 Battery costs will be affected by the charging regime used (see section 9.3.4). It is possible that the cost per mile of the battery will be greater under this type of refuelling infrastructure because it will almost certainly result in many and frequent shallow opportunity charges. There is a relationship between the average depth of discharge of the battery and its cycle life. The lifetime amount of energy delivered by the battery is affected by the average depth to which it is discharged before being recharged. There is an optimal depth of discharge, but unfortunately there is some disagreement in the literature as to where this optimum actually lies. Battery economics are very sensitive to the way in which the battery is treated and this is quantified and discussed more fully in sections 9.2.6 and 9.3.4.

At this stage it should be pointed out that opportunity charging may result in frequent undercharging of batteries, as a lunch hour or visit to the shops will not always give time to recharge fully. Even if there is sufficient time to charge fully, there is a constant pressure on motorists to keep their batteries as full as possible and so the state of charge may not get down to the optimum depth of discharge very often before opportunity charging resumes. Undercharging over a long period will cause irreparable damage to a battery and therefore will increase battery costs. The residual lead sulphate, particularly in the negative plate, expands and blocks off the previously porous sponge lead, thus reducing the capacity. This could however be prevented to some extent by ensuring that full charges are given as often as possible at home or elsewhere.

3 Although the daily range of the EV can be increased by opportunity charging during the day, there is great inconvenience caused by the lengthy refuelling time involved. Firstly the driver may not have enough time to wait for a charge if he is in a hurry for some reason,

or because he has to drive further than the range of the vehicle and the time available for opportunity charging permit. Secondly he may not be able to find a recharge point at the desired location. The day's journey is slowed down by the need to recharge and there is always a risk of not being able to return home if the driver attempts a journey that is outwith the vehicle's basic self-sufficient range. It is perhaps a mistake to expect the EV to be used in applications where the basic range is regularly insufficient for the daily mileage. In commercial applications where regular shifts are being worked a suitable schedule might more easily be arranged but for the domestic motorist whose plans are less rigid it represents an inconvenience and a risk.

4 In the application potential analysis the effects of different charging regimes were simulated. The benefit of having a plentiful supply of publicly available recharge points in the island situation which could be used whenever the vehicle was stationary and away from home was minimal. An increase of between 2% and 4% in the number of island miles that were achievable was recorded using such a refuelling infrastructure. This figure in itself is extremely optimistic about the increase in application potential because it was based on the assumption that vehicles could be recharged wherever they were and whenever they were stationary. In practice, public recharge points are very unlikely to be as numerous as this.

The increase in the achievable miles due to the availability of recharge points decreases as the range of the vehicle is improved. The worth of such a system becomes less and less as the technology advances. The value of a public recharging infrastructure, at least in the island situation, must be called into question because of the minimal benefit that it offers.

Department of Transport statistics show that over 90% of light goods vehicles and private cars travel on average less than 50 miles per day. The vast bulk of charging can therefore be done at home. For long journeys, even with the possibility of opportunity charging, the total journey would probably still be infeasible as the range can only be extended by a small amount by opportunity charging.

In summary we can say that a system of on-board battery charging at public recharge points is more compatible with EV technology than the battery exchange system. A public recharging infrastructure would increase effective EV range, albeit by a small amount. However the advantages are likely to be minimal because the costs of the energy used, and the probable effects on battery life and costs, swing the economics in a direction unfavourable to the EV. The economic case is by no means outstandingly in favour of the EV compared to the ICE and any additional costs would be significant. In addition, the decrease in mileage disruption is small and the amount of use that needs to be made of such a system is also likely to be small. An infrastructure of this type probably has a use but only for cases where a small increase in range is more important than the costs involved. It is arguably the case that EVs should not be expected to perform all the tasks that an ICE presently handles and should only be substituted where it can cope adequately with the required daily mileages. It is however possible that this type of refuelling infrastructure would develop as battery and charger technology develops. Until now, most EVs do not carry suitable battery chargers on-board as they tend to be very large and heavy pieces of equipment. The advent of small lightweight on-board chargers which are an integral part of the vehicle would overcome many of the problems and costs outlined above, although the use of such an infrastructure would still be very limited and would decrease as improved batteries push the basic EV range upwards.

7.3.4 HOME RECHARGING

The third possible refuelling infrastructure is for EV owners to do all their battery charging at home or wherever the vehicle is normally kept. This system may of course be used in conjunction with one of the other possibilities discussed above. The concept of recharging the EV at home is quite appealing to most, because of the natural control and convenience afforded by this method. The ability to refuel one's own vehicle, practically at any time, provides a dimension of freedom which may not exist if other forms of EV refuelling are adopted. Even the current ICE and its associated refuelling infrastructure do not offer the flexibility of being able to refuel at home at any time. There seem to be no inhibiting constraints on the introduction of a home recharging infrastructure for EVs. No additional power requirements or electrical wiring would be necessary in most cases if recharging is done overnight when power demands are generally lower. The only real costs associated with a home refuelling system would be the cost of the electricity used. This is by far the simplest and, in the majority of cases, the most convenient method of refuelling. The owner can make use of cheap off-peak electricity tariffs thus minimising energy costs and he can charge the vehicle when it is not required for travelling, thus minimising his inconvenience. He can practise whatever charging regime best suits his need and his financial preferences. Charging could be restricted to night-time only to exploit cheap tariffs, or he may be prepared to pay full rates for daytime charging. The difference that this makes to overall running costs is calculated in the economic analysis (section 9.3). Home recharging does not however overcome the basic problem of range limitation, but as has been pointed out earlier, to expect anything more of an EV is not recognising realistically the nature of the vehicle and the uses to which it can be put. Home charging has several other associated problems however. Not all houses have a suitable outside electricity supply and for some vehicles a standard 13 Amp supply would not provide a large enough current, or a quick enough charge. A heavier duty supply may have to be installed. A TRRL report [8] estimated that it would cost in the region of £70 (updated to 1988) to install a 26 Amp supply to a house. In general however, the costs associated with this method of refuelling, the ease and reliability for operators, coupled with the fact that there is very little travel disadvantage associated with it, make it the best overall type of refuelling infrastructure for the introduction of electric road vehicles. During the initial period of EV introduction, it is likely that the purchase of EVs would be confined to those who could make do with home recharging alone. As EVs become more popular and common it is conceivable that it may become economically attractive to establish extra refuelling points elsewhere, but this is seen as a result of EV introduction and not the cause.

7.3.5 SOME FURTHER POSSIBILITIES.

Mention must be made of one or two other suggested alternatives. Firstly, power could be supplied directly to the vehicle via a power source laid in the roadway. This could both propel the vehicle and replenish depleted batteries as the vehicle moves. It was estimated however [8] that the cost of electrifying only motorways and trunk roads would be much greater than even a battery exchange system. Maintenance costs would also be very high. Such an idea is clearly unsuitable for the island situation.

Another alternative would be for the motorist who is going on a longer journey to carry an auxiliary power source which would be towed in a trailer. This power source could be in the form of a battery or a small diesel generator. With lead-acid batteries, the performance limitations imposed by the battery weight would make this option infeasible. A small generator would not be capable of supplying energy cheaply enough to compete adequately with the ICE. Indeed there would be little point in operating an EV if diesel was available cheaply enough to use in this way. This would seem to be defeating the purpose of introducing EVs in the first place. However for the occasional longer journey it might increase range sufficiently to enable completion of the journey. Generators would probably be hired so that the individual operator could avoid the heavy capital cost of owning both the EV and the generator.

7.3.6 SUMMARY AND CONCLUSIONS

Any research or development or study which is based on the assumption that EVs will be universally acceptable and used fails to take account of the realistic potential of such vehicles. Such an approach is likely to retard the development of the technology and adversely affect public acceptance. It is doubtful that the electric car will ever take over completely as the means of private transport, even when oil eventually runs out. The study of a suitable infrastructure must be based on this realistic approach. The nature of the vehicle points to its most suitable uses, and this in turn indicates the probable nature of its introduction and the most suitable and practical infrastructure for its introduction and use. A battery exchange system is likely to be prohibitively expensive and difficult to establish and operate successfully. A charging network with publicly available recharge points would not solve the problem of the EV's limited range and long refuelling time and would add to the cost of EV operation. The contribution that such a system would make to the application potential for EVs in the island situation would be minimal and would only reduce the expected mileage disruption by a very small amount. In addition, as the basic range of EVs increases with technological advances, the already minimal benefits of public recharging points is eroded even further.

Charging at home is undoubtedly the most convenient, suitable and economical system for the bulk of refuelling needs, especially in the early years of EV introduction. The House of Lords Select Committee report on EVs recommended that,

> "Manufacturers must do what they can to make a specialised recharging infrastructure for EVs unnecessary" (see appendix 9).

7.4 ELECTRICITY DISTRIBUTION NETWORK

7.4.1 INTRODUCTION

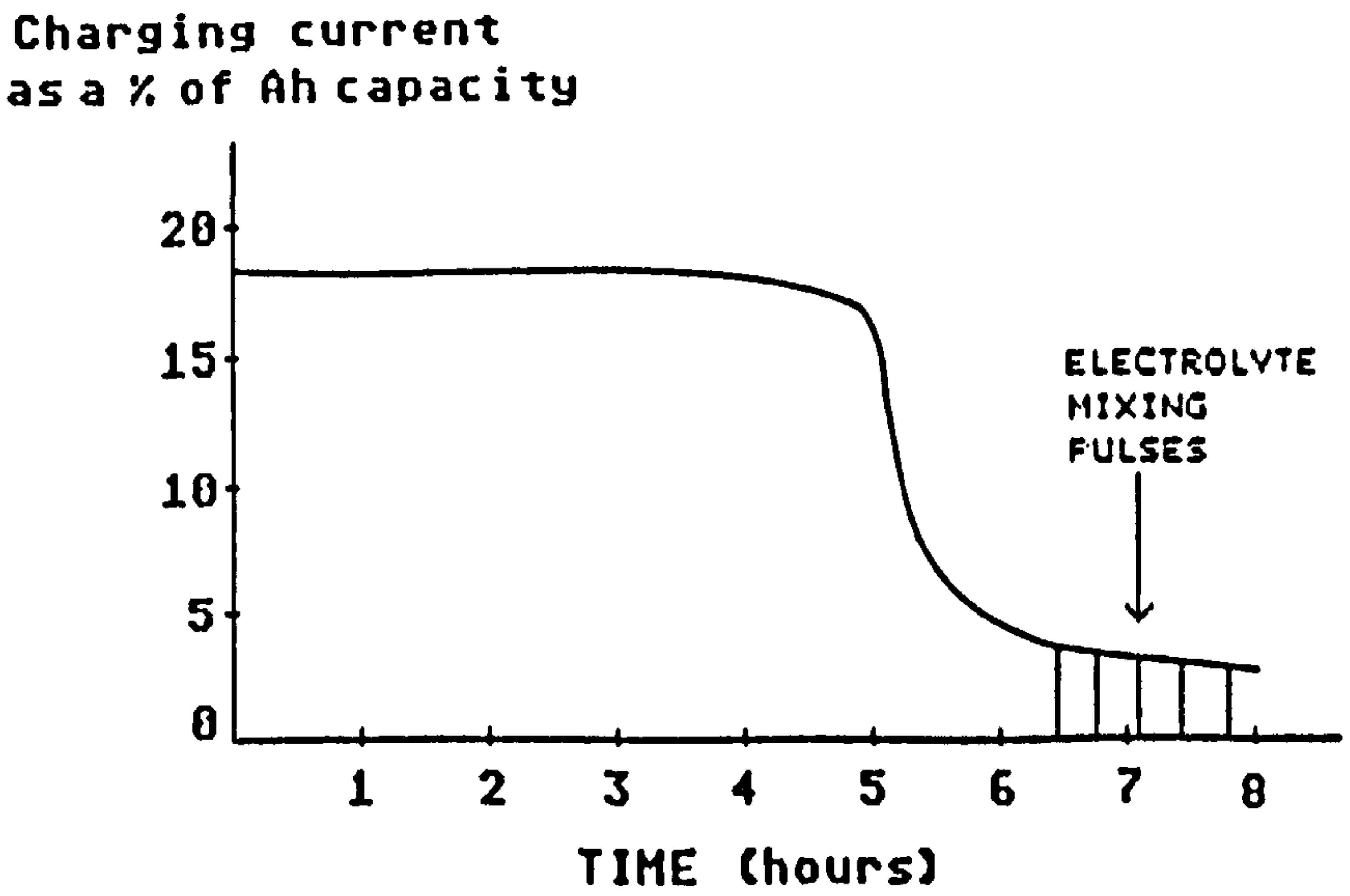
Not only do potential EV operators need to be persuaded that an refuelling infrastructure exists (even if this means charging at home), but they also need to be confident that this infrastructure is capable of providing the energy that they require. This section examines the energy demands of high performance EVs and the likely demands in the islands. The present supply position is then described both in terms of the capacity of the system and the distribution network. Future changes in the pattern of demand and the existing supply are presented, and finally the effect of a population of EVs is examined to see how the system would handle the extra electricity demand.

7.4.2 THE ELECTRICITY DEMAND GENERATED BY EVs

The amount of energy required to power an EV depends upon its range, payload, the energy density of the battery system, the charger efficiency and the efficiency of the electric propulsion system. The EV performance simulation constructed for this project and described in section 6.3 took all the factors associated with the vehicle, battery and drive patterns into account when arriving at an estimate of the energy use per mile. However the charger and battery charge efficiency also represent areas where energy is lost. The efficiency of a good charger is in the region of 90%. The charge efficiency of lead-acid batteries varies according to the state of charge but an average figure of around 80% can be used. This allows for the fact that recharging is less efficient when the battery is recharged after partial discharges. Using the vehicle energy consumption figures and allowing for charging losses, the gross amount of energy used by the test vehicle in the simulation was about 0.33 Kwh/mile.

A battery recharging profile is the curve of input power to the battery from the electricity supply point versus time. Battery charging should be tailored to optimise the charging process. There is a trade-off between speed of charge, charging efficiency, charger cost and battery cycle life. The best kind of charge begins at a relatively high current input which reduces as the battery becomes more fully charged. Fig 7.3 shows a typical recharging profile.

FIG 7.3 TYPICAL 8 HOUR BATTERY CHARGING PROFILE



Using this charging profile and the efficiencies above, the average island motorist travelling 8216 miles per year will consume 52.6 Kwh of electricity per week.

A. SIMULATION MODEL TO PREDICT ELECTRICITY DEMANDS

The aggregate amount of energy required to fuel an electric car population on the islands is an important factor in an examination of the suitability of the electricity infrastructure. So also is the timing of this demand. Each car journey uses energy from the batteries and each interval between journeys provides an opportunity to replenish this energy from the public electricity supply. The detailed sequence of journeys and journey intervals makes it a complicated task to draw profiles of the likely pattern of demand. It was a recognition of this complexity that led to the decision to construct a simulation model to examine the likely impacts of a population of EVs on the islands (see appendix 1).

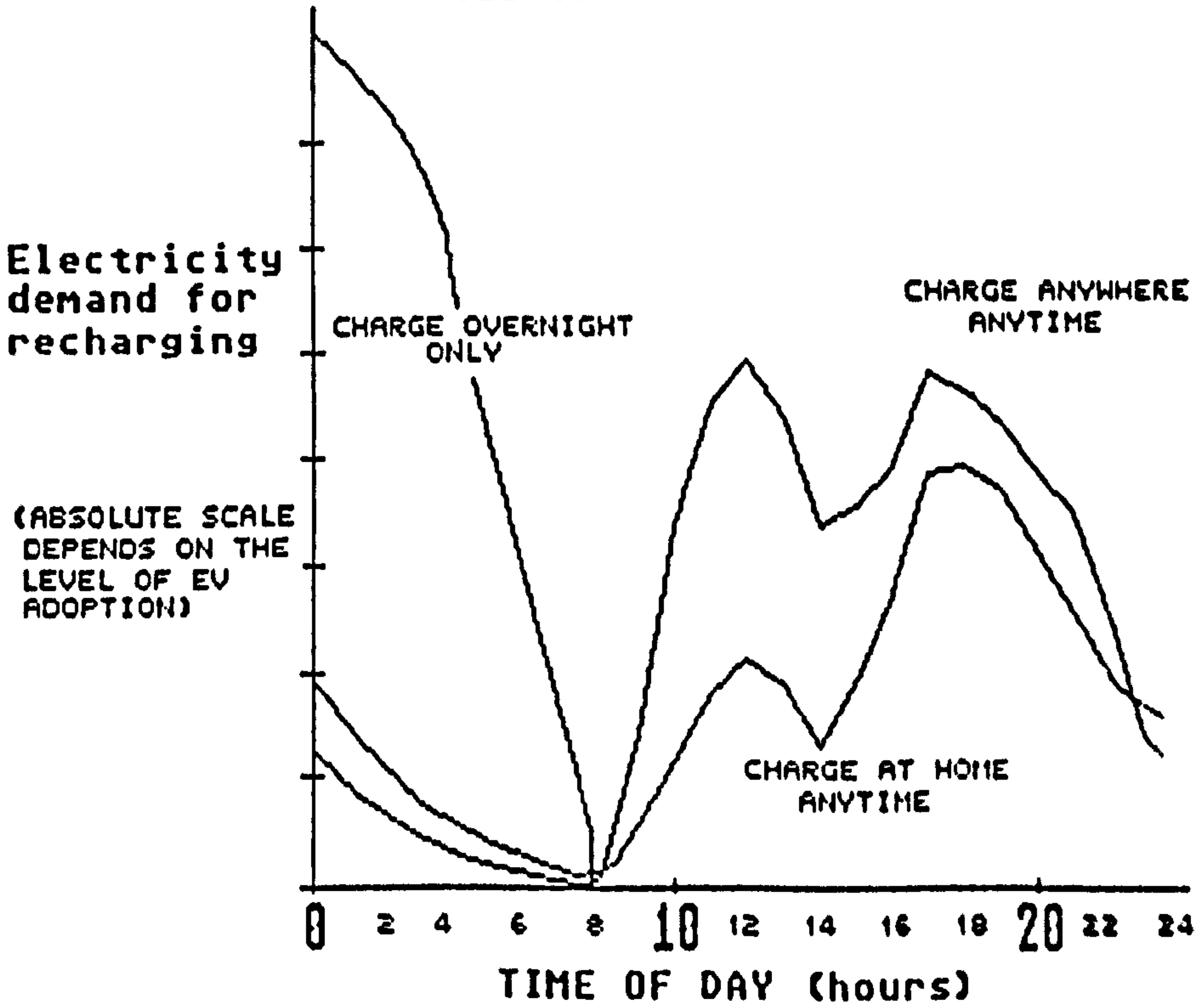
Data on a large number of journeys over a significant period of time had already been collected for the application potential analysis and this same journey data was used for this simulation. Vehicles were assumed to be 100% charged at the start of the period of time analysed. Each time a journey was undertaken, the energy used and the new state of charge (SOC) was calculated. Each time the vehicle became stationary again it was assumed available for charging and, depending on the charge regime being used, charging was resumed. Charging continued until the next journey or until the battery was fully charged again. The new SOC was calculated and the current drawn from the public electricity supply was determined throughout the duration of the charge. If the period available for charging was less than 30 minutes, charging was assumed not to take place. The location of the vehicle after each journey was recorded when the data was gathered, and charging was only resumed if the location and the charging regime permitted. The three basic charging regimes described in section 6.7.7 were employed. It was assumed that motorists had no foreknowledge of their journey requirement but made an attempt to charge the battery whenever the forementioned constraints allowed.

The charging current at any point in the charge was estimated using a charge profile similar to the one shown in fig 7.3. An equation was established to relate the current drawn to the battery state of charge. As the SOC increases, the charging current reduces according to the relationship shown. At any particular moment in time there may be many EVs charging on the island and the simulation added the charging current from all the charging vehicles for each minute of the 24 hour day.

B. SIMULATED DEMAND PROFILES

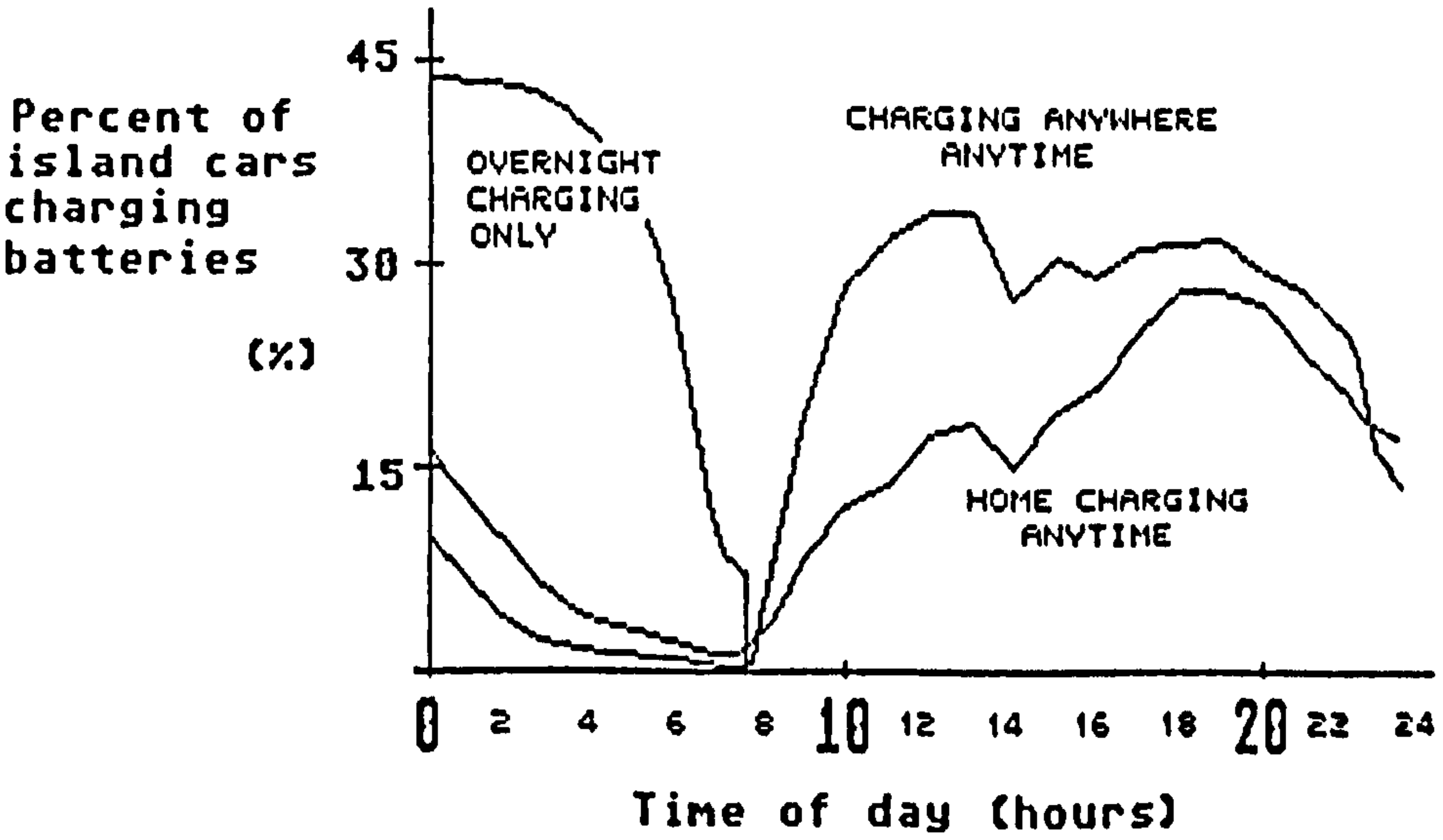
A daily demand profile was constructed for each charge regime. Although there is a little difference from day to day, the general pattern of peaks and troughs are very similar and the curves show the average of five separate days (fig 7.4). The demand shown for each hour is the average demand during that hour and not the peak demand.

FIG 7.4 SIMULATED DEMAND FOR ELECTRICITY DUE TO BATTERY CHARGING
(Lewis and Harris)



If all charging must take place at home, it can be seen that the morning peak in demand is much smaller in magnitude than would be the case if charging could take place anywhere. Indeed, although the difference in demand resulting from the different charging regimes is most noticeable during the morning peak, the entire demand profile resulting from home charging is smaller than for the less restrictive charging regime, except for a few hours in the middle of the night. This difference can be accounted for by the reduction in overall vehicle usage and hence electricity demand which is caused by the lack of charging facilities outside of the owner's premises. Once again, the demand resulting from the 'charge anywhere' regime must be regarded as the upper theoretical limit of demand as this calculation is based on unrealistically optimistic assumptions. If charging facilities were available away from home they would not be so numerous as to permit charging absolutely anywhere at any time. The realistic demand profile will therefore be closer to the 'charge-at-home-only' regime. The proportion of the EV fleet that is charging at any particular time can also be shown under the two regimes. A very similar picture appears (fig 7.5).

FIG 7.5 SIMULATED PERCENTAGE OF ISLAND CARS CHARGING BATTERIES (Lewis and Harris)



In reality, most recharging will be likely to occur when the vehicle is parked at home, even if opportunity charging points were available elsewhere. Energy costs would be greater from public charging points and not every vehicle would be able to park next to one. For most drivers, recharging would commence most conveniently as soon as the vehicle is parked at home. Immediate recharging upon arrival home would make later visits to the vehicle unnecessary and would increase the potential range of the vehicle for unforeseen journeys. This recharge strategy assumes that electricity costs are constant throughout the day. If off-peak tariffs are available, it may cause motorists to shift their recharging to more economical times of day. It was calculated in the application potential analysis that if all charging is confined to the white meter periods a reduction in feasible miles of 4% throughout the island would be experienced compared to the 'charge-at-home-anytime' regime (see section 6.7.8 and fig 6.22).

The electricity board could spread the peak out over a longer period of time by staggering the starting time for cheap tariffs in different areas. This is common practice.

7.4.3 THE EXISTING ELECTRICITY SUPPLY POSITION

At present the islands of Lewis and Harris are served by a Diesel fuelled generating station at Stornoway. It is rated at 30.29 MW but rarely operates at over 20 MW. In addition there are two gas turbines rated at 11 MW each stationed at the oil platform construction yard outside Stornoway. These were purchased at less than a fifth of their value from the Irish generating board which was in financial difficulties. There are two small hydro schemes on the islands giving a total of 1.54 MW. In total, the installed plant is capable of supplying 53.83 MW.

THE CABLE

On the 7th November 1984, the North of Scotland Hydro Electricity Board (NSHEB) announced plans to link the Outer Hebrides to the national grid via submarine cables at a cost of £28 million. This was expected to result in annual savings on expensive diesel generating costs of between £2 million and £2.5 million. There would be no financial benefit to consumers, who pay the same for their electricity as consumers on the mainland. The NSHEB has tried unsuccessfully in the past to impose a 10% surcharge on the islanders. Plans for the cable have been bitterly opposed by some conservation groups because of the impact of overhead cables on scenic areas in Skye. Only in December 1987 were plans formally approved by the Secretary of State for Scotland after a grant of £9.982 million was made available under the European Regional Development Fund. The projected cost of the project at this time stood at £35 million and later discussion with the NSHEB put the cost at £40 million. The NSHEB originally stated that the cable would be capable of supplying "something in the region of 22-25 MW. However the project is now underway for an 18.5 MW cable. This will be incapable of supplying all the energy demands on the islands during peak periods in the winter and the existing generating plant will be kept on standby for these periods. The project is due to be completed in 1991.

It would appear to be a short sighted move to install a cable that cannot even meet existing peak demand, not to mention any growth in demand in the future. However, the cable represents the largest cable that can be laid within certain technical and economic limits. According to the NSHEB, a larger cable would have to be of a different type from the projected one, utilising different technologies and would require several times the level of investment.

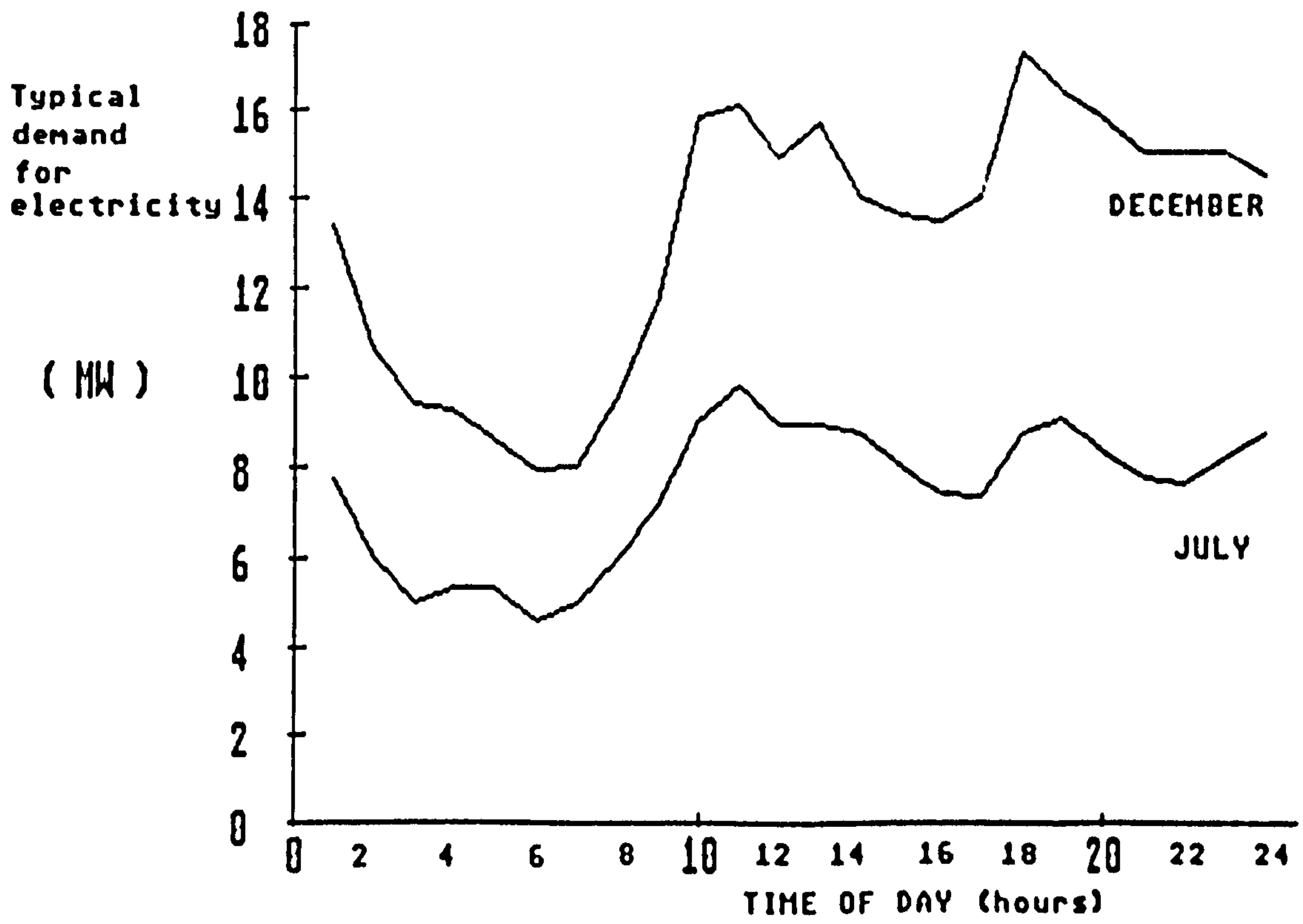
CURRENT AND FUTURE DEMAND

The peak demand that the NSHEB can expect at present is around 21 MW. This is only likely in the winter on very cold days at between 5 and 6 pm. This is however quite rare and in January 1988 only 11 hour time periods exceeded 18.5 MW (the capacity of the cable). This was 1.6% of the total generating time and gives some indication of the extent of the contribution that the existing plant will need to make once the cable is installed.

The NSHEB claim that they do not expect significant growth in demand in the foreseeable future. Demand has risen over the last few years to a peak in the region of 21 MW but it seems to be hovering around the current level and is not expected to grow except perhaps at an extremely slow rate. There will be plenty of generating capacity available to meet any potential growth

Fig 7.6 below shows typical demand profiles for the islands at different times of year. It can be seen that the average profiles are well within the capabilities of the cable and only occasional peaks will require the operation of the diesel or gas fired generators.

FIG 7.6 TYPICAL HOURLY DEMAND FOR ELECTRICITY IN LEWIS & HARRIS



7.4.4 THE IMPACT OF ELECTRIC VEHICLES

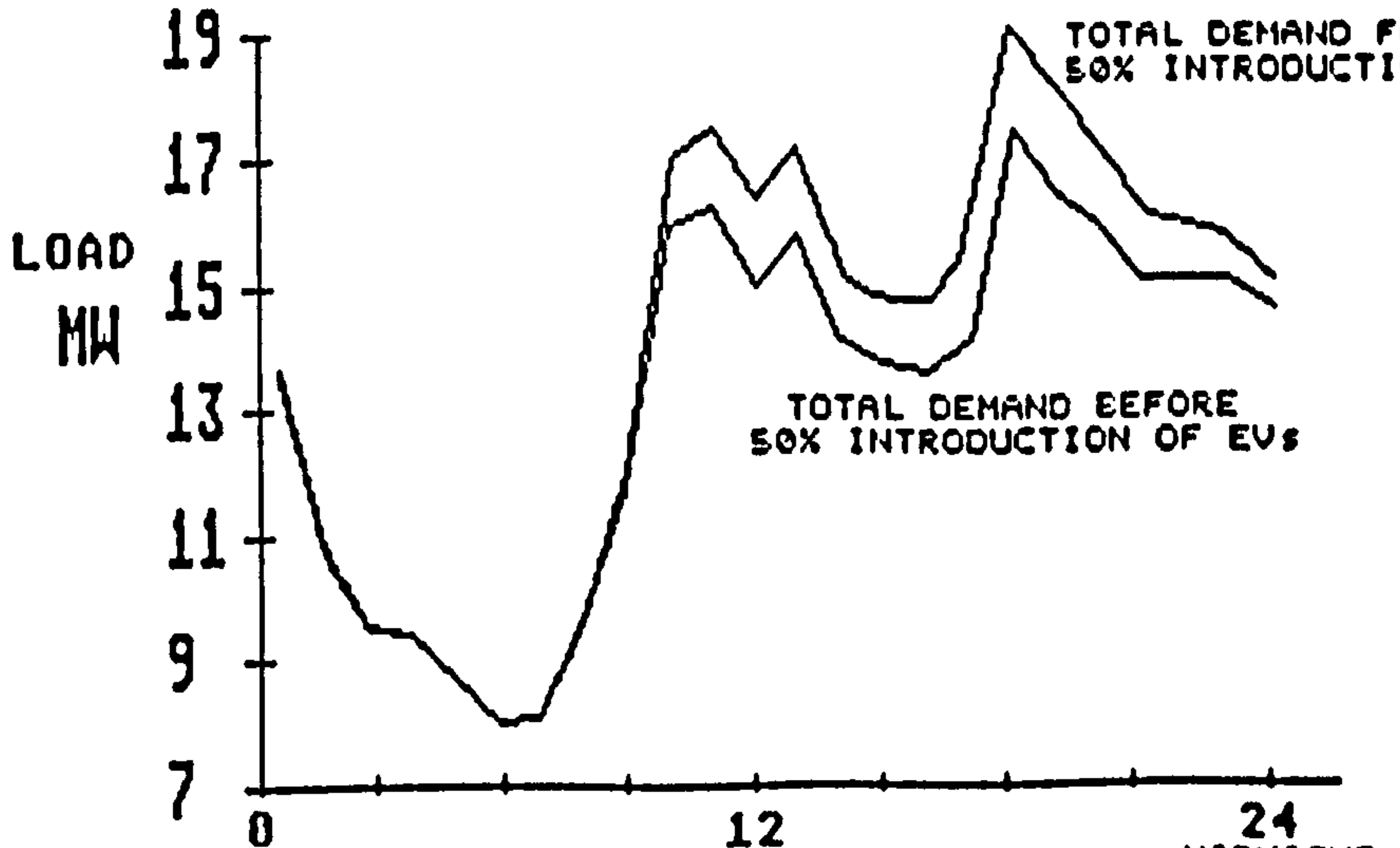
The likely extra electricity demands generated by the presence of EVs on the islands can now be examined in the light of the supply capacity of the NSHEB. This will be examined at four different levels, the overall supply capability, the overhead distribution network, the individual transformers and finally the household situation.

A. THE OVERALL GENERATING CAPACITY

The present island demand profiles and the EV charging demand profiles from the simulation model can be matched to show the addition to the basic demand resulting from EV battery charging. The EV demand profile shown in fig 7.4 only shows the relative hourly demands and not the actual magnitude of demand that the electricity company could expect. The size of this demand is of course dependent upon the size of the EV population on the islands. From the application potential calculations in section 6.7 a relevant range of EV populations to consider can be estimated - it is unlikely that more than 50% of vehicles will be replaced by EVs on the basis of current technology (see also chapter 9). There are currently 4436 cars in Lewis and Harris and the following analysis examines how a population of 2218 cars on the island would affect the energy supply position.

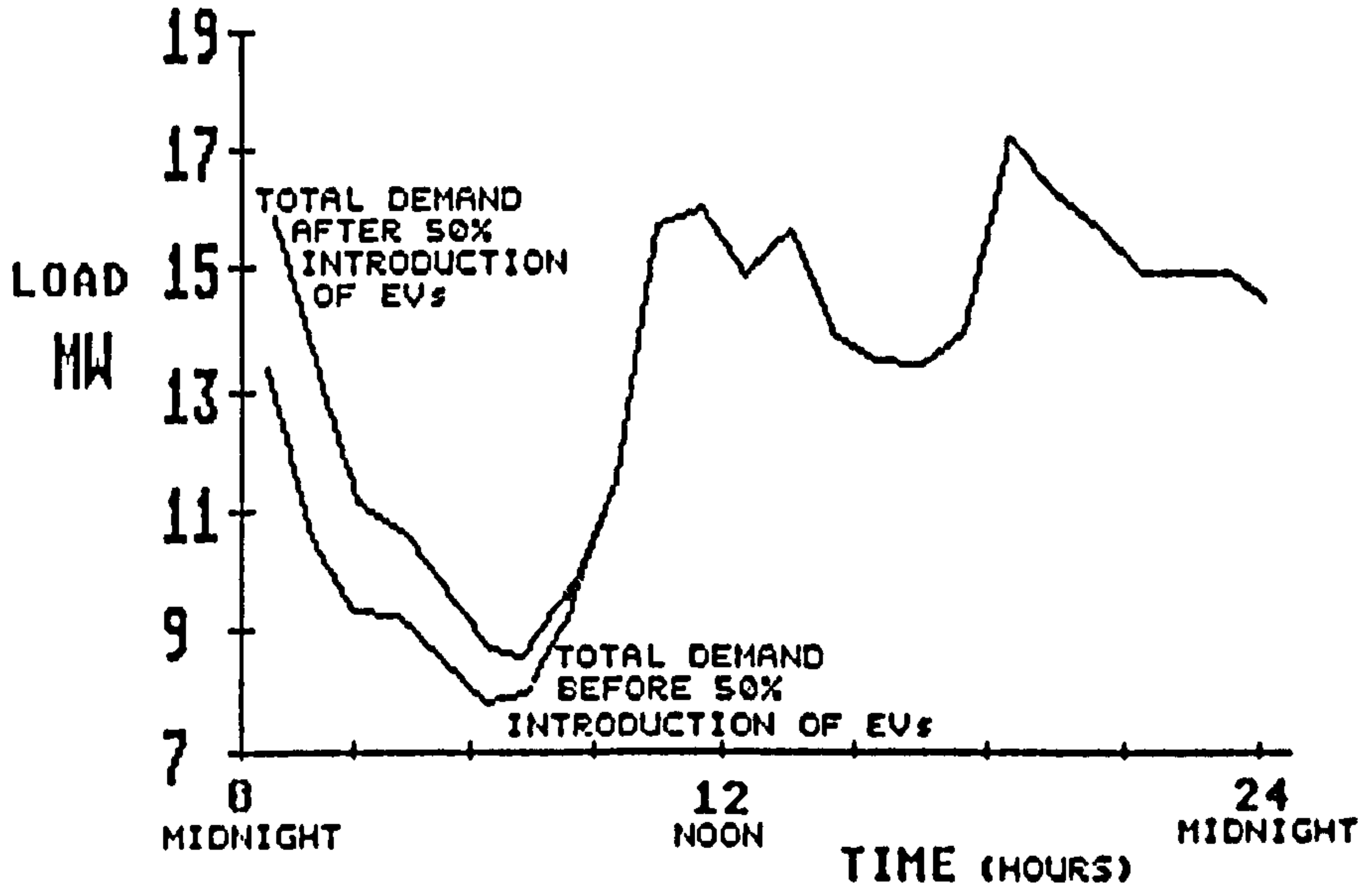
Using a 'charge-anywhere' policy or a 'charge-anytime-at-home' policy as shown in fig 7.4 the extra demand will affect the overall island demand as shown in fig 7.7.

FIG 7.7 Load profile assuming charging anywhere anytime and 50% electric vehicle adoption



The magnitude of the power required for vehicle charging is small in comparison to existing demand. Even if 50% of vehicles on the islands were electric, the peak recharging power required following a charge anywhere anytime policy would only just exceed 1 MW and the average recharging power would be in the region of 0.5 MW. Smaller EV populations will obviously make smaller demands which are almost negligible in comparison with existing demand. Unfortunately, the peaks in the recharging demands, whether charging is allowed anywhere or only at home, correspond closely with the peaks in other demands and hence recharging increases the overall peak demands on the generating system in direct proportion to the size of the EV population. In addition, the periods of lowest recharging requirements correspond to the troughs in the recharge demands. Recharging is aggravating the fluctuations in load instead of load levelling. This may not be a problem for the generating capacity at present, but once the cable is in operation this additional peak time demand will require the old generating plant to be operated on more numerous occasions. The cost of operating this plant is much higher than the cost of grid electricity, and it will be even more expensive once it is operating on standby and simply generating small amounts of electricity. The extra demands, arising from recharging needs, has to be seen as marginal demand, requiring the use of old expensive plant from time to time. This would not be to the NSHEB's advantage as this electricity has to be subsidised. If however the extra demand, however small, could be scheduled for periods of low demand, the presence of EVs could actually lower generation costs by helping to level the daily load. The NSHEB is already committed to encouraging as many consumers as possible to install white meter facilities and use off-peak electricity. There is no cost to the consumer for the installation of the necessary metering equipment but a small increase (4.8%) in the price of day time electricity is charged. The effect of confining all charging to off-peak times is shown in fig 7.8.

FIG 7.8 Load profile assuming white meter charging only and 50% electric vehicle adoption



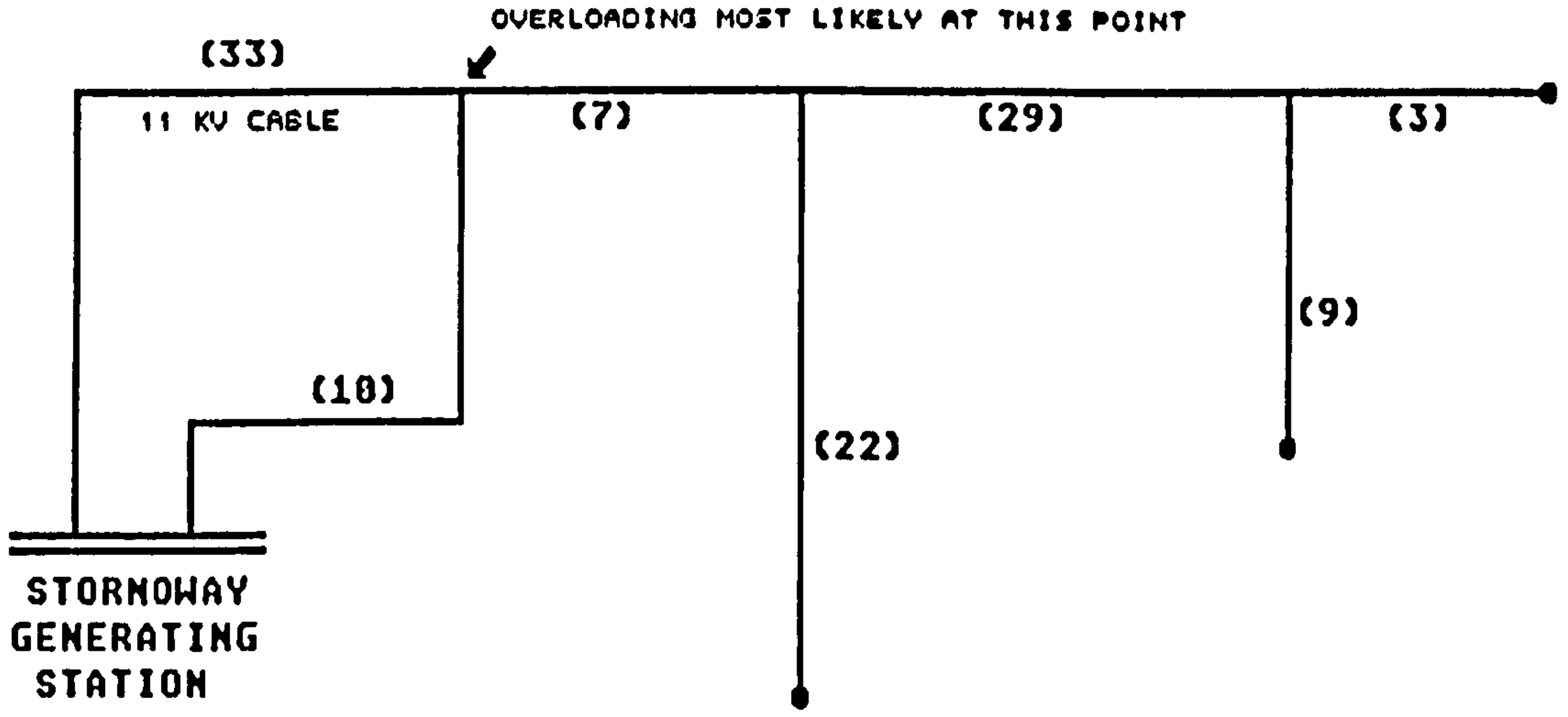
There is an initially high power demand as motorists commence charging but this diminishes as charging continues and charging currents drop. Motorists are unlikely to confine all charging to these times but the price difference should help to alleviate peak time problems. Section 9.3 examines the relative costs to the motorist of utilising differentially priced electricity.

8. THE ELECTRICITY DISTRIBUTION NETWORK

The islands are served by a 33 KV network which splits up into an 11 KV network. From this individual transformers serve small groups of consumers. It was seen as unnecessary in the context of this research to examine every part of the distribution network on the island in detail. Instead one particular area was selected for scrutiny - the Point Peninsula east of Stornoway. This area of the island contains 13.6% of the total population and is one of the most densely populated areas.

According to the NSHEB, this is probably the most heavily used section of the distribution network apart from Stornoway itself, and it is certainly the section with least spare capacity. It is served by two 11 KV lines coming from the generating station in Stornoway as shown in fig 7.9.

FIG 7.9 ELECTRICITY DISTRIBUTION NETWORK ON THE POINT PENINSULA



NB - THE NUMBERS IN BRACKETS SHOW THE NUMBER OF TRANSFORMERS ON EACH SECTION OF LINE
TOTAL NUMBER OF TRANSFORMERS = 113

At present 16 transformers (14%) are overloaded during peak periods. The 11 KV cable is 0.017 square inches cross section. It is made of Cadmium Copper and is capable of carrying 150 Amps. The section of the network where overloading is most likely is indicated in fig 7.9. This is the point where current will be at its greatest. At this point the cable is capable of a load of :

$$\begin{aligned} \text{LOAD} &= \text{VOLTAGE} \times \text{CURRENT} \\ &= 11 \times 150 \\ &= 1.65 \text{ MW} \end{aligned}$$

The maximum night-time load on this cable has been found to be 0.75 MW and the maximum daytime load is around 1 MW. the greatest demand recorded was 1.1 MW. Seven percent of the island population depend on this stretch of cable and if we assume that 50% of vehicles are electric and that there is no incentive to charge during the day, this would lead to a maximum increase in demand of 0.1 MW. Even if all vehicles were electric and all charging took place at the same time and all batteries were totally discharged at commencement of charge, the extra demand would still be less that 0.8 MW, so the cable would only be in danger of being overloaded at peak demand times. This is a hypothetical situation and using the simulation results it can be seen that even if all vehicles charged during the same 8 hour period, maximum demand would be in the region of 0.14 MW. This represents no threat to the sufficiency of the distribution network.

C. TRANSFORMERS

Although the submarine cable and the overhead distribution network would appear to be capable of the extra load, it is the individual transformers which could present a bottleneck. On the Point peninsula the average transformer size is 29.6 Kw and after deducting non domestic consumers (e.g lighthouse, factories, airport etc.) each transformer supplies an average of 28 head of population. For this analysis average population statistics are assumed. Average maximum daytime demand per transformer (i.e the average of the maximum daily loads recorded) is 18.4 Kw but 14% of transformers are overloaded at peak hours. The likely charging demands per transformer can be calculated from the simulation model,

1 Average Max. charging demand (charging anytime, 50% EV adoption) = 2.2 Kw
2 Average Max. charging demand (all charging to be done in the same 8 hour period, 50% EV adoption) = 3.1 Kw
3 Max. possible demand (all batteries flat and charged at the same time) = 6.8 Kw

Because the figures are based on a very small number of EVs (between 2 and 3 per transformer) the variation in demand is likely to be very much greater than for the whole island. A particular transformer might have to supply more than its fair share of vehicles and the case of several vehicles all commencing charge within a short space of each other is not an unrealistic scenario. It is extremely difficult to estimate the likely extent of overloading and the resultant costs on an average basis, due to the non-normal pattern of transformer size and utilisation. But the increase in load would undoubtedly cause more overloading on already overloaded transformers, unless all charging could be confined to night-time hours. Even in this case some transformers would still suffer. On average, the needs of EVs would not cause a problem except possibly at peak times but the distribution of the extra load between transformers will not be even. Ultimately the presence of an EV population will necessitate replacement of many transformers. The present replacement policy of the NSHEB is to replace either (a) when the transformer fails or (b) when there are numerous complaints concerning reduced voltage. Continued encouragement by the board to use white meter electricity is helping to alleviate the problem.

The average life of transformers is 20 to 25 years, depending on demand growth and location. If EVs were to be adopted in the islands it is unlikely that this would happen suddenly. The average car age is 5.1 years and 9.9% of cars are less than 1 year old. If we assume that cars are replaced at a steady rate, then a complete changeover to EVs would take place over a period in excess of 10 years. During this period the NSHEB would expect to have replaced 50% of their transformers anyway. The overloaded ones would probably be among the first to be replaced as these tend to be the smallest and oldest ones. The resultant replacement cost to the NSHEB due to EV introduction would be much smaller than at first anticipated. The Board in Stornoway say that transformers would be replaced on an individual basis, looking at each case separately, and that a more radical replacement policy would neither be merited nor effective, especially at expected rates of EV adoption.

D. HOUSEHOLDS

The pattern and level of electricity demands in individual households varies according to location. In Stornoway and the surroundings where about 20% of the population lives, the average peak electricity demand lies between 6 and 8 Kw per household. Outside of the town however, in the crofting communities, average peak demand is only about 1.5 to 2 Kw. These rural households depend heavily on peat and solid fuels for space and water heating and in many cases for cooking as well. A household running an electric car would add a maximum of about 4 Kw to their demands during periods of charging. This in itself presents no problem but some households may want to charge at greater rates than is possible using a standard 13 Amp outlet. A TRRL report [8] presented the likely costs associated with installing higher rate supplies for refuelling points. All costs are in £1980s and are resource costs. A 7% rate of return on capital is used when calculating annualised installation costs.

OUTLET	CAPITAL COST (£)	LIFE (YEARS)	ANNUALISED COST (£)
In Garage			
13 Amps	10	21	0.86
26 Amps	50	21	4.30
52 Amps	400	21	34.40
Outside			
13 Amps	60	21	5.16
26 Amps	100	21	8.60
52 Amps	450	21	38.70

For reasonably sized supplies the costs are small and it is doubtful if anyone would want a 52 Amp outlet as charging at this rate would damage the battery pack of a medium sized electric vehicle.

7.4.5 SUMMARY AND CONCLUSIONS

Estimating charging requirements for electricity is a complex calculation if it is to be done as realistically as possible. Simulation can allow the inclusion of all journeys and opportunity charges in the calculation. It was found that the results varied with different charging regimes and with the availability of recharging points. EV load demands are very small in comparison to other island demands, at any credible level of EV introduction. When the extra demand was added to existing island demand it was clear that the present existing capacity could easily supply all the necessary power. Once the cable is installed however it will not be sufficient for peak time demands, and the presence of EVs would aggravate this problem at peak times. Also, the cost of the marginal electricity would be expensive to generate. The existing overhead distribution network is more than adequate but the individual transformers may present a problem. Present overloading may be increased by battery charging but transformers are continually being replaced and updated and the NSHEB do not see this as a problem. Motorists who either do not have a suitable outside charging point, or who would like an outlet with a higher rating, should be able to have one installed at a reasonable cost. The daily charging load pattern could be manipulated to some extent by the NSHEB using time of day tariffs. This could alleviate or solve the problems mentioned above. The Board are already pushing the installation of white meter equipment to achieve a certain amount of load levelling and nearly all of the required EV recharging could be done at off-peak times without any detrimental effects.

The problems highlighted in this section do not appear to be unsurmountable and should not cause any barrier to the successful introduction of electric vehicles on the islands.

CHAPTER 8

SAFETY ASPECTS OF ELECTRIC ROAD VEHICLES

CHAPTER 8

SAFETY ASPECTS OF ELECTRIC ROAD VEHICLES

8.1 INTRODUCTION

The prospect of substantial numbers of high performance electric road vehicles being introduced as substitutes for conventional ICE vehicles raises issues in addition to the obvious ones concerning performance, reliability and cost. While these are of prime importance to potential operators, other considerations are essential to ensure the acceptance and confidence of motorists. One such consideration is the issue of safety. 9.1% of island motorists stated that safety was their prime consideration when purchasing a new vehicle and 31.7% stated that it was an important factor to them. This section examines how the safety of electric road vehicles is perceived by potential operators and what are the relevant safety issues. There are also design and legislation implications to be considered. Information on EV safety and perceived safety has been collected from the operating experience of EV users, designers and manufacturers and from the Delphi analysis described earlier.

8.2 THE PERCEIVED SAFETY OF ELECTRIC ROAD VEHICLES

It is not only important that EVs should be safe to operate but it is essential that they are perceived by the general public as being at least as safe as their present vehicles and that they offer a safe means of transportation. Furthermore, if the EV is already perceived as being safe then it is incumbent on developers and manufacturers to ensure that these perceptions are accurate and that their product lives up to realistic expectations. There are very few high performance EVs in circulation as yet so the public is fairly unfamiliar with them. Opinions on safety will still have to be formulated and the public should be given as much information as possible to enable informed opinions to emerge. Participants in the Delphi analysis were asked the following questions,

> "Do you think that the perceived safety of electric vehicles will affect consumer acceptance and confidence in EVs and/or affect willingness to buy? In what way? What do you think will be the source of these concerns? (i.e batteries, charging facilities, vehicle design and stability, electronics etc?)"

All those who responded suggested that EVs are already perceived as a very safe form of transport and that there are very few perceived safety problems. This is possibly due to their low performance in terms of speed and acceleration. These characteristics in themselves do not necessarily make a vehicle safer than a faster equivalent but they do impose some restrictions on various forms of driver abuse. This is reflected in some cases by reduced insurance premiums (see section 9.2.9). One of the most widely expressed safety worries concerns the presence of hazardous liquids in the batteries. The large quantity of sulphuric acid in lead-acid batteries has led many people to question the overall vehicle safety especially in accident situations. Although there are real dangers associated with the battery system, which will be discussed below, many of the perceived dangers result from either lack of knowledge or biassed perceptions. Many seem to ignore the fact that ICE vehicles carry large volumes of extremely flammable fuel on board which can easily be ignited in an accident.

Manufacturers and developers should strive to ensure that vehicles are designed for maximum safety before they reach the market place. The perceived safety of EVs would be adversely affected, diminishing customer acceptance, if there were any bad accidents which were widely publicised.

A few fires or explosions will not encourage confidence but it does depend to a certain extent on when such incidents happen. The R101 Zeppelin explosion put an end to UK passenger airships for a long time but an air crash does not seem to dent the air travel image today. It would seem that the public can accept risks if the advantages are proved to be great enough. The EV must be seen to offer advantages to the operator that offset any potential safety costs. To build up this acceptance and loyalty will take time and operational proof in the early stages of commercialisation. Much will depend on the incorporation of visible safety features, especially in relation to aspects of the EV which are new or different from the conventional ICE. The charging and maintenance of batteries might be a case in point. The North West Electricity Board which operates a large fleet of electric vans suggests that perceived safety is unlikely to be a significant factor with fleet users but that there might be more reluctance amongst private users. Experience would seem to substantiate this belief as several of the islanders expressed interest and concern over EV safety whereas HILL Electric, a manufacturer of commercial electric vehicles states that they have had a positive reaction from every fleet client to whom their design has been exposed.

The relevant safety issues are not necessarily the same as those that are perceived, and realistic information needs to be provided on potentially hazardous areas of operation and the appropriate safety precautions. The following is a list of such areas.

8.3 RELEVANT SAFETY ISSUES

8.3.1 BATTERIES AND THEIR CONTENTS

The main component in an EV which is different from the ICE or mains electric vehicle is the battery. Any energy storage system is potentially hazardous if the energy is released quickly. In the case of the battery this can be electrical energy from a short circuit or heat from a chemical reaction. There is also the possibility of noxious chemicals being released.

Whether lead-acid batteries or advanced batteries such as the sodium-sulphur battery are used, there are significant volumes of hazardous substances contained in the battery pack. These could cause severe burning in contact with skin and in the case of the high temperature sodium-sulphur system, the consequences of a battery rupture could be extremely serious. Sodium will explode on contact with a wet road surface, and molten sulphur is also a very dangerous substance. In addition the sulphur dioxide fumes generated by the system pose a potential hazard. The vehicle and battery pack should be designed to minimise the risk of chemicals escaping whatever the circumstances. Operating experience however indicates that battery packs are very robust and can withstand considerable stresses. Chloride Silent Power Ltd., one of the main developers of the sodium-sulphur battery claim that they have largely overcome the design problems associated with sodium-sulphur battery safety. By positioning the battery pack low down in the vehicle or outside the basic shell, e.g under the floor, the risk of human contact with dangerous chemicals is reduced. Another resulting benefit is to lower the centre of gravity of the vehicle, thus making it more stable and less likely to overturn. Overturning would represent one of the potentially most serious accidents with regard to a ruptured battery system. One electric Sherpa van which did overturn righted itself due to the added weight low down and was driven away from the scene of the accident! It should be relatively simple to protect the battery cells from damage in all but the most severe accidents, and present designs would appear to do this. Petrol and diesel fuels are also very dangerous substances and this tends to be forgotten in the debate. Electric vehicle experts taking part in the Delphi questionnaire considered fossil fuels to be more dangerous forms of fuel. Refuelling with petrol is also a dangerous operation which is taken for granted, and this has to be weighed against the dangers of battery charging. Lead-acid battery charging is hazardous because it results in the evolution of hydrogen gas during and after charging. Overcharging the battery in a confined space is dangerous because of the possible build-up of hydrogen creating a fire risk. Hydrogen can form an explosive mixture with oxygen or air over a wide range of concentrations, and where quantities of batteries are grouped together special precautions must be taken. Hydrogen will ignite with a fuel/air ratio as low as 4%, and in battery charging areas it is recommended that the hydrogen content of the local atmosphere should not exceed 2%. The gas produced is difficult to ignite by the application of heat but is easily ignited by the smallest spark. Various design and safety precautions can be utilised to minimise the risk of explosion. Firstly, it would be foolish to position contactors, electric motors or any other spark-producing equipment too close to the battery compartment. Secondly, the evolution of gas obviously puts a premium on using chargers that are correctly matched to the batteries that they have to charge. Chargers should have automatic cut-outs to prevent overcharging, and charging regimes should be employed which charge at optimal rates so as to control the gassing stage of the charge. Thirdly, battery compartments must be thoroughly ventilated to prevent the formation of pockets of gas and to dispel gases during charging and discharging. In addition, hydrogen sensors could be used in the control scheme for charging lead-acid batteries. Many of these safety precautions would of course add to costs.

8.3.2 HIGH VOLTAGES

High performance electric vehicle battery packs generate high voltages because in general, motor/controller and lead weight are minimised, efficiency and performance are maximised and cost is lowered as the voltage level is increased. The ETV-1 test vehicle utilises a 108

Volt battery pack while the Bedford and Sherpa vans have a 218 Volt system. On the other hand, battery and safety considerations for both the vehicle occupants and maintenance personnel would suggest the desirability of relatively low voltages. There have been a number of proposed European and American standards on the highest recommended battery and motor voltages. Many manufacturers consider that 72 Volts is the upper safe limit, while some think that 92 Volts should be the limit. Voltage levels below approximately 50 Volts are generally considered safe for human contact and the protective devices required are less stringent at levels below this. However in a DC system using semiconductor motor control, there may be peak voltages in certain parts of the circuitry which are much larger than the nominal battery pack voltage. Hazardous voltages are therefore developed in EVs and protective measures have to be taken, so maintenance personnel will have to be trained accordingly. Components or circuits which may have very high voltages should be identified and clearly marked if they cannot be isolated, and special attention should be given to designing for a sensible layout and adequate insulation. Electrical systems must be adequately sealed to protect against short circuits. These are most likely to occur in a crash in which the battery or traction circuit is damaged. This hazard can be minimised by multiple fusing of the battery cells and traction circuits. Circuit breakers could also be used. It is recommended that all EVs should carry a fire extinguisher for electrical fires, i.e CO2 or CCl4 canisters. Open-hood protection can be installed to render the electrical system totally inactive whenever the bonnet is raised. This involves disconnecting the battery at the energy source terminals. A "panic button" could also be an integral part of the control system so that the operator has the ability to render the electrical drivetrain system inactive for any reason.

8.3.3 SILENT OPERATION

Risks of vehicle/pedestrian collisions could be greater with EVs because of the lower levels of noise emission, although there is no information available on the extent that quieter vehicles would increase this risk. There is no doubt that ICE noise acts as a useful warning of an approaching vehicle, especially when visibility is poor. Some vehicles have been fitted with an audible warning device which is activated when the vehicle is in reverse.

8.3.4 LIKELIHOOD OF COLLISION

There is no conclusive evidence that electric vehicles are more or less likely to be involved in collisions but there are some vehicle characteristics which might affect this risk. Firstly, the typical acceleration and top speed performance of EVs is considerably lower than that of the ICE. The ability to accelerate out of trouble or to overtake safely is reduced. This of course may be offset by a reduction in the number of collisions caused by reckless driving. EVs tend to be significantly heavier than their ICE counterparts because of the battery weight and so there is additional momentum involved. Although it is difficult to make comparisons, typical weight increase for EV "conversions" have been estimated to be from 20-40% when using lead-acid batteries [1]. This added momentum would call for an efficient braking system. One fleet operator of electric Bedford vans, Fleet Advisory Management Services, found that over a four year evaluation scheme there were no major accidents with the EVs, and that there was a very significant decrease in the incidence if minor accidents inherent in inner city usage [2].

8.3.5 CRASHWORTHINESS

Crashworthiness expresses the ability of a vehicle to survive in various degrees following specified types of accidents. Conventional vehicles are tested under stringent simulations of crashes and there are very specific requirements for passenger survival. There is no reason why

EVs should not be expected to meet the same standards. This presents challenges for the engineering and design of EV structures. The vehicle must be as lightweight as possible to enhance performance yet at the same time be effective in crashworthiness and occupant protection. The need to save weight could mean that the vehicle shell would not be as protective as with an ICE vehicle. However, as mentioned above, the EV will tend to be heavier overall than the equivalent ICE and this could be a general advantage in terms of crashworthiness. The heavy mass of the battery, especially when the individual batteries in the battery pack are arranged linearly in an underbody location, is an excellent means of absorbing the kinetic energy of the crash.

8.3.6 ELECTRICAL INTERFERENCE

It has been reported by Lucas Batteries Ltd that the electronic controller, if unscreened, can, under certain circumstances, affect or even inhibit the operation of cardiac pacemakers, with serious consequences. However Lucas have ascertained and implemented ways of keeping this danger to what they believe to be a safe level.

8.4 DESIGN AND LEGISLATION CONSIDERATIONS

From all of the above safety issues it can be seen that there are major challenges facing the designers and manufacturers of EVs. Electrical safety, crashworthiness, fire hazards and chemical safety are all real issues affecting design. In addition, it should be noted that legislation concerning the construction and use of road vehicles is, naturally at present, based on ICE vehicles. This could unwittingly be to the detriment of electric vehicles if measures are not taken to accommodate differences in the two technologies. For example, it is possible that the use of regenerative braking could be accidentally legislated against by regulations on braking, on the grounds that it only operates on one axle or because the extent of the braking is not constant for a given pedal pressure at all speeds. Another example would be the audible warning system case mentioned previously where the inclusion of such systems may cause difficulties over the legislation regarding the sounding of audible warnings on vehicles, especially at night. Separate investigations and considerations are therefore necessary regarding the two technologies before universal regulations are enforced.

8.5 SAFETY OF VEHICLE AND BATTERY DISPOSAL IN THE ISLANDS

8.5.1 INTRODUCTION

Not only should EVs be as safe as possible to operate but the ultimate disposal of the vehicles and their batteries should also be considered in terms of safety. Public acceptance will be affected by concern for safety of disposal although this concern will probably be expressed by society's willingness to accept the technology rather than by the individual operator. Waste disposal is a sensitive and emotive subject and the public becomes concerned when proposals for new waste disposal facilities threaten to destroy the local environment and to disrupt patterns of land use.

This section examines the current and expected situation in the Western Isles with regard to the quantities and nature of the waste generated, the facilities in existence for its disposal, the likely impact of a population of battery powered vehicles and the reaction of the local authority to such a proposition. Although the advent of the battery powered vehicle will create waste disposal problems wherever they are used, this analysis is restricted in its interest to the particular circumstances and problems created in the Western Isles. Once again it is argued that the methodology used and the issues raised will be of value for similar analyses in different situations.

8.5.2 RESPONSIBILITIES OF LOCAL AUTHORITIES

Waste disposal is one of the four most basic public health services provided by local authorities, the others being Public Water Supply, Sewerage and Refuse Collection. An inadequacy in any of these services can seriously impede economic development or disadvantage the inhabitants of an area. Section 2 of the Control of pollution Act 1974 requires the Council as Waste Disposal Authority to ensure that adequate and satisfactory arrangements exist for the disposal of all waste situated or likely to be situated in its area. These mandatory duties require the Council to carry out a survey of present and forecast needs, identify and analyse relevant issues and formulate a waste disposal strategy for its area over the duration of the plan period. The Western Isles Council (Comhairle Nan Eilean) has constructed such a plan for a 15 year period as from 1987, although it has recognised that it may be necessary to review their policies before the end of that period [3].

8.5.3 WASTE DISPOSAL ISSUES GENERATED BY EVs

Before the impact of EVs on the waste disposal authority can be examined or the appropriate policies established, it is necessary to calculate the magnitude of any types of waste that are likely to be generated by EVs. The most obvious wastes relate to the battery system which contain chemical and/or solid metal materials. With lead-acid batteries, there is a large quantity of lead in each battery and it will be increasingly important that this lead should be collected and recycled for future use. Although there is an adequate supply of lead for current consumption levels, it is a relatively scarce world resource and if a large population of electric vehicles were to be supported worldwide, recycling would be essential. It has been calculated [4] that current production levels of lead would have to be increased by 5 to 8 times to support a world population of 27 million vehicles.

The following table shows estimates of the material requirements for typical electric and petrol cars [4].

TABLE 8.1

ESTIMATED MATERIAL REQUIREMENTS FOR TYPICAL ICE & EV

MATERIAL	WEIGHT OF MATERIALS (Tonnes)	
	PETROL	ELECTRIC
Iron & steel	0.78	0.663
Copper	0.015	0.035
Other non-ferrous (principally Al:Zn)	0.036	0.02
Plastics		0.18
Glass	0.09	0.05
Other materials		0.17
TOTAL (body)	0.912 Tonnes	1.10 Tonnes
Battery		
Lead		0.56
(sodium)		(0.10)
(sulphur)		(0.10)

NB - The criterion for comparison used in this study was vehicle payload efficiency.

It can be seen that there are substantial amounts of lead contained in each vehicle battery. If this lead is not collected, it is possible that islanders would dispose of old batteries simply by leaving them lying on the land, as they do at present with much of their waste. This could be a real health hazard for grazing sheep and for the public water supply.

In addition, with lead-acid batteries, there will be on average about 30 litres of sulphuric acid and this will have to be safely disposed of at the end of the useful life of the battery. Considering that the average life of the battery packs on the islands will be about 5 years (calculated by computer simulation - see fig 9.12), each vehicle will be responsible for about 6 litres of waste sulphuric acid per year. If 50% of the island cars were to be electric, this would result in over 12.5 tonnes of sulphuric acid waste per year.

The relative lifetimes of ICE and EV bodies is discussed in section

9.2.4 and it is generally agreed that EVs will last longer than ICEs. This being the case, the problem of disposal of vehicle shells would be reduced on the islands.

8.5.4 QUANTITY AND NATURE OF ISLAND WASTE

The waste disposal survey conducted in 1985/86 by the Council identified some 90,200 tonnes of waste disposed of each year in the Islands. While in national terms the quantities of waste may not be large, it is produced in significant quantities throughout the island chain. The separation of the Western Isles from the mainland and the population scatter present some unusual waste disposal problems. The following table shows the total weight of waste produced for each of the recommended list of categories.

TABLE 8.2

SUMMARY OF WASTE GENERATED (WESTERN ISLES. SURVEY OF 1985/86)

GENERAL CATEGORY OF WASTE		TONNES	%
Household & Commercial		14250	16
Industrial Non Hazardous		2450	3
" Hazardous		100	0.1
Medical, surgical & veterinary		150	0.2
Mine & Quarry	Mine	NIL	
	Quarry	15100	17
Agricultural		2050	2
Construction & Demolition		54000	60
Sewage, Sludge, etc		1750	2
Old cars, Vehicles & Trailers		350	0.4
TOTAL		90200	100

Over 75% of the waste produced is from two major groupings: Construction & Demolition Works and from Mines & Quarries. Most of the former category of waste comes from civil engineering works such as road construction, the remainder coming from the building trade. Most of this is not disposed of at recognised waste disposal sites and although it is chemically inert it can cause difficulty in disposal. The remaining categories of waste are disposed of at landfill sites operated by the

Western Isles Council.

8.5.5 HAZARDOUS WASTE

As can be expected from an isolated rural area with little industry, the volume of hazardous waste generated is fairly insignificant, being almost entirely generated from within the islands. Over the last 5 years totals of hazardous wastes as defined by the Control of Pollution (special waste) Regulations 1980 have amounted to less than 100 tonnes per annum on average. They consist mainly of asbestos contaminated insulating materials from public buildings etc and these have been co-disposed with household wastes at the Council's main landfill site by burial in identified areas. Other materials do arise from time to time from school science departments and these have been transported to the mainland because they were considered too hazardous to dilute and tip at landfill sites. The local depot of BP has a periodic requirement for disposal of tank residues and interceptor wastes which are also transported by a specialist waste disposal contractor, usually to Glasgow. The total volume of both is usually less than 1 tonne per annum and it has been uneconomical to provide facilities for these small amounts on the islands. Limited quantities of oils have been accepted for landfill where it can be absorbed by other tipped wastes.

8.5.6 OLD CARS, VEHICLES AND TRAILERS

Scrap metal has always presented a significant problem in the islands. The scrap metal trade in this area is very sensitive to fluctuations in the world price of scrap metal, because it is only when prices are very high that the costs of transportation by sea and the transportation of specialist machinery to the island for periodic visits by merchants make the collection worthwhile. Cars and other vehicles brought in from the mainland seldom leave again and usually end their life as spare parts. Once all the useful parts have been stripped off, the shell is either presented for disposal, or more often is left to rust on crofts or common grazing land, or sometimes they are used as stores. The islands are covered with unofficial dumps of cars and until recently there was no local scrap merchant. The Council has offered a free uplift and disposal service from time to time over the last 10 years, aimed at keeping down the accumulation of old cars, especially in very open landscape. Since 1984 however, Council spending demands in other areas has led to a termination of this service, but in 1985 world prices of scrap led a privately sponsored scrap collection service to clear much of the backlog of vehicles not already disposed of by landfill. This continued in 1986. An estimated 350 to 400 tonnes of scrap from old cars etc is still taken to landfill sites, and this is estimated to be between 30% and 50% of the total scrap from this source on the islands. The extension in vehicle life expected from EVs should reduce this problem in proportion to the increase in life experienced in practice.

The Western Isles Council is joining together with Orkney and Shetland Councils in recommending new legislation regarding disposal of old vehicles. The new system would involve a £100 charge being made on all vehicle sales, and this would be refundable when and if the vehicle is ultimately disposed of to a recognised scrap merchant or suitable landfill site.

8.5.7 LIKELY FUTURE WASTE CONDITIONS

Population changes have the greatest effect on production of household and commercial wastes and the Council foresees no change in population characteristics. It anticipates an 8% increase per annum in waste over the next few years but an ultimate levelling off by the end of the planned 15 year period. The gradual increase in industrial development is expected to give rise to an 8% increase in total by the end of the period. The category of most interest when considering the impact of EVs is that of hazardous waste and since the total amount produced by the

Western Isles is small and widely distributed, the capacity of the current sites to absorb hazardous waste will always be small according to the Council. Given this small capacity, any large amounts of waste would have to be disposed of on the mainland at the producer's expense. The quantity of such waste is unlikely to be significant on a national scale.

8.5.8 METHOD OF DISPOSAL

The relatively small quantities of waste produced in the many island locations means that centralising disposal and the use of capital intensive disposal techniques such as incineration are uneconomic and impractical. Recycling of waste has not been economic in the past because of the cost of collecting re-useable materials from remote locations and the cost of transporting the waste in bulk to the mainland. This problem is typified by the number of old vehicles abandoned in remote locations, which creates an eyesore. In fact, over two thirds of island waste is not disposed of at Council sites at all (see below).

TABLE 8.3

METHOD OF WASTE DISPOSAL

METHOD OF DISPOSAL		TONNAGE/YEAR
Landfill sites operated by Council		24600
Private or on-site landfill		
Quarry (on-site)	15100	
Construction & Demolition	46500	
Other	1500	
TOTAL PRIVATE		63100
Incineration at source (clinical)		150
Sea (sludges)		1750
Reclamation (steel)		600
	TOTAL	90200

Almost half of all the waste dumped at Council landfill sites is delivered privately at present so it is understandable that many unauthorised dumps, containing vehicle remains and discarded agricultural and bulky household waste, continually spring up in the rural parts of the island. If this were to continue to be the case once a large population of EVs was introduced, there might be instances of discarded batteries lying unattended on common grazing land.

8.5.9 POLICIES FOR WASTE DISPOSAL

The Council has established policies for waste disposal which allow for the particular problems facing the islands. The islands do not lend themselves to centralised disposal and none of the methods of pre-treating waste before disposal are attractive because of their high capital costs and the small amount of wastes to be disposed of in any of the island locations. Furthermore the natural geography of the area lends itself to landfill disposal, provided adequate precautions are taken to prevent water pollution and windblown litter. The intention is to continue with a policy of landfill disposal as the principal method. The creation of numerous Civic Amenity sites is aimed at reducing the problem of vehicle shells being abandoned throughout the island. These sites will be located in each strategic settlement area. In addition the Council intends to tighten up on site management. At present none of the private disposal sites are licensed and none of the Council's own tips have resolutions as required under the Control of Pollution Act 1974. In particular the Council sites will be operated so as to prevent

a) pollution of water;
b) a danger to public health;
c) serious detriment to the amenity of the area.

The Council will seek to ensure that private tips are also operated in a similar manner to its own sites, and once this has been achieved continuous monitoring will be necessary to prevent relaxation of standards. Charges will be made to transfer the cost of commercial and industrial waste disposal to the producer and away from the rate-payer (community charge payer). This may encourage unauthorised or 'fly' tipping and may also have a bearing on the disposal of wastes associated with electric vehicles.

8.5.10 COUNCIL RESPONSE TO THE ADVENT OF ELECTRIC VEHICLES

The scenario of a population of electric cars being used on the islands was presented to the Council and this section reports on the response.

Firstly, the scattered and rural nature of the communities would probably make the problem less severe than in densely populated or urban areas. Probable total amounts of sulphuric acid were considered small enough to cope with under present conditions, without need to transport to the mainland. It is anticipated that small amounts of acid would be disposed of privately throughout the island and with likely EV populations this was seen as no problem. Similarly, the nature of the chemical was not considered hazardous enough to cause undue concern. Hazardous waste is defined by its potential to harm people and does not include wastes capable of damaging the environment. Provided that the policies for safe tipping mentioned above are not violated, dumping of any acid by the Council would be by landfill. After dilution and further absorption by other wastes it was considered highly unlikely that water supplies would be detrimentally affected by the amounts of acid mentioned in section 8.5.3. The large landfill site at Stornoway would be capable of absorbing these amounts. The problem associated with discarded vehicle shells should if anything be alleviated slightly due to the increased operating life expected from EVs.

The only scenario that the Council considered worthy of consideration was the case where acid was collected centrally by garages or scrap dealers. At present there are no scrap dealers on the islands but the presence of recycleable lead in significant volumes might stimulate this. If the acid was collected centrally there would be accumulations of waste acid which would have to be disposed of in relatively large quantities. Pre-treatment would possibly be necessary before centralised dumping but there might be a resulting problem in preventing unauthorised tipping because pre-treatment or neutralisation by the addition of alkali would have to be paid for by the dealer. Ultimately this cost would be passed on to the individual motorists.

8.6 SUMMARY AND CONCLUSIONS

Safety of EV operation will be of great importance to potential operators and their perception of this safety could affect their willingness to purchase and use them. Because there are few high performance EVs in use, the public is relatively unfamiliar with them and opinions on vehicle safety are still at a formative stage. Designers and manufacturers must ensure that there is adequate information to enable informed opinions to emerge. Furthermore, because the EV is already perceived by many as being safe, it is important that every effort should be made by developers to ensure that the product lives up to realistic expectations. There are several aspects of EV technology, such as traction batteries and their contents and the presence of high voltages, which may require special attention in order to ensure acceptable operating safety.

There do not appear to be any insurmountable problems concerning the safety of disposal of EVs and their lead-acid batteries in the island situation. The advent of high temperature, high performance advanced batteries may necessitate special action for disposal but the mechanism for disposal already exists even although it would be more expensive and the burden of this cost would undoubtedly fall on the consumer. The time horizon of the current waste disposal plan is 15 years and it is unlikely that advanced batteries will be the predominant energy source for EVs within this period. The process of research, development, testing and successful commercialisation will probably be slow unless there is a more pressing stimulus or need for such batteries.

CHAPTER 9

THE DESIRABILITY AND ACCEPTABILITY OF EVs FOR THE ISLANDS

CHAPTER 9

THE DESIRABILITY AND ACCEPTABILITY OF EVs FOR THE ISLANDS

"No man ever knowingly chooses the worse of two alternatives."
Pythagoras

9.1 INTRODUCTION

Ultimately, a new technology will not be adopted unless it offers some advantages over the technology it is replacing. The advantage could be in terms of performance, utility or safety but one of the strongest incentives to adopt a new technology is the economic case surrounding it. In the case of the EV there are certain operating disadvantages as compared to the ICE but the desirability in terms of the ownership costs may adequately compensate for these. An economic analysis is therefore central to an assessment of vehicle desirability. In addition, the 'acceptability' of the technology and its various attributes as expressed by motorists' attitudes and preferences is examined in section 9.4 in order to describe the market potential for EVs in the islands.

9.2 ECONOMIC ANALYSIS

9.2.1 INTRODUCTION AND OBJECTIVES OF ECONOMIC ANALYSIS

Ultimately the commercial success of electric road vehicles will depend upon their economic advantages for their owner-operators. The House of Lords Select Committee report on EVs recommended that,

> "The Government's objective should be to allow the EV to prove whether it can compete with the ICE vehicle on equal terms before oil supplies actually run down." (see appendix 9)

Previous chapters have examined other important requirements of a personal mode of transport, such as performance, safety and reliability, but these can only be put into context and judged meaningfully when they are seen in the light of the costs involved. Thirty-seven percent of islanders questioned stated that economy was the primary consideration when purchasing a vehicle and only 22% of respondents did not quote it as a major consideration. It is evident therefore that the EV will have to offer some economic advantages to the operator before motorists are likely to be persuaded to substitute it for the conventional ICE vehicle. Indeed this economic advantage must be great enough to compensate for the disadvantage that the high performance EV will never be able to meet the all-round performance of its ICE counterpart. For the individual, the EV should be seen mainly as a replacement technology for the ICE and not as an addition to it. It is unlikely that many motorists would purchase an EV in addition to an existing ICE vehicle because of the large additional capital expenditure.

The cheaper running costs associated with the EV would be very unlikely to repay its entire capital cost. The EV would only be replacing a proportion of the variable costs of the ICE. However, when an EV replaces an ICE, the savings in running costs only need to repay the initial cost differential between the EV and the ICE before the operator makes an overall saving. The economic case for the EV is best made when the EV replaces the total costs, both fixed and variable, of the existing ICE vehicle. The economic analysis carried out in this chapter is based upon this premise.

For the EV to gain wider public acceptance and confidence it is important that it should offer considerable cost savings to operators. Although there may be a small number of "innovators" who are prepared to accept this new technology at an early stage because of their faith in it, the majority of potential consumers in the general public will need more persuasion. A demonstrable advantage is therefore important if any significant commercialisation is to take place over and above the stage where 'innovators' adopt the technology.

In the context of this economic analysis it was decided to analyse the data in the same manner as in the other simulation models, i.e each island motorist will be assessed separately on the basis of his own individual operating characteristics rather than using generalised or averaged figures (see section 5.2.4 for rationale). There were two main aims for this analysis,

1 To provide information relevant to the overall market potential for EVs on the islands, by determining what proportion of motorists could reasonably be expected to make savings by operating an EV in place of an ICE.

2 At both macro and micro levels to identify those factors which have an effect on the strength of the economic arguments in favour of EVs. Also, to assess the relative importance of uncertainties and variabilities in the numerous economic variables. These variables can be separated into those which represent uncertainties in the future state of the technology and its associated costs, and those which represent differences in the manner in which the technology is applied. The former are uncontrollable by the operator while the latter are largely a matter of how the vehicle is managed by its owner. Because the type of vehicle with which we are dealing is not yet a widely available or commercially developed technology there are many costs which are not yet easy to determine accurately. There are so many uncertainties attached to such things as the capital costs, the maintenance and running costs, the lifetimes and performance of the vehicles that an extensive sensitivity analysis is necessary as the means of examining their relative effects. There are two types of uncertainty: firstly, the uncertainty surrounding the magnitude of

various costs in the short term after the vehicles become available and secondly, the longer term magnitude of these costs as the technology matures and the effects of scale come into play. On the other hand, the effect of such variables as the charging regime practised by the operator require a different analytical approach. The implications of the effects of this latter type of variable are important when it comes to drawing conclusions on optimal operator management strategies.

9.2.2 THE ECONOMIC ANALYSIS MODEL

The calculations are based on a discounted cash flow model where the annual costs associated with running both an ICE vehicle and an EV is calculated for each island driver interviewed. The differences in cash flows in each of the time periods can be treated as an 'incremental project' and it is the Net Present Value of this project in which we are interested. A problem exists however in that this incremental project is not a 'pure' and 'simple' project, i.e there is more than one net outflow of cash during the life of the project. This makes an Internal Rate of Return (IRR) calculation difficult as there will be several IRRs associated with the project. Also, because ICEs and EVs are likely to have different operating lives, a direct comparison is difficult. One way of getting round this problem is to consider a series of projects of both ICE and EVs such that the overall life of each chosen pathway has the same duration. This is done by finding the lowest common multiple of the vehicle lives. For example, if we assume that an ICE has a 6 year life and an EV an 8 year life then if we consider a 24 year period we would use either 4 EVs or 6 ICEs. It is then possible to consider the incremental cash flows realistically as we are back at the starting point and have completed a cycle of investments. In the model, the technique used to evaluate the incremental project is slightly different in practice but yields exactly the same answer. We use what is called a 'capital recovery factor' (CRF) which effectively spreads a capital outlay over the period of its life and also adjusts for the time value of money. In effect we are calculating the annuity which has the same terminal value as the outlay. It is the constant annual cost having the same NPV as the actual payments comprising that item (see ref [1] for a fuller discussion). This saves using the lowest common multiple of investment lives while being the same calculation in effect. We arrive at an ANNUAL EQUIVALENT COST of the investment. The formula for the capital recovery factor is,

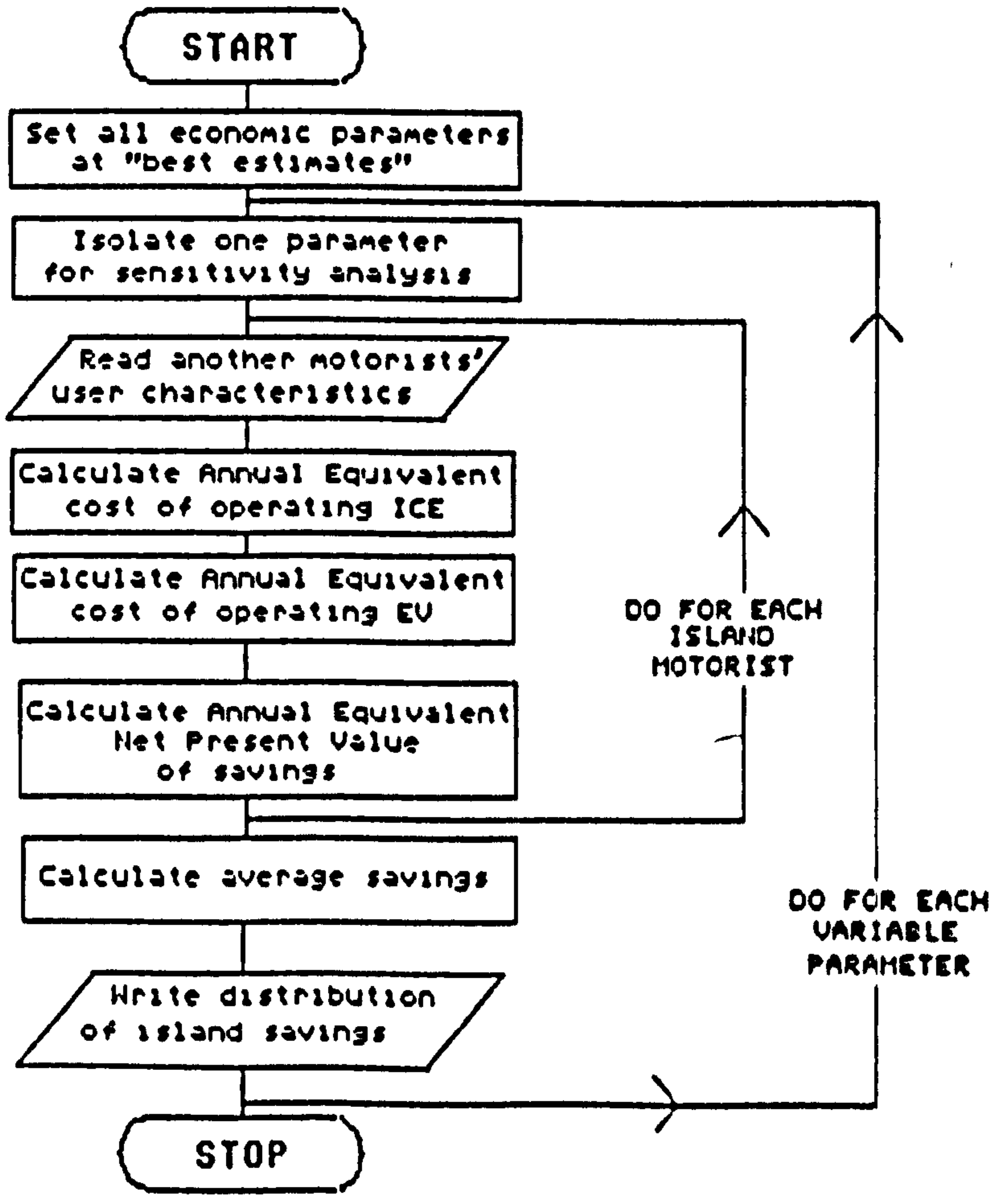
$$\frac{i \times (1+i)^n}{(1+i)^n - 1} \times \text{Capital outlay} \qquad \text{where } i = \text{discount rate}$$

$$n = \text{investment life}$$

There is an implicit assumption underlying these methods, which is that each vehicle will always be replaced by an identical vehicle (with identical costs) at the end of its life, i.e there is 'constant chain replacement'. This has an important implication, namely, if there are any significant developments in the technology or its associated costs expected during the life of a vehicle, the owner will miss out on these until he comes to replacement. He may well be better off therefore buying the vehicle with the shorter life to begin with (i.e the ICE), even though its annual equivalent total cost is greater, in order to capitalise on the cost savings of the new vehicle sooner. In reality however, a buoyant second hand market would help to iron out these problems. To incorporate pure speculation into the model would not only mean that the annual equivalent cost method would be rendered inoperable but it would also make the analysis very complex and the results confusing.

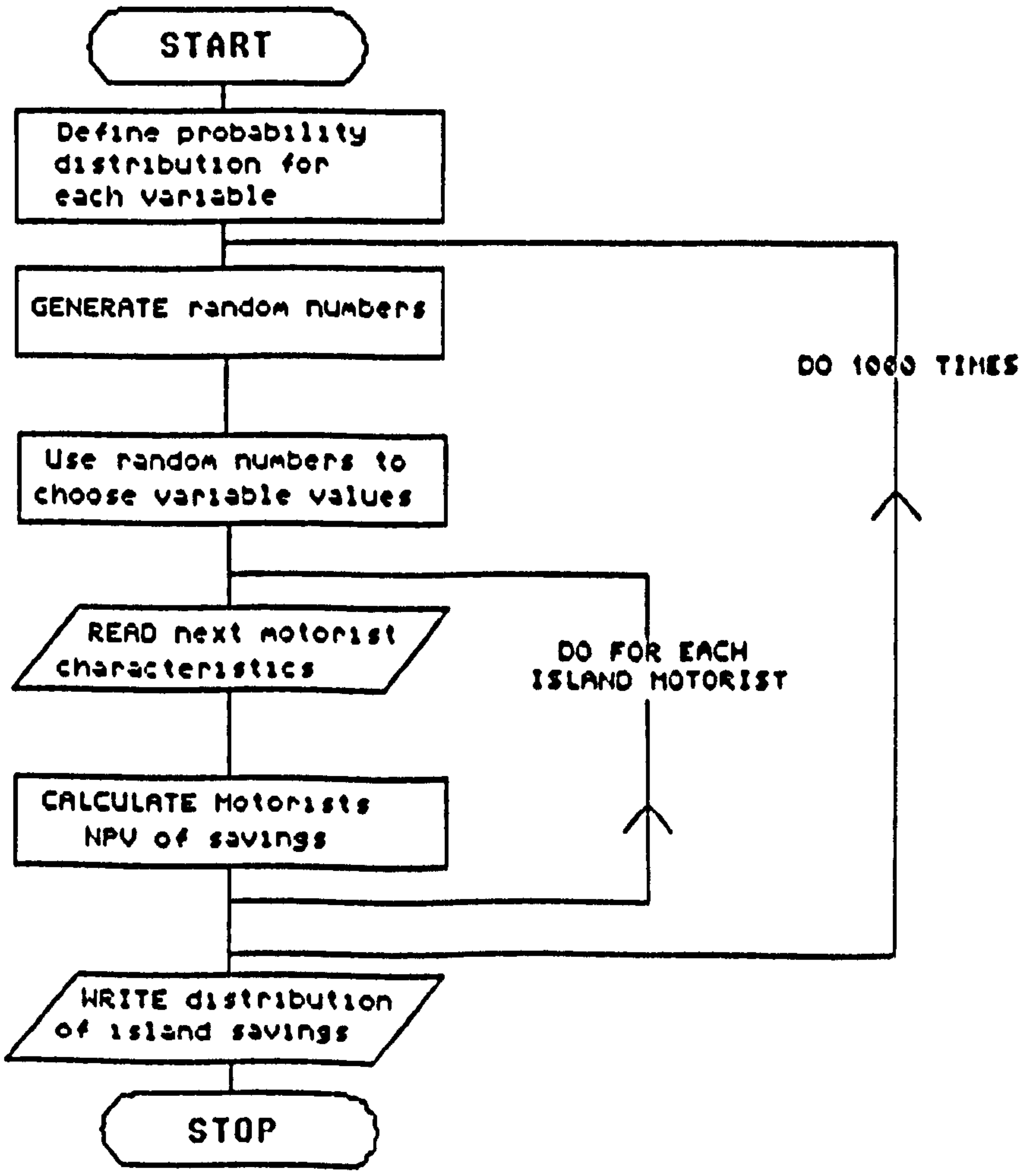
The model was designed to allow a sensitivity analysis to be carried out for each of the uncertain economic variables. Values for these variables were established by referring to expert opinions via a Delphi analysis (results in appendix 5), and also by referring to the relevant literature and operating experience. A 'best estimate' for each variable was chosen as the base case and the variables were varied one at a time while holding the rest constant at the best estimate. This enables the relative effect and importance of each variable on the potential cost savings to be isolated and examined individually. The flow chart in fig 9.1 shows how the model operates.

FIG 9.1 FLOW CHART OF ECONOMIC ANALYSIS SIMULATION PROGRAMME



While this approach yielded valuable insights into the sensitivity of savings on each uncertain parameter, it was felt that in order to get a fuller picture of the likely economic case for EVs in this application, all the variables should be allowed to interact simultaneously. The range of annual savings will therefore be much greater as we may have several pessimistic or optimistic estimates for the values of the variables at the same time. Two methods were used to facilitate this approach. Firstly, a scenario approach was adopted where any set of inputs could be selected manually. The model was run using ALL the most pessimistic and then ALL the most optimistic estimates for the various parameters. This of course lays the boundaries of the likely outcomes. Secondly, a Monte Carlo simulation model was developed to vary the value of the economic inputs at random. This required assigning probability distributions to each of the uncertain variables. While this is of necessity a subjective operation, it was considered worthwhile in order to get a feel for the range and distribution of potential savings. Data for the input distributions was compiled from the range and frequency of estimates in the literature and replies to the Delphi questions (distributions are listed along with the simulation programme listing in appendix 1). The operation of the Monte Carlo model is described in the flow chart shown in fig 9.2.

FIG 9.2 FLOW CHART OF MONTE CARLO VERSION OF ECONOMIC SIMULATION



In the course of defining the economic variables of relevance and in choosing realistic values for them, several simplifying assumptions have been necessary. Table 9.1 shows the various cost headings examined in the model and the range of values used.

TABLE 9.1

TABLE OF ECONOMIC VARIABLES AND THEIR CHOSEN VALUES

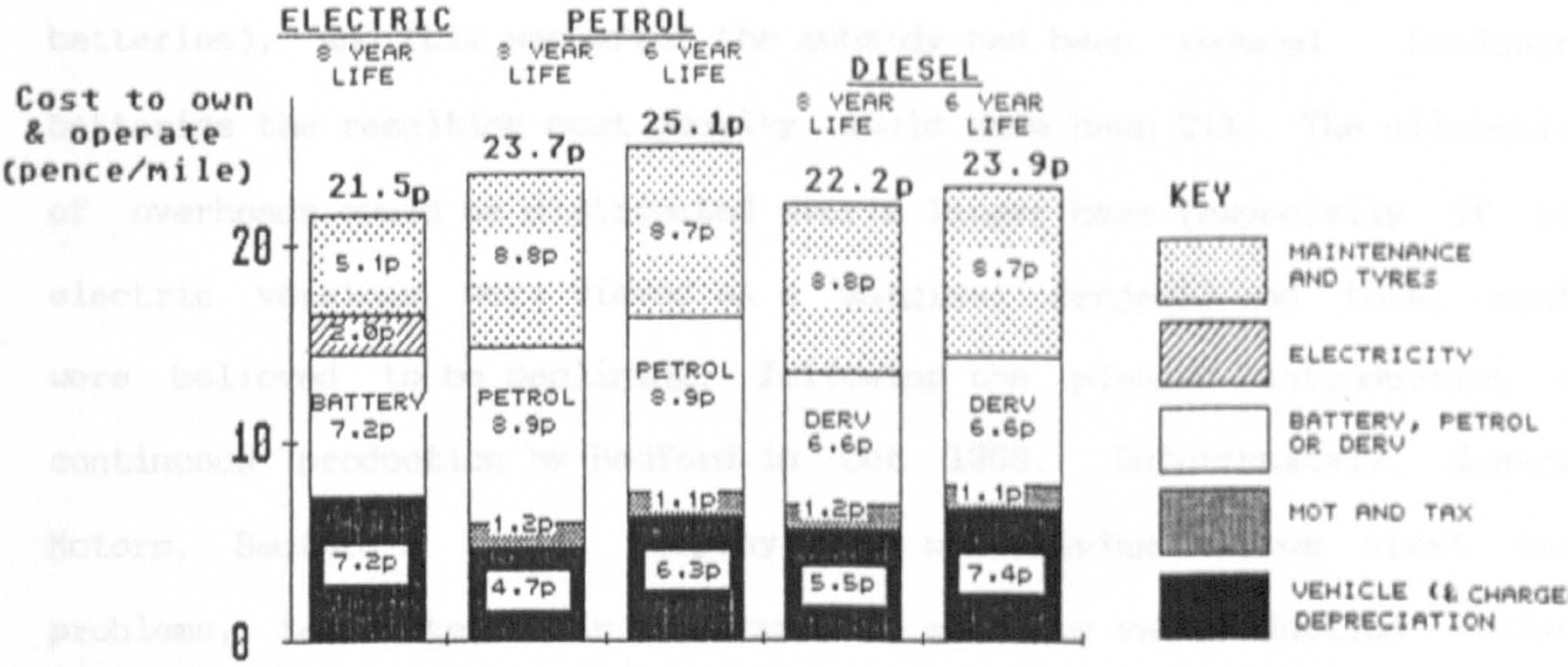
	VARIABLE	'BEST ESTIMATE'	LOWEST	HIGHEST
1	ICE life	7 years	5 years	10 years
2	Ratio of EV to ICE lifetimes	1.5	1.0	2.0
3	ratio of EV to ICE capital costs	1.3	1.0	2.0
4	Ratio of future battery cost to present cost	0.75	0.5	1.0
5	Ratio of EV to ICE maintenance costs	0.5	0.3	1.0
6	Cost of electricity per Kwh	3.5p	2.2p	7.5p
7	Cost of petrol per gallon	£ 1.80	£ 1.60	£ 3.00
8	Electricity consumption per mile (whrs net)	241	200	350
9	Cost per ICE routine service	£60	£ 40	£80
10	ICE purchase price	£5000	£3000	£8000
11	Discount rate	7%	5%	9%

In order to demonstrate the relative importance of the various operating costs LCEVS constructed cost comparisons between their EVs and the equivalent ICEs. These are shown in fig 9.3.

The following sections discuss the choice of values used in this chapter along with any assumptions or simplifications.

FIG 9.3

COST COMPARISONS FOR 1-TONNE PAYLOAD PANEL VANS (Bedford CF50)
(Source - Electric Vehicle Association publication March 1984)



9.2.3 VEHICLE CAPITAL COST

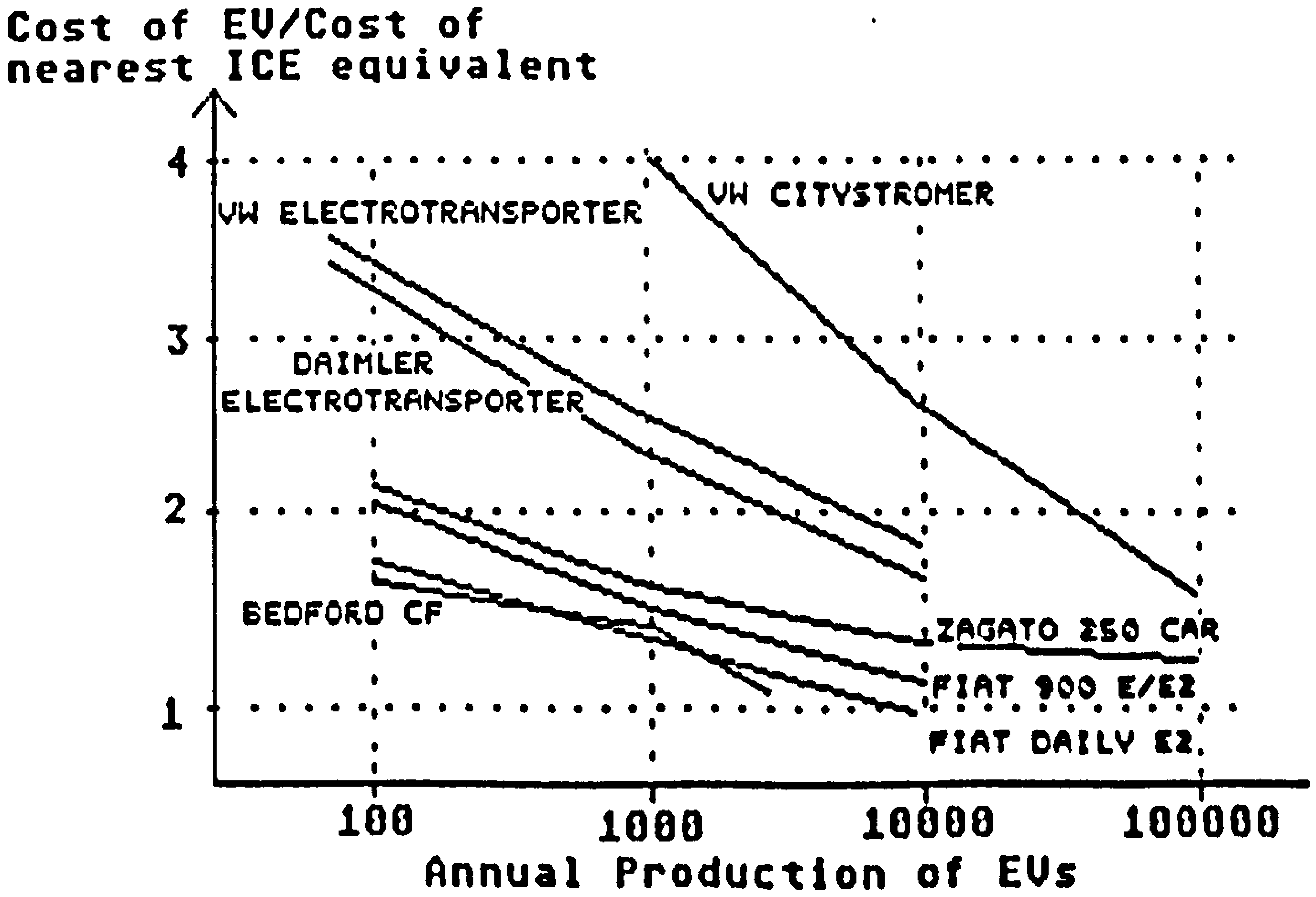
The model used a basic vehicle purchase price, the price of the substitute EV being calculated by multiplying the ICE price by a ratio representing the initial cost penalty that can be expected. The price of batteries was not included at this stage. It is commonly believed that an electric version of a car will cost more than its petrol or diesel counterpart. Certainly, attempts at commercial production have confirmed this to varying degrees [2]. The major reason for this is undoubtedly the limited production volumes involved. Design, development, production and marketing costs have to be recovered from very limited production quantities relative to the huge quantities of mass produced ICE vehicles. One of the most successful attempts to reduce this initial cost penalty was made by the Lucas Chloride electric Bedford CF delivery van. This vehicle used the same mass produced shell as the conventional versions and the electric drivetrain was designed so that it could be fitted on an assembly line just like a standard component. Small production runs of electric versions were scheduled alongside petrol and diesel vans. There was a government subsidy given on each drivetrain, which helped to reduce the price, but Lucas Chloride had hoped to reduce the initial cost penalty from approximately 100% over the ICE price to nearer 50-60% (including batteries), and this was after the subsidy had been reduced. Excluding batteries the resulting cost penalty would have been 21%. The allocation of overheads could be distributed over a larger base (especially if the electric versions were viewed as a 'marginal' project) and total costs were believed to be declining, following the planned introduction of continuous production by Bedford in Oct 1986. Unfortunately, General Motors, Bedford's parent company, who were having various short term problems, terminated their commitment to electric van production. Plans were scrapped. Nevertheless, the above account does illustrate what could be possible in the future and it highlights the problem of the scale of production. It also lends strength to the argument that the existing large vehicle manufacturers are in the best position to exploit the EV technology (discussed in section 4.3.4).

The initial cost penalty associated with EVs can also be partially explained by the high cost of the drivetrain components relative to a petrol or diesel engine. Core steel and copper are three to four times the price of mild steel, so the raw material costs of EV components are greater [3]. In addition, for a given power output an electric motor is generally about 5 times heavier than a petrol motor [4]. On the other hand the manufacturing of ICE engines involves high temperature casting, multiple machining and fitting which make the production process more costly than that of the mechanically simpler electric traction motor. In spite of this, the electric traction unit will probably be more expensive than the ICE unit.

High EV component costs are also partly due to low production volumes, some components being virtually hand made, leading to consequent prototype-scale price penalties. It should also be noted that most EV components are constructed to much higher (BS) standards than most ICE parts. Life expectancy of motors and most control components is 20 years and it is arguable that it would be a retrograde step to alter this, as although initial penalties may be high, the ultimate savings over the investment life is greater. Some people have been tempted to argue that control and drive systems of EVs are over elaborate and also that the whole vehicle design is based upon traditional ICE practice and performance leading to higher than necessary costs. Information concerning the production costs or likely production costs of EVs is difficult to obtain because it is held by the manufacturers who naturally keep their details confidential. However the Cost 302 team managed to persuade the manufacturers of 5 electric vans and two electric cars to estimate production costs for various scales of production. See fig 9.4.

FIG 9.4

COST RATIOS OF EVs AND THEIR ICE EQUIVALENTS
(source - ref 7, estimates by manufacturers concerned)

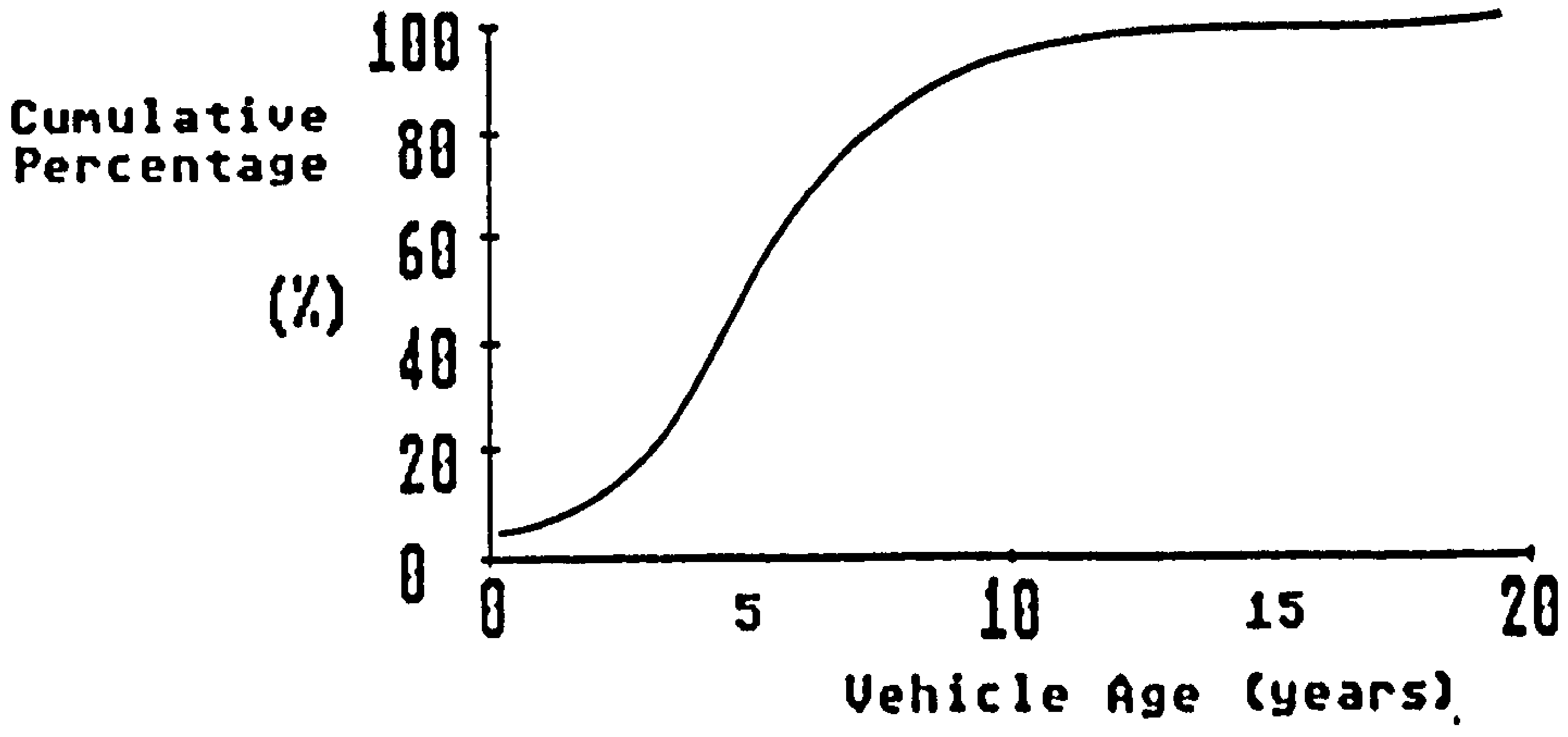


Respondents to the Delphi analysis were asked if they thought that the cost differential could ever be eliminated and 56% said that they considered it possible.

9.2.4 VEHICLE USEFUL LIVES

The useful life of the EV was calculated by multiplying the life of the equivalent ICE vehicle by a ratio estimate. Figures were collected on the islands for the distribution of vehicle ages. The cumulative percentage of cars and their ages is shown below in fig 9.5.

FIG 9.5 Cumulative Percentage of Vehicles Below Given Ages
(source - island survey via questionnaires)



These figures show that the number of cars on the road older than 5 years begins to decline. This decline continues more rapidly until after 10 years there are very few vehicles still on the road. These two figures were chosen for the most optimistic and pessimistic estimates for vehicle life. A seven year life represents the 'best estimate' of vehicle life. It is commonly accepted that the EV will have a longer operating life than ICE vehicles and this has obvious implications for lifetime operating costs. The high standard of construction of many EVs coupled with the absence of heavy engine vibration are possibly responsible for giving the EV a longer life expectancy. The drivetrain itself, although very complex in terms of electrical operation, is mechanically relatively simple. There are fewer moving parts and the configuration is quite simple. As mentioned above, most EV components are built to very high British

Standards and the life expectancy of most motors and controllers is 20 years or more. It is not unusual to find EVs operating perfectly after 15 or 20 years. Crompton Electricars claim an operating life of 30 years or more for their vehicles. The experience of milk float operators and similar low performance vehicles seems to substantiate this statement. Although these vehicles belong to a different class of technology, there is no reason in principle why similar benefits should not accrue to operators of high performance vehicles. Islanders are quick to point out that the salt air is very cruel to bodywork and that an EV shell would not last any longer than the ICE shell. Undoubtedly there is some truth in this assertion but the lowered body stresses are believed to lead to increased life. Furthermore, additional treatment of the shell during manufacture is a recommendable course of action as prolonged shell life would match the longevity of the electric drivetrain and reduced whole life costs would be likely to result. One fleet operator of 3 electric Bedfords reported that the normal company policy of vehicle body and paint refurbishment at 27 month intervals became unnecessary with the EVs and that the refurbishment period became 48+ months [5]. A longer expected vehicle life is also evidenced in the fact that LCEVS and Bedford were prepared to lease their electric Bedford vans over an 8 year period.

9.2.5 MAINTENANCE AND SERVICE COSTS

The EV has no gearbox, clutch, exhaust, carburettor, cooling system or ignition system. Instead the numerous high maintenance components of an ICE are replaced by an electrical motor and solid state control unit. This increased mechanical simplicity should lead to lower maintenance costs since the number and frequency of serious repairs is greatly reduced (see section 7.2). Motor maintenance is limited to routine air filter changes and occasional brush inspection. The control unit requires no maintenance and a high level of reliability should ensure low repair costs. With the Bedford van, the controller was readily accessible compared with an equivalent mechanical transmission, permitting any faults to be quickly diagnosed by means of simple fault finding equipment. Lucas Chloride claims that the only routine maintenance tasks are the watering of the battery pack (recommended at 3 week intervals if there is heavy use) and periodic inspection of the battery and its associated systems. A centralised watering system allows topping-up to be a quick and simple operation. Owing to the routine nature of the majority of EV servicing tasks, the maintenance costs for the EV are assumed by Lucas Chloride and others to be constant throughout the vehicle life at around 50% of the average ICE cost [5][6]. Other estimates put this figure at closer to 30% [7]. A further cost benefit which is not usually taken into account because it is difficult to quantify, is the reduced downtime associated with an EV, which implies a reduced requirement for stand-in or standby vehicles. (This is not perhaps as relevant to the private user as to the commercial user). Again, experience with low performance vehicles substantiates the claim that EV maintenance costs are minimal in comparison with the ICE equivalents. To date however, there have been problems with the reliability of prototype high performance vehicles, especially in relation to the battery system. (see section 7.2) It is not unreasonable to expect improvements in future as 'teething' problems are solved. The economic model treats routine service costs and the more undefinable costs associated with repairs and failures separately. Although there is a link between the two it is difficult to establish the relationship, so they have been considered separately.

Figures usually quoted for the ratio of EV to ICE maintenance costs normally assume that both vehicles are serviced in accordance with manufacturers' recommendations. While this is a reasonable assumption to make in the case of commercial vehicles, the case of the private individual is not as straight forward. It was discovered in the islands that 51% of motorists do not follow manufacturers' guidelines but only service their vehicle when a fault occurs. Similarly 14% carry out their own servicing at substantially reduced costs. This 'ad-hoc' approach to routine maintenance, especially in older vehicles, could alter the relative advantage of EV simplicity. Some however would argue that this type of service policy would lead to higher repair costs in the long run and therefore the costs would tend to balance out. While the probable result would be to the detriment of the EVs economic case, the effect is likely to be minimal except in the case of high mileage drivers, who are unlikely to use an EV in any case because of the limited range.

9.2.6 BATTERY COSTS

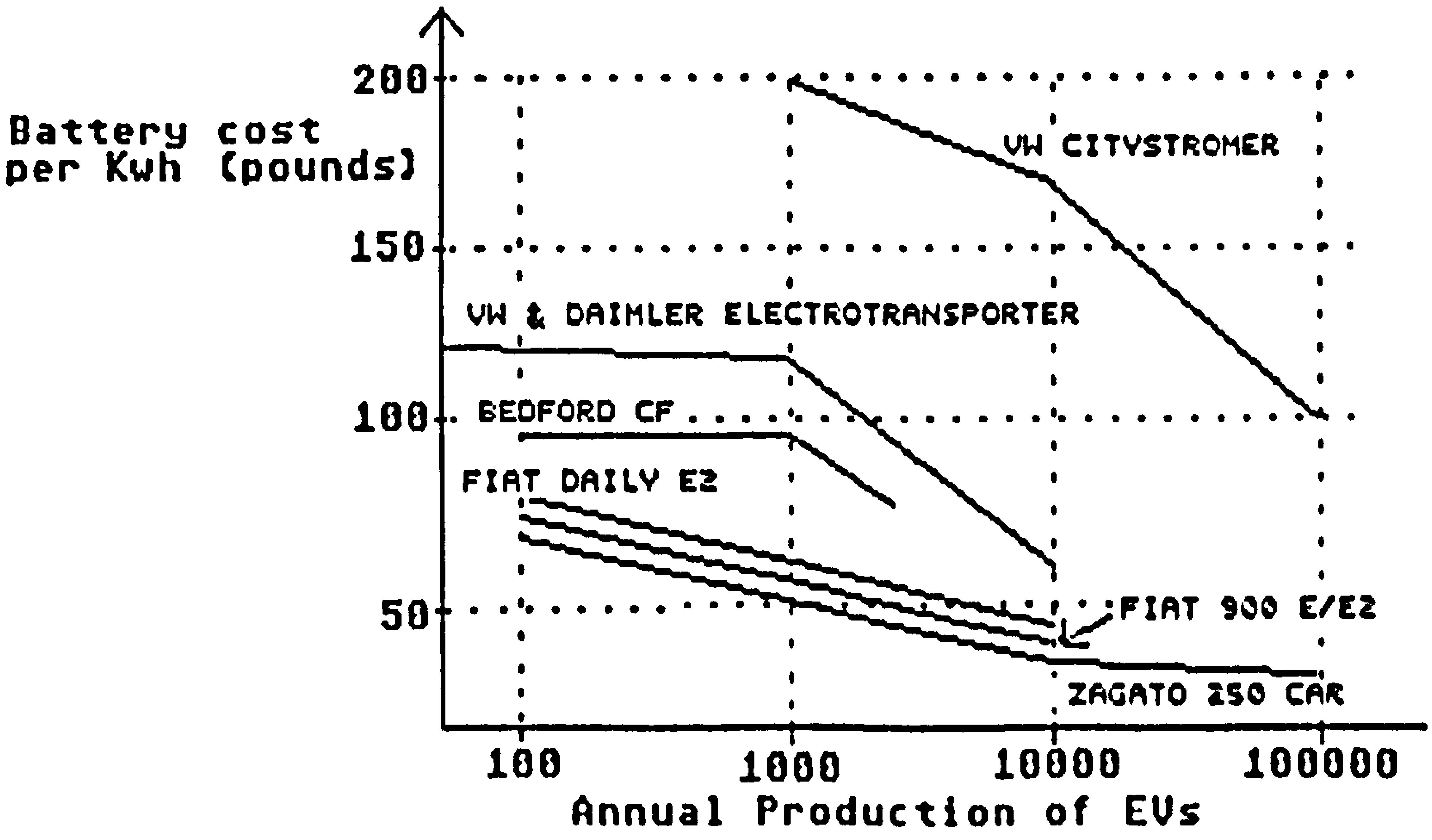
The battery of an EV represents a large fraction of the total running cost and the overall economics associated with running an EV are very dependent upon the cost of this energy source. The battery cost in this analysis has been treated separately from the capital cost of the vehicle. It is essential to recognise that the battery and charger have no direct equivalents in the ICE vehicle. In addition, the battery will usually have a different life from the basic vehicle, and an operator could be expected to consume several battery packs during the life of the vehicle, the number being closely linked to the particular use patterns of the operator.

Lucas Chloride made an attempt to recognise these difficulties by offering a battery lease arrangement whereby the battery pack was leased from the company over a four year period so that the cost could be spread over the battery life and could more easily be seen as balancing against petrol costs. This contributes towards balancing out the ownership costs due to the fact that the monthly lease costs can be directly offset by the substantial operating cost savings. This also helps to alleviate the heavy initial vehicle purchase price and to bring the initial capital cost of the vehicle more into line with a conventional vehicle. In the case of the private domestic user however this arrangement might not be as suitable, since use patterns tend to be much more variable, and therefore there would be a wide variation in the expected benefits of the scheme. Battery costs are therefore crucial to the acceptance of domestic EVs. Battery prices are usually quoted in £ per Kilowatt hour of storage capacity and although this is not the normal way of costing an energy source, it is necessary in the case of a stored energy source like a battery. To simply cost a battery in terms of amp hours would be to ignore the voltage and hence size of the battery.

At present, lead-acid battery packs for high performance vehicles cost between £75 and £120 per Kilowatt hour capacity. To buy the individual 6V blocks and construct your own battery might cost more in the region of £145 per Kwh at today's retail prices. The lower costs are due to commercial arrangements and quantity discounts. The basic figure used in this study is £100 per Kwh as this represents a realistic average figure which should be attainable given any reasonable production volume of EVs. (Production runs of Bedford vans were small (approx. 120 vehicles per run), and only 304 vans were built in total, yet the battery packs cost around £75/Kwh.) In the model, this basic figure was varied in the sensitivity analysis to allow for possible future real reductions in battery prices. Measures which could be taken to improve battery performance were discussed in chapter 2 but no mention was made of the costs associated with them. There are two ways to decrease the battery costs for operators; one is to reduce initial purchase price and the other is to improve the lifetime energy throughput of the battery. Of course, some combination of the two approaches is also possible. There is a certain amount of trade-off between the two measures as performance enhancing measures such as electrolyte circulation will increase initial costs. Although the UK has a well established traction battery industry, they are not produced in the same sort of volumes associated with the common starter type battery. The market for traction batteries as reported in 1980 amounted to 1.22 million cells per year but the vast majority of these were of the lower performance type associated with materials handling vehicles. High performance batteries are more expensive at present. A questionnaire circulated to participants in the industry resulted in 60% of respondents stating that future price reductions should be possible, the major factor in this reduction being the volume of production. Mass production around a specific size, fully automated production and more consistent high quality, more use of plastics and less use of lead, standardisation and improvements in active material utilisation, were all quoted as measures that would help to bring initial costs down. Mr F Wykes, Chairman of the Battery Vehicle Society suggested that costs could be reduced by increasing the proportion of lead which is active in the battery by reducing the weight of inactive lead in the grids supporting the active lead/lead dioxide pastes, while increasing the mechanical strength of the grids to prevent distortion and thus give longer charge/discharge cycle life. The lead-antimony alloy grids could be replaced by lead plated or dipped aluminium grids already plated with copper to give good metal to metal bonding. Aluminium is stiffer and stronger than lead and a better conductor of electricity. (Copper-plated aluminium is already used in aluminium cabling). These modifications would not necessarily reduce the initial cost of the battery, but would reduce overall battery cost by achieving longer life, combined with lower weight for the same capacity and power output. Copper-plated magnesium from alkaline solution could be a lighter weight alternative for lead plated or dipped electrolyte grids, although the electrical conductivity of magnesium is not as good as that of aluminium, though still better than lead. The lead plating or dipping would have to be of a high quality to prevent battery acid getting through to the copper and aluminium/magnesium underneath. Scrap merchants, however, would not like these composite metal lead acid batteries and the economical use of lead depends on its high recycleability as the earth's crust supply of lead is strictly limited (see table 2.5). Respondents to the questionnaire suggested that these measures along with others could result in cost reductions of anything between 10% and 60%. The COST 302 report compiled figures on potential battery cost reductions due to scale of production for various vehicle battery packs. These are shown diagramatically in fig 9.6.

FIG 9.6

BATTERY COSTS AT VARIOUS LEVELS OF PRODUCTION
(source - ref 7, Estimates by manufacturers concerned)



The German Urban Transport Research report carried out a similar piece of research for battery prices in Germany where it was estimated that reductions of 50% could be achieved for volumes in excess of one million cells per year [8]. This corresponds to an annual production of somewhere in the region of 20,000 battery packs for a standard high performance electric car. This in turn corresponds to a market of approximately 10,000 electric cars as each vehicle can be expected to use at least 2 battery packs during its life on average.

9.2.7 BATTERY LIFE

The longevity of battery life is just as important for EV economics as the initial first cost. It is very heavily dependent upon the type of use made of the battery. Such things as the charging regime employed, the type of driving terrain, the style of driving and the duty cycle involved, all have an effect on the lifetime amount of energy delivered by the battery and its cycle life. It is felt that previous economic studies of EVs have neglected this aspect of costs and have made over simplifying and unrealistic assumptions. The Lucas Chloride cost figures for the Bedford and Sherpa vans are based on the assumption that the battery will last for exactly 4 years, regardless of individual use patterns. This figure is estimated from the assumption that the van will be used for 45 miles, 200 days a year. Most island drivers' patterns of use are much less rigid than that. Similarly the COST 302 study used a simplified linear relationship between daily mileage and useful life. While this is probably a reasonable simplification for a macro type analysis of this sort, it was considered inadequate for a micro study of a specific application like the present one, so a different approach was taken. Battery cost is such a large and important factor in EV economics (see fig 9.3) that every measure should be taken to understand and describe it as fully as possible. Figures for each island driver's expected battery life were calculated during the application analysis simulation stage. Each driver's particular use pattern was taken into account, along with the typical expected island terrain. In addition various charging regimes were simulated. Unfortunately there is no clearly defined relationship between battery cycle life and the above mentioned variables. The most basic and fundamentally important relationship in this respect is the trade off between the depth of discharge and battery cycle life. There have been several different descriptions of this relationship for lead-acid batteries, both by theorists and by battery manufacturers [9][10].

Whatever the equation describing the relationship between DOD and cycle life, it is possible to calculate the total energy throughput during the battery life by multiplying the number of cycles obtained by the energy delivered in each cycle. This might be measured in terms of kilowatt-hours (or it might be translated into the number of miles travelled). The resulting energy throughput equation will be a quadratic equation in terms of Depth of discharge (DOD) because the cycle life has been expressed in terms of DOD (see above) and, in general, the energy delivered in each cycle is the product of DOD and the energy storage capacity of the battery,

$$ET = E_o \frac{D}{100} L \quad .... (1)$$

where ET = Lifetime energy throughput
E_o = Battery energy storage capacity
D = Depth of discharge (%)
L = Number of cycles (a function of DOD e.g as shown in fig 9.7)

By optimising this generalised energy throughput equation we can determine the optimal depth of battery discharge between charges. This is done by differentiating the energy throughput equation and setting this to zero. For this analysis two different descriptions of the relationship between DOD and cycle life were used, and the resulting difference in battery life and hence economics is examined.

The first equation originates from correspondence with Chloride Motive Power Batteries Ltd [9]. It is a three stage linear equation as shown in fig 9.7. The Chloride equation implies that there is an optimal average depth of discharge around 80%. This is shown on fig 9.8. This figure is also suggested in ref [11]. It can be seen that although there is a maximum point in the curve at around 80%, the energy throughput is not very sensitive to the average DOD between approximately 50% and 85% DOD.

FIG 9.7 Relationship between average depth of discharge and expected battery cycle life for Chloride lead-acid traction batteries
(Figures supplied by Chloride Motive Power)

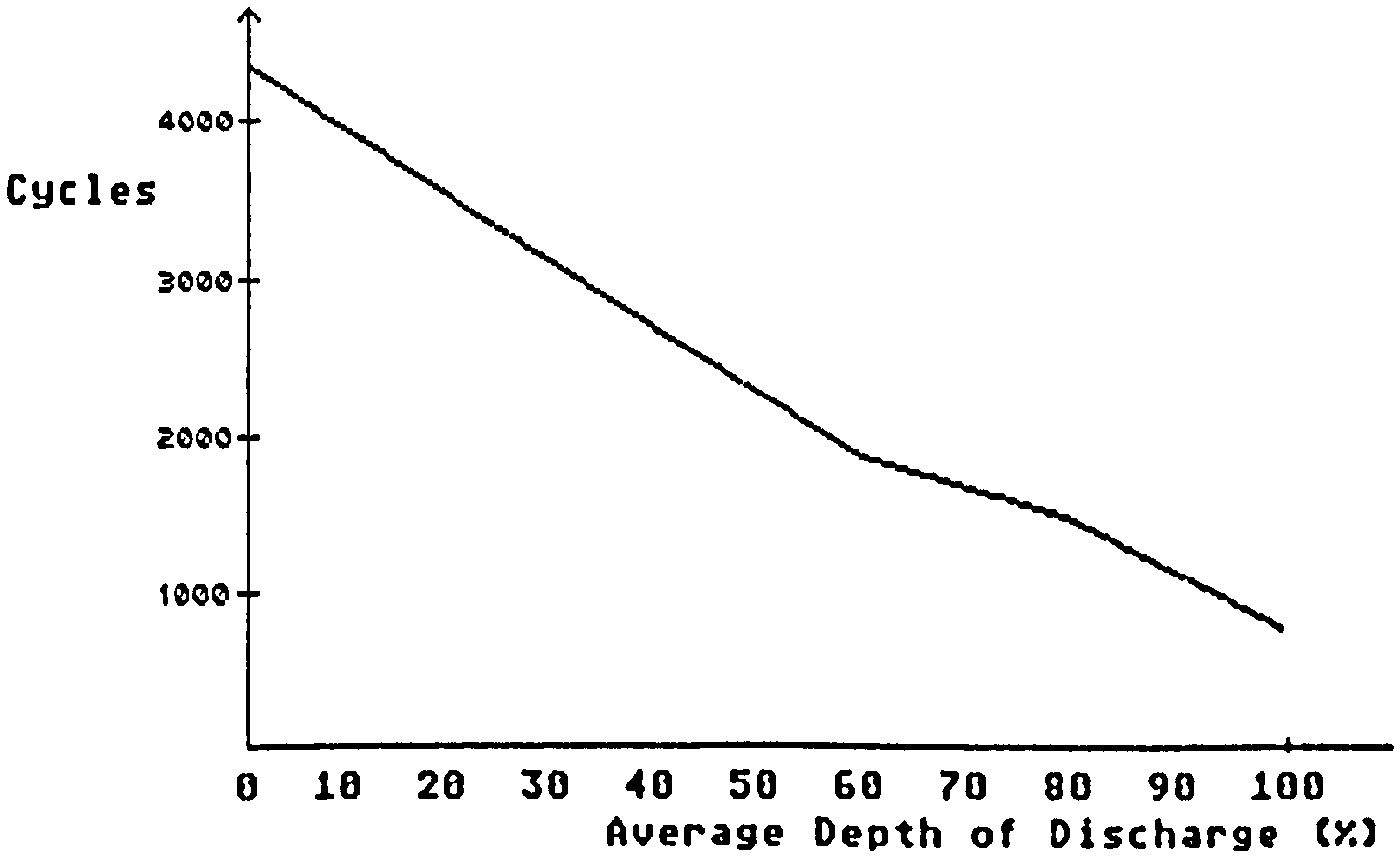
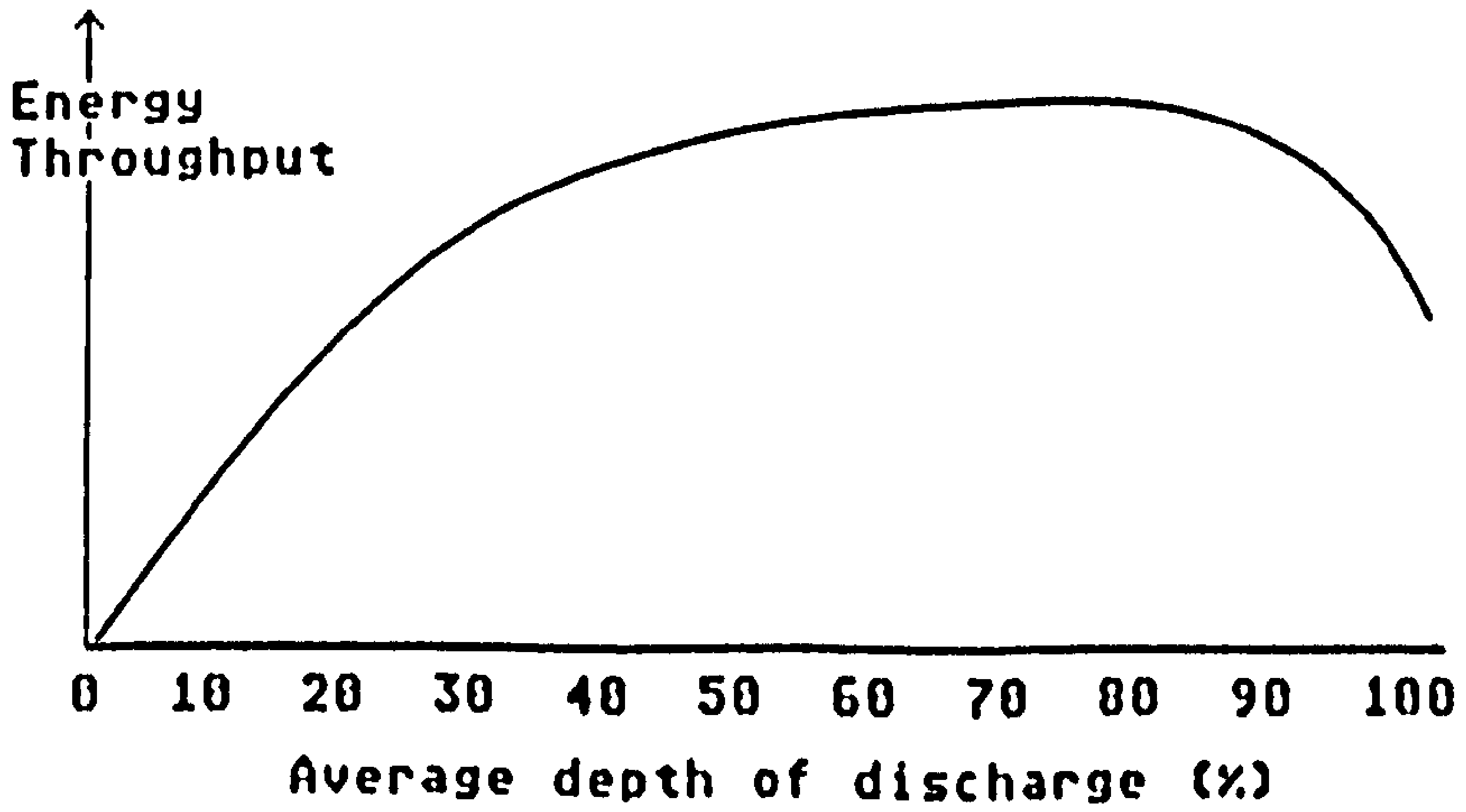


FIG 9.8

Relationship between average depth of discharge and battery lifetime energy throughput.



The second equation was taken from ref [10] and takes the form of a logarithmic curve. This gives a much lower value for optimal depth of discharge (see fig 9.10). The authors report that although there is a certain amount of spread in the raw data, the general trend suggests a semi-logarithmic relationship of the form,

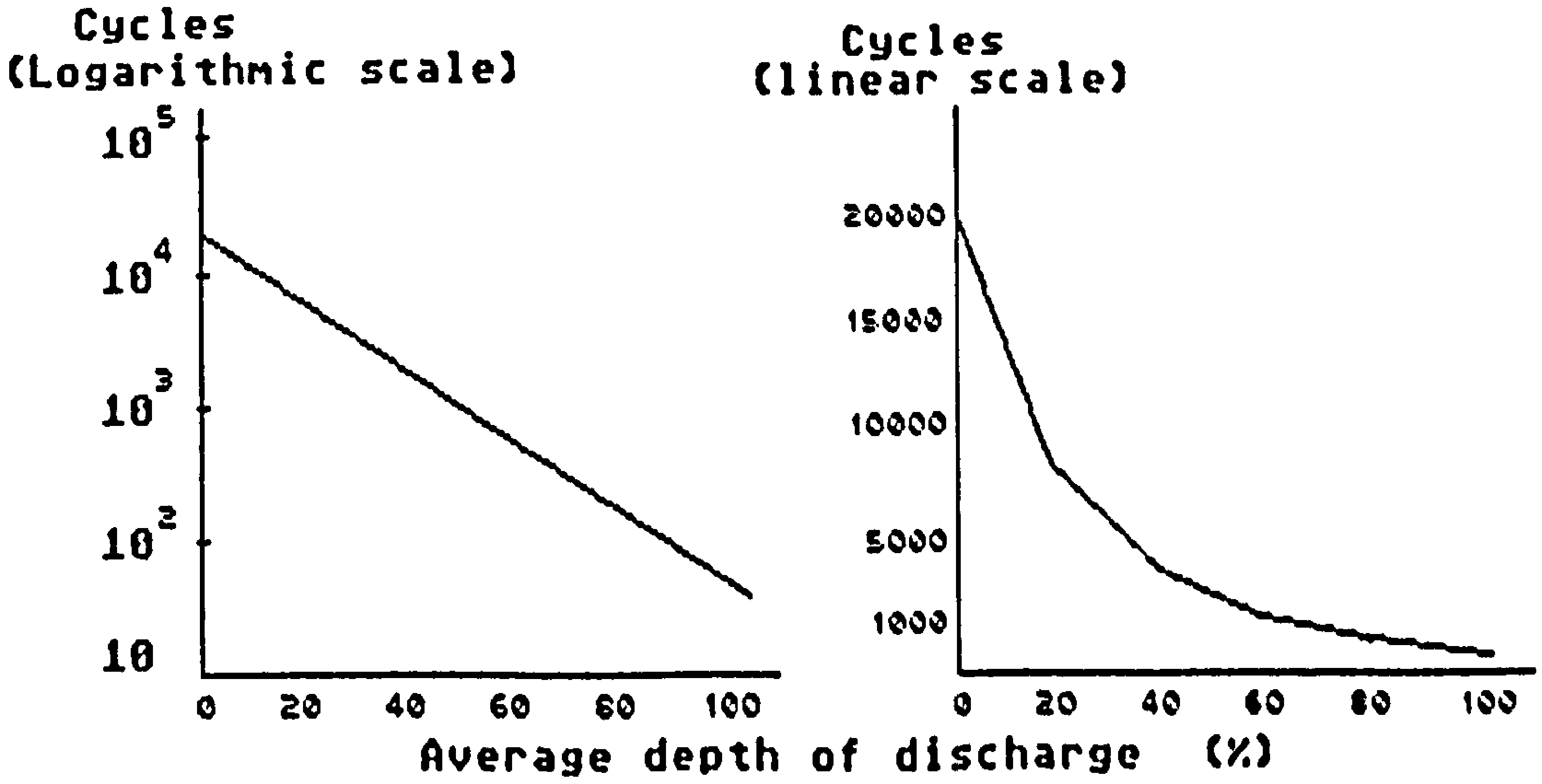
$$L = L_o e^{mD} \;\; \ldots\ldots\ldots\ldots \;\; (2)$$

where L = Battery Cycle Life
L_o = Lifetime in cycles obtained by extrapolating cycle life data to zero DOD.
D = Depth of discharge in percent.
m = Slope of plot of natural logarithm of L/L_o versus D.

The slope of the plot will be negative because cycle life decreases as average DOD increases. This slope may be evaluated for each battery system using data from fig 9.9 or by referring to the original experimental data.

FIG 9.9

Relationship between average depth of discharge and expected battery cycle life for lead-acid batteries
(Using semi-logarithmic equation from ref 10)



Again the resulting energy throughput function can be maximised by differentiating and setting to zero,

$$ET = E_o \frac{D}{100} L \;\; \ldots\ldots\ldots\ldots \;\; (1)$$

Substituting for L from equation (2),

$$ET = E_o \frac{D}{100} L_o e^{mD}$$

Differentiating with respect to D,

$$\frac{dET}{dD} = \frac{E_o L_o}{100} e^{mD} + \frac{E_o L_o}{100} mD\, e^{mD}$$

setting to zero,

$$\frac{dET}{dD} = \frac{E_o L_o}{100} e^{mD} (1+mD) = 0$$

The peak value of ET is located at the value of D that makes this derivative equal to zero. This condition occurs when,

$$1 + mD = 0$$

Thus the optimal value of D is,

$$D_{opt} = -\frac{1}{m}$$

Using the values reported in ref [10] we find the optimal depth of discharge to be around 25% as shown in fig 9.10.

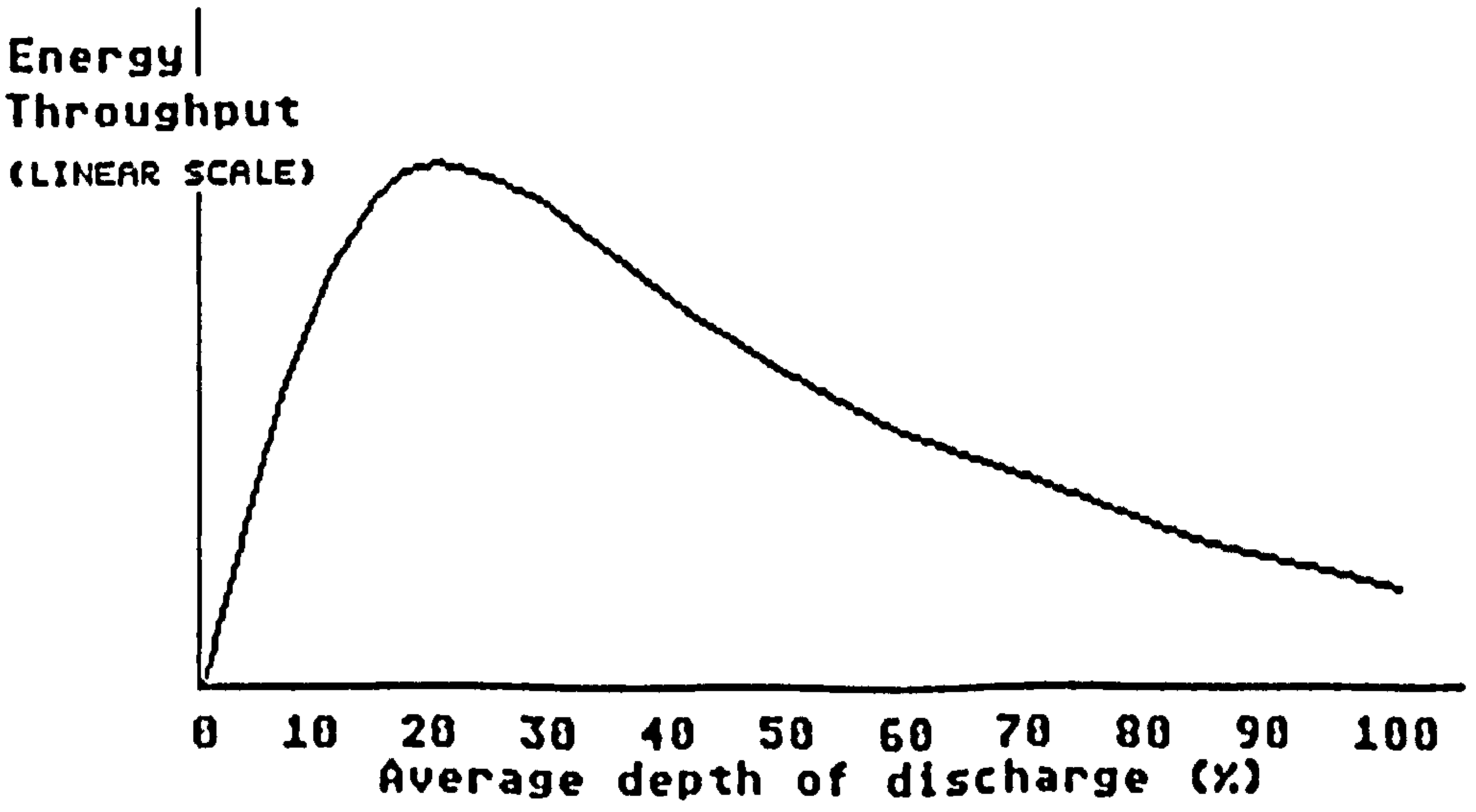


FIG 9.10

Relationship between average depth of discharge and total lifetime energy throughput. (semi-logarithmic equation)

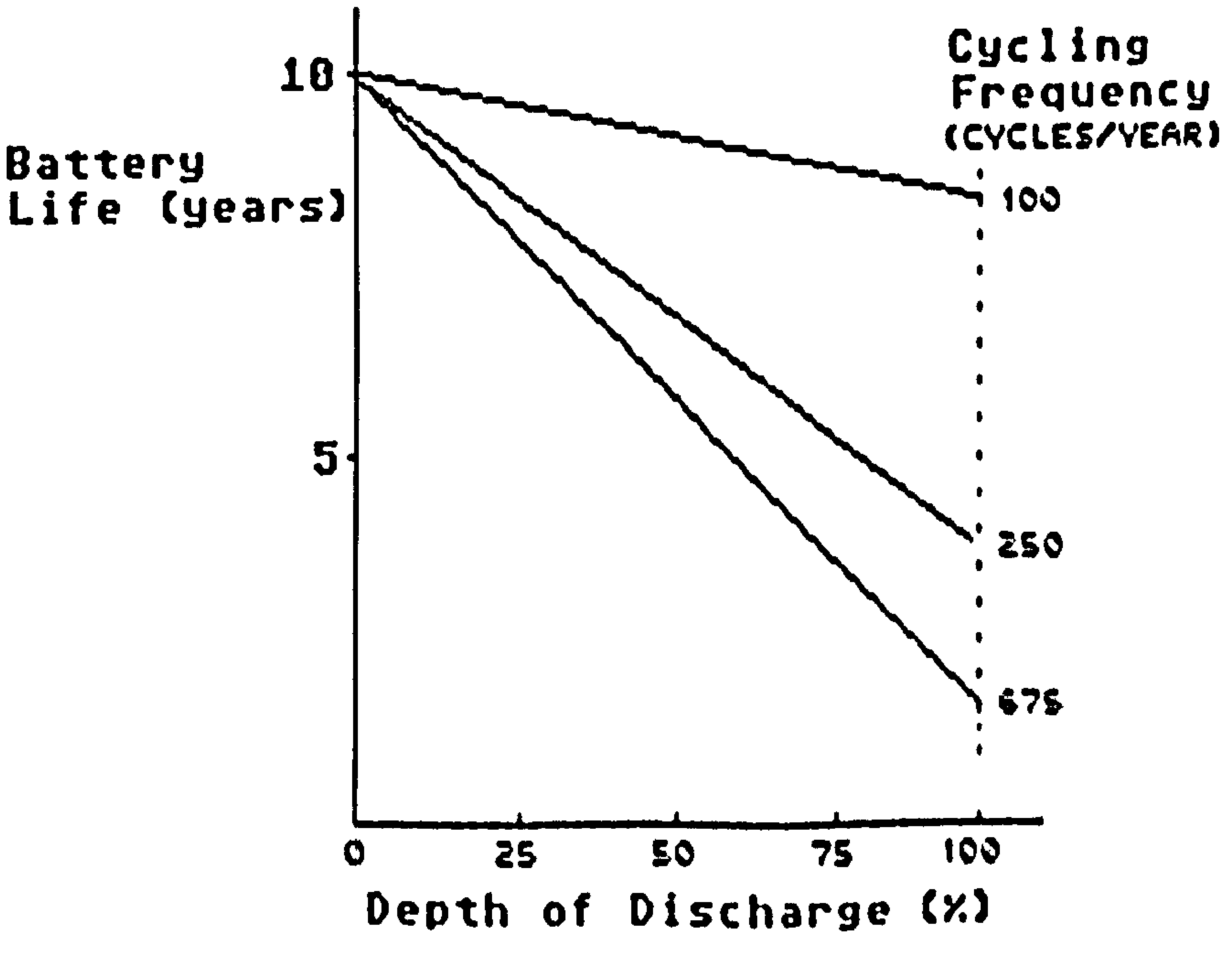
The different optimal depth of discharge resulting from the different cycle life relationships have important implications for the charging regime practised by operators and therefore the economic argument. The above descriptions of battery life actually attempt to describe battery life dependence on <u>regular</u> depth of discharge and it is not clear what allowance is made for variability in the DOD during battery life. It is highly unrealistic to expect an EV battery to be depleted to the same depth on every cycle. This was very evident after examining the journey data in the application potential analysis and from this it appears that the variability in DOD for island drivers is greater than can be expected for commercially used vehicles.

Rather than compromise by simply using the average battery DOD for each driver when calculating battery cycle lives, an attempt was made to incorporate the variability as well. Each time the battery was charged, the depth of this charge was recorded and the battery life which would result from regular charging at this depth was calculated. The fraction of this cycle life which is represented by this charge was then calculated and subtracted from the total life of the battery. For example, using the Chloride formula, a charge of 66%, if repeated regularly, would result in a cycle life of 1780 cycles. One particular 66% charge therefore represents 1/1780 of the battery life and the battery life is depleted by that factor. The next charge and its associated life-depletion factor is then calculated in a similar manner. The unavoidable assumption being made under this method is that each charge is independent in its effects on battery life-depletion from all other charges. There is insufficient experimental evidence to support or contradict this assumption but it is considered to be more realistic than simply averaging the DOD.

In addition to the effects of depth of discharge on battery life, it has been suggested [10] that the effects of corrosion (which correlate closely with battery age), imply that a battery has a finite calendar life even if it only receives limited use. A battery that is cycled fairly infrequently, or alternatively is discharged only slightly during each cycle, is subject to little internal stress. Its lifetime under these conditions is therefore controlled by the natural age related corrosion effects. Increasing the amount of energy taken from the battery during each discharge accelerates the aging process by bringing factors other than corrosion into action. McDonald [10] suggests that plotting battery lifetime in years versus ampere-hours discharged per Kg of active material (which is proportional to DOD) tends to collapse the data onto a common origin, fig 9.11.

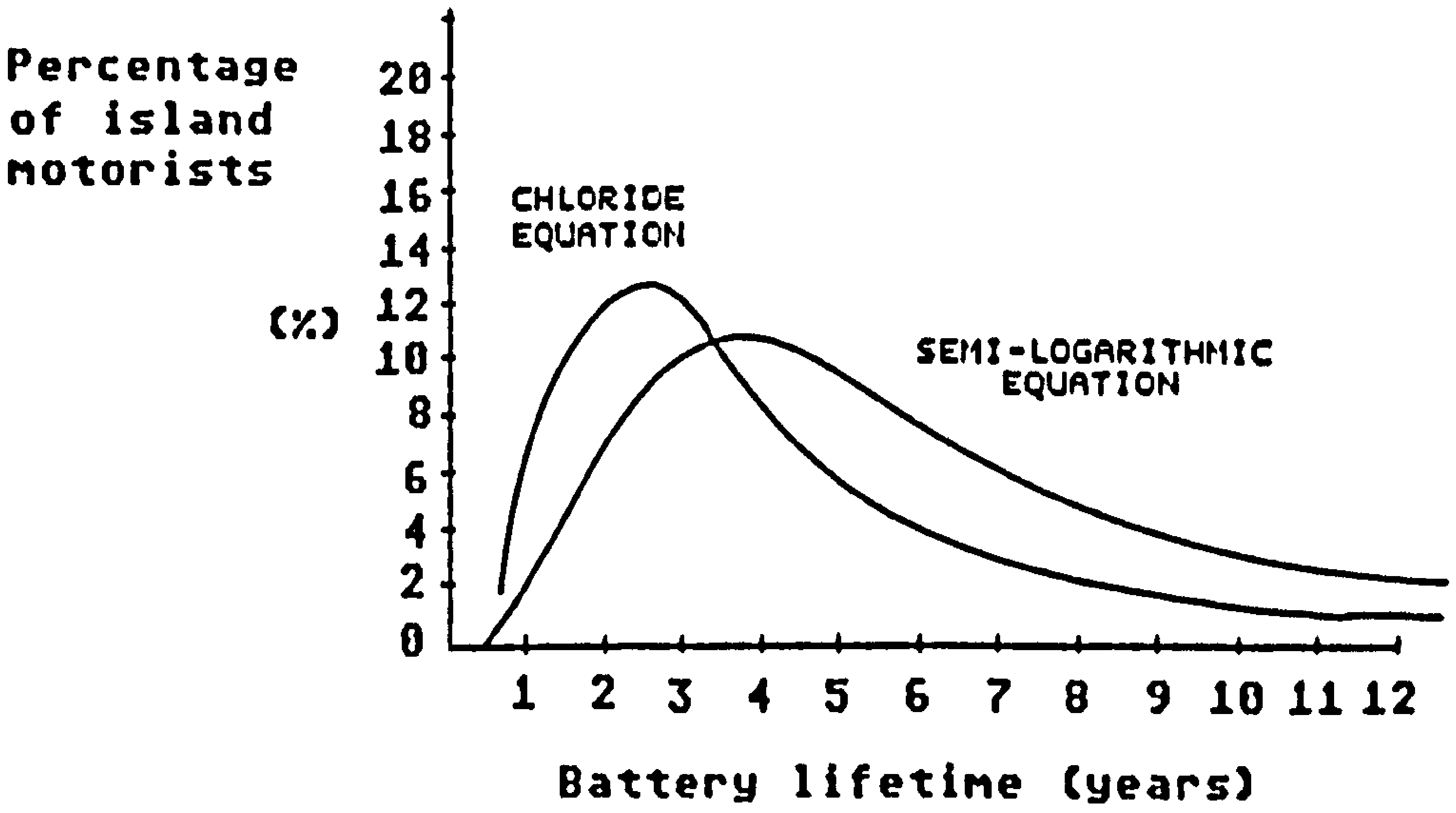
FIG 9.11

Battery life in years versus DOD with cycling frequency as a parameter.
(Source - reference 10)



The application analysis simulation described in chapter 8.7 calculated each motorist's expected battery life in miles. However for some low mileage motorists, this lifetime translates into extremely long calendar lifetimes. The spread of battery lifetimes in years is shown in fig 9.12.

FIG 9.12 DISTRIBUTION OF EXPECTED BATTERY LIFETIMES (Years) FOR ISLAND MOTORISTS FOR TWO DIFFERENT BATTERY FORMULAE
(Assuming home recharging at any time)



In order to take into account the aging processes described above, batteries were assumed to be limited to a maximum of ten years life regardless of mileage. This was the 'cut-off' point for any motorist who was estimated to have a potentially greater battery life.

Because the expected battery life for each motorist will be different and because the battery life will be different from the vehicle shell life, it is important to treat the battery as a different investment from the vehicle. In order to maximise the economic advantage of EVs, it will be necessary to be able to transfer batteries between vehicles whenever a new shell is purchased. There would be little point in scrapping a battery which still had some life left in it. Similarly, or alternatively, it would be advantageous to establish a second hand market for batteries so that vehicles could either be sold second hand complete with second hand battery or so that motorists could sell their battery at some stage during its useful life. For the purposes of this economic appraisal, the flexibility offered by a second hand market is assumed.

9.2.8 ENERGY COSTS

The cost of the energy required to operate an EV is generally recognised as offering considerable savings relative to the ICE, this being one of the major attractions of the EV and one of the major stimuli in its development. The EV is considerably more energy efficient than the ICE (see chapter 3) and the relative cost of off-peak electricity is less than that of oil-based fuels. The energy costs in this analysis have been calculated using the energy consumption figures calculated for the EV in the performance simulation and comparing these with the manufacturers' figures for petrol consumption for each island motorist's car. Petrol costs are slightly more expensive on the islands than in more central urban areas (approximately 10% greater) whereas electricity prices are the same as on the mainland. In actual fact the generation costs for the diesel generated electricity in the Western Isles is considerably greater than mainland costs but no surcharge is made to islanders. There is a subsidy on island electricity at present but this will cease to be necessary when the islands are linked to the national grid. The Orkney islands are already linked. Each particular EV use would have to be assessed on its own merits and allowances made for these costs. A sensitivity analysis was carried out around energy costs and possible price rises in the future. The values used for this sensitivity analysis are shown in table 9.1. For the purposes of the Monte Carlo simulation, the prices of electricity and petrol were held fixed at presently available prices. The relative economic advantage of the EV will be affected by the time of day that charging takes place, as off-peak electricity rates are less than 50% of the peak rates.

9.2.9 TAX AND INSURANCE COSTS

At present electric road vehicles are exempt from any form of road tax in Great Britain in order to encourage their development and use. While it is unlikely that this concession will continue when EVs are widely used, tax costs are assumed to be nil for the duration of the investment under examination because it is argued that they will continue to remain so until there are even greater cost savings attributable to EVs in other respects, making them more attractive. While it is true that some of the smaller and more remote islands are already exempt from road tax, these islands represent a very small number of motorists, and mileages on these islands are so small that it is doubtful whether EVs would be a suitable substitute for the ICE. Lower running costs would never offset the additional purchase costs.

Electric road vehicles are also exempt from the MOT test, and again this is partly to act as an incentive, but it is also due in part to their reported longevity and safety record. Again this exemption is assumed to continue throughout the period of the analysis.

At present, there is no evidence that electric road vehicle conversions of existing ICE vehicles attract different insurance premiums from their ICE counterparts, although insurance rates for electric milk floats are currently more than 30% lower than for comparable diesel or petrol powered vehicles [12]. There are very few high-performance electric vehicles in operation, and communication with the General Accident Insurance Company would suggest that until there are larger numbers to insure and the factors which influence premiums are better established in their case, they will not be given special attention. Insurance companies calculate premiums on a formula basis where certain vehicle and driver characteristics are taken into account. The age and convictions of drivers will obviously remain the same, as will the weighting given to the geographic region. The relevant vehicle characteristics however are arguably different. Firstly, the performance of the vehicle in terms of top speed and acceleration is assessed, claim frequency being related to performance. Although at first sight this may appear to argue in favour of EVs because high performance vehicles represent the greatest risk, the lower end of the performance range has its own associated risks. General Accident pointed out that the limited range would mean that EVs will be used largely for commuter vehicles in and around urban areas. This represents a type of use which is characterised by short frequent trips in busy traffic with much vehicle manoeuvering. Typically this manoeuvering results in more bumps and scrapes and hence insurance claims. Because a larger proportion of vehicle use will be of this type than for an equivalent small ICE vehicle, the element of the premium which is attributable to this factor is likely to be increased.

A second major element in the premium formula is the cost of repairs and spare parts for any particular vehicle. Standard bodywork repairs and those which relate to parts in common with the ICE equivalent will not be affected but any repairs associated with parts unique to EVs will have to be assessed separately. Once again it is possible that this will be to the detriment of insurance costs as parts will not be produced in the same volumes as ICE parts and their distribution and availability is unlikely to equal them. This is an important factor for prospective EV manufacturers to bear in mind and it might lend support to the belief that it is the existing large vehicle manufacturers who are best placed to exploit the technology. The more standardised the EV components and construction can be, the lower the associated repair and parts costs are likely to be. A corresponding reduction in premiums could therefore be expected. Similarly, the higher initial purchase price of the basic vehicle implies that it is more costly to replace. So far EVs have gained a good reputation for safety on the road. They usually have a very low centre of gravity because the battery pack is typically located low down. This helps to contribute to good road holding capabilities and associated safety. In tip-tests, the Bedford CF van remained upright until it was tilted in excess of 65 degrees from horizontal [13]. The case of the electric Sherpa van which rolled over and righted itself due to the weight of the battery and which could still be driven away has been mentioned previously.

Most of the above discussion relates to electric conversions of ICE vehicles and it is uncertain how, if at all, insurance premiums will differ from the ICE vehicle. When considering EVs of a totally new, 'ground-up' design, the issue becomes even more uncertain. New or different construction materials, different safety designs and different production and repair methods may all significantly affect the risks and costs borne by insurers. Present designs are based upon traditional ICE practice and performance. It is doubtful that ICE vehicles would be built as they are if they were as limited in performance as EVs. Purpose built designs could take advantage of the inherent performance reductions, resulting not only in potentially cheaper insurance but in reduced production costs as well.

For the purpose of this analysis, the relative insurance premiums for EV and ICE vehicles were assumed to be the same due to the lack of information and uncertainty surrounding the area.

9.2.10 THE COST OF CAPITAL

The concept of the cost of capital is perhaps not quite as relevant for the private individual as it is for the commercial user where only projects offering returns in excess of the financing costs are considered. The discount rate or required rate of return for commercial projects incorporates the required return for the level of risk undertaken. Where cash flows are known with certainty there is no risk, so the 'risk-free' rate of return is used (e.g the Treasury Bill rate). There is considerable uncertainty surrounding the cash flows in this analysis but it is not easy to incorporate these into the cost of capital or discount rate in the domestic situation. Perhaps it is simpler not to incorporate a measure of risk in the discount rate but to realise that the more uncertain the cash flows are, the greater has to be the economic incentive to invest. In addition, the individual will probably require greater returns than the opportunity cost of capital used by businesses in order to entice him away from the established ICE and to compensate for the differences in the service offered due to the lower performance. He is also less likely to take a 'whole life' view of the project. The motorist requires a mode of transport as a necessity in most cases and the opportunity cost of capital is not usually as major a consideration as the absolute amount of the outlay. However, because of the different cash flows attributable to the two projects considered here (i.e EV or ICE), there will be an element of financing costs. This may not be apparent to the individual islander, especially since the difference in cash flows is fairly complex and often changes in sign from year to year. Nevertheless it is accounted for and is taken into account in the capital recovery factors mentioned previously. The discount rate used corresponds to the return an investor could expect from a secure, low risk investment such as a building society deposit after adjusting for general inflation (see below). A sensitivity analysis was undertaken to examine the effect of changes in interest rates.

9.2.11 GENERAL ASSUMPTIONS

A. INFLATION

When using discounted cash flow techniques, either the actual monetary cash flows after adjustments for inflation can be used, or the real money cash flows in today's terms can be used. If today's prices are used with no adjustment for inflation, the discount rate used will have to be the 'real' rate of interest which allows for the effects of inflation. 'Real' rates of interest tend to vary much less significantly than monetary rates and are much easier to predict than general inflation rates. It is therefore possible to perform the whole analysis without having to predict inflation rates. Because it is extremely difficult to forecast inflation rates, especially over such a long period of time as is represented by longer projects such as the one under are consideration, it is normally easier to follow this approach. However, even if today's prices and real interest rates are used, there will be some items which rise in price at greater or lesser rates than the general price index. These still have to be allowed for as special variations. In this analysis, the only costs treated in this manner are the costs of electricity and petrol. This was done by assigning a greater range of possible values to them in the sensitivity analysis.

B. CAPITAL OUTLAY

An EV is likely to cost more in the first instance than an ICE equivalent. A vehicle with a higher initial cost may not be within the scope of many motorists even though it offers future and whole life savings. This may apply especially to younger motorists and to many island motorists who have lower than average incomes. In addition, the periodic large outlays necessary for battery packs might be a disincentive to EV operation regardless of the fact that this is offset by reduced petrol costs. It is a characteristic of the islanders that high running costs represent much less of a problem than capital outlays. We have to ignore these considerations in the economic calculations.

C. FUEL BILLS

A similar problem to the last one is the timing of fuel bills. When using an EV, instead of paying for petrol every few days, a motorist who charges his batteries at home will be faced with a larger than usual electricity bill every quarter. This may discourage some people from using an EV and this is not taken into account in the model. However, when the likely electricity bills are examined, it becomes apparent that this should not be quite as large a barrier as one might expect since the quarterly fuel bill associated with an island vehicle of average annual mileage would only be approximately £23. The equivalent value of petrol fuel for the same period would cost approximately £110.

D. NEW FOR NEW

The assumption underlying the model is that a new EV is compared with a new ICE vehicle. There is no known data available on the subject of likely secondhand markets and values for this type of high performance electric car. While "new for new" would be a reasonable assumption for the business user or the motorist who is in the habit of buying new vehicles, it does not perfectly describe the situation throughout the islands. Seventy-four percent of islanders stated that they tend to buy secondhand vehicles and many of these vehicles are of a considerable age. If we further assume however that EVs and ICEs will depreciate in roughly the same manner then the implications of the "new for new" assumption are not so unrealistic. While the magnitude of the costs and savings will probably be different for the secondhand buyer, they will remain in proportion to the costs associated with new vehicles.

9.3 RESULTS OF ECONOMIC SIMULATION

9.3.1 INTRODUCTION

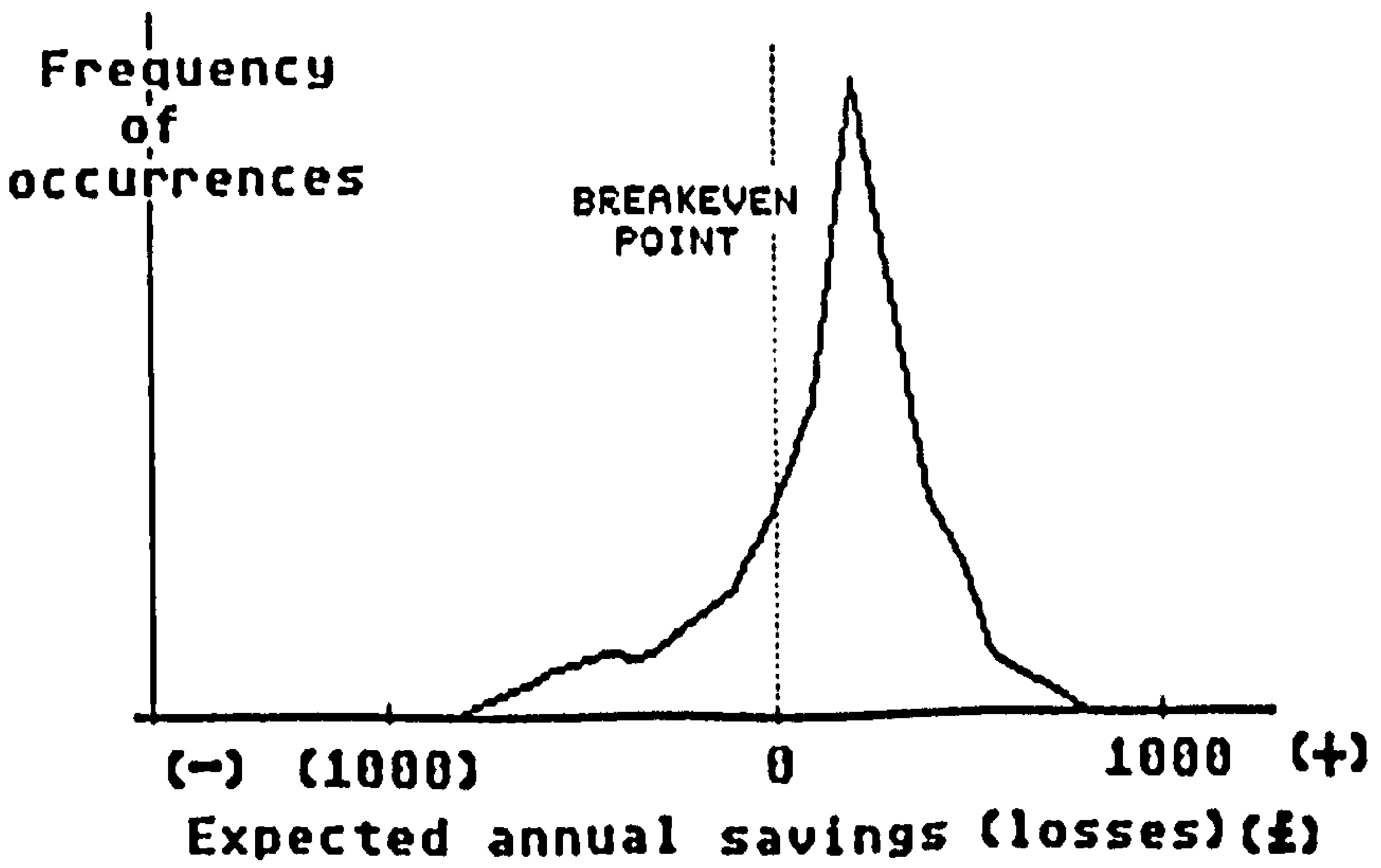
As a result of carrying out the extensive sensitivity analysis, and recognising the various possible charging regimes, battery models and the different islands examined, there is a large output from the basic model and Monte Carlo simulation. This enables a picture to be built up which gives a 'feel' for the complexity and uncertainty involved.

The figures presented in this analysis represent annual expected costs and savings. These annual expected figures do not correspond to the actual cash flows in any particular year. Actual cash flows will vary greatly from year to year as capital outflows and running costs are combined to make up the cost of operating a vehicle. However, as explained in section 9.2.2, it is difficult to compare investment projects with different lives, and therefore it is also difficult to present the economic advantage or disadvantage of EVs relative to ICEs, without using some sort of annual figure. The most appropriate comparison is between the annual equivalent costs, which simply spread the overall costs of the project over the duration of its life in an annualised fashion. The basis of calculation has been discussed earlier. Many of the results are given in the appendices (appendix 4) but the following are summarised results for Lewis and Harris.

9.3.2 THE BASIC CASE

A distribution of the expected annual savings of all the island motorists, using the 'best estimates' for each of the economic variables (see table 9.1) and using the annualised cost of the vehicles over their lifetimes, is shown in fig 9.13. These figures were calculated under the assumption that all vehicle charging takes place at home whenever the vehicle is not in use. Battery life is assumed to follow the semi-logarithmic relationship described in section 9.2.7. This will be referred to as the 'base case'

FIG 9.13 Distribution of expected annual savings or losses for island motorists using EVs



BASE CASE - assumes charging at home anytime and semi-logarithmic battery formula, and 'best estimates for economic variables. Vehicle range = 52 miles.

COMMENTS

1 Under this particular regime the majority of drivers (76%) would make savings from operating a replacement EV. In some cases the savings can be substantial, the maximum amount being £738. The average annual savings would be £107

2 There is a wide spread in the level of savings. The range of results is £1600. Savings are very dependent therefore upon the particular driving habits of the operator.

3 Some operators can be expected to make substantial losses through operating an EV. The greatest loss calculated is £862.

4 Presumably motorists will require a 'reasonable' level of savings to entice them away from the ICE and to compensate for the loss of flexibility that they will experience with an EV. It is not therefore so relevant to look at the number of motorists exceeding the breakeven point as to examine the spread of savings in excess of this point. In this particular case 37% of motorists would save over £200 per year and 9% would save over £400 per year. A large proportion of motorists will indeed make substantial savings. This would suggest that there may be some market potential for EVs in the island application. Market potential is examined in more detail in section 9.4.

9.3.3 SENSITIVITY ANALYSIS

Table 9.2 shows summary results of the sensitivity analysis. The assumptions regarding the charging regime and battery characteristics are maintained for the time being, i.e charging takes place at home. (Figures for savings are annualised figures and figures in brackets are negative).

TABLE 9.2

SUMMARISED RESULTS OF SENSITIVITY ANALYSIS

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (as above)	-	107	738	(862)	76
ICE life (years) (EV life = 1.5xICE life)	10	74	705	(898)	73
	5	148	779	(821)	78
Ratio of EV to ICE lifetimes	1.0	(204)	427	(1174)	16
	1.2	(48)	584	(1017)	48
	1.5	107	738	(862)	76
	2.0	258	890	(711)	88
Ratio of EV to ICE capital cost	1.0	314	945	(655)	90
	1.3	107	738	(862)	76
	1.6	(99)	532	(1069)	38
	2.0	(375)	257	(1344)	3
Ratio of future battery costs to present costs	0.5	303	890	(217)	94
	1.0	(88)	586	(1507)	54
Ratio of EV to ICE maintenance costs	0.3	135	770	(792)	78
	0.8	66	691	(968)	72
	1.0	38	660	(1038)	67
Cost of electricity pence/Kwh	2.2	146	783	(764)	79
	5.2	56	681	(990)	70
	6.0	33	654	(1051)	67
	7.5	(12)	603	(1164)	60
Cost of petrol £/gallon	1.65	67	668	(940)	72
	2.0	163	832	(758)	79
	2.5	301	1067	(497)	93
	3.0	440	1302	(235)	96
Electricity used per mile (Wh)	200	125	759	(817)	78
	350	60	685	(982)	72
Cost for ICE routine service(£)	40	80	658	(882)	73
	80	135	818	(842)	78
Purchase price of ICE vehicle(£)	3000	94	725	(875)	75
	8000	127	758	(842)	76
Discount rate %	5	149	779	(809)	78
	9	63	696	(917)	72

NB "Base case values" : these are the 'best estimates' of the economic variables as listed in table 9.1, with the 'charge at home anytime' charge regime and the semi-logarithmic battery life equation.

COMMENTS

1 Each time one of the economic variables is changed, (leaving the other variables at their base case values) the whole distribution shown in fig 9.13 above moves to right or left. The magnitude of this shift depends upon the relative importance of the variable being examined in terms of its contribution to total costs.

2 The variables which affect the annual savings most are the ratio of EV to ICE lives and the ratio of EV to ICE capital costs. There is still great uncertainty surrounding the probable values of these variables once the technology is more commercially available, and the results shown above indicate that these are critical parameters. The implication is that every effort should be made by manufacturers to ensure that the difference in initial purchase price is as small as possible. If the ratio of capital costs cannot be kept well below 2, there are very few motorists who can be expected to make any significant savings from operating an EV. Similarly, unless the EV can be built to last at least as long as the ICE, its economic advantage is doubtful in the majority of cases.

3 Other variables which have a <u>moderate</u> effect on the economics are (1) future battery costs, (2) petrol costs. These variables do not appear to be quite as critical as those mentioned in the previous section but they are still significant. If lead-acid battery costs were to remain at present levels, significant savings would be available to approximately half the island motorists. However if this cost element can be reduced, it greatly increases the market potential. Base case calculations used the present pump price of petrol but it can be seen that as petrol costs rise even moderately, there is a large increase in the number of motorists making savings.

4 Some of the economic variables would appear to have little effect on the economic case. These are,

(a) the absolute lives of the vehicles (not the relative lives)
(b) the ratio of EV to ICE maintenance costs
(c) the cost of electricity per Kwh
(d) routine ICE service costs
(e) the absolute purchase price of the ICE (not the relative price)
(f) the discount rate.

Changes in the maintenance and service costs and the cost of electricity have a relatively small effect because they represent small fractions of the overall running costs. The absolute lifetimes and purchase prices are not nearly as important as the relative differences between ICE and EV. The greater the absolute purchase prices, the more favourable this is to the EV, and the greater the absolute lives, the more favourable this is to the ICE. Rises in the discount rate adversely affect the economics of the EV because of the higher levels of capital outlay involved at early stages.

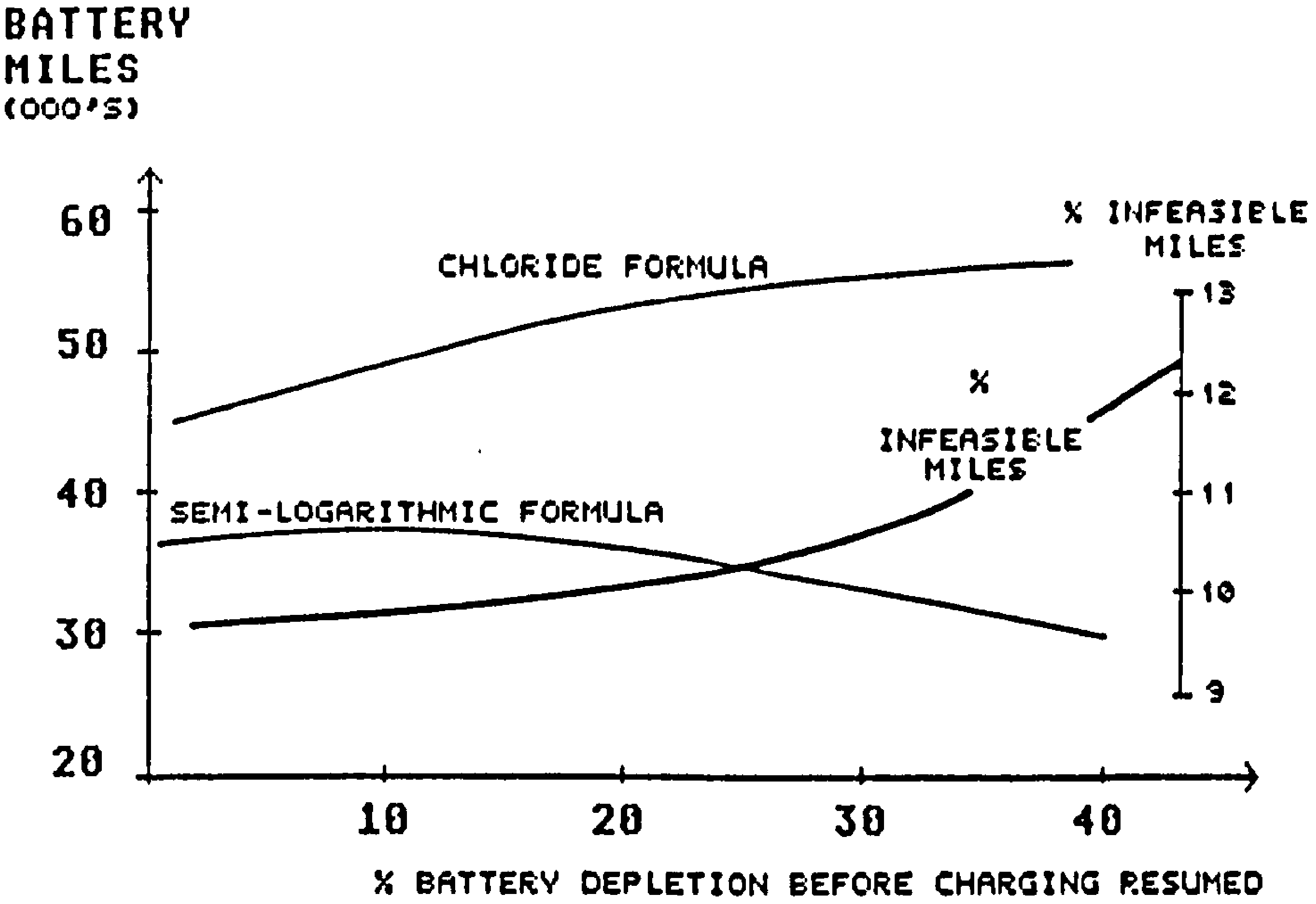
9.3.4 CHARGING REGIMES AND BATTERY FORMULAE

Table 9.3 shows how the charging regime employed and the battery life formula assumed affect the base case figures in table 9.2. Various charging regimes are considered,

(a) at home overnight only
(b) at home anytime (base case)
(c) anywhere anytime.

These regimes are described in section 6.7.7. In addition, charging regimes where drivers refrain from charging the battery until it has reached a certain depth of discharge are considered. By avoiding excessively frequent shallow charges it may be possible to prolong battery life and hence reduce costs. However there will be a trade-off between battery life and the application potential. The longer an individual leaves his battery before charging, the more he is likely to experience inconvenience due to insufficient vehicle range. Fig 9.14 shows the effect of simulating different charging regimes on battery life and application potential.

Fig 9.14 Trade-off between average battery lifetime and the percentage of island miles that can be completed under different charging regimes.



The diagram shows that the two different battery formulae described in section 9.2.7 lead to very different conclusions on the advantage of following a 'wait until' charging regime where the battery is not charged until a pre-specified depth of discharge has been reached. Using the Chloride figures, battery life can be extended by refraining from charging when the battery is only slightly discharged. However, if battery cycle life is more accurately represented by the logarithmic equation, the opposite conclusion is drawn, i.e battery life is extended by opportunity charging at shallow depths of discharge. These results are consistent with the difference in the optimal depth of discharge calculated in section 9.2.7, Chloride figures indicating that the optimal depth of discharge is much greater than that using the logarithmic equation so that frequent shallow charges reduce overall cycle life . Whatever the effect that 'wait until' charging regimes have on battery life, the effect on the application potential will be the same regardless of the cycle life formula used. It is evident that the percentage of infeasible miles is increased as motorists refrain from excessive opportunity charging but the question of whether or not this is acceptable must be answered by balancing the disadvantage with the cost advantage. These cost implications are shown in table 9.3.

TABLE 9.3

SUMMARISED RESULTS OF THE EFFECTS OF CHARGING REGIMES AND BATTERY CYCLE LIFE FORMULAE ON THE ECONOMIC CASE

CHARGING REGIME & BATTERY FORMULA USED	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
	AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (AT HOME ANYTIME- SEMI-LOGARITHMIC)	107	738	(862)	76
AT HOME OVERNIGHT SEMI-LOGARITHMIC	344	788	67	100
ANYWHERE ANYTIME SEMI-LOGARITHMIC	225	925	(795)	92
AT HOME ANYTIME CHLORIDE FIGURES	335	900	45	100
AT HOME OVERNIGHT CHLORIDE FIGURES	382	880	67	100
ANYWHERE ANYTIME CHLORIDE FIGURES	291	839	(200)	95
BASE CASE WAIT UNTIL DOD > 20%	85	744	(859)	70
BASE CASE WAIT UNTIL DOD > 40%	56	750	(868)	63
BASE CASE CHLORIDE FIGURES WAIT UNTIL DOD > 20%	369	911	59	100
BASE CASE CHLORIDE FIGURES WAIT UNTIL DOD > 40%	376	903	59	100

COMMENTS

1 It is increasingly evident that improved information on the relationship between battery cycle life and average depth of discharge would help to determine optimal policies of battery recharging.

2 A 'wait until' charging regime only saves money if the Chloride battery description is the most realistic representation. However the difference that such a regime would make to annual savings is minimal. The average saving for the islands of Lewis and Harris would only increase by £41 if motorists refrained from recharging until the battery was at least 40% discharged. The extent of the saving however will vary from one motorist to another and this kind of battery management may be worthwhile for certain individuals. In general however it would not appear to be a very valuable measure to take when seen in the light of fig 9.14.

3 Using Chloride figures, the most economical charging regime appears to be to charge at home overnight. Charging at home anytime however makes very little difference to the overall economics and although the average level of savings is slightly less (£47), the maximum saving calculated has actually increased by £20. Charging anywhere anytime is the least advantageous regime in terms of costs and it can be seen that some motorists stand to make significant losses by operating an EV and using this charging regime. It should be recalled that according to the earlier results (table 9.2), the cost of the electricity used (off-peak or standard tariff) made very little difference to annual savings and so the effects of different charging regimes presented above are largely due to the effects that opportunity charging has on the battery life. When using the logarithmic equation, the position is slightly different. Again the optimal regime in terms of costs is to charge at home overnight; the difference however lies in the fact that it is

better to make use of opportunity charging anywhere than only at home. Of course, the case for an individual may be very different from the average case.

4 The relative worth of using different regimes cannot simply be measured in term of monetary savings. The effects on the usefulness of the vehicle must also be considered. The above figures should therefore be studied in the light of the graphs of application potential presented in section 6.7 and each motorist will have to make up his own mind on what penalties he is prepared to pay.

5 In practice it is probable that motorists will not follow any one charging regime but habits will vary according to needs. With certain levels of foreknowledge of future needs and by applying recommend guidelines on optimal battery management policies, the motorists will be able to achieve even greater savings than are indicated above.

9.3.5 SCENARIO APPROACH - 'BEST' AND 'WORST' CASES

The above analysis and sensitivity analysis have only looked at cases where one variable is examined in isolation from all other variables. This gives little insight into the case where several variables take values other than the 'best estimate'. A scenario approach was adopted to look at the 'worst' and 'best' cases. All the variables listed in table 9.1 were simultaneously set at the most pessimistic and then the most optimistic estimates in turn (values shown in table 9.1). Although it is unlikely that every relevant variable will take such an extreme value at the same time, this provides an upper and lower boundary for the economic case. Scenarios are shown using different charging regimes and battery life formulae.

TABLE 9.4

SUMMARY RESULTS OF SCENARIO ANALYSIS

1 SCENARIOS USING MOST OPTIMISTIC ESTIMATES FOR ECONOMIC VARIABLES

CHARGING REGIME &	ANNUALISED SAVINGS (£)			% OF MOTORISTS
BATTERY FORMULA USED	AVERAGE	MAXIMUM	MINIMUM	MAKING SAVINGS
BASE CASE (AT HOME ANYTIME-SEMI-LOGARITHMIC)	690	1335	219	100
AT HOME OVERNIGHT SEMI-LOGARITHMIC	822	1339	481	100
ANYWHERE ANYTIME SEMI-LOGARITHMIC	768	1459	264	100
AT HOME ANYTIME CHLORIDE FIGURES	842	1456	481	100
AT HOME OVERNIGHT CHLORIDE FIGURES	846	1403	481	100
ANYWHERE ANYTIME CHLORIDE FIGURES	812	1415	481	100
BASE CASE CHLORIDE FIGURES WAIT UNTIL DOD > 20%	865	1463	481	100
BASE CASE CHLORIDE FIGURES WAIT UNTIL DOD > 40%	870	1458	481	100

(Economic variables - see table 9.1)

2 SCENARIOS USING MOST PESSIMISTIC ESTIMATES FOR VARIABLES

CHARGING REGIME &	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS
BATTERY FORMULA USED	AVERAGE	MAXIMUM	MINIMUM	MAKING SAVINGS
BASE CASE (AT HOME ANYTIME- SEMI-LOGARITHMIC)	(1197)	(591)	(2792)	0
AT HOME OVERNIGHT SEMI-LOGARITHMIC	(933)	(583)	(1603)	0
ANYWHERE ANYTIME SEMI-LOGARITHMIC	(1040)	(343)	(2702)	0
AT HOME ANYTIME CHLORIDE FIGURES	(894)	(422)	(1383)	0
AT HOME OVERNIGHT CHLORIDE FIGURES	(883)	(525)	(1315)	0
ANYWHERE ANYTIME CHLORIDE FIGURES	(952)	(504)	(1696)	0
BASE CASE CHLORIDE FIGURES WAIT UNTIL DOD > 20%	(848)	(407)	(1245)	0
BASE CASE CHLORIDE FIGURES WAIT UNTIL DOD > 40%	(837)	(385)	(1165)	0

It is evident from the tables that the two scenarios examined represent very different situations and lead to very different conclusions. At one extreme, all island motorists could be expected to make significant annual savings and at the other extreme all would make significant losses. The likelihood of either of these scenarios occurring is remote and the original figures in parts 9.3.2 and 9.3.3 are a fair estimate of the likely outcome.

9.3.6 MONTE CARLO SIMULATION

A Monte Carlo model was built to examine the case where all the economic variables interact at random. (See section 9.2.2 for a description and flow chart). Again this model was used for each different charging regime and battery life formula. Each economic variable used in this model has to be assigned a probability distribution and this is by necessity a subjective operation. The variables used and their assigned probability distributions are shown in appendix 1. These input distributions were compiled from the range of estimates found in the relevant literature and from the Delphi analysis results. The output distributions shown in figs 9.15 and 9.16 were constructed by running the basic economic simulation model for each island driver a large number of times, but on each run the values for each of the relevant economic variables was chosen at random from their respective probability distributions. One thousand iterations of the model were completed for each island driver and each estimate of expected annual savings was recorded. This gives us some idea of the likely economic outcome of using EVs. Each driver was assumed to operate an EV in place of his ICE, and allowing for the uncertainty surrounding the various costs, the resulting distributions show the chance of making savings of all levels. A similar distribution could have been constructed for each individual motorist but this would only show variation due to the uncertainty of future costs and would not show the variation due to different use patterns as well.

FIG 9.15

DISTRIBUTION OF POSSIBLE SAVINGS USING MONTE CARLO MODEL AND SEMI LOGARITHMIC BATTERY LIFE FORMULA

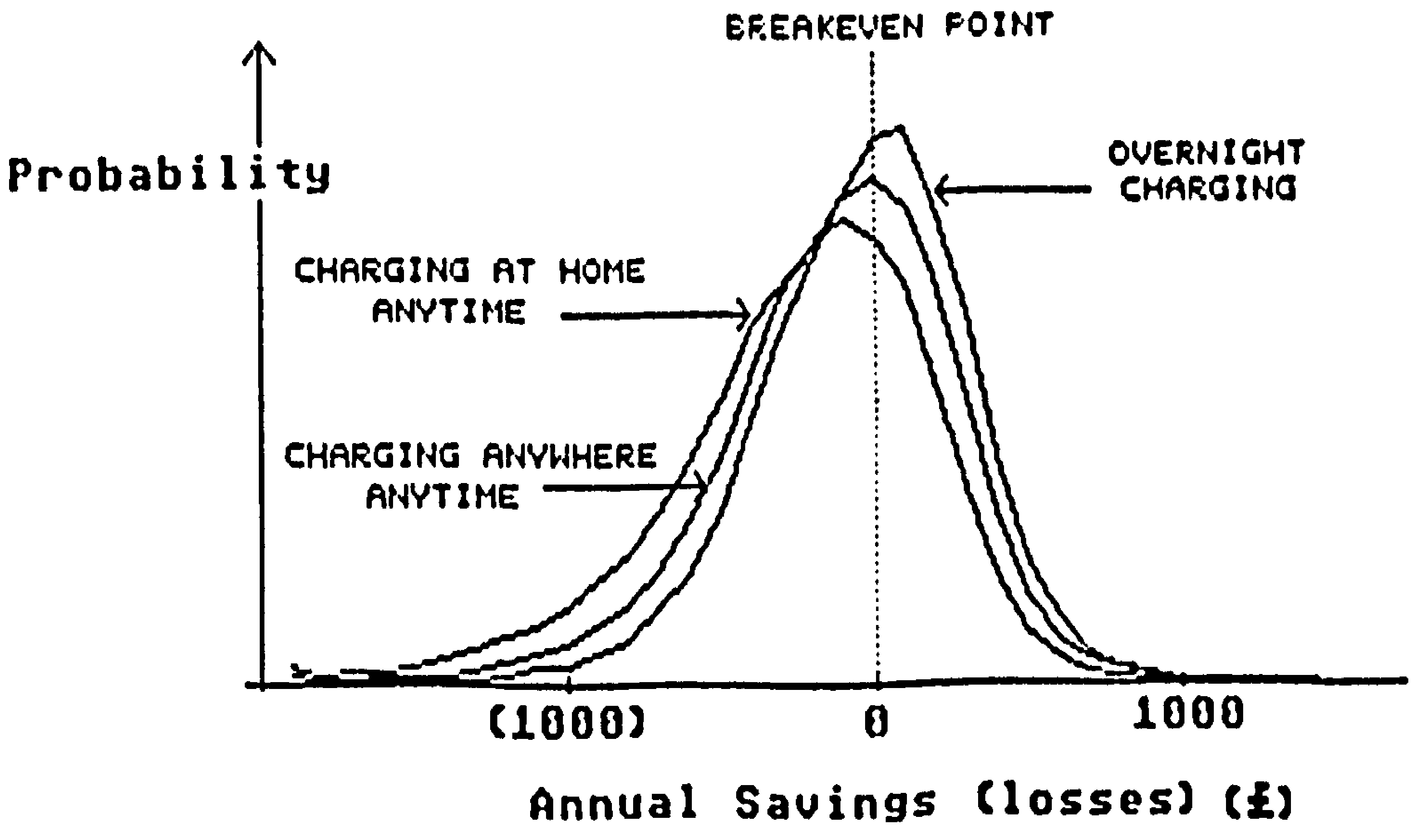
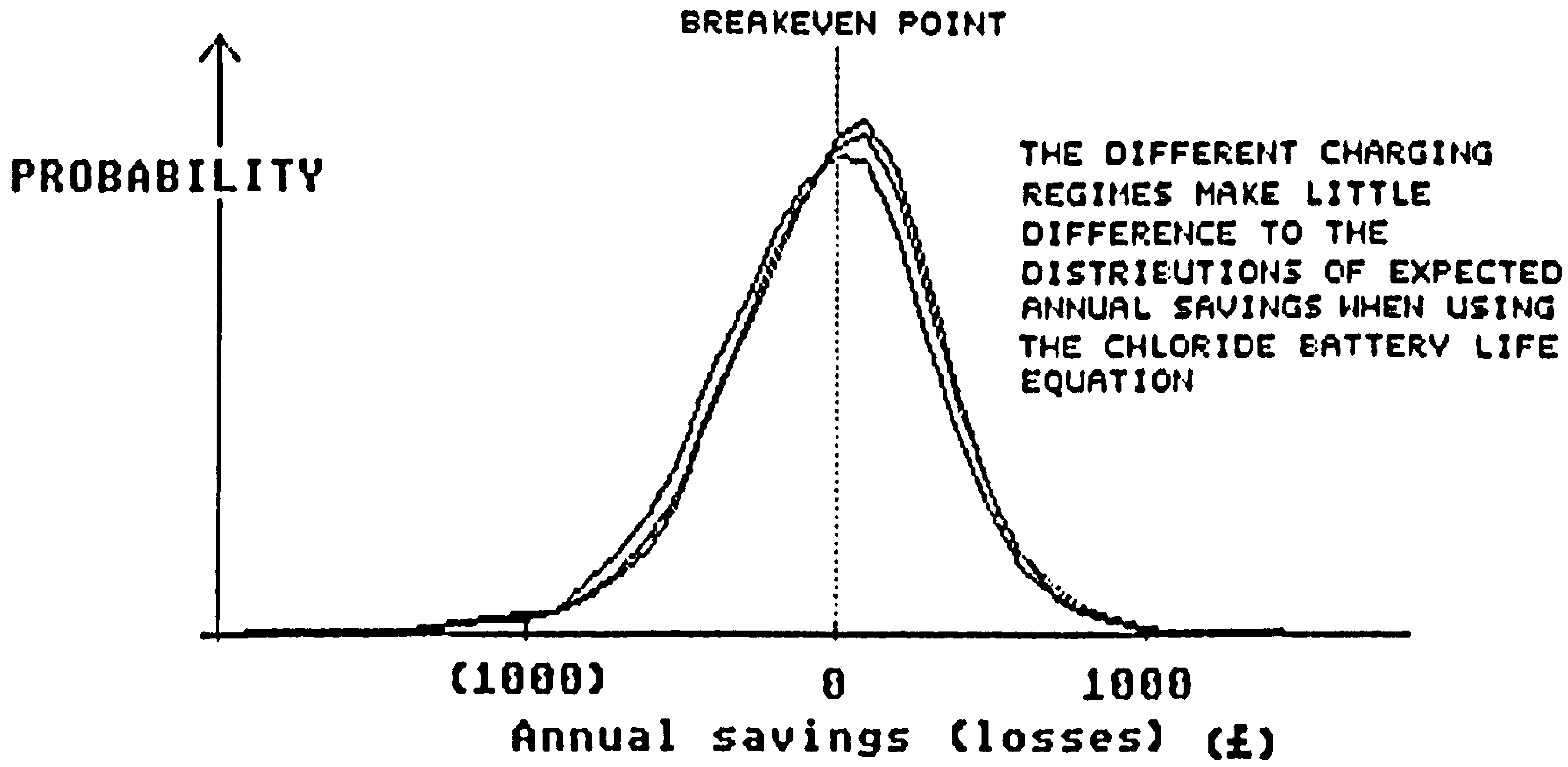


FIG 9.16

DISTRIBUTION OF POSSIBLE SAVINGS USING MONTE CARLO MODEL AND CHLORIDE BATTERY LIFE FIGURES



COMMENTS

1 Both battery life equations give similar though not identical results. There is a significant probability that savings will be achievable using an EV for some island motorists. The average levels of savings is around the breakeven mark, although this varies slightly with the charging regime employed.

2 The semi-logarithmic battery life equation results in the overnight charging regime having the highest expected annual savings overall. Charging at home anytime results in the lowest distribution of savings, however there is not a large difference resulting from the different charging regimes.

3 Using the Chloride battery life figures, the difference due to the charging regimes is even smaller than the above. The order of preference is different in that charging anywhere anytime is the least desirable option in terms of costs.

4 The above conclusions agree with the results of both the scenario analysis and the original sensitivity analysis in section 9.3.3

9.4 MARKET POTENTIAL ANALYSIS

9.4.1 INTRODUCTION

Now that the performance, reliability, realisability, safety and economic case for EV technology has been assessed it is necessary to examine what market potential exists. The market potential can be described as that proportion of the application potential which actually holds the promise of substitution at a given point in time. Having established how many households could, from a technical point of view, operate an electric vehicle (application potential), it is now a matter of estimating how many of these might actually want to buy an electric car under certain circumstances. Because high-performance EV technology is unfamiliar to most motorists it is difficult to quantify the market potential for EVs with great accuracy or certainty and any attempt at quantification must be exploratory and provisional. The approach adopted in this particular analysis was to describe and examine those characteristics of vehicle use patterns and motorists' attitudes which are likely to influence the acceptability of EVs in the islands. By examining such factors it is possible to predict firstly, how the market potential would be affected by future technological and economic developments and, secondly, how the reorganisation of current use patterns and driving habits could increase the level of market potential. In other words, there are many vehicles presently lying outwith the current market potential which might be added to it if certain limiting barriers connected with the technology or current use patterns were removed. Chapter 11 looks more closely at some possible future developments in EV technology that might affect the potential usefulness and desirability of EVs. In this section the market potential is examined firstly by amending the basic application potential in the light of further motorist-specific factors such as the ability to park and charge easily, and secondly by examining the attitudes, needs and wants of island motorists.

9.4.2 DATA COLLECTION

Data on the various market influencing factors were collected on the island from individual motorists by means of a questionnaire (see section 5.3.3 and appendix 5). These factors fell broadly into six main areas,

1 The ability of motorists to reorganise their daily travel requirements in such a way as to increase the potential for an EV to perform as an adequate substitute for their present ICE vehicle. This might involve the re-scheduling of duties between vehicles in a multi-vehicle household or the hiring of an ICE vehicle for journeys to the mainland.

2 The ability of motorists to operate an electric vehicle adequately. This includes such things as the necessity for prospective owners to have appropriate parking facilities where there is access to charging facilities.

3 The preferences, needs and attitudes of motorists concerning the attributes of their personal mode of transport. Some may place great importance upon the top speed and acceleration of their vehicle, while others may place greatest importance upon reliability or economy. The suitability of an electric car will depend upon the individual's preferences, priorities and the strength of his demands.

4 The attitudes of motorists towards the cost savings necessary in order to draw their loyalties away from the ICE. Each individual will have 'his own price' and his own strength of loyalty to his present type of vehicle. It will take different levels of incentive for each in order to compensate for the loss of flexibility associated with the EV.

5 The reactions and attitudes of those interviewed towards the general idea of electric vehicles and also their attitudes towards the possibility of personal ownership. Conclusions can be drawn on the willingness of motorists actually to purchase an EV. Also, the perceived problems with electric cars in the mind of island motorists are not necessarily the real problems or drawbacks. Using all of the

data above, it is possible at this stage in the analysis to examine the difference between the two. The action necessary to reconcile the two can then be highlighted. This may take the form of additional research and development in some area of technology in order to make it more suited for real island needs or it may take the form of educating potential operators about the technology or helping them to come to a more realistic understanding of what their real needs actually are.

6 In addition to the above market influencing factors, quantitative and factual data was gathered to assist in the analysis. The age of currently owned vehicles, the number of cars in the household, vehicle costs and other non subjective data were collected to assist in the determination of market potential.

9.4.3 DESCRIPTION AND EXAMINATION OF THE MARKET

Cannon [15] suggests that the key steps in marketing analysis are, defining the market through measurement of its key features, diagnosis of its purchasing process, definition and description of target groups and segments, and analysis of competitive positions. He suggests that basic questions should be asked, especially the "who, what, where, when, how and why of the markets the firm is in or seeks to enter". The following market analysis is based on this approach and centres largely on descriptions of the relevant market characteristics. A screening process is then used to eliminate progressively unsuitable cases. All figures relate to the islands of Lewis and Harris and unless otherwise stated, all cost and application potential figures relate to a vehicle of 52 mile range and a charging regime where all charging takes place at home only.

9.4.4 TECHNICAL AND USE PATTERN FACTORS

A. ABILITY TO CHARGE

All households are supplied with normal 13 Amp electricity circuits and these would be adequate for most charging needs unless quick charging is desired. The cost of installing higher rated outlets has already been discussed in section 7.4.4, but in addition to having a suitably rated outlet, potential operators must also have a suitably positioned outlet and suitable vehicle parking space. This would seem to be a possible problem for people living in more built up areas where parking is largely in the street. Table 9.6 gives a breakdown of where island motorists park their cars when at home.

TABLE 9.6 CAR PARKING LOCATIONS

LOCATION	PERCENTAGE OF CARS
Garage	22.1
Drive	43.6
Side of house	11.8
Street	21.0
Other	1.5
	100.0%

13.2% of all households said that they did not have easy access to an electricity supply for their cars. Many of those parking their cars in the street said that electricity could easily be supplied to their vehicles, but it will be assumed for the remainder of this study that these are not suitable candidates for an EV substitute in the short term. Unless new charging points are installed in the street itself, it would be very unwise and potentially dangerous to run a cable over the pavement. If we eliminate such cases and the remainder of the cases who claimed that they had no suitable outlet, we are left with 75.3% of vehicles.

B. TRIPS TO THE MAINLAND

Although mileages on the islands are limited, once a vehicle is on the mainland the daily mileages that can be expected are far in excess of the range of an EV. Any motorist who is in the habit of taking his vehicle to the mainland would not be expected therefore to buy an EV as the sole replacement for his ICE vehicle unless he could be persuaded to leave his vehicle on the island. Table 9.7 shows the distribution of the frequency of trips to the mainland with vehicles.

TABLE 9.7 MAINLAND JOURNEYS

No. OF JOURNEYS/YEAR	% OF CARS
0	48.5
<1	7.2
1	29.4
2	4.4
>2	10.5
	100.0

48.5% of domestic vehicles never leave the islands and a further 7.2% leave only on very rare occasions. This represents the basic number of vehicles which could most easily be replaced given certain other suitable characteristics. It can be seen that the potential target market could be doubled if the remainder of motorists did not take their vehicles to the mainland. This should be borne in mind by any EV manufacturer who wishes to increase the market. To take a car on the ferry costs approximately £60 return to the mainland, so if it were possible to hire a conventional ICE vehicle at the mainland ferry terminals for a reasonable price, many motorists might be persuaded to leave their own vehicles at home. 61% of those motorists who are in the habit of taking a car to the mainland said that they would be prepared to hire a vehicle instead provided that it was not too expensive. It might therefore be in the interests of EV manufacturers to provide a cheap car hire service to EV owners as part of a sales package in order to increase the potential market significantly. This service might even be provided at subsidised prices because of the compensating EV sales. The cheaper the hire charges the more prepared motorists will be to leave their cars on the island. Manufacturers would have to undertake a cost-benefit analysis of such a proposal. A total of 82.7% of vehicles either never leave the island or their owners stated that they would be prepared to hire a car for mainland journeys.

C. HOUSEHOLDS WITH MORE THAN ONE VEHICLE

This is another application which offers potential for EV substitution. Many of the barriers to introduction are eliminated and previous studies which have examined the domestic EV market have almost invariably restricted their scope to the case of the 'second vehicle' [8] [16]. This is very understandable in the case of mainland vehicles because of the variability in the mileage demands made on the principal vehicle in the household. The argument so far for the island case has been based on a belief that even the principal cars in island households will often have mileage patterns compatible with those of high performance EVs. However, island households with more than one vehicle may offer even more potential for EV use than single car households or city motorists with several vehicles. 29.4% of island motorists operate more than one vehicle. Of this 29.4%, 67% stated that they regarded one of their vehicles as a 'second vehicle' and 88% said that it was possible to reorganise the use of their vehicles so that one of them never undertook mileages outside the range of an electric car (i.e approximately 50 miles per day). This gives a base line total of 12.9% of island vehicles which are suitable for substitution on the "second vehicle basis" provided that the operators are willing to buy and that the costs are attractive.

It would be a mistake however to relegate the EV to the position of 'second vehicle', especially in the island situation. It has already been shown that the electric car used as the basis of the performance simulations would be capable of a 52 mile range with only one charge per day and that it could satisfy between 87% and 94% of island mileage needs depending on the charging regime employed. In addition, over 98% of island journeys could be undertaken by EVs, so it would seem logical to regard the EV as the principal vehicle in the household and the ICE as the vehicle which undertakes the rarer longer journeys. If a motorist is going to own both, he will make his largest savings by operating the EV as much as possible because of the significantly lower variable costs associated with it.

9.4.5 MOTORIST WANTS AND ATTITUDES

A. ATTITUDES TOWARDS VEHICLE ATTRIBUTES

Motorists were questioned regarding the qualities they look for when selecting a new vehicle. The responses are summarised in table 9.8.

TABLE 9.8 DESIRED VEHICLE ATTRIBUTES

	% OF MOTORISTS RESPONDING:-	
ATTRIBUTE	MOST IMPORTANT	IMPORTANT
Reliable	52.1	93.0
Economical	36.6	78.2
Safety	9.1	31.7
Appearance	5.6	19.0
High performance	3.5	9.1
Space	-	12.7
Comfort	-	3.5
Easy maintenance	-	3.5

Only the first five attributes listed above were specifically asked about in the questionnaire but the other responses were suggested by respondents. Although it is difficult to choose one particular characteristic only which is of prime importance, the results above provide some understanding of what type of vehicle would be acceptable to most people. Reliability and economy are undoubtedly the most sought after qualities, whereas high performance and attractive appearance are not top priorities. These attitudes and wants fit in well with the attributes offered by high-performance EVs that have been discussed in previous chapters.

In addition, islanders were questioned in more detail about their attitudes to specific vehicle characteristics and capabilities. They were not at this point told about electric vehicles although some of the later questions made it fairly obvious what was being proposed.

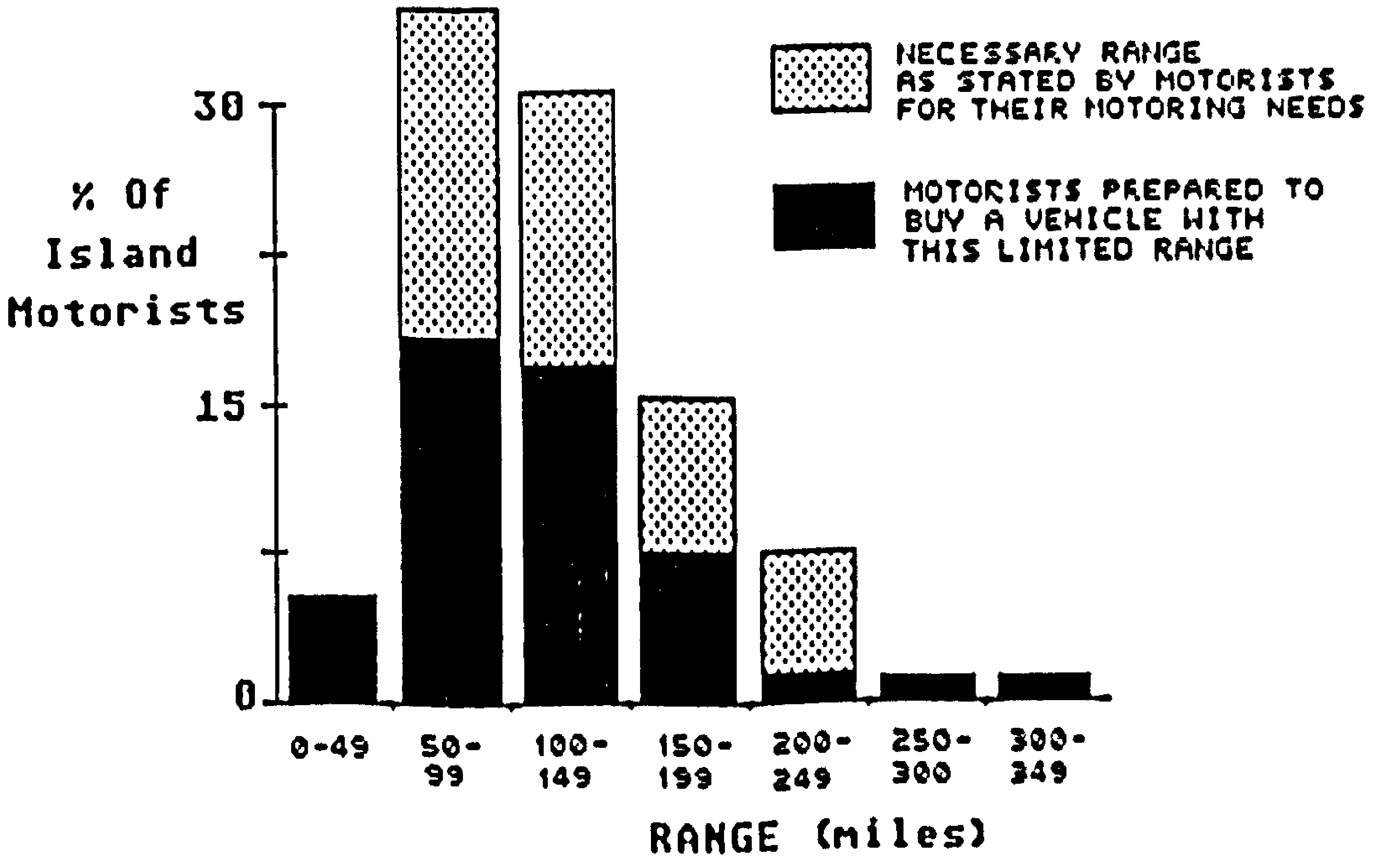
ACCELERATION. Interviewees were asked if they would consider buying a car which had acceleration capabilities similar to a van or diesel car. 73% replied that they would and a further 3% said that they might. An analysis of the vehicles currently operated by island motorists showed that the average acceleration figure as quoted by 'Which Car' magazine is in the range of 15 seconds to reach 60 mph. Only 5% of islanders owned cars which could reach this speed in less than 12 seconds. The electric car used as the basis of the performance simulations has a much slower acceleration profile, taking around 10 seconds to reach 35 mph and about 30 seconds to reach 60 mph [17]. The acceleration at speeds below 30 mph is fairly comparable with a standard small ICE car but at greater speeds performance is significantly poorer. This is due to the torque profile of traction motors which develop maximum torques at relatively low speeds. However island motorists did not seem too reluctant to sacrifice some of this acceleration performance.

MAXIMUM SPEED. Interviewees were asked if they would consider buying a car with a top speed of 70 mph. 76.5% stated that this would be acceptable and many even stated that anything more was undesirable on the islands. Indeed the island roads are not suitable for high speed cruising, many of them being single track and fairly tortuous. Top speeds in this range would not cause as much of a problem on the islands as on the mainland roads and motorways. The average maximum speed for the cars currently operated on the islands is 94 mph but of course the speed limit on island roads is the same as that on the mainland.

LONG RECHARGE PERIOD. Interviewees were asked if they would consider purchasing a car which had to be connected to a power supply over-night. 44.1% said that they would. It must be borne in mind that 13.2% of households stated that they did not have easy access to a suitable electricity outlet and 22% of vehicles are parked in the street overnight. Of those who had suitable parking and charging facilities 74.1% said that they would consider purchasing a vehicle which had to be connected to a power supply overnight.

LIMITED DAILY RANGE. Interviewees were asked if they would consider purchasing a vehicle which had a daily range of 60 miles. Only 28.5% said that they would consider this. Respondents were then asked if this range could be extended to 100 miles, would this be fully adequate, only just sufficient or inadequate for their needs. 50% replied that it would be fully sufficient, a further 24.2% that it was only just sufficient and 25.8% that it would be inadequate. These responses were consistent with the answers to an earlier question about mileage patterns where 53% stated that they would never expect to travel more than 100 miles in any single day. However the analysis of the logbook data showed that over 80% of drivers did not exceed this mileage over the period of data recording. The next question asked motorists what daily range their vehicle would need to have in order to be suitable for their needs and would they consider purchasing a car which was limited to this range. The distribution of necessary ranges is shown in fig 9.17 along with the numbers who stated a willingness to operate such a vehicle.

FIG 9.17 NECESSARY AND ACCEPTABLE VEHICLE RANGES



Again, no effort was made at this stage to introduce respondents to the concept of electric cars and the response to this question about limited daily range should be balanced with the responses to questions directly relating to electric cars after information and likely cost data had been given.

B. ATTITUDES TO COSTS

A picture of the typical attitudes to capital and running expenditure on vehicles was established by indirect and direct questioning. The average price paid for a vehicle by island motorists was £3407 but the distribution is skewed: 20% paid less than £1000 and 50% paid less than £2900. Only 20% paid £5000 or more. 76.5% of cars were purchased second-hand and 73.5% of vehicle owners said that they were in the habit of buying second-hand vehicles. 4.4% said that they sometimes bought new and sometimes bought second-hand cars. The remainder (15%) were in the habit of buying new vehicles whenever they purchased a car. Electric cars are likely to cost more than their ICE counterparts and it could be argued that if a motorist was already in the habit of buying second-hand vehicles, he may be averse or unable to spend large amounts on a new vehicle and the initial cost penalty associated with electric vehicles would only aggravate the situation. Two further questions were asked to investigate this hypothesis.

a) Vehicle owners were asked which of the following costs they considered to be the MOST important when considering their next vehicle,

TABLE 9.9

	COST	% OF MOTORISTS RESPONDING
1	Running costs and vehicle economy	23.5
2	Initial purchase price	22.1
3	Both 1 & 2 are equally important	54.4

This does show that the majority of motorists are concerned with a 'whole life' view of the costs involved and that there is difficulty in separating the two cost elements. EVs would have to be viewed in this way to be attractive to most prospective purchasers.

b) Owners were further asked if they would consider buying a more expensive vehicle than they would otherwise do if the running costs were low enough to pay back the difference over the lifetime of the vehicle. No reference was made to any particular payback period or the magnitude of the necessary additional capital expenditure. The question was simply aimed at exploring a general attitude. 82.4% stated that they would pay more initially if the difference were recovered.

C. ATTITUDES TO ELECTRIC CARS

The objective of the following part of the investigation was to establish the level of awareness of the technology amongst the target population and their attitudes towards it. It is important to understand what people see as its limiting aspects and their worries about it. These can then be compared with the real technical limitations. The importance of this lies in the potential for developing recommendations for suitable action aimed at narrowing the gap between perceptions and reality. This may involve more technical research and development or alternatively, suitable education and demonstration programmes or both. Once all the questions about user characteristics and attitudes had been answered, interviewees were introduced to the concept of EVs. They were read a passage describing the state-of-the-art high performance electric road vehicle (see appendix 5). They were then questioned on their attitudes, worries and willingness to accept or adopt EVs. Firstly, 58.2% of respondents said that they were not aware that such vehicles existed, but it is suspected that this is an underestimate as many other respondents showed signs of lack of familiarity and awareness. When asked to scale their general response and attitudes towards the idea of electric cars the replies shown in table 9.10 were recorded along with the reasons suggested for these responses (table 9.11).

TABLE 9.10 GENERAL ATTITUDES TO ELECTRIC CARS
(After information on EVs had been provided)

RESPONSE	% OF RESPONDENTS
Very Positive	42.9
Favourable	21.4
Indifferent	29.9
Sceptical	2.9
Negative	2.9
	100.0

TABLE 9.11 GENERAL COMMENTS MADE

COMMENT	% OF RESPONDENTS
Good for second car	32
More economical	14
Reliable	13
Don't know enough	12
Not advanced enough	12
Oil supplies limited	8
Poor range/inconvenient	6
Less pollution	5
We don't need them yet	2

It is interesting to note at this stage how low down in the list of general responses/opinions is the inconvenience of a limited range. Also the majority of people were more interested in features that would directly affect them than in environmental or scarce resource issues. This trait became even more pronounced when respondents were questioned about their own willingness to operate an EV and the reasons for any reservations. However, a surprisingly high number of people said that they could imagine that they might buy an electric car instead of a conventional car if there were cost savings available. 25.4% said that they could foresee their purchase of an EV while a further 54.4% said "perhaps". Only 19.4% said unequivocally that they would not. These results were quite unexpected and surprising and because many of those who expressed a willingness to buy an EV were those who had previously said that they would not accept some of the limitations outlined in the questionnaire, it can be seen that there is a greater willingness to accept these limitations when they are associated with an EV than when they are associated with an ICE.

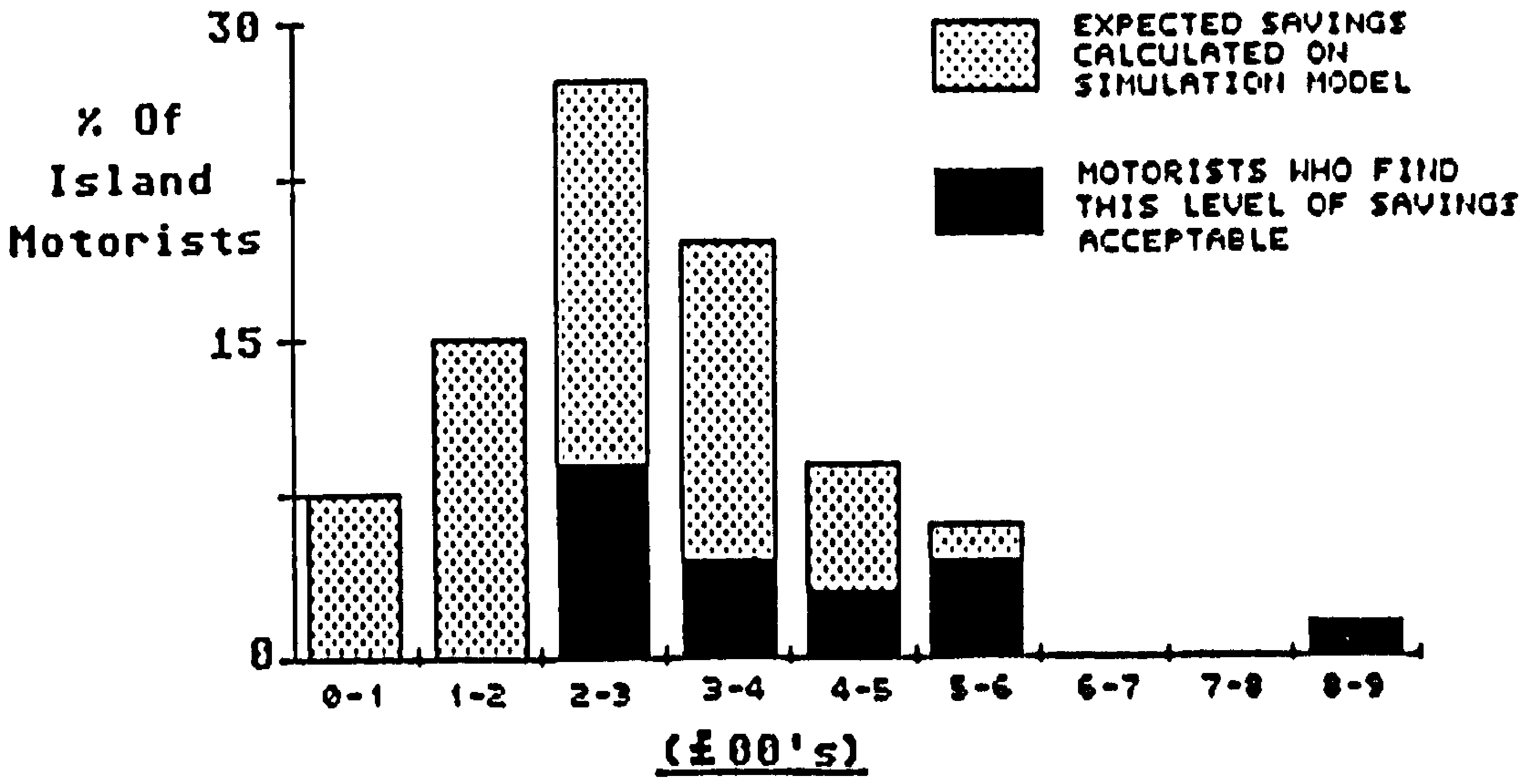
The following table shows the replies to the question of what respondents consider to be the main reasons for anyone NOT buying an electric car. This was an opportunity to express concerns, criticisms and attitudes towards personal ownership.

TABLE 9.12 PERCEIVED MISGIVINGS ABOUT BUYING AN EV

REASON	% OF RESPONDENTS
Limited or inadequate range	34.8
Fear of power cuts	9.0
Loss of freedom	8.6
Don't know enough about it	7.1
Inconvenience of charging	6.1
Poor acceleration	4.9
Not advanced enough yet	4.5
Aversion to change	4.5
Needs more testing	4.5
Purchase cost	4.2
No-one else has one	4.2
Low speed	1.6
Availability of spare parts	1.6
Unsure about reliability	1.6
Concern about load capabilities	1.4
Concern about payback period	1.4

The major misgiving now concerns the limited range and loss of freedom. Other limiting features of the technology such as poor acceleration and low speeds are not a major cause of concern. Surprisingly also, the costs of ownership do not feature strongly. Ultimately, the willingness to buy will be a compromise decision between the benefits of reduced lifetime costs and the sacrifices in terms of convenience and freedom. Interviewees were questioned about the strength of the value that they place on the convenience and freedom associated with their present mode of transport. Firstly they were asked if they would consider buying a vehicle with the characteristics of an electric car if it gave rise to weekly savings of £5 (annual savings of £250). Secondly they were asked how much they would have to save in costs in order to persuade them to buy. This can be compared with the levels of expected savings calculated in the economic evaluation simulation. 32.4% expressed a willingness to buy given a £5 per week saving. Fig 9.18 shows the distribution of annual savings as calculated in the economic analysis and the number of motorists who would be expected to make their specified minimum annual savings

FIG 9.18 EXPECTED & ACCEPTABLE ANNUAL SAVINGS



A total of 28.4% of motorists would be expected to make greater savings than the minimum that they stated they would require before they could be persuaded to buy an EV. There were no islanders who were prepared to accept less than £150 annual equivalent savings.

9.4.6 ESTIMATION OF MARKET POTENTIAL

The market characteristics outlined so far have provided valuable insights into the nature of the market but it is difficult to quantify accurately or meaningfully the overall market potential for EVs in the islands in terms of the number of vehicles which actually hold the promise of substitution under present conditions. Table 9.13 summarises the percentages of motorists who are free from the various technical barriers and who expressed favourable attitudes.

TABLE 9.13

SUMMARY STATISTICS OF MARKET INFLUENCING CHARACTERISTICS

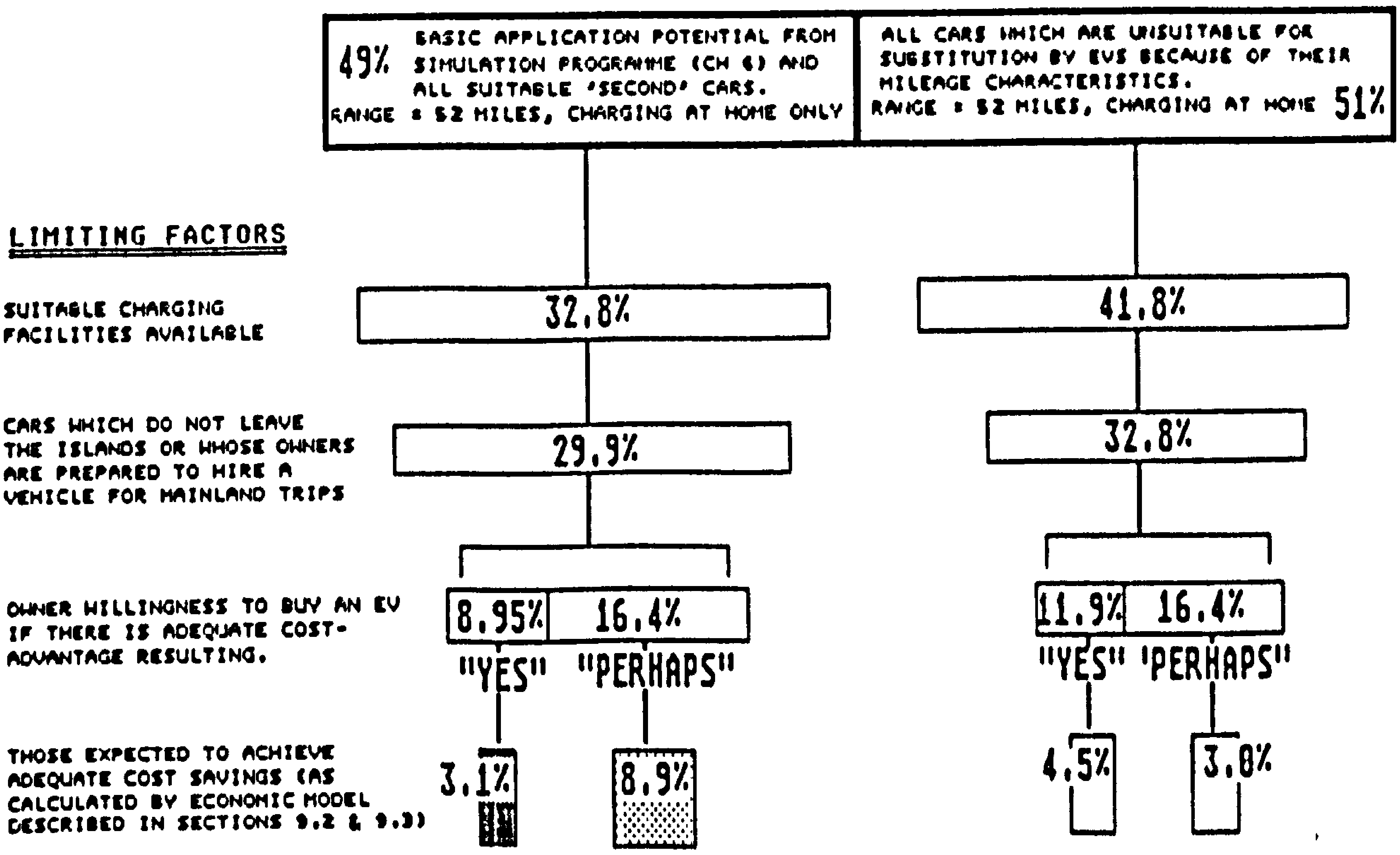
INFLUENCING FACTOR	% OF MOTORISTS
1 TECHNICAL AND HABITUAL FACTORS	
Suitable mileage patterns (original application potential, home recharging only and 53 mile basic vehicle range).	37.2
Suitable 'second' vehicles	8.1
Suitable charging facilities	75.3
No mainland trips (or prepared to hire when on mainland)	82.7
Cost savings expected (for a vehicle with 53 mile range and all charging done at home)	76.0
2 MOTORIST ATTITUDES	
Motorists prepared to accept reduced acceleration	73.0
Motorists prepared to accept reduced top speed	76.5
Motorists prepared to accept charging restrictions (of those who have suitable facilities)	74.1
Motorists prepared to accept range limitations	26.5
Motorists expressing willingness to purchase an EV	25.4

It is clear that the factor which causes the greatest concern is the limited vehicle range. However, market acceptance could also be increased by varying degrees by improving the other vehicle performance characteristics, by the provision of charging facilities and by encouraging motorists not to take their vehicles to the mainland.

An estimation of current market potential can be achieved by using a screening process on the original survey data to progressively eliminate vehicles which would be unsuitable for substitution because of one or more of the reasons discussed above. This is shown diagramatically in fig 9.19. The left-hand figures show those vehicles which remain in the market potential as various technical and economic barriers eliminate unsuitable cases. The right-hand figures show all those vehicles which would remain within the market potential except for the inadequate range of the substitute EV.

FIG 9.19 MARKET POTENTIAL ANALYSIS (LEWIS AND HARRIS)

All figures come from island survey data and relate to the percentage of vehicles in the islands. Those vehicles which are not suitable for substitution by EVs are eliminated progressively to leave the remaining market potential.



Under present conditions there are 3.1% of islands cars which could be substituted by EVs and whose owners expressed willingness to substitute at the present level of expected savings. This is the most basic measure of market potential at the present time. A further 8.86% of vehicles are owned by people who said that they might consider substitution, so the real potential for EV substitution lies somewhere between 3.1% and 11.96% of island vehicles.

Interestingly, 5.5% of motorists said that they could foresee themselves buying an EV, but an analysis of their driving patterns and habits showed that they were unsuitable candidates for EV substitution for one reason or another. A further 16.7% of motorists proved to be unsuitable candidates for substitution but stated that they would "perhaps" buy an EV. It can only be assumed that these motorists would either be prepared to tolerate a certain level of inconvenience and reorganisation or they were not fully aware of the implications of EV ownership.

These calculations of market potential have been based on the assumption that the EV substitute has a 52 mile range (from performance simulation analysis) and that all charging must be done at the owners premises. However, the estimated annual savings and basic application potential changes if technical or economic conditions change, so the estimated market potential can also be expected to change. The methodology used in this analysis allows the effects of such changes to be examined. Fig 9.20 shows a renewed calculation of market potential for a vehicle with a 100 mile range (the charging regime remains unchanged as do the cost characteristics of the vehicle).

If fig 9.20 is compared with fig 9.19 it can be seen that many of the vehicles which fell outside the application potential in fig 9.19 but which were suitable for substitution in other respects have shifted into the basic application potential and market potential in fig 9.20. The resulting market potential has risen to between 6.0% and 16.4% of island cars.

Similarly, the effects of changes in economic conditions can be examined. Fig 9.21 shows the changes in market potential resulting from a rise in the price of petrol to £2.50 per gallon.

FIG 9.20 MARKET POTENTIAL ANALYSIS (LEWIS AND HARRIS)
All figures come from island survey data and relate to the percentage of vehicles in the islands. Those vehicles which are not suitable for substitution by EVs are eliminated progressively to leave the remaining market potential.

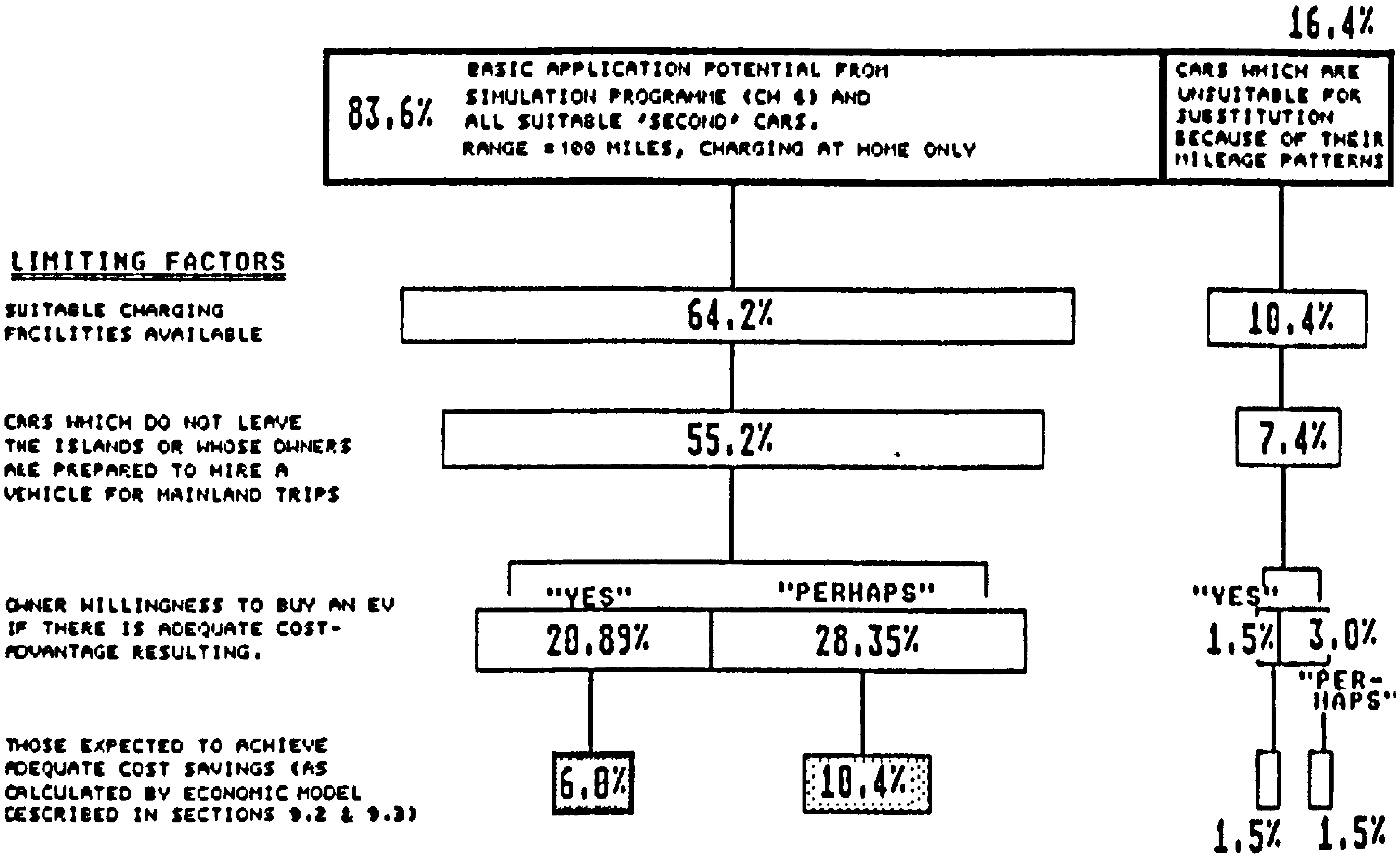


FIG 9.21 MARKET POTENTIAL SENSITIVITY ANALYSIS (LEWIS AND HARRIS)
All figures come from island survey data and relate to the percentage of vehicles in the islands.

	MARKET POTENTIAL (percent of island cars)		
	THOSE WILLING TO BUY	THOSE WHO SAID THAT THEY "MIGHT" BUY	TOTAL
1 RANGE = 52 MILES (from fig 9.19)	3,1%	8,86%	11,96%
2 RANGE = 52 MILES AND PETROL COSTS £2.50 / GALL	6,0%	12,0%	18,0%
3 RANGE = 100 MILES (from fig 9.20)	6,0%	10,4%	16,4%
4 RANGE = 100 MILES AND PETROL COSTS £2.50 / GALL	10,4%	13,4%	23,8%

For a vehicle with 52 mile range the market potential lies between 6.0% and 18.0% of island cars and for a vehicle with 100 mile range the market potential lies between 10.4% and 23.8%.

It is evident that vehicle range and the economic case surrounding the use of EVs are the greatest barriers to acceptance and adoption of EVs. In the basic case represented in fig 9.13 (derived from economic analysis, see table 9.1) 76% of motorists can be expected to make savings by using an EV in place of their existing ICE vehicle but many of these do not make great enough savings to encourage them to change to EVs (see fig 9.18). Only 28.4% of motorists would be expected to make greater savings than the minimum that they would require. If petrol cost £2.50 per gallon 93% of motorists would be expected to make annual savings, but only 40.3% would accept these as adequate. 25.4% of motorists stated that they would require savings in excess of £700 per year before they would accept the performance limitations typical of EVs, and 9% said that they would not accept these limitations whatever the savings were. Although there are substantial savings available (see section 9.3) they are inadequate in many cases to encourage adoption.

The estimates of market potential can be translated into absolute numbers of vehicles. There are approximately 4450 domestic vehicles on the islands of Lewis and Harris. A market potential of between 3.1% and 11.96% represents between 138 and 532 vehicles. This can be translated into a measure of sales potential which expresses the level of annual sales that could be expected once an electric vehicle population is established. If it is assumed that EVs will have a longer lifetime than ICE vehicles by a factor of 1.5 (see section 9.2.4) then each vehicle will be replaced approximately every 10 years. This translates into an annual sales potential of between 14 and and 53 new vehicles every year for the islands of Lewis and Harris. Of course there are many island communities in Scotland similar to these islands and if these are assumed to hold similar proportions of market potential, the total current market potential would be more in the region of 682 to 2631 vehicles giving an annual sales potential of 68 to 263 vehicles (current vehicle population statistics obtained from Transport Statistics HMSO publication). Table 9.14 shows the range of estimated market and sales potentials for the Western Isles, and for all the Scottish islands, for several technical and economic conditions.

TABLE 9.14
MARKET AND SALES POTENTIAL ESTIMATES

ECONOMIC & TECHNICAL CONDITIONS	LOCATION	ESTIMATED MARKET POTENTIAL (Vehicles)	ESTIMATED SALES POTENTIAL (Vehicles/year)
1 Present conditions (52 mile range)	Lewis/Harris	138 - 582	18 - 58
2 "	Scottish islands	682 - 2631	68 - 263
3 EV range = 100 miles	Lewis/Harris	267 - 730	27 - 73
4 "	Scottish islands	1320 - 3608	132 - 361
5 Petrol cost = £2.50	Lewis/Harris	267 - 801	27 - 80
6 "	Scottish islands	1320 - 3960	132 - 396
7 EV range = 100 miles & petrol = £2.50/gall	Lewis/Harris	463 - 1059	46 - 106
8 "	Scottish islands	2288 - 5236	229 - 524

9.5 SUMMARY AND CONCLUSIONS

It can be seen that the most limiting technical feature of the EV for domestic island motorists is the basic daily range. This was presented in the application analysis and it was seen that as vehicle capabilities increased, the application potential increased dramatically. With present vehicle ranges the potential is limited but range increases which can reasonably be expected (see chapters 2 and 11) would enable the EV to be suitable for most island motorists. However it is the attitudes of motorists and their economic demands that will limit EV adoption in the forseeable future. Even if vehicle range is extended, the market will be restricted by such attitudes. This is partly a matter for suitable education and demonstration programmes which are aimed at showing potential market segments how suitable the EV is for their real needs (see section 4.4). However, the expected levels of savings that would accrue to the majority of motorists are still inadequate for their demands. Expected savings will rise as fossil fuels rise in price and the technology matures. Motorists may gradually accept more reasonable levels of saving as the technology becomes more familiar and its use becomes more widespread. In addition, in the event of fossil fuel shortages, the EV may be preferred because of the security of utility offered by it.

The current market and sales potential in Lewis and Harris and even throughout the Scottish islands is small in comparison to ICE markets. However, even at these small levels of potential, island communities could offer a very useful and valuable market for EV manufacturers seeking new or additional markets. This is especially true if there are advantageous technical developments (see chapter 11) or suitable economic developments (section 9.2). In addition, there are huge numbers of island communities in the World which together might offer considerable market potential for EV developers.

CHAPTER 10

A CASE STUDY - GROCERY VANS AND SCHOOL BUSES

CHAPTER 10

A CASE STUDY - GROCERY VANS AND SCHOOL BUSES

10.1 INTRODUCTION

Although this study is concerned predominantly with the potential for domestic electric vehicles in the island application, this section looks at a slightly different vehicle and application. However, the methodology used for the case of the domestic vehicle is applied to this further analysis as a case study.

There are certain peculiarities about the Western Isles which deserve special attention and which present special opportunities for the EV. The Western Isles are unique in many respects; religious, cultural, agricultural, commercial and industrial. The pattern of grocery shopping is also different from most mainland areas in that many islanders depend upon "mobile shops" for a large part of their shopping. The islands are well supplied by such travelling shops which supply the more remote villages on a regular basis. The operator-owners of these businesses usually operate two or more vehicles for this purpose. One vehicle is used for selling the groceries and is normally a large van capable of storing a surprisingly wide variety of goods while the second vehicle is normally a smaller van, usually a Bedford or Sherpa 1 tonne van, and is used entirely for collecting stores from the island capital, Stornoway. Both of these vehicles have a very fixed and predictable pattern of use. Many operators use several vans, all of which have limited mileage but regular use. There are currently 63 licensed operators of registered food vehicles in

Lewis and Harris. Many of the larger vehicles which are used as shops are quite old but the smaller supply vehicles are very similar in nature to the electric conversions available and would appear to have use patterns which are very well suited to the electric versions.

Similarly, the dispersed nature of the island population necessitates the daily transportation of a large percentage of school children to and from the schools. Although there are many primary schools, there is only one large secondary school on the island and one technical college, both of which are in Stornoway. Children from other islands have to reside in Stornoway during the week but pupils from Lewis and Harris travel daily via a large fleet of school buses. Most of these buses are small mini-buses which travel relatively short distances. Once again, the routine nature of their use and the type of vehicle would suggest that they would be prime candidates for substitution by electric equivalents. Although these applications are slightly different from the mainstream case of electric cars, there is good reason to examine them.

a) Assessing the potential in the above applications allows the methodology for assessment which has been developed to be illustrated and tested.

b) It is commonly accepted that commercial electric vehicles are more likely to succeed in the market place before private domestic vehicles (see section 4.2.3). It is wise therefore to identify areas where electric vans could feasibly be used, as successful introduction of these will increase awareness of the technology and act as a stimulus to the private market.

c) This study is concerned with electric vehicle potential and introduction in the island situation and would be incomplete without a look at some of the more promising applications.

d) Because electric cars are still very much at the laboratory stage of development, accurate information on their performance, costs, reliability and so on is still very tentative and uncertain. While this study has attempted to examine and reduce some of these uncertainties, there is still a lot to be learned about their operation in practice. Electric commercial vehicles however, and electric vans in particular have been produced for some time now and there is much more reliable operating experience and information available. Apart from making analysis more straight-forward and accurate, this will help to provide insights into the nature of the vehicles and their assessment.

There may well be other suitable applications such as Post Office vans or building contractors' vans. Information has not been gathered on these. Discussion with the local Hydro Board, the Council transport department and several private building contractors suggested that the mileage of these vehicles is too variable and often too large to merit special investigation.

Data was collected by means of a questionnaire which was circulated by post. In Lewis and Harris 30% of all the registered food vehicle operators and 33% of school mini-bus operators provided information about their mileage patterns, type of vehicles used and vehicle requirements.

The remainder of this section will be based upon Lucas Chloride electric conversions of the Bedford CF and Freight Rover Sherpa 1 tonne vans.

10.2 VEHICLE PERFORMANCE

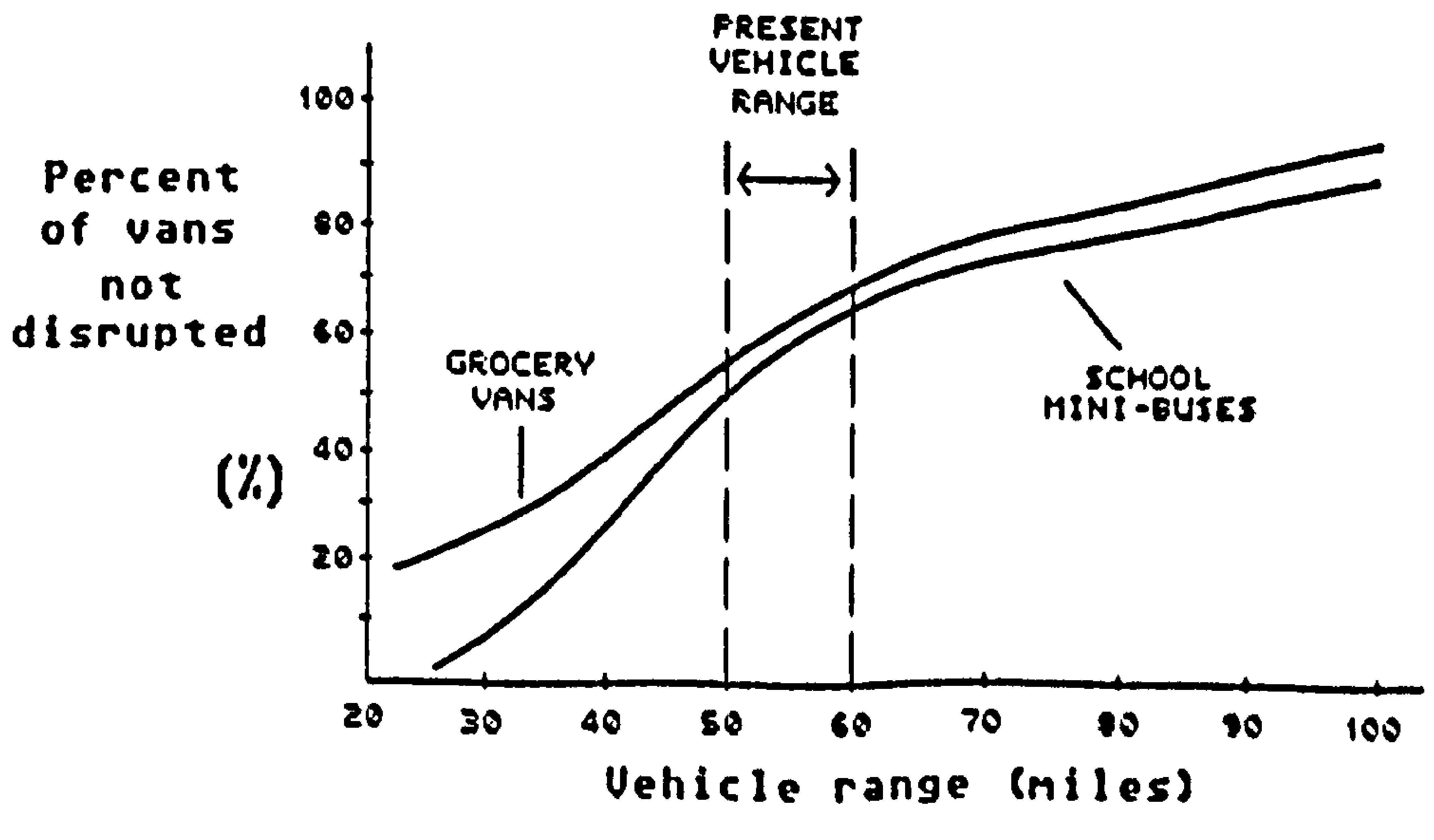
Lucas Chloride report operating ranges for their electric vans of 50 miles under city driving conditions when fully laden [1]. In practice, operators such as the electricity boards have reported ranges of between 50 and 60 miles. Of course, the driving style of individual drivers affects this, but once the driver becomes familiar with the vehicle these ranges are achieved. In addition, it has been found that if the battery runs flat during a journey, a short rest period of about 20 to 30 minutes has enabled the battery to recover enough without any recharge to permit approximately 5 more miles to be achieved. From the simulations undertaken during this research it was shown that typical island ranges corresponded closely to those achieved in urban areas. Energy consumption is reported by manufacturers and operators as being approximately 1.0 Kwh/mile. Again this figure corresponds to simulation results.

Vehicle specifications claim that the maximum gradient ability from stationary is 16% [1]. This is adequate for all island roads. Maximum cruising speed is 60 mph [1].

10.3 APPLICATION POTENTIAL

Using the same definition of application potential as in section 6.7, (i.e number of vehicles which could be substituted without causing any 'inconvenience' and assuming present driving patterns) we can establish a relationship between vehicle range and application potential. This is shown in fig 10.1. In this analysis it is assumed that opportunity charging is not utilised and that all charging takes place overnight. This is not unrealistic as these vehicles are always on the move when they are being used but sit idle for long periods of time at the owner's premises outside of working hours.

FIG 10.1 APPLICATION POTENTIAL FOR VANS VERSUS VEHICLE RANGE



10.4 RELIABILITY AND OPERATING EXPERIENCE (See also section 7.2)

Lucas Chloride EV Systems Ltd reported that their electric conversions were extremely reliable in operation and would result in reduced downtime [2] compared to ICE versions, but operating experience suggests that this is optimistic. It would be fair to say that many of the problems experienced have been of a 'teething' nature, and that once these are ironed out the electric vans should indeed be more reliable than the ICE counterparts. There are many fewer moving parts and reduced heavy vibration, not to mention the absence of an exhaust system, gear box, clutch system and so on. The SSEB who run a fleet of over 80 such vans report that they experienced many problems connected with the control mechanism. Strathclyde University Energy Unit have been helping with these problems since Lucas Chloride and Bedford ceased to sell and service these vehicles. Operating experience in the US has shown that batteries constituted the number one problem with electric vehicles [3]. More than 80% of all maintenance actions reported by site operators are related to batteries. The SSEB have also reported that the batteries demand much attention but this is expected to reduce as experience is gained and minor problems are solved. This is certainly the case with the better established electric vehicles such as milk floats or industrial EVs.

10.5 REFUELLING AND AVAILABILITY

It is assumed that all charging will take place at home with these vehicles. There would seem to be no problems associated with this except that operators will have to install larger electricity outlets than the normal 13 Amp sockets, and fire safety regulations would have to be observed. The vans have large batteries and they require a starting charging current of 30 Amps. In chapter 7 the adequacy of the electricity distribution network and the costs of installing larger electricity outlets was examined and once again there seems to be little barrier to the use of electric vans for grocery rounds and school routes.

10.8 ECONOMIC ANALYSIS

The costs provided by Lucas Chloride as an aid to comparison with the ICE versions are based on the assumption that the van is used for exactly 45 miles a day, 5 days a week and is charged every night. In addition the costs are given in 1985 terms so it was considered necessary to revise some of the costs and assumptions.

a) Maintenance costs are reported by Lucas Chloride as being 50% of the ICE cost per vehicle but tyres are slightly more expensive due to the increased vehicle weight. The ICE maintenance costs are based on figures quoted in 'Commercial Motor' Tables of operating costs.

b) Petrol price has been revised at £1.85 per gallon and ICE fuel consumption is assumed to be 18 miles per gallon. It is assumed that commercial operators will be able to pass on the VAT charge on the petrol and hence net fuel costs are £1.57 per gallon.

   Electricity is priced at 2.1 pence per Kwh and field trials have established an energy consumption of 1.0 Kwh/mile.

c) The EV is exempted from the MOT test and road tax but the ICE incurs these standing charges.

d) The EV is assumed to have an 8 year operating life and the ICE a 6 year life. Both of these figures are probably on the conservative side, especially on the islands where vehicles have a fairly modest mileage. An extension of these lives would favour the EV economics relative to the ICE. Vehicle costs are totally written off over the vehicle life, there is no residual value and the EV cost excludes the cost of the battery. Once again a capital recovery factor is used as in chapter 9 to annualise the depreciation cost. The discount rate is fixed at 9%.

e) The reported battery costs were all calculated for a fixed daily mileage of 45 miles, 250 days a year. This according to Chloride batteries is the optimal depth of discharge and will result in minimum battery costs. In reality, very few vehicles can be expected to meet these restrictive assumptions so it was considered necessary to revise the basis of calculation. The average daily depth of discharge which would result from present island driving patterns was used to calculate the battery cycle life expected and hence the total miles expected. Knowledge of each vehicle's annual mileage allows the battery life in years, and hence annual cost, to be calculated for each vehicle individually. Battery cycle life was calculated using the techniques described in section 9.2.7.

Instead of calculating all costs on a 'per mile' basis as Bedford and Lucas Chloride have suggested, it is more accurate and allows more account to be taken of the individual case if battery and vehicle costs are annualised. A reasonable revision of costs based on those supplied by LCEVS is shown in table 10.1.

TABLE 10.1 EV VERSUS ICE OWNERSHIP COSTS

COST	EV	ICE
Maintenance & Tyres	5.8 p/mile	9.9 p/mile
Fuel costs	2.1 "	8.7 "
MOT and Tax	-	£120 /year
Vehicle depreciation	£1220 /year	£1232 "
Battery	"individual"	-

From the above costs we can establish a formula for determination of individual annual savings,

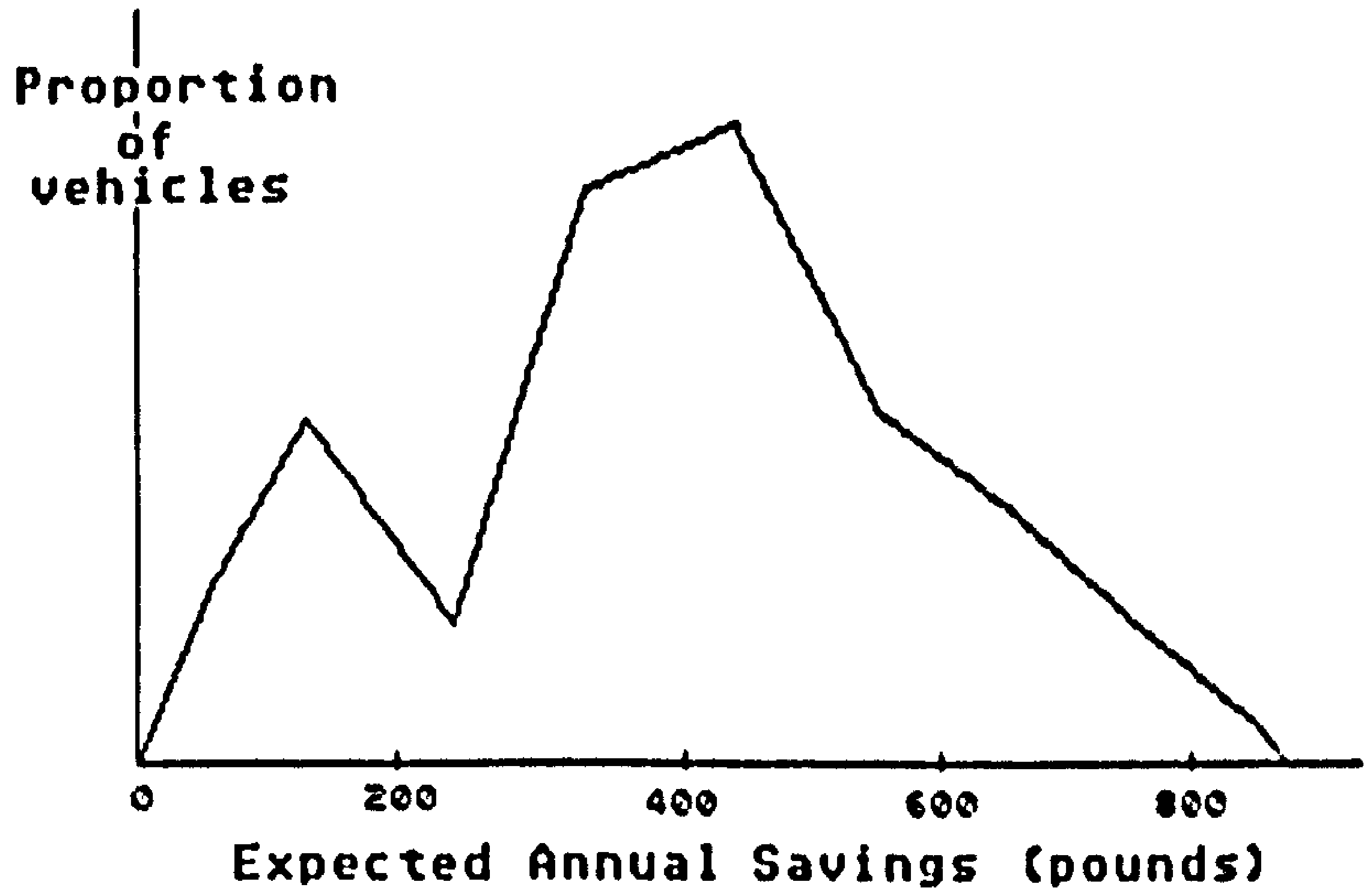
Difference in MOT, tax, depreciation, = £132/year
Difference in cost/mile (maintenance, tyres, fuel) = 10.5p/mile

ANNUAL SAVINGS = £132 + (miles/year x 10.5 pence) - Battery costs

Using this formula each case was evaluated separately and fig 10.2 shows the resulting spread of savings.

FIG 10.2

DISTRIBUTION OF EXPECTED ANNUAL SAVINGS FOR GROCERY VANS AND SCHOOL MINI-BUSES



There were 13% of vehicles which had too high a daily mileage to be suitable for substitution by EVs. 35% of vans have suitable average daily mileages but exceed the EV maximum range on too many occasions to be considered seriously for substitution. This leaves 52% of vans (the basic figure for application potential) which would experience no inconvenience through being electric and which could expect to yield cost savings if they were electric. Of course it may be that the level of savings available to those operators who are currently exceeding the daily range from time to time might be adequate to entice operators away from the ICE and reorganise their travel patterns in order to substitute an electric van.

It is interesting to note that the average expected saving for mini-buses is £503/year whereas for grocery vans it is £347/year. The difference is due to the higher utilisation of mini-buses (33% greater annual mileage) and the more fixed and regular nature of their travel patterns. This makes them very good candidates for EV substitution.

10.7 MARKET POTENTIAL

All vehicles were expected to give rise to annual savings if they were electric and these expected savings were substantial. In the case of the domestic vehicle, the freedom and the joy of motoring offered by the ICE would lead to a certain amount of reluctance on the part of the owner to change to an EV. With commercial vehicles however it is expected that these barriers will not be so strong and that commercial operators will place more importance on operating costs. Another barrier to market potential is the habit some drivers have of occasionally taking their vehicles to the mainland where long mileages are incurred. 84% of grocery vans and 70% of school mini-buses never leave the islands. This is a higher percentage than for domestic vehicles. Of those vehicles which remain on the island throughout their lives, 62% of grocery vans and 63% of mini-buses have suitable mileage patterns and economic savings, giving a theoretical market potential of 52% and 44% respectively.

This figure represents the upper limit of market potential without reorganisation of travel patterns. Such reorganisation due to the availability of cost savings could increase the market potential, but it is impossible at this stage from the data gathered to estimate the magnitude of this increase. Although there would appear to be a considerable market potential, it is difficult to predict how much of this will be realised and converted into sales. In general, operators suggested that they were concerned with 'whole life costs' and not just initial purchase cost or daily running costs. 82% stated that they would consider buying a more expensive vehicle in order to reap whole life savings. Nevertheless, 52% of grocery vans and 65% of mini-buses were purchased secondhand. It might be difficult to persuade operators to spend large amounts of money for a new electric van as a substitute for a cheaper secondhand ICE van. If it is assumed that the 82% who were prepared to pay more for a vehicle and whose operating characteristics are suitable will actually purchase, we have a resulting market potential of 43% of grocery vans and 36% of mini-buses. This translates into a total of 47 vans and 22 school mini-buses in Lewis and Harris. Although this may appear to be a small total, it would represent one of the largest electric van fleets anywhere in the country. Only the SSEB operate a fleet of comparable size. These results are significant; the presence of 69 electric Bedford or Sherpa vans in Lewis and Harris could be expected to heighten public awareness of the possibilities of the technology as well as to increase confidence in it. There may well be other suitable applications for electric one tonne vans on the islands and this would stimulate their exploitation.

CHAPTER 11

FUTURE DEVELOPMENTS AND THEIR IMPLICATIONS FOR EV POTENTIAL

CHAPTER 11

FUTURE DEVELOPMENTS AND THEIR IMPLICATIONS FOR EV POTENTIAL

> "The rapid progress true science now makes, occasions my regretting sometimes that I was born so soon. It is impossible to imagine the height to which may be carried, in a thousand years, the power of man over matter"
>
> Benjamin Franklin to Joseph Priestly, 1780

11.1 INTRODUCTION

As with any technology, EV technology is constantly moving forwards in terms of performance and costs and any estimate or prediction of application potential, market potential or economic success will soon change in the light of advances. This section is concerned with highlighting some of the areas where progress is being made and where future advances are most probable. However the objective of such an analysis is not simply to describe the technology but rather to examine the effect that possible future advances will have on the capabilities, desirability and usefulness of the EV. The idea behind this approach is more akin to a sensitivity analysis than a survey of the technology, the emphasis being on the implications of developments from whatever source rather than the developments themselves. An attempt will be made to establish relationships between the state-of-the-art and the potential for EV introduction.

The approach taken throughout this study has been one where real life situations have been modelled and simulated in order to provide understanding of the systems examined. This approach facilitates the varying of input parameters that is characteristic of sensitivity analyses.

It is not simply technological developments which will affect the potential usefulness of EVs. Economic, political and environmental developments will also be influential. There are three fundamental areas which will be affected by future developments, firstly vehicle performance, secondly the economic case and thirdly consumer acceptance. These areas often overlap and one development can be the cause of progress in more than one area. In particular, consumer acceptance is largely a function of the first two categories since consumers are primarily concerned with vehicle performance and costs. These three will be examined in turn.

11.2 VEHICLE PERFORMANCE

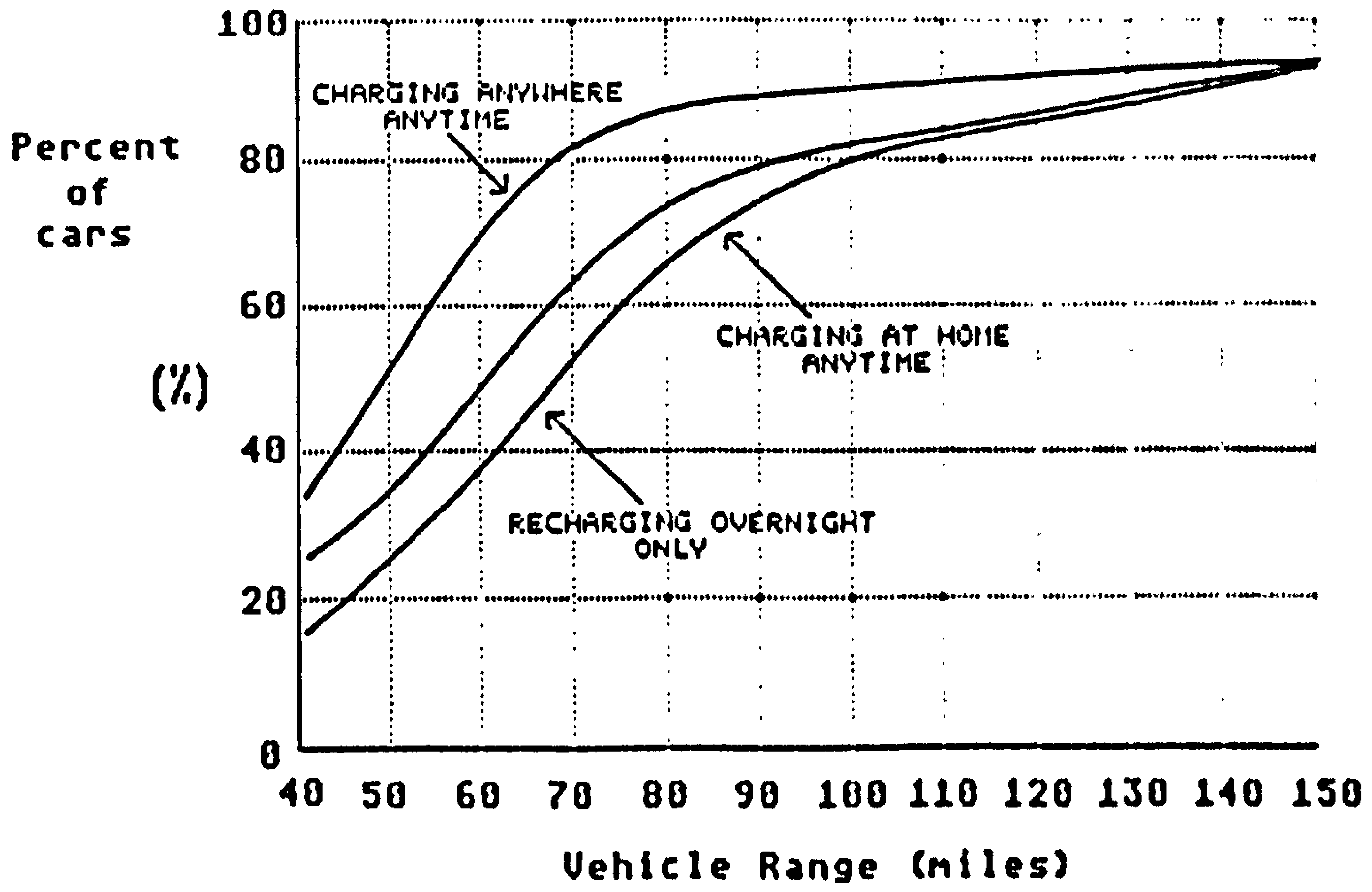
11.2.1 INTRODUCTION

Technically, the major limiting feature of the EV is the inability to carry enough energy. All the limitations such as range, speed, acceleration and grade climbing ability stem from this basic problem.

There are two kinds of technological developments which will lead to increased performance. The first of these is advances in energy source technologies which will enable the vehicle to carry more stored energy on board. The second is advances which lead to more efficient utilisation of the available energy. While work continues in both areas, it is the lure of advanced batteries, with their relatively large contribution to improved performance, which occupies much of the effort and imagination of developers. The rewards are potentially much greater than the second kind of development. The sodium-sulphur battery for example could lead to an increase in basic range of two to three times that of the present.

In chapter 6 a relationship between vehicle range and application potential was established for the island situation using a simulation model. Regardless of where the increase in range is derived from, it is not difficult to see how sensitive the potential for EV introduction is to any favourable range development. This basic relationship is shown in fig 11.1. It is also possible using the framework of this project to go on to see how the market potential is affected (see section 9.4.6 and fig 9.19). Any performance development or improvement should be evaluated in terms of how it affects vehicle range and hence application potential as shown in the graph below.

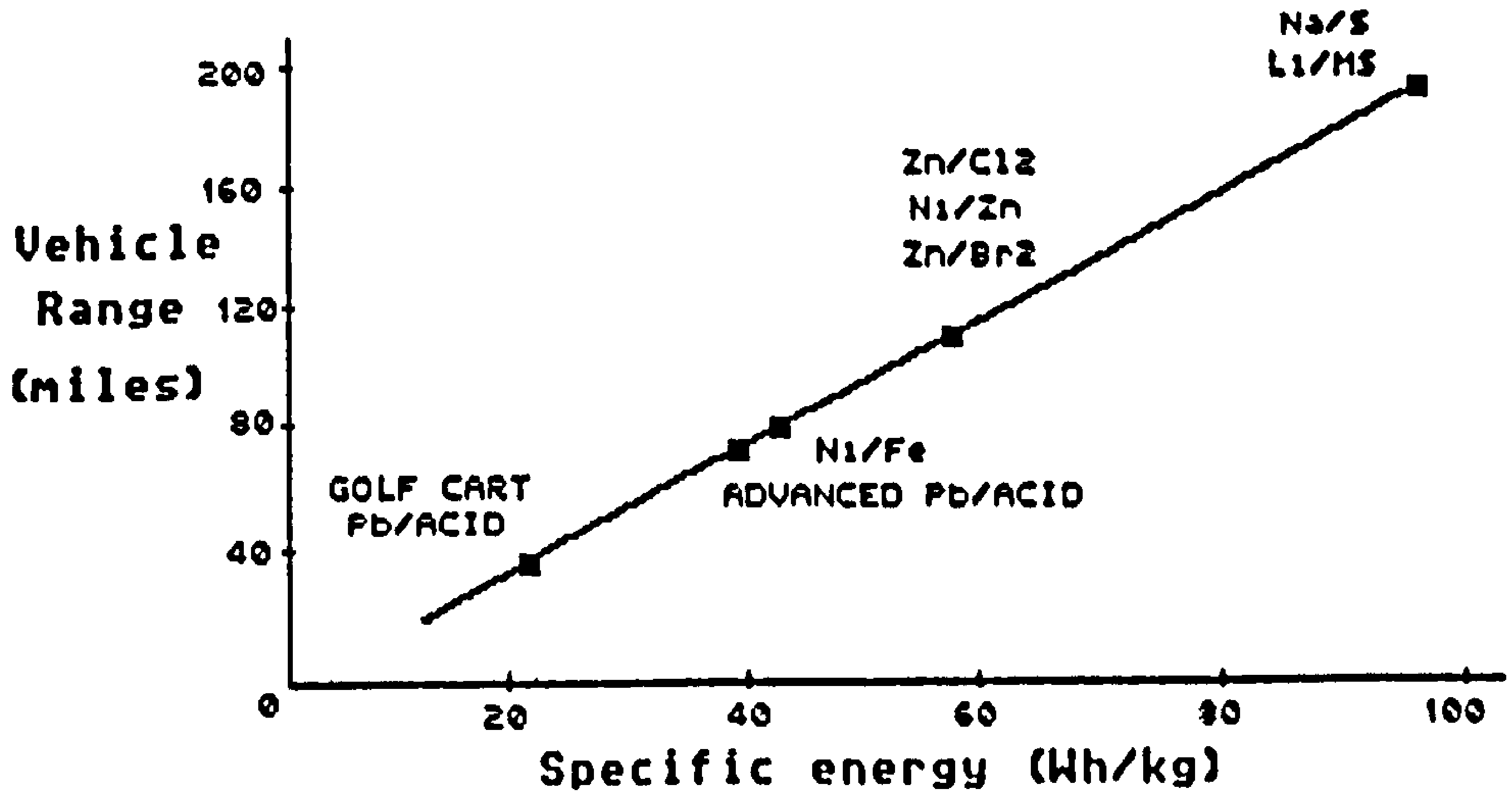
FIG 11.1 Percentage of island cars experiencing no inconvenience, versus vehicle range (Lewis/Harris



11.2.2 BATTERIES

The increase in range and subsequent application and market potential resulting from alternative battery systems will vary for different vehicles and duty cycles. Also, it was shown in chapter 6 that the performance of EVs is more sensitive to the duty cycle than petrol engined vehicles. It is possible to get some idea of the potential impact of new battery systems by using performance simulation models such as the one developed in section 6.3. Figure 11.2 shows the relationship between battery specific energy (Wh/Kg) and range for one particular vehicle under one particular duty cycle. The relationship is characteristic of the general case.

FIG 11.2 Relationship between specific energy and range for passenger vehicle (using the simulation model)



Assumes :- 1) Average energy consumption 200 Wh/kg
2) Driving cycles - Highway 55 mph
- 5-J227 A/D cycles

This is of necessity a simplification of the situation as a new type of battery will bring with it a new charging time and cost function which will also affect the application and market potential. (In this chapter each of the developments mentioned is examined in isolation from the others for ease of presentation).

The important point is that alternative battery systems could extend basic vehicle range to the extent that the application and market potential would be greatly increased. A doubling of the specific energy could lead to a doubling of vehicle range which in turn would lead to a reduction in infeasible miles in Lewis/Harris of approximately 87% (see fig 8.22) and an increase in the number of vehicles which could be substituted by EVs of approximately 130% (see fig 8.21). There would also be a substantial increase in market potential (see fig 9.20). In section

2.7 the various alternative battery systems and their associated specific energies were discussed along with current development difficulties. It is evident that the doubling or even trebling of battery specific energy, which would result from successful development of the sodium-sulphur, sodium-iron chloride or sodium-nickel chloride batteries, can reasonably be expected to be achieved within the foreseeable future. Such developments in specific energy and their implications for vehicle usefulness are not outwith the bounds of reason or prudent expectation.

11.2.3 AERODYNAMICS

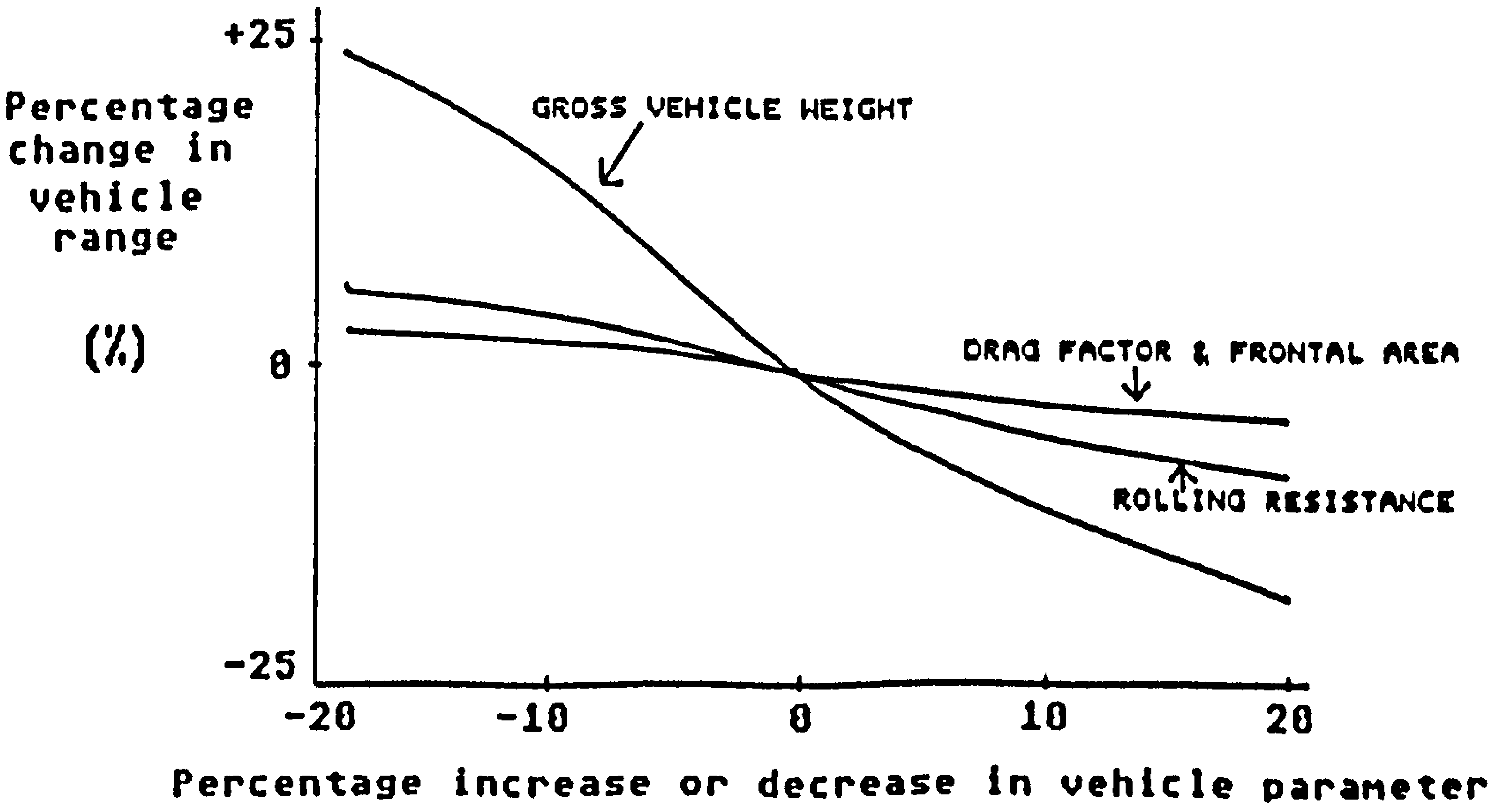
The aerodynamic drag is one of the four elements of resistance that necessitate the expenditure of tractive energy (section 6.3.3). It is a function of two principle factors; vehicle frontal area and the drag factor. Using the performance simulation model described in section 6.3 it is possible to examine the sensitivity of vehicle range to improvements in shell design and this is shown in fig 11.3. In modern vehicles the aerodynamic drag has been significantly reduced compared to vehicles of even 10 or 20 years ago. In 1930 a model "A" Ford had a drag coefficient of 0.83 while in 1955 the factor was 0.5. Modern cars have drag factors in the region of 0.25 - 0.30 [1]. Much design effort goes into styling the vehicle, and improved drag factors become more and more difficult to achieve. The EV would have to be narrower or lower than present shell designs, with a smaller frontal area. F Wykes of the Battery Vehicle Society and the Motor Industry Research Association suggests that the only way to achieve significant reductions in drag is to build a much narrower vehicle with room for a driver and 3 passengers seated in line, one behind the other. It is debatable however whether or not such a vehicle would be acceptable to the consumer. In practice, the exterior styling of the EV must be based on the fact that the consumer is resistant to radical changes in automobiles especially those novel design characteristics which are unique to a new type of vehicle such as the EV. In addition it must be remembered that improved aerodynamic drag values are also beneficial to the ICE vehicle and this will reduce any balance of advantage in favour of the EV. However, the improvement in performance resulting from a reduction in drag factor will be greater for the EV than for the ICE because of the EV's greater energy efficiency. Also, it should be remembered that the arguments in favour of the use of EVs are not simply concerned with primary energy efficiency but with oil substitution. Increases in EV range from whatever source are therefore of interest, regardless of improvements in ICE technology.

Areas which offer some scope for improved drag factors are,

- Enclosing the underbody with a flush pan.
- Cooling and ventilation improvements.
- The use of flush glass
- Reduction of protuberances such as antenna, handles and bumpers.
- Reduction of lift drag.
- Suitably designed contours.

FIG 11.3 Sensitivity of vehicle range to changes in vehicle parameters

(a) Drag factor and frontal area
(b) Rolling resistance
(c) Gross Vehicle Weight (GVW)



From fig 11.3 it can be seen that even significant reductions in aerodynamic resistance make very little difference to EV range, possibly because of the relatively low speeds involved in island driving. It is increasingly difficult to reduce drag by large amounts so the contribution to vehicle range that can be expected in the future is relatively small. A survey of predicted improvements in vehicle design, carried out in 1982 showed that estimated future improvements in drag coefficient lay between 2 and 6%. [2]

11.2.4 ROLLING RESISTANCE

Rolling resistance is only partially controllable by the vehicle designer as the road surface and type of road is an important contributory factor to rolling losses. The size of stone chips used, the evenness of the surface and the straightness of the road all have an influence. In the Western Isles, many of the roads are built on top of boggy peatland and a car traversing a section of this kind of road will establish a wave motion in the tramac which can increase rolling resistance and decrease fuel efficiency [3]. However, it is possible to reduce rolling losses by fitting improved tyres but there is a trade off between rolling resistance and noise, vibration and harshness of ride. Once again the scope for further improvements in tyre technology is becoming more limited. Estimates lie in the range of 2.5% [2]. The relationship between rolling resistance and vehicle range shown in fig 11.3 suggests that there are only limited range improvements likely to result from this source.

11.2.5 GROSS VEHICLE WEIGHT

Vehicle range is quite sensitive to the total weight of the system as can be seen in fig 9.3. The EV is more sensitive to gross weight than the ICE because of its higher energy efficiency and low performance. Gross vehicle weight could be reduced by the use of lighter construction materials such as aluminium and magnesium alloy extrusions and castings or large one-piece plastic/fibreglass mouldings or carbonfibre, GRP or ABS. However the effect of such materials on vehicle safety and consumer acceptance should also be borne in mind. Table 11.1 gives possible weight reductions for various vehicle components as envisaged by Ford Motor Company [1].

TABLE 11.1 - POSSIBLE WEIGHT REDUCTIONS FOR EV COMPONENTS

COMPONENT	WEIGHT KG	POSSIBLE COMPONENT CHANGES	WEIGHT REDUCTION (Kg)
Body structure	353	Material substitution (aluminium, plastic) and panel simplification.	40
Glass	40	High strength tempered glass	18
Trim	43	Plastic substitution Flocked carpet	4
Seats	35	Hammock type, thin shell	7
Sound deadening	7	Reduced amount	3
Bumpers	26	Aluminium or plastic	9
Front suspension	42	Twin I-Beam	7
Rear suspension	29	Component simplification	5
Brakes	36	Aluminium with integral drum and wheel	3
Steering	23	Rack and pinion	11
		TOTAL SAVINGS	107 Kg

A weight reduction of 107 Kg would represent about 10% of the typical family car and would lead to a range increase of approximately 12%.

Many of the weight reducing measures shown in table 11.1 have become standard practice since Ford compiled these figures but there is still room for improvements, especially in terms of vehicle structure. Estimates of likely reductions in vehicle mass all suggest that between 6 and 10% reduction could be achieved [2].

The use of AC traction motors instead of the conventional DC systems would also reduce weight (see table 2.1). Ford have been involved in developing an integral AC motor and multispeed transaxle configuration which is expected to be smaller, less expensive, lighter, more energy efficient and better suited to high volume manufacture than conventional systems [4].

There are many ways in which weight could be reduced by improvements in battery design. About half the weight of a lead-acid battery consists of inert materials [5], e.g supports, separators, connectors, terminals and packaging. One recent development which may be of particular use to the EV industry is the discovery of plastics that can conduct an electric current [6]. This could result in lighter batteries and weight savings in conductors. Reducing the weight of inactive battery materials or increasing the utilisation of active ones both lead to an increase in battery specific energy which would give the vehicle a greater range for the same weight of batteries (see fig 11.2) or the same range with a smaller battery (see section 2.6,2 and appendix 11 for a discussion of research into lead-acid battery developments).

11.2.6 CHARGERS AND CHARGE TIMES

The battery charger is the link between the Electricity Board and the vehicle user. It is also one of the least efficient single components between the electricity socket and the road; efficiencies are typically in the region of 70-80%. Improvements in charger technology will not directly affect the vehicle's performance but they may lead to greater convenience and reduced costs.

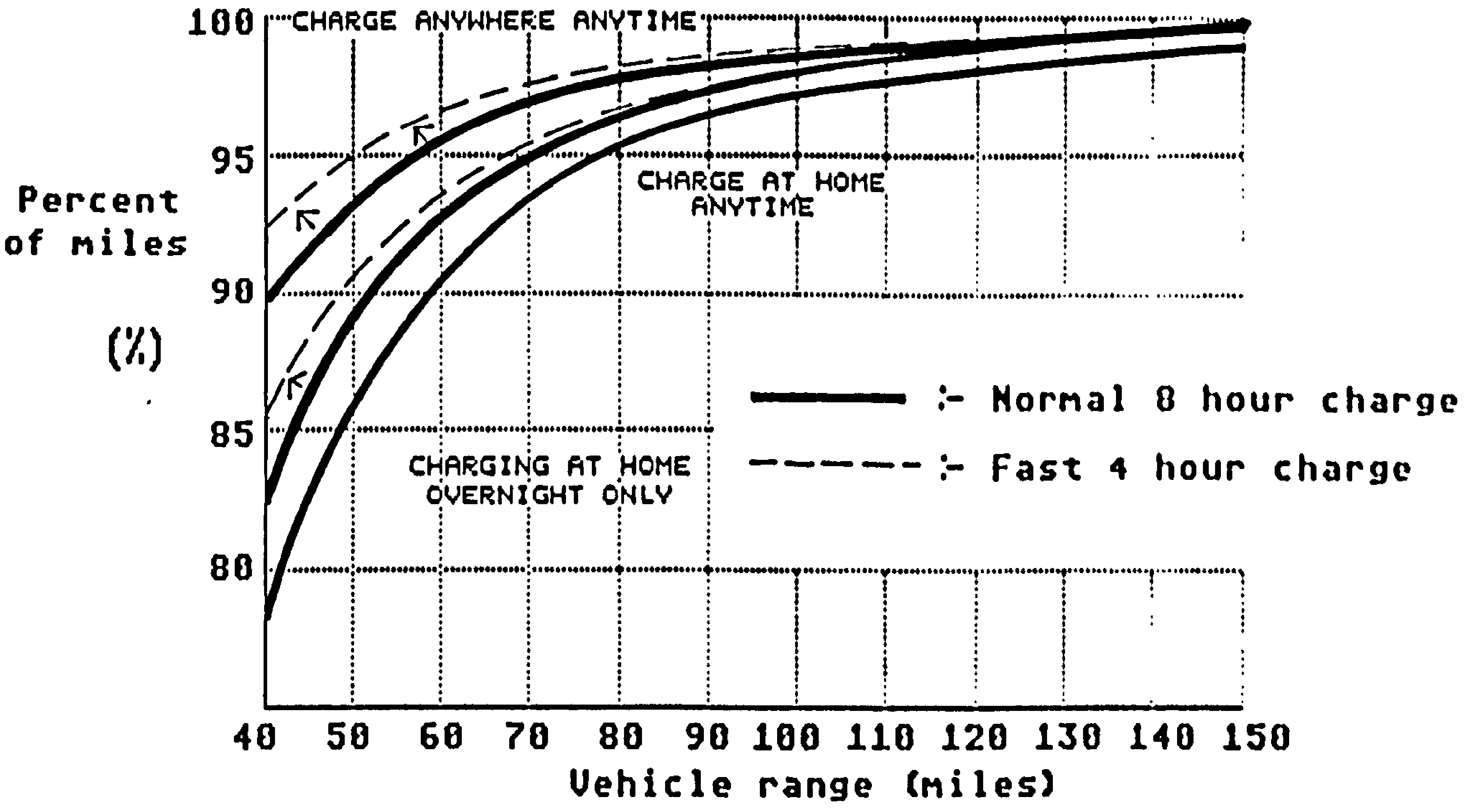
High frequency electronic switching techniques have improved efficiency and reduced size, weight and cost. For example, a Spegal charger weighing 168 Kg has now been reduced to only 35 Kg. This has allowed practical 'on board' chargers to be developed in the last few years and the use of these gives much greater flexibility in the use of EVs, as recharging can be carried out wherever there is a suitable power supply and not simply at home. This could enhance the daily range of EVs. The difference made to daily range by opportunity charging was established in section 6.7 and shown in fig 6.21.

The use of microelectronics in chargers has also enabled improvements in terms of product cost, reliability, maintenance and additional facilities [7]. Lucas Chloride have been developing an 'intelligent' battery charging system which calculates the optimal rate of charge given the time available, the battery history and state of charge. It prevents operator abuse and overcharging, and is designed to minimise loss through electrolysis of water (described in section 2.6.3). The use of such a charger would enhance battery life and hopefully reduce daily energy costs.

If charging time could be reduced without damaging the battery or if new battery types were used which require shorter charging periods, refuelling would not represent such an inconvenience and disruption to desired mileages. Lead-acid batteries can be charged quickly using high currents but so far there is no effective way of preventing consequent lifetime damage to the battery. However, sodium-sulphur batteries are reported as requiring only four to five hours for a complete recharge [8] and the effect that this would have on application potential in the islands is shown in fig 11.4.

It can be seen that a 50% reduction in refuelling time has a surprisingly small effect on the percentage of infeasible miles and the number of cars experiencing no inconvenience does not rise significantly either. This is due largely to the fact that those miles which are infeasible are attributable to a small number of long journeys which still remain infeasible even with a quicker refuelling rate.

FIG 11.4 Percent of island miles which are feasible, versus vehicle range at different charging rates



11.2.7 SYSTEMS DESIGN AND ENGINEERING

The performance of EVs is expected to improve as the builders engineer the vehicle more as a system and come to regard it as a complex interaction of many components. At present, many EVs are still built from standard off-the-shelf parts with little effort towards incorporating components that are optimised or designed specifically for electric vehicles. These are compromise vehicles assembled from standard vehicles, with whatever EV components are available, and they have not had the benefit of any real systems engineering. A systems approach would design and match components such as the motor and controller, battery subsystems, and the design of the gear box and transaxle system. Subsystem development must be guided by a strong systems consciousness. It is difficult to estimate by how much such an approach could improve the overall efficiency and range of the EV because, apart from the advances in the individual components, there may be a certain amount of synergy arising from interactions between subsystems.

11.2.8 SUMMARY OF DELPHI RESPONSES

The following is a summary of the responses obtained from experts in the Delphi analysis to the question "What developments or innovations do you think would be most advantageous or helpful for the success of the electric car in terms of performance?"

	SUGGESTED ADVANTAGEOUS DEVELOPMENTS	% OF RESPONDENTS SUGGESTING THIS
1	Higher energy & power density battery.	82
2	Use of new and lighter construction materials & new magnetic materials.	38
3	Advanced motor and controller subsystems.	19
4	Lightweight, efficient on-board chargers.	13
5	Improved aerodynamics.	11
6	Better energy management systems.	6

11.3 VEHICLE OWNERSHIP COSTS

The second area where innovations and technological advances can advance the case for EV is in the field of ownership costs. The above performance improving measures should of course be evaluated for their effect on costs and should only be incorporated if the improvement in performance warrants the additional cost.

Section 9.2 has already discussed the cost elements associated with EVs and a comprehensive sensitivity analysis was carried out to examine future changes in costs. However this section reports on suggestions arising from the Delphi analysis. The question was "What developments or innovations do you think would be most advantageous or helpful for the success of the electric car in terms of the economic case for its use?" The headings below have already been discussed in previous sections.

SUGGESTED ADVANTAGEOUS DEVELOPMENTS	% OF RESPONDENTS SUGGESTING THIS
1 Rise in oil prices, disruption of supply, relative fuel cost of electricity down.	63
2 New advanced cheaper battery.	50
3 Volume production of EVs, involvement of large manufacturers.	38
4 Use of new lightweight materials and suitable construction technology.	37
5 Stricter legislation on environmental matters.	31
6 Tax advantages for EV owners.	30
7 Cheaper, improved motors and switchgear.	19
8 Systems design, purpose built EVs.	6
9 Government involvement and evaluation.	6

11.4 CONSUMER ACCEPTANCE

11.4.1 SUMMARY OF DELPHI RESPONSES

Consumer acceptance is largely a function of vehicle performance and cost but there are other factors involved in gaining the confidence of the public. Section 9.4 reported on the responses of island motorists and below are the responses of the experts participating in the Delphi analysis. The question was "What developments or innovations do you think would be most advantageous or helpful for the success of the electric car in terms of consumer acceptance?"

SUGGESTED ADVANTAGEOUS DEVELOPMENTS	% OF RESPONDENTS SUGGESTING THIS
1 Range and driving performance.	36
2 Ease of refuelling, fast charging etc.	29
3 Accurate fuel gauge. (see below)	27
4 Adequate demonstration programmes.	15
5 Simple maintenance. Simplicity.	15
6 On board chargers.	7
7 Driveability.	7
8 The option for purchasers to choose a battery system that fits their needs. (see below)	7

11.4.2 ACCURATE FUEL GAUGE

An accurate knowledge of the state-of-charge of the battery in an EV will often be of critical importance, and may well influence the confidence that people have in the vehicle as a reliable means of transport. Even with ICE vehicles, drivers become apprehensive as the fuel gauge approaches empty, because of lack of confidence in the accuracy and reliability of the gauge. This concern becomes more pronounced for the driver of the EV because the range of the EV is much more limited in the first place and it is not so easy to refuel in remote situations as the ICE. The limited range will thus become even more limited as drivers are fearful and cautious about becoming stranded. In addition it is more difficult to measure accurately the charge remaining in a battery than it is to measure the quantity of petrol in the tank. Batteries behave differently at different ages and under different discharge patterns and it is difficult to model accurately the discharge curve. Whereas the ICE holds a fixed amount of fuel and the fuel remaining can be calculated either by direct measurement or from knowledge of how much has already been used, the lead-acid battery cannot be modelled so easily. The amount of energy supplied during discharge varies according to the nature of the discharge.

Attempts have been made to build fuel gauges for lead-acid batteries [9], but none has been entirely reliable. With the use of microprocessor technology it might be possible to monitor the instantaneous current during discharge and, by using a model similar to that developed in this study for range prediction, to calculate the energy already used, but there would still have to be a reliable method of estimating the remaining energy also. This is one area where advances could significantly influence public confidence.

11.4.3 CONSUMER CHOICE OF BATTERY PACK

Though not strictly a technological development, allowing the customer the freedom to select a battery pack which is most suitable for his particular need would represent an innovation in terms of the total product offered. The potential owner should be able to choose the battery system in terms of cost and capacity to suit his requirements, since the battery system will always represent a significant part of the total ownership costs. This is an option that is already available on some electrified mechanical handling equipment. Because of the limited amount of energy that can be stored on board an EV and because of the great affect that the duty cycle has on the consumption of that energy, it is more important than ever, in order to optimise range and minimise costs, that the vehicle system be purpose built for the intended application. To enable this to be done will involve a certain amount of technological development, so that the vehicle body would be capable of taking different sizes of battery pack with minimal alteration, and the electrical components would be designed to handle different power sources. Manufacturers will need to offer a wide range of models, but in order to be able to do this without jeopardising valuable economies of scale, vehicle designs will have to allow for the maximum model differences with the minimum of structural or assembly differences. This obviously calls for good design efforts. By matching the battery system to the use patterns of particular vehicles, the battery depreciation costs borne by the owner could be optimised. In section 9.2.7 the relationship between average depth of discharge and battery lifetime energy-throughput was discussed, and it can be seen that there is considerable scope for reduction of battery costs by suitable choice of battery capacity for each particular application, so that the average depth of discharge is as close to the optimal level as is realistically possible.

11.5 SUMMARY AND CONCLUSIONS

Any attempt to predict the potential usefulness and acceptability of EV technology must take into consideration the likely or possible developments in technology and economic conditions which could affect this potential. The major barriers to the introduction of EV technology are the limited range of the vehicle and the lack of cost savings which are adequate to compensate many drivers for the reduction in their flexibility of travel. However, there is at present considerable application and market potential for EVs in the islands, and future developments which would greatly enhance the level of EV potential in this particular application can reasonably be expected in the foreseeable future. The most advantageous developments for the case of EV use in the islands centre largely on the successful development of improved lead-acid or alternative battery systems, and on the technological improvements and the volume production which are essential for the reduction in operating costs. It is also true that general economic conditions relating to the price of fossil fuels and environmental concerns which result in stricter legislation on environmental matters will also improve the general economic case for electric vehicle introduction.

Engineering improvements which reduce aerodynamic drag or rolling resistance are unlikely to have a significant effect on EV range but reductions in vehicle mass would have a greater impact. The advent of reduced charging times resulting from the development of advanced or alternative battery systems would have very little impact on application potential for EVs, as such a development would not greatly decrease the mileage inconvenience associated with EVs.

Using the models and the methodology which have been established for this particular study, the effect that future technological or economic developments would have on the case for EV introduction, whether in terms of the vehicle performance and application potential or the economic case and market acceptability of EVs could be readily assessed.

CHAPTER 12

CONCLUSIONS

> "There is no more common error than to assume that, because prolonged and accurate mathematical calculations have been made, that the application of the results to some fact of nature is absolutely certain".
>
> A N Whithead

1 From the analysis in this study it has been shown that EV technology has advanced greatly from the familiar low-performance milk float type of vehicle and that a credible alternative to ICE vehicles already exists for certain applications.

2 There are clear advantages to be gained in our society by substituting parts of the present ICE vehicle fleet with EVs. These include,

a) The displacement of fossil fuels from the transportation sector, providing an inherently greater flexibility in the energy base and increased national independence and security.

b) Reduction in uncertainty regarding future transportation systems.

c) Greater control over environmental pollution.

d) An opportunity for British industry in a potentially significant export market.

e) Greater control over national generating capacity due to load-levelling effects. This could lead to improved generating efficiency and greater flexibility in the choice of generating plant.

3 These advantages accrue primarily to society at large and not to the individual operator. It would seem to be in the best interests of society as a whole for the Government to transfer some benefits to individual operators thus sharing advantages between the individual and the community. This could assist in stimulating demand in advance of the time when transport options become more restricted, thus reaping the above benefits.

4 Because the case for EVs rests largely on the need to safeguard long term flexibility in the transport sector, the stimulus for research and development has not come from the short term vocal demands of the market place. This has had three major consequences,

a) The initiative for research and development has largely been taken by governments acting as guardians in the interest of long term welfare. The level of involvement of individual governments has depended on individual circumstances but, with the exception of the US national EV programme, activity and funding has been modest. Governments must take the initiative in encouraging development because of the possibly long term nature, yet significant national benefits, of the technology.

b) The research and development activity which has been undertaken has concentrated predominantly on technological improvements and there have been few techno-economic studies. Research has been fragmented, lacking overall coherence and coordination. The result is that although the technology is well advanced there has been little commercial development. Large vehicle manufacturers have experimented with high cost prototype electric cars as part of their long term research interests but there has been little attempt to develop these for commercial introduction. The most successful, and the only serious attempt at commercialisation has undoubtedly been the LCEVS/Bedford venture. However, any similar approach or attempt will face the same risk of discontinuity of involvement on the part of the cooperating vehicle manufacturer unless there is greater immediate incentive for development.

c) Development efforts have been sensitive to the short term supply and price of oil. Consequently, after heightened interest following the oil crises, the enthusiasm and publicity surrounding high performance EV development has lessened in the last few years in the light of recent oil price slumps. A sense of urgency with regard to energy, oil and the environment is required so that the necessary research, development and investment is forthcoming at an early stage. The lead times involved in such a major technological and sociological change as that of the widespread introduction of EVs could be considerable, so action should be taken, while there is still a relatively cheap and plentiful energy supply available, which will allow a sustainable alternative transport system to be developed.

5.1 The battery energy system is the predominant feature of the high performance EV and largely determines the development of the state-of-the-art in terms of vehicle performance. The battery electric vehicle is more limited in its performance than the ICE and probably always will be. Although a systems engineering approach to the entire vehicle is necessary, the other components such as the motor, controller and transmission offer less scope for significant improvements in operating performance.

5.2 The lead-acid battery has historically been the most widely and successfully used energy source for EVs. This will probably continue to be the case in the short and medium term, even although it exhibits poorer energy storage characteristics than many of the alternative battery systems under development. Even with successful development of alternative systems, the lead-acid battery is likely to remain as a good all round compromise energy source for many EV applications because it has several distinct advantages,

a) A large manufacturing industry already exists.

b) So far it still has the lowest overall material costs of all the alternatives.

c) It is the most fully developed system.

d) There has been more field testing and operating experience and therefore more understanding of the lead-acid system than of any other.

5.3 There has been considerable effort in the development of alternative systems over the last 20 years and their ultimate success probably depends as much on the determination to develop as on the inherent characteristics of the systems. Primary contenders for EV battery systems include the sodium-sulphur battery and the more recent sodium-iron chloride and sodium-nickel chloride systems. All three types operate at high temperatures, and engineering efforts have had to be directed towards solving thermal management and safety problems. Successful commercialisation of these systems for EVs could lead to a doubling or even trebling of basic EV range, but their need to be maintained at high operating temperatures through regular use means that they will not be as suitable in the short term for many EV applications as the lead-acid battery.

5.4 Regardless of which system is ultimately developed and used, the present development of EV technology based on lead-acid batteries must not be neglected in a period of waiting for better and better power sources. The technology is already viable using currently available lead-acid batteries and in many applications it is also economically viable.

6.1 If EV technology is to be commercialised successfully, a link is required between the technology improvement effort and the market place.

6.2 The diffusion process needs to be managed in such a way as to provide this link.

6.3 A broadly based marketing strategy must give due consideration to the functional and psychological needs of motorists as well as ensure that the technology is adequately exposed and promoted.

6.4 The vehicle should be designed as far as possible to meet user needs and expectations and encourage confidence. Initially this could probably be done most successfully by the involvement of existing volume vehicle manufacturers who have the resources, facilities, and the service and distribution networks that would be required to provide a credible product.

6.5 A marketing orientation must also recognise the nature of EV technology and its likely diffusion pattern. The performance limitations of EVs make them unsuitable for many uses, but they could clearly have a role in applications where these limited performance characteristics are not critical to the successful completion of the typical duty cycles involved. It is very much a case of 'horses for courses'.

6.6 The adoption of EVs is likely to be a gradual process in which those applications and market segments to which they are most suited will be the first to adopt. With the diffusion of any innovation there has to be a starting point which builds the necessary confidence and experience for further introduction. In managing the diffusion of EV technology it is necessary to identify market segments where EVs could be introduced at an early stage. One such segment is island communities, where travel patterns tend to be more compatible with the abilities of EVs. Other segments which have previously been the focus of attention include the electrification of light duty delivery vans and domestic urban vehicles in multi vehicle households. In the interests of maintaining an EV industry which is well placed for future growth in the light of further technological development and changing economic and energy related conditions, it is necessary in the short term to continue efforts to introduce the technology into those segments where it can already be used successfully. Island communities represent such a segment.

6.7 In the management of new technologies, government has a vital role in reflecting the needs and aspirations of society. With EV technology, Government support is needed to provide the required financial, administrative and legislative incentives to encourage development and early adoption in suitable applications.

7.1 In the assessment of any application for EVs, and in this particular case of island communities, a real need for a suitable and practical methodology for assessment was identified. Previous studies have generally lacked a broad methodology for assessment which takes a holistic view of the problem. This has led to the necessity for unrealistic and unreasonably limiting assumptions, and consequently the results of such studies have been of questionable value.

7.2 A major aim of this study has been to construct a working methodology which would enable the relevant factors and their interactions to be incorporated in the analysis. The resulting approach concentrates at one level on assessing EV's ability to satisfy the general requirements of a personal mode of transport, and at another level on the suitability of EVs for individual motorists' use patterns and requirements. This has been facilitated by the use of computer simulations which have been used to model real life situations and systems as closely as possible.

7.3 Although this study has been primarily concerned with one hitherto unresearched application for EVs, the methodology and the models constructed are generally applicable to other potential EV applications. The basic relationships contained in the models are not specific to the islands, so they are flexible and adaptable and can be used to evaluate a wide range of situations provided that suitable application-specific data are collected. The form and content of the data which have been central to this study has been identified and condensed in such a way as to make it applicable to studies of other EV applications. In addition, suitable collection techniques and instrumentation for recording this data have been documented.

8.1 The assessment of the potential for EV introduction in Lewis and Harris indicates that there is currently a small but significant market potential for early introduction of state-of-the-art EVs. The magnitude of this potential is estimated to lie between 3% and 12% of island cars. This translates into a total of between 138 and 530 vehicles. Understandably, the level of market potential can be expected to vary as technological improvements increase the performance capabilities of the EV and as economic factors alter the cost savings available. Performance improvements which would double the basic vehicle range can reasonably be expected within the foreseeable future and are not outwith the bounds of reasonable or prudent expectation. Such developments would approximately double the market potential on the islands.

8.2 In addition to the above market potential for domestic vehicles, there is also a potentially realisable market for electric grocery vans and school mini-buses on the islands. Approximately 43% and 36% of these vehicles respectively, offer the potential for replacement by

EVs. This translates into a total of 69 vehicles in Lewis and Harris at present.

9.1 The real barriers to EV introduction on the islands have been identified by examining the various requirements of a personal mode of transport. Each of these requirements has been assessed in terms of the size of the barrier, if any, that it imposes on EV introduction. There are many interconnections and trade-offs between these factors.

9.2 EV operating performance in terms of gradeability was found to be adequate for all island situations and therefore presents no barrier.

9.3 Similarly the speed and acceleration of an EV would be adequate on island roads on the basis of current driving patterns.

9.4 The range of the vehicle however is one of the major barriers to the vehicle's usefulness and hence its acceptability, as at present only 37% of island cars would not be 'inconvenienced' by the range limitation (assuming charging at home only) After allowing for suitable 'second' vehicles this figure rises to 49%. However if this barrier is regarded in terms of the miles which are infeasible using EVs, the barrier is much less severe. Only 9.6% of island miles could not be undertaken by EVs and this figure is further reduced, albeit by a small amount, if charging facilities are available in public locations. The range-dependent application potential is sensitive to the basic vehicle range, and if the current range were doubled, over 80% of cars and 97% of island miles fall within the application potential. Such improvements in range can reasonably be expected in the foreseeable future.

9.5 In this study it has been found that the use of regenerative braking to increase range would be minimal in the islands, and unlikely to be cost effective, although such systems might be of more significant use in urban situations.

9.6 The inherent safety of EV technology for operators, and the mechanisms for disposing of used vehicles and batteries on the islands are adequate to ensure that they pose no barriers to introduction.

9.7 Although current state-of-the-art EV reliability has generally not yet met the expectations of developers, the problems encountered are regarded as short term 'teething' problems and there is no reason to expect that EVs will not be more reliable than current ICE vehicles.

9.8 The problem of refuelling of electric vehicles is closely related to those associated with the limited basic range. Whilst the electricity demand generated by the recharging requirements of a population of EVs would not create an insurmountable problem for the North of Scotland Hydro Electricity Board, it is the time involved in battery charging that imposes the range limitations.

9.9 A system of battery exchange stations, where depleted batteries are swapped for charged ones, would not be feasible on economic or logistical grounds. Also, if a battery exchange infrastructure is to provide the primary source of energy for EVs, it would have to be introduced on a widespread scale before EVs could be introduced - therefore it is an untenable concept.

9.10 The alternative policy of providing public recharging points at strategic locations would be minimal in its impact on application because it does not alleviate the basic problem of the time required for refuelling. Neither would such a system be cost effective.

9.11 Fast recharging of batteries using high currents would adversely affect the economic case for EVs while contributing very little to the application potential.

9.12 The basic limitation of EV range is largely unavoidable and should be accepted as inherent in the current technology. The EV should be introduced where this particular limitation is not critical and where the basic range is adequate. Attention should be focused on the significant proportion of island motorists who would suffer no range inconvenience, while efforts should continue to increase basic vehicle range, thus enlarging the application potential.

9.13 Ultimately the willingness of motorists to adopt EV technology will be determined by the financial benefits expected. Even under present economic conditions and with the economic parameters surrounding current EV technology there are cost savings available to the majority of island motorists in Lewis and Harris, and in many cases the expected savings are substantial. However these savings have to be balanced against the disadvantages, and in many cases in the islands the expected savings are still inadequate to compensate motorists for the loss of flexibility inherent in EV technology. Under the present technological limitations the strength of the economic case for the EV is one of the major barriers to its introduction.

10.1 The identification of the real barriers to EV introduction is essential to any assessment of the potential inherent in any particular application. It is only through such identification that conclusions can be drawn regarding the real potential and its sensitivity to future developments, and recommendations made on the action which is necessary to minimise or reduce the effects of these barriers.

10.2 Undoubtedly the major, and only real barriers to EV introduction on the islands are the limited basic range of EVs and the economic case surrounding their use. Measures which should be taken, and the likelihood of alleviating this situation, have largely been outlined already but three final conclusions can be drawn.

a) Continued technical research is required, especially in the area of battery energy sources, in order to increase operating range which will always be the major cause of concern for operators.

b) Island motorists should be provided with adequate information to enable them to re-examine their current attitudes and aspirations regarding personal transportation and the potential of EVs to fulfil their needs. Motorists should be encouraged to define and evaluate realistically what their motoring needs are. People generally purchase products whose specifications exceed their personal requirements, making re-education and re-assessment of their real needs a priority in the case of EVs. As fossil fuels increase in price, it will become increasingly necessary for them to establish priorities and restrict their motoring. Attitudes towards unlimited personal transport and flexibility will probably have to change over time. If motorists can be brought to appreciate this, they may be more receptive to the idea of operating an EV. Similarly, the ability of the EV to undertake the vast majority of island motoring requirements should be pointed out so that the EV is not seen as a poor second but as an adequate primary vehicle. The EV should be presented as offering relative advantages over the ICE. People generally purchase products whose specifications exceed their personal requirements, making re-education a priority.

c) Because EVs offer certain advantages to society as a whole, the Government should encourage development and introduction through the means at its disposal (see conclusion 3. and it should re-allocate some of the benefits so that individuals can gain from them directly. This would help to strengthen the economic case for EV ownership.

11 On the basis of the analysis carried out during this study it is suggested that the island communities of Lewis and Harris hold a small but significant potential for the early introduction of EVs at present, and that this potential could be increased significantly through a variety of measures and developments. Existing vehicle manufacturers and prospective EV manufacturers should also be made aware of this potential market. The introduction of EVs in the islands could stimulate wider knowlege of, interest in, and diffusion of the technology. It is therefore worthwhile pursuing.

RECOMMENDATIONS FOR FURTHER WORK

There are a number of areas of research which are relevant to this field where further work could be beneficial.

1 The need for better understanding and description of the real life operating characteristics of EV batteries under duty cycles typical of EV operation is fundamental to a reduction in the uncertainties surrounding the potential of the technology. The battery more than any other component is difficult to model accurately because of the lack of adequate relationships which describe the complex interaction of electrochemical phenomena inherent in battery systems. Battery testing under appropriate conditions is needed as the basis for establishing working relationships and realistic equations especially in two major areas,

   a) the relationship between the energy supplied on discharge and the demands placed on the battery in terms of the rate of discharge and the variability in the rate of discharge.

   b) the relationship between battery cycle life and the variability in discharge history.

2 Now that a preliminary analysis has been made for the islands of Lewis and Harris, further work is justified to verify the resulting market potential in such a way as to stimulate appropriate development actions. This would require a feasibility study or assessment programme which may need to gather independent information, possibly by field testing of suitable vehicles on the islands and by closer discussion with island motorists, in order to assess the practical potential for introduction more accurately and conclusively.

3 The methodology developed for this study should be used in the assessment of other possible applications for EV potential. There are many 'island' situations throughout the world in which there might be considerable unrealised potential.

4 This study has concentrated on the case of the battery electric vehicle but further investigation is needed into the technical and practical feasibility of alternative technologies in order to place the potential of EV technology in perspective. Once again the methodology used in this study could be useful in any such assessment of the potential for future alternative systems. Hybrid electric vehicles might provide a suitable 'stepping stone' to long term battery EV introduction, provided the economic and technical barriers can be overcome. Similarly, fuel cells, although not as fully developed for traction purposes as secondary battery systems, could offer an alternative to fossil-fuel-based transportation. Alternative combustion fuels such as alcohols and biogas might also be competitive with battery systems in the longer term.

5 Although the primary energy related advantages of EVs is the flexibility of energy source that they offer and the lack of dependency

on oil, the conservation of fossil fuels for premium uses is also of extreme importance. Further techno-economic and socio-economic work should be done to investigate fully the impact that EV introduction could have on the energy base, oil conservation and national benefit. The magnitude of the oil conservation potential of EVs is a necessary base from which to assess the wider potential implications. Evaluation of this magnitude would require the analysis of different types of crude oil, refining techniques, the interaction of transport and other oil uses, and the prevailing political and economic climates.

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CONTENTS OF APPENDICES

APPENDIX 1

LISTINGS OF COMPUTER PROGRAMMES USED

1. PERFORMANCE SIMULATION FORTRAN PROGRAMME

This simulation programme is used to predict such measures as EV range, energy consumption, component efficiencies, average current, masximum current, peak power demands and available regenerative energy. The model is used to predict these measure for an EV under particular driving cycles. Fuller description is given in section 6.3.

PROGRAMME LISTING

```
C     ELECTRIC VEHICLE SIMULATION PROGRAMME
C     READ IN USER SPECIFIED INPUTS, VEHICLE CHARACTERISTICS,
C     DUTY CYCLE, TIME INCREMENT,
      REAL CYCLE(1600,3)
      REAL REG(90)

C     VEHICLE CHARACTERISTICS FOR ETV-1 TEST VEHICLE
         GVW=1795
         DRAG=0.32
         RR=0.01
         FA=1.875
         MMAXS=5000
         TORMAX=140

C     BATTERY CHARACTERISTICS
      BV=108
      BLOCKS=18
      AH=190
      SOC=100
      RRAD=0.28
      GRRAT=5.68
C     READ THE JOURNEY PROFILE AND THE TIME INCREMENT
      READ(37,*)LRUN,SEC
      SDL=CYCLE(1,2)

C     SET ALL COUNTERS TO ZERO
         CDIST=0
         CWATS=0
         CREGEN=0
         COUNT=0
         TIME=0
         CTRANEF=0
```

```
        CMOTEF=0
        CCONTF=0
        BPEVER=0
        CBCUR=0
        CSYSTF=0
        BPMAX=0
        BCMAX=0
        CAH=0
   50 M=1
  150 M=M+1
     TIME=TIME+1
C    READ IN VALUES FOR NEW TIME INCREMENT
        DATAPT=CYCLE(M,1)
        SPN=CYCLE(M,2)
        GR=CYCLE(M,3)
        VELL=SDL
        VELN=SPN

C    CALCULATE AVERGE SPEED DURING INCREMENT, DISTANCE TRAVELLED
     DURING TIME INCREMENT, CUMULATIVE DISTANCE TRAVELLED AND VEHICLE
     ACCELERATION OR DECELLERATION OVER TIME INCREMENT
        AVEL=(VELN+VELL)/2
        DIST=AVEL*SEC
        CDIST=CDIST+DIST
        ACCL=(VELN-VELL)/SEC

C    CALCULATION OF THE ELEMENTS OF TRACTIVE EFFORT, 1)AERODYNAMIC
     DRAG, 2)ROLLING RESISTANCE, 3)INERTIAL EFFORT AND 4)GRADIENT
     RESISTANCE.
          FDRAG=0.613*DRAG*FA*VELN**2
          FROL=RR*GVW*9.81
          FACCL=GVW*1.1*ACCL
          GR=GR*0.017453292
          FGRAD=GVW*9.81*SIN(GR)
          FTOTAL=FDRAG+FROL+FACCL+FGRAD
       IF(FTOTAL.LE.0)SYSTEF=0
       IF(FTOTAL.LE.0)BATPOW=0
       IF(FTOTAL.LE.0)BATCUR=0
       IF(FTOTAL.LE.0)PERDIS=0

C    ENERGY AND POWER CALCULATIONS
     ENERGY=FTOTAL*DIST
     RPOWER=ENERGY/SEC

C    CALCULATION OF AVAILABLE REGENERATIVE ENERGY
         IF(RPOWER.LE.0)REGENW=(RPOWER/3600)*SEC
         IF(RPOWER).LE.0)CREGENW=CREGENW+REGENW
         IF(RPOWER.LE.0)REGPOW=RPOWER
         IF(FTOTAL.GE.0)GO TO 20
         Y=-2000
         Z=1
   10    IF(REGPOW.GT.Y)REG(Z)=REG(Z)+1
         IF(REGPOW.GT.Y)GO TO 20
         Y=Y-2000
         Z=Z+1
         GO TO 10
   20 IF(FTOTAL.LE.0)GO TO 160
     COUNT=COUNT+1

C    CALCULATION OF ROAD TORQUE AND WHEEL AND MOTOR SPEEDS
```

```
      RTOR=FTOTAL*RRAD
      SPMOT=AAVEL/(RRAD*6.283))*GRRAT*60.0
      TORTO=RTOR/GRRAT


C     CALCULATION OF COMPONENT EFFICIENCIES
      IF(RTOR.LE.0)TORTO=0
      IF(TORTO.LE.3.0)TORTO=3.0

C     CALCULATION OF TRANSMISSION EFFICIENCY IN EACH TIME INCREMENT
      IF(TORTO.LT.10)TRANEF=(-279-(14.0*(SPMOT/MMAXS))-(1.61*(TORTO))+
     C(8.49*(SPMOT/MMAXS)**0.425)+(305*(TORTO)**0.1)-
     C(63.7*((SPMOT/MMAXS)**0.425/(TORTO)**1.15)))/100
      IF(TORTO.GE.10)TRANEF=(28.4-(7.47*(SPMOT/MMAXS))-(0.119*(TORTO))+
     C(7.28*(SPMOT/MMAXS)**0.425)+49.5*(TORTO)**0.1)-
     C(154*((SPMOT/MMAXS)**0.425/(TORTO)**1.15)))/100
      TORTI=TORTO/TRANEF

C     CALCULATION OF MOTOR EFFICIENCY IN EACH TIME INCREMENT
      IF(SPMOT.LT.2800)EFMOT=0.39+(1.1*(SPMOT/MMAXS))+
     C(0.986*(TORTI/TORMAX))-(0.42*(SPMOT/MMAXS)**2)-
     C(0.4*(TORTI/TORMAX)**2)-(1.3*(SPMOT/MMAXS)*(TORTI/TORMAX))-
     C(0.01*(SPMOT/MMAXS)/(TORTI/TORMAX))
      IF(SPMOT.GE.2800)EFMOT=(0.679+(0.442*(SPMOT/MMAXS))+
     C(0.712*(TORTI/TORMAX))-(SPMOT/MMAXS)**2)-
     C(0.218*(TORTI/TORMAX)**2)-(1.09*((SPMOT/MMAXS)*(TORTI/TORMAX)))-
     C(0.0136*((SPMOT/MMAXS)/(TORTI/TORMAX))))

C     CONTROLLER EFFICIENCY IN EACH TIMNE INTERVAL
      IF(SPN.LT.11.1)CONTEF=(0.0108*SPN)+0.65
      IF(SPN.GE.11.1)CONTEF=(0.005*SPN)+0.795
      IF(SPN.GE.17.33)CONTEF=0.99

C     CALCULATION OF OVERALL SYSTEM EFFICIENCY AND AVERAGE EFFICIENCY
      FOR EACH OF THE COMPONENTS
         SYSTEF=TRANEF*EFMOT*CONTEF
         CTRANF=CTRANF+TRANF
         CMOTEF=CMOTEF+EFMOT
         CCONTF=CCONTF+CONTEF
         CSYSTF=CSYSTF+SYSTEF

C     CALCULATION OF BATTERY DEMANDS
        BATPOW=RPOWER/SYSTEF
        IF(BATPOW.GT.30000)BPOVER=BPOVER+1
        IF(BATPOW.GT.BPMAX)BPMAX=BATPOW
        WHRS=(BATPOW/3600)*SEC
        CWATS=CWATS+WHRS
        IF(SOC.GE.50)VOLDIS=5.9+(0.004*SOC)
        IF(SOC.LT.50)VOLDIS=5.7+(0.008*SOC)
        TERVOL=VOLDIS-((BATPOW/BLOCKS)/VOLDIS)*0.003
        TERVOL=VOLDIS-((BATPOW/BLOCKS)/TERVOL)*0.003
        TERVOL=VOLDIS-((BATPOW/BLOCKS)/TERVOL)*0.003
        BATCUR=BATPOW/(TERVOL*BLOCKS)
        IF(BATCUR.LE.0)GO TO 155
        CBCUR=CBCUR+BATCUR
        IF(BATCUR.GT.BCMAX)BCMAX=MATCUR

C     CALCULATION OF BATTERY DEPLETION IN EACH TIME INCREMENT
      PERDIS=(BATCUR*SEC/(AH*36))*(5*BATCUR/AH)**0.325
      GO TO 156
```

```
 155 PERDIS=0
 158 SOC=SOC-PERDIS
     AHUSED=BATCUR/3600
     CAH=CAH+AHUSED

C    RESET THE SPEED TO THE SPEED IN THE LAST TIME INCREMENT
 160 SDL=CYCLE(M,2)
C    TEST TO SEE IF THE BATTERY IS EXHASUTED
     IF(SOC.LE.0)GO TO 200
C    TEST FOR THE END OF THE CURRENT DRIVING CYCLE
     IF(M.LT.LRUN)GO TO 150
     IF(M.GE.LRUN)GO TO 50


C    FINAL CALCULATIONS AND OUTPUT
 200 WATKMS=CWATS/CDIST*1000
     WATMLS=WATKMS*1.609
     RANGEK=CDIST/1000
     RANGEM=RANGEK/1.609
     AHLEFT=AH-CAH
     TDT=TIME/26.0
     AVCUR=CBCUR/COUNT
     AVMEF=CMOTEF/COUNT
     AVTREF=CTRANF/COUNT
     AVCONTF=CCONTF/COUNT
     AVSYSF=CSYSTF/COUNT
         WRITE(32,999)
         WRITE(32,998)RANGEM
         WRITE(32,997)RANGEK
         WRITE(32,996)WATMLS
         WRITE(32,995)WATKMS
         WRITE(32,994)CAH
         WRITE(32,993)AHLEFT
         WRITE(32,992)TDT
         WRITE(32,991)AVCUR
         WRITE(32,990)BCMAX
         WRITE(32,989)AVMEF
         WRITE(32,988)AVTREF
         WRITE(32,987)AVCONF
         WRITE(32,986)AVSYSF
         WRITE(32,985)BPMAX
         WRITE(32,984)BPOVER
         WRITE(32,983)CREGENW
     DO 30 AA=1,20
         WRITE(32,982)REG(AA)
  30 CONTINUE

 999   FORMAT( ' SIMULATION RESULTS')
 999   FORMAT( ' RANGE IN MILES          =         ',F8.3)
 999   FORMAT( ' RANGE IN KILOMETERS     =         ',F8.3)
 999   FORMAT( ' KWHRS USED PER MILE     =         ',F8.3)
 999   FORMAT( ' KWHRS USED PER KM       =         ',F8.3)
 999   FORMAT( ' TOTAL AMP HOURS USED    =         ',F8.3)
 999   FORMAT( ' REMAINING AMP HOURS     =         ',F8.3)
 999   FORMAT( '   TOTAL DRIVING TIME             =     ',F8.3)
 999   FORMAT( '   AVERAGE BATTERY CURRENT        =     ',F8.3)
 999   FORMAT( '   MAXIMUM BATTERY CURRENT        =     ',F8.3)
 999   FORMAT( '   AVERAGE MOTOR EFFICIENCY       =     ',F8.3)
 999   FORMAT( '   AVERAGE TRANSMISSION EFF       =     ',F8.3)
 999   FORMAT( '   AVERAGE CONTROLLER EFF         =     ',F8.3)
```

```
 999   FORMAT( '   AVERAGE SYSTEM EFFICIENCY    =     ',F8.3)
 999   FORMAT( '   MAXIMUM BATTERY POWER        =     ',F10.3)
 999   FORMAT( '   POWER EXCEEDED               =     ',F8.3)
 999   FORMAT( '   REGENERATIVE ENERGY          =     ',F9.3)
 999   FORMAT( '     REGENERATIVE POWER FREQUENCY       ',F8.1)
     STOP
     END
```

2. APPLICATION POTENTIAL FORTRAN PROGRAMME

This programme is designed to analyse the data collected from the journey logbooks issued to island motorists. Each motorist's driving patterns are analysed in turn to calculate such measures as the anual mileage, the proportion of miles, journeys or days which would be infeasible given certain variable assumptions concerning the range of the vehicle and the charging regime employed. The miles that each motorist can be expected to get from his battery is also estimated. The output of this programme forms the input to a SPSSX programme which analyses it.

PROGRAMME LISTING

```
C     PROGRAMME TO ANALYSE LOGBOOK DATA
C     VARIABLE ASSUMPTIONS :- CHARGING  REGIME  1)DURING  OFF-PEAK
C                              HOURS  AT HOME,  2)AT HOME  ANYTIME,
C                              3)ANYWHERE ANYTIME.
C                             VEHICLE RANGE
C     READ IN DRIVING DATA
      REAL DBOOK(5000,6)
      REAL CHAR(50)
      REAL DIST(40)
      REAL ID1,ID2,HOUR1,HOUR2,TMINS1,TMINS2,MILES1,MILES2,LOCAT
      REAL INFJ,INFDA,J,ID3
      READ (37,100)((DBOOK(M,N),N=1,6),M=1,1985)
  100 FORMAT(F3.0,F4.0,F4.0,F2.0,F6.0,F2.0)
      A=0
      B=1
C     RESET FOR EACH NEW CASE
  110 A=A+1
      B=B+1
      INFJ=0
      INFDA=0
      ONAWAY=0
      TDAYS=0
      DISTDA=0
      CINFM=0
      RANGE=51.98
      CDEPFACT=0
      INFDDA=0
      SOC=100
      DISTM=0
      DISTT=0
      SDIST=1000
      CDAYS=0
      D=0
      C=0
      J=0
      INFCH=0
      INWMCH=0
      SDATE=DBOOK(A,2)
```

(Appendix 1 cont.)

```
      ID3=DBOOK(A,1)
      GO TO 200
C     RESETTINGS FOR A NEW DAY LOOP
  120 DISTDA=0
      A=A+1
      B=B+1
      C=C+1
      INFDDA=0
      GO TO 200
C     RESETTINGS FOR A NEW JOURNEY
  130 A=A+1
      B=B+1
      DINFM=0
C     READ THE VARIABLES FOR THE NEXT JOURNEY
  200 ID1=DBOOK(A,1)
      ID2=DBOOK(B,1)
      DATE1=DBOOK(A,2)
      DATE2=DBOOK(B,2)
      HOUR1=DBOOK(A,3)
      HOUR2=DBOOK(B,3)
      TMINS1=DBOOK(A,4)
      TMINS2=DBOOK(B,4)
      MILES1=DBOOK(A,5)
      MILES2=DBOOK(B,5)
      LOCAT=DBOOK(A,6)
  300 IF(ID2.NE.0)GO TO 600
  400 IF(DATE2.NE.DATE1)GO TO 500
C     JOURNEY LOOP
      TIMEJ=((HOUR2-HOUR1)*60)+(TMINS2-TMINS1)
      IF(MILES2.LT.MILES1)MILES2=MILES2+1000
      DISTJ=MILES2-MILES1
      DISTDA=DISTDA+DISTJ
      TIMEP=TIMEJ-(DISTJ*2)
  420   DOD=(DISTJ/(1.25*RANGE))*100
        SOC=SOC-(1.25*DOD)
        IF(DOD.GT.80)DOD=80
        IF(DOD.LT.0)DINFM=-((SOC/100)*RANGE)
        IF(SOC.LT.0)SOC=0
        CINFM=CINFM+DINFM
        DINFM=0
        IF(SOC.LE.0)INFJ=INFJ+1
        IF(SOC.LE.0)INFDDA=INFDDA+1
      IF(LOCAT.EQ.0)GO TO 450
      IF(SOC.GT.100)GO TO 450
      IF(TIMEP.GT.480)TIMEP=480
      IF(TIMEP.LE.0)TIMEP=1)
      CHARGE=1.26-(0.014*SOC)+(18.2*(TIMEP/60))-
     C(0.0923*((TIMEP/60)**3))+
     C(0.415*(60/TIMEP))-(0.104*SOC*(TIMEP/60)))
      SOC=SOC+CHARGE
      IF(SOC.GT.100)EXCESS=SOC-100
      IF(SOC.GT.100)CHARGE=CHARGE-EXCESS
      D=D+1
      CHAR(D)=CHARGE
      IF(SOC.GT.100)SOC=100
      BIT=EXP(CHARGE*-0.045)
      CYCLES=2000*BIT
      DEPFACT=1/CYCLES
      CDEPFACT=CDEPFACT+DEPFACT
  450 IF(ID2.NE.0)GO TO 660
```

```
      IF(DATE2.NE.DATE1)GO TO 560
      J=J+1
      GO TO 130
C     CALCULATIONS FOR THE END OF A DAY
  500 DAYDIF=DATE2-DATE1
      IF(DAYDIF.LT.1)DATE2=DATE2+31
      IF(INFDDA.NE.0)INFDA=INFDA+1
      DAYS=DATE2-DATE1
      TDAYS-TDAYS+DAYS
      IF(DAYS.EQ.1)TIMEON=(((24-HOUR1)*60)-TMINS1)+((HOUR2*60)+TMINS2)
      IF(DAYS.EQ.1)TMWMON=((HOUR2*60)+TMINS)+60
      IF(DAYS.GT.1)TIMEON=(((24-HOUR)*60)-TMINS1)+
     C((HOUR2*60)+TMINS2)+((DAYS-1)*1440)
      IF(DAYS.GT.1)TMWMON=(((HOUR2*60)+TMINS2)+60)+((DAYS-1)*1440)
      IF(MILES2.LT.MILES)MILES2=MILES2+1000
      DISTJ=MILES2-MILES1
      DISTDA=DISTDA+DISTJ
      DIST(C)=DISTDA
      DISTT=DISTT+DISDA
      INFM=0
      TIMEPON=TIMEON-(DISTJ*2)
      TMWMON=TMWMON-(DISTJ*2)
      TIMEP=TIMEPON
      IF(LOCAT.EQ.0)ONAWAY=ONAWAY+1
      LDAY=MAX(DISTM,DISTDA)
      SDAY=MIN(SDIST,DISTDA)
      SDIST=SDAY
      DISTM=LDAY
      CDAYS=CDAYS+1
      GO TO 420
  560 J=J+1
      GO TO 120
C     CALCULATIONS FOR THE END OF EACH CASE
  600 DIST(C)=DISTDA
      DISTT=DISTT+DISTDA
      CDAYS=CDAYS+1
  660 SDAY=MIN(SDIST,DISTDA)
      LDAY=MAX(DISTM,DISTDA)
      SDIST=SDAY
      DISTM=LDAY
      IF(DATE1.LT.SDATE)DATE1=DATE1+31
      TDAYS=TDAYS+1
      DISTFEAS=DISTT-CINFM
C     FINAL CALCULATIONS ON A YEARLY BASIS
      BATMLES=(DISTFEAS/CDEPFACT)
      PINFD=(INFDA/C)*100
      PINFJ=(INFJ/J)*100
      PINFM=(CINFM/DISTT)*100
      AVDAY=DISTT/CDAYS
      YINFD=(365/TDAYS)*INFDA
      YMILES=DISTT*(365/TDAYS)
      YINFM=(YMILES*PINFM)/100
      PINFCH=(INFCH/C)*100
      YINFCH=(365/TDAYS)*INFCH
      YINWMCH=(365/TDAYS)*INWMCH
      PONAWAY=(ONAWAY/(C-1))*100
      D1=0
      D2=0
      DO 10 E=1,D
      D1=D1+CHAR(E)**2
```

(Appendix 1 cont.)

```
      D2=D2+CHAR(E)
   10 CONTINUE
      CHARBAR=D2/D
      CHARSTD=SQRT((D1-((D2**2)/D))/(D-1)
      S1=0
      S2=0
      DO 20 I=1,C
      S1=S1+DIST(I)**2
      S2=S2+DIST(I)
   20 CONTINUE
      XBAR=S2/C
      STDEV=SQRT((S1-((S2**2)/C(C-1))
C     WRITE STATEMENTS
      WRITE(32,999)ID3,TDAYS,C,DISTM,SDIST,AVDAY,STDEV,YMILES,YINFM
      WRITE(32,998)PINFM,PINFD,PINFJ,YINFD,PINFCH,CHARBAR,CHARSTD,
     CPONAWAY,BATMLES
  999 FORMAT( F7.1,2F5.1,F6.1,3F5.1,F8.1,F7.1)
  998 FORMAT( F11.1,2F5.1,F6.1,F5.1,2F6.1,F5.1,F9.1)
      IF(ID2.EQ.999)GO TO 1000
      GO TO 110
 1000 STOP
      END
```

3. SIMULATION PROGRAMME TO PREDICT RECHARGING ENERGY DEMAND OF EVs IN LEWIS/HARRIS

This model is used to predict the demands that would be made on the electricity distribution network resulting from an introduction of electric cars (see section 7.4)

PROGRAMME LISTING

```
C     READ IN DRIVING DATA ARRAY
      REAL DBOOK(5000,6)
      REAL ID1,ID2,HOUR1,HOUR2,TMINS1,TMINS2,MILES1,MILES2,LOCAT
      REAL INFJ,INFDA,J,ID3
      REAL PERIOD(16000)
      DO 10, C8=1,16000
      NUMCARS(C8)=0
   10 CONTINUE
      READ(37,100)((DBOOK(M,N)N=1,6),M=1,1828)
  100 FORMAT(F3.0,F4.0,F4.0,F2.0,F6.0,F2.0)
      A=0
      B=1
      SOC=100
  110 A=A+1
      B=B+1
      RANGE=53
C     SPECIFY THE VARIABLES FOR THE JOURNEY
      ID1=DBOOK(A,1)
      ID2=DBOOK(B,1)
      DATE1=DBOOK(A,2)
      DATE2=DBOOK(B,2)
      HOUR1=DBOOK(A,3)
      HOUR2=DBOOK(B,3)
      TMINS1=DBOOK(A,4)
      TMINS2=DBOOK(B,4)
      MILES1=DBOOK(A,5)
      MILES2=DBOOK(B,5)
      LOCAT=DBOOK(A,6)

      IF(ID2.EQ.999)GO TO 250
      IF(ID2.NE.0)SOC=100
      IF(ID2.NE.0)GO TO 110
      IF(DATE2.LT.DATE1)DATE2=DATE2+31
      IF(DATE1.LT.13)GO TO 110
      IF(DATE2.GT.23)GO TO 110
      IF(LOCAT.EQ.0)GO TO 110
      C=DATE1-13
      IF(MILES2.LT.MILES1)MILES2=MILES2+1000

C     CALCULATE LENGTH OF THE JOURNEY, THE TIME TAKEN AND THE TIME
      DURING WHICH THE VEHICLE IS STATIONARY BETWEEN JOURNEYS.
      DISTJ=MILES2-MILES1
      DAYS=DATE2-DATE1
      IF(DAYS.EQ.0)TIMEJ=((HOUR2-HOUR1)*60)+(TMINS2-TMINS1)
      IF(DAYS.NE.0)TIMEJ=(((24-HOUR1)*60)-TMINS1)+((HOUR2*60)+
     CTMINS2)+((DAYS-1)*1440)
      TIMEP=TIMEJ-(DISTJ*2)
      IF(TIMEP.LT.30)GO TO 110
```

```
      RESTH=HOUR1+(C*24)
      RESTM=TMINS1+(DISTJ*2)
  120 IF(RESTM.LT.60)GO TO 140
           RESTM=RESTM-60
           RESTH=RESTH-1
           GO TO 120

C     CALCULATE  THE  MAGNITUDE  OF  BATTERY  DEPLETION  FOT   THE
      PARTICULAR JOURNEY
  140 DOD=(DISTJ/(1.25*RANGE))*100
           SOC=SOC-(1.25*DOD)
           IF(DOD.GT.80)DOD=80
           IF(SOC.LE.0)SOC=0
      Z=(RESTH*60)+RESTM
  160      TIMEP=TIMEP-30

C     CALCULATION OF CHARGING CURRENT FOR EACH MINUTE OF  ANALYSIS
      PERIOD FOR EACH INDIVIDUAL CAR.
           CURRENT=10-(SOC/10)
      DO 200, C1,30
           PERIOD(Z)=PERIOD(Z)+CURRENT
           NUMCARS(Z)=NUMCARS(Z)+1
           Z=Z+1
  200 CONTINUE

C     CALCULATION OF THE AMOUNT OF CHARGE RETURNED TO THE BATTERY
      CHARGE=11.178-(SOC*0.066)
      SOC=SOC+CHARGE
      IF(SOC.GT.100)EXCESS=SOC-100
      IF(SOC.GT.100)CHARGE=CHARGE-EXCESS
      IF(SOC.GT.100)SOC=100
      IF(SOC.EQ.100)GO TO 110
      IF(TIMEP.GE.30)GO TO 160
      GO TO 110
  250 Z=480
      PERHOUR=8
  260 SUM1=0
      SUM2=0
      PEAK1=0
      PEAK2=0
  300 DO 400 CW=1,60
           SUM1=SUM1+PERIOD(Z)
           SUM2=SUM2+NUMCARS(Z)
           CURPEAK=MAX(PERIOD(Z),PEAK1)
           CARPEAK=MAX(NUMCARS(Z),PEAK2)
           PEAK1=CURPEAK
           PEAK2=CARPEAK
           Z=Z+1
  400 CONTINUE

C     CALCULATE AVERAGE TOTAL CHARGING CURRENT FOR EACH MINUTE AND
      HOUR OF THE DAY DURING THE ANALYSIS PERIOD AND WRITE.
      AVCUR=(SUM1/60)
      AVCAR=(SUM2/60)
      WRITE(32,900)PERHOUR,AVCUR,CURPEAK,AVCUR,CARPEAK
  900 FORMAT( F6.1,F9.1,F9.1,F6.1,F6.1)
      PERHOUR=PERHOUR+1
      IF(PERHOUR.LE.264)GO TO 260
 1000 STOP
      END
```

4. ECONOMIC ANALYSIS FORTRAN PROGRAMME

This programme is designed to evaluate the economic case for each of the island motorists under examination. The basic programme is given in this appendix but it is easily adapted to examine the effect of any particular change in any of the prameters on which the economic case rests. This version is designed to perform a sensitivity analysis on each of these parameters.

PROGRAMME LISTING

```
C     PROGRAMME TO EVALUATE THE ANUAL EXPECTED SAVINGS OR  EXPENSE
C     ASSOCIATED WITH OPERATING AN ELECTRIC VEHICLE ON THE  ISLAND
C     COMMUNITIES FOR WHICH DATA IS GATHERED.  EACH OPERATOR  HAS
C     HIS ECONIMIC SITUATION ASSESSED INDIVIDUALLY AND THE  OUTPUT
C     IS SUMMARISED.

      REAL CYCLE(100,6)
      REAL MAXSAVE,MAINTCOS,NUMCARS,ICESERCO,MAINTR,LIFE
      REAL ICECAPC,ICEENER,MAINTICE,MAINTEV,LEAST,MOT,MPG,MINSAVE
      REAL S(80),H(50)
      NUMCARS=74
      READ(37,*)((CYCLE(M,N),N=1,6),M=1,NUMCARS)
      PURPRICE=5000
      CAPCOSTV=1.25
      BATPRICE=2000
      BATRATIO=0.75
      ICESERCO=60
      MAINTR=0.5
      DISCRATE=0.07
      LIFE=7
      VEHLIVES=1.65
      COSTELEC=0.035
      COSTPETR=1.8
      WHMLE=241
      TAX=100
      Z=1
      SUM1=0
      MINSAVE=5000
      MAXSAVE=-5000
C     SET COUNTERS TO ZERO
        CC1=0
        CC2=0
        CC3=0
        CC4=0
        CC5=0
        CC6=0
        CC7=0
        CC8=0
        CC9=0
        CC10=0
        CC11=0
```

```
C    SENSITIVITY  ANALYSIS.   EACH PARAMETER HAS  SEVERAL  POSSIBLE
     VALUES, A NEW ONE IS USED ON EACH ITTERATION.
100 DO 90,C1=1,4
     IF(C1.EQ.1)CAPCOSTV=1.3
     IF(C1.EQ.2)CAPCOSTV=1.0
     IF(C1.EQ.3)CAPCOSTV=1.6
     IF(C1.EQ.4)CAPCOSTV=2.0
     IF(CC2.GE.4)VEHLIVES=1.5
     IF(CC2.GE.4)GO TO 1000
 110      DO 80 C2=1,4
          IF(C2.EQ.1)VEHLIVES=1.5
          IF(C2.EQ.2)VEHLIVES=2.0
          IF(C2.EQ.3)VEHLIVES=1.2
          IF(C2.EQ.4)VEHLIVES=1.0
          CC2=C2
          IF(CC3.GE.3)BATRATIO=0.75
          IF(CC3.GE.3)GO TO 1000
 120 DO 70 C3=1,3
     IF(C3.EQ.1)BATRATIO=0.75
     IF(C3.EQ.2)BATRATIO=0.5
     IF(C3.EQ.3)BATRATIO=1.0
     CC3=C3
     IF(CC4.GE.5)COSTELEC=0.035
     IF(CC4.GE.5)GO TO 1000
 130      DO 60 C4=1,5
          IF(C4.EQ.1)COSTELEC=0.035
          IF(C4.EQ.2)COSTELEC=0.022
          IF(C4.EQ.3)COSTELEC=0.052
          IF(C4.EQ.4)COSTELEC=0.060
          IF(C4.EQ.5)COSTELEC=0.075
          CC4=C4
          IF(CC5.GE.5)COSTPETR=1.8
          IF(CC5.GE.5)GO TO 1000
 140 DO 50 C5=1,5
     IF(C5.EQ.1)COSTPETR=1.8
     IF(C5.EQ.2)COSTPETR=1.65
     IF(C5.EQ.3)COSTPETR=2.0
     IF(C5.EQ.4)COSTPETR=2.5
     IF(C5.EQ.5)COSTPETR=3.0
     CC5=C5
     IF(CC6.GE.4)MAINTR=0.5
     IF(CC6.GE.4)GO TO 1000
 150      DO 40 C6=1,4
          IF(C6.EQ.1)MAINTR=0.5
          IF(C6.EQ.2)MAINTR=0.3
          IF(C6.EQ.3)MAINTR=0.8
          IF(C6.EQ.4)MAINTR=1.0
          CC6=C6
          IF(CC7.GE.3)WHMLE=241
          IF(CC7.GE.3)GO TO 1000
 160 DO 30 C7=1,3
     IF(C7.EQ.1)WHMLE=241
     IF(C7.EQ.2)WHMLE=200
     IF(C7.EQ.3)WHMLE=350
     CC7=C7
     IF(CC8.GE.3)ICESERCO=60
     IF(CC8.GE.3)GO TO 1000
 170      DO 20 C8=1,3
          IF(C8.EQ.1)ICESERCO=60
          IF(C8.EQ.2)ICESERCO=40
```

```
          IF(C8.EQ.3)ICESERCO=80
          CC8=C8
          IF(CC9.GE.3)LIFE=7
          IF(CC9.GE.3)GO TO 1000
 180 DO 18 C9=1,3
     IF(C9.EQ.1)LIFE=7
     IF(C9.EQ.2)LIFE=10
     IF(C9.EQ.3)LIFE=5
     CC9=C9
     IF(CC10.GE.3)PURPRICE=5000
     IF(CC10.GE.3)GO TO 1000
 190      DO 16 C10=1,3
          IF(C10.EQ.1)PURPRICE=5000
          IF(C10.EQ.2)PURPRICE=3000
          IF(C10.EQ.3)PURPRICE=8000
          CC10=C10
          IF(CC11.GE.3)DISCRATE=0.07
          IF(CC11.GE.3)GO TO 1000
 192 DO 14 C11=1,3
     IF(C11.EQ.1)DISCRATE=0.07
     IF(C11.EQ.2)DISCRATE=0.05
     IF(C11.EQ.3)DISCRATE=0.09
     CC11=C11
1000 Z=1
     M=1
     MAXSAVE=-5000
     MINSAVE=5000
     SUM1=0
     DO 1010 X=1,40
     H(X)=0
1010 CONTINUE
     DO 10 W=1,NUMCARS


C    CALCULATION SECTION OF PROGRAMME
C    DEFINITION OF INPUTS
     SERVICE=CYCLE(M,1)
     SERVFRQ=CYCLE(M,2)
     MPG=CYCLE(M,3)
     SERVINT=CYCLE(M,4)
     YMILES=CYCLE(M,5)
     BATMLES=CYCLE(M,6)

C    CALCULATION OF CAPITAL RECOVERY FACTORS
     EVLIFE=LIFE*VEHLIVES
     CRFICE=(DISCRATE*((1+DISCRATE)**LIFE))/(((1+DISCRATE)**LIFE)-1)
     CRFEV=(DISCRATE*((1+DISCRATE)**EVLIFE))/
    C(((1+DISCRATE)**EVLIFE)-1)
     BATLIFE=BATMLES/YMILES
     IF(BATLIFE.GT.10)BATLIFE=10
     BLIF=BATLIFE
     CRFBAT=(DISCRATE*((1+DISCRATE)**BLIF))/(((1+DISCRATE)**BLIF)-1)

C    ANUAL EQUIVALENT CAPITAL COSTS
          EVCAPC=CRFEV*(CAPCOSTV*PURPRICE)
          ICECAPC=CRFICE*PURPRICE
          BATCAPC=CRFBAT*BATPRICE*BATRATIO

C    LEGAL COSTS
          MOT=(12*(LIFE-3))/LIFE
```

```
C    ENERGY COSTS
          IF(MPG.EQ.0)MPG=30
          ICEENER=(YMILES/MPG)*COSTPETR
          GWHMLE=(WHMLE/0.7)/1000
          EVENER=(YMILES*GWHMLE)*COSTELEC

C    MAINTENANCE COSTS
          MAINTCOS=0.016*YMILES
          MAINTEV=MAINTCOS*MAINTR
          IF(SERVFRQ.EQ.9.9)SERVFRQ=0.5
          IF(SERVFRQ.EQE.0)SERVFRQ=0.33
          SERVICE=SERVFRQ*ICESERCO
          SERVEV=SERVFRQ*(MAINTR*ICESERCO)

C    OIL COSTS
          OIL=0.001*YMILES

C    TOTAL ANUAL EQUIVALENT COSTS
          ANEQICE=ICECAPC+MOT+ICEENER+OIL+TAX+SERVICE+MAINTCOS
          ANEQEV=EVCAPC+EVENER+SERVEV+MAINTEV+BATCAPC
          ANEQCOST=ANEQICE-ANEQEV

C    FINAL CALCULATIONS
          S(Z)=ANEQCOST
          SUM1=SUM1+S(Z)
          GREATEST=MAX(MAXSAVE,S(Z))
          LEAST=MIN(MINSAVE,S(Z))
          MAXSAVE=GREATEST
          MINSAVE=LEAST
          Y=2000
          X=40
1200      IF(S(Z).GT.Y)H(X)=H(X)+1
          IF(S(Z(.GT.Y)GO TO 1220
          Y=Y-100
          X=X-1
          IF(X.LT.1)H(1)=H(1)+1
          IF(X.LT.1)GO TO 1220
          GO TO 1200
1220 Z=Z+1
     M=M+1
  10 CONTINUE
     M=1
     AVSAVE=SUM1/NUMCARS

C    WRITE STATEMENTS
       WRITE(32,999)
       WRITE(32.998)C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11
       WRITE(32,997)H(1),H(2),H(3),H(4),H(5),H(6),H(7),H(8),H(9),
    CH(10),
    CH(11),H(12),H(13),H(14),H(15),H(16),H(17),
    CH(18),C(19),C(20),
       WRITE(32,996)H(21),H(22),H(23),H(24),H(25),H(26),H(27),
    CH(28),H(29),H(30),
    CH(310,H(32),H(33),H(34),H(35),H(36),H(37),
    CH(38),H(39),H(40)
       WRITE(32,993)AVSAVE,MINSAVE,MAXSAVE
 999 FORMAT( ' C1  C2  C3  C4  C5  C6  C7  C8  C9  C10  C11')
 998 FORMAT( '9F4.0,2F5.0)
 997 FORMAT( 20F6.0)
```

```
 996 FORMAT( 20F6.0)
 993 FORMAT( F16.1,2F18.1)
  14 CONTINUE
  16 CONTINUE
  18 CONTINUE
  20 CONTINUE
  30 CONTINUE
  40 CONTINUE
  50 CONTINUE
  60 CONTINUE
  70 CONTINUE
  80 CONTINUE
  90 CONTINUE
2000 STOP
     END
```

5. MONTE CARLO SIMULATION PROGRAMME TO EVALUATE ECONOMIC CASE FOR EVs IN THE ISLANDS (see section 9.3.6)

PROBABILITY DISTRIBUTIONS OF ECONOMIC VARIABLES USED

VARIABLE	VALUE	PROBABILITY
Ratio of EV to ICE capital costs	1.0	0.1
	1.3	0.4
	1.6	0.3
	2.0	0.2
Ratio of EV to ICE useful lives	1.0	0.2
	1.2	0.3
	1.5	0.4
	2.0	0.1
Ratio of future to current battery capital costs	0.5	0.1
	0.75	0.6
	1.0	0.3
Ratio of EV to ICE maintenance costs	0.3	0.1
	0.5	0.4
	0.8	0.3
	1.0	0.2
EV energy consumption (Wh/mile)	200	0.1
	241	0.7
	300	0.2
Routine service cost of ICE vehicle (£)	40	0.2
	60	0.4
	80	0.4
ICE useful life (years)	5	0.2
	7	0.4
	10	0.4
Discount rate (%)	5	0.1
	7	0.7
	9	0.2

PROGRAMME LISTING

```
C     PROGRAME TO EVALUATE THE ANUAL EXPECTED SAVINGS OR EXPENSE
C     ASSOCIATED WITH OPERATING AN EV IN THE ISLANDS.  A MOTE
C     CARLO SIMULATION APPROACH IS USED.

      REAL ICECAPC,ICEENER,MAINTICE,MAINTEV,LEAST,MOT,MPG,MINSAVE
      REAL MAXSAVE,MAINTCOS,NUMCARS,ICESERCO,MAINTR,LIFE
      REAL S(80),H(50)
      REAL CYCLE(100,6)
      REAL (V15)

C     GENERATION OF RANDOM NUMBERS FOR MONTE CARLO SIMULATION
C     SUBROUTINE FROM NAG LIBRARY
      DOUBLE PRECISION G05CAF
```

(Appendix 1 cont.)

```
      INTEGER I
      EXTERNAL G05CAF
      EXTERNAL G05CBF
      CALL G05CBF(0)

      NUMCARS=67
      READ(37,*)(CYCLE(M,N),N=1,6),M=1,NUMCARS)
      PURPRICE=5000
      CAPCOSTV=1.25
      BATPRICE=2000
      BATRATIO=0.75
      ICESERCO=60
      MAINTR=0.5
      DISCRATE=0.07
      LIFE=7
      VEHLIVES=1.65
      COSTELEC=0.035
      COSTPETR=1.8
      WHMLE=241
      TAX=100
      Z=1
      SUM1=0
      MINSAVE=5000
      MAXSAVE=-5000
      DO 30 A=1,1000

         DO 40 I=1,11
           V(I)=G05CAF( )
 40      CONTINUE
      IF(V(1).LT.0.4)C1=1
      IF(V(1).GE.0.4)C1=2
      IF(V(1).GE.0.5)C1=3
      IF(V(1).GE.0.8)C1=4
         IF(V(2).LE.0.4)C2=1
         IF(V(2).GT.0.4)C2=2
         IF(V(2).GE.0.5)C2=3
         IF(V(2),GE.0.8)C2=4
      IF(V(3).LE.0.6)C3=1
      IF(V(3).GT.0.6)C3=2
      IF(V(3).GT.0.7)C3=3
         IF(V(4).LE.0.4)C6=1
         IF(V(4).GT.0.4)C6=2
         IF(V(4).GT.0.5)C6=3
         IF(V(4).GT.0.8)C6=4
      IF(V(5).LE.0.7)C7=1
      IF(V(5).GT.0.7)C7=2
      IF(V(5).GT.0.8)C7=3
         IF(V(6).LE.0.4)C8=1
         IF(V(6).GT.0.4)C8=2
         IF(V(6).GT.0.6)C8=3
      IF(V(7).LE.0.4)C9=1
      IF(V(7).GT.0.4)C9=2
      IF(V(7).GT.0.8)C9=3
         IF(V(8).LE.0.7)C11=1
         IF(V(8).GT.0.7)C11=2
         IF(V(8).GT.0.8)C11=3

      IF(C1.EQ.1)CAPCOSTV=1.3
      IF(C1.EQ.2)CAPCOSTV=1.0
      IF(C1.EQ.3)CAPCOSTV=1.6
```

```
      IF(C1.EQ.4)CAPCOSTV=2.0
         IF(C2.EQ.1)VEHLIVES=1.5
         IF(C2.EQ.2)VEHLIVES=2.0
         IF(C2.EQ.3)VEHLIVES=1.2
         IF(C2.EQ.4)VEHLIVES=1.0
      IF(C3.EQ.1)BATRATIO=0.75
      IF(C3.EQ.2)BATRATIO=0.5
      IF(C3.EQ.3)BATRATIO=1.0
         IF(C4.EQ.1)COSTELEC=0.035
         IF(C4.EQ.2)COSTELEC=0.022
         IF(C4.EQ.3)COSTELEC=0.052
         IF(C4.EQ.4)COSTELEC=0.060
         IF(C4.EQ.5)COSTELEC=0.075
      IF(C5.EQ.1)COSTPETR=1.8
      IF(C5.EQ.2)COSTPETR=1.65
      IF(C5.EQ.3)COSTPETR=2.0
      IF(C5.EQ.4)COSTPETR=2.5
      IF(C5.EQ.5)COSTPETR=3.0
         IF(C6.EQ.1)MAINTR=0.5
         IF(C6.EQ.2)MAINTR=0.3
         IF(C6.EQ.3)MAINTR=0.8
         IF(C6.EQ.4)MAINTR=1.0
      IF(C7.EQ.1)WHMLE=241
      IF(C7.EQ.1)WHMLE=200
      IF(C7.EQ.1)WHMLE=300
         IF(C8.EQ.1)ICESERCO=60
         IF(C8.EQ.2)ICESERCO=40
         IF(C8.EQ.3)ICESERCO=80
      IF(C9.EQ.1)LIFE=7
      IF(C9.EQ.2)LIFE=10
      IF(C9.EQ.3)LIFE=5
         IF(C10.EQ.1)PURPRICE=5000
         IF(C10.EQ.2)PURPRICE=3000
         IF(C10.EQ.3)PURPRICE=8000
      IF(C11.EQ.1)DISCRATE=0.07
      IF(C11.EQ.1)DISCRATE=0.05
      IF(C11.EQ.1)DISCRATE=0.09

1000  Z=1
      M=1
      DO 10 W=1,NUMCARS

C     CALCULATION SECTION OF PROGRAMME

C        READ USER SPECIFIC VARIABLES
      SERVICE=CYCLE(M,1)
      SERVFRQ=CYCLE(M,2)
      MPG=CYCLE(M,3)
      SERVINT=CYCLE(M,4)
      YMILES=CYCLE(M,5)
      BATMLES=CYCLE(M,6)
      EVLIFE=LIFE*VEHLIVES

C        CALCULATION OF CAPITAL RECOVERY FACTORS
      CRFICE=(DISCRATE*((1+DISCRATE)**LIFE))/(((1+DISCRATE)**LIFE)-1)
      CRFEV=(DISCRATE*((1+DISCRATE)**EVLIFE))/
     C(((1+DISCRATE)**EVLIFE)-1)
      BATLIFE=BATMLES/YMILES
      IF(BATLIFE.GT.10)BATLIFE=10
      BLIF=BATLIFE
```

```
      CRFBAT=(DISCRATE*((1+DISCRATE)**BLIF))/(((1+DISCRATE)**BLIF)-1)

C        CALCULATION OF ANNUAL EQUIVALENT CAPITAL COSTS
      EVCAPC=CRFEV*(CAPCOSTV*PURPRICE)
      ICECAPC=CRFICE*PURPRICE
      BATCAPC=CRFBAT*BATPRICE*BATRATIO

C        LEGAL COSTS
      MOT=(12*(LIFE-3))/LIFE

C        ENERGY COSTS
      IF(MPG.EQ.0)MPG=30
      ICEENER=*YMILES/MPG)*COSTPETR
      GWHMLE=(WHMLE/0.7)/1000
      EVENER=(YMILES*GWHMLE)8COSTELEC

C        MAINTENANCE COSTS
      MAINTCOS=0.016*YMILES
      MAINTEV=MAINTCOS*MAINTR
      IF(SERVFRQ.EQ.9.9)SERVFRQ=0.5
      IF(SERVFRQ.EQ.0)SERVFRQ=0.33
      SERVICE=SERVFRQ*ICESERCO
      SERVEV=SERFREQ*(MAINTR*ICESERCO)

C        OIL COSTS
      OIL=0.001*YMILES

C        TOTAL ANNUAL EQUIVALENT COSTS
      ANEQICE=ICECAPC+MOT+ICEENER+OIL+TAX+SERVICE+MAINTCOS
      ANEQEV+EVCAPC+EVENER+SERVEV+MAINTEV+BATCAPC
      ANEQCOST=ANEQICE-ANEQEV

C        FINAL CALCULATIONS
      S(Z)=ANEQCOST
      SUM1=SUM1+S(Z)
      GREATEST=MAX(MAXSAVE,S(Z))
      LEAST=MIN(MINSAVE,S(Z))
      MAXSAVE=GREATEST
      LEAST=MINSAVE
      Y=2000
      X=40
1200  IF(S(Z).GT.Y)H(X)=H(X)+1
      IF(S(Z).GT.Y)GO TO 1220
      Y=Y-100
      X=X-1
      IF(X.LT.1)H(1)=H(1)+1
      IF(X.LT.1)GO TO 1220
      GO TO 1200

1220  Z=Z+1
      M=M+1
  10  CONTINUE
      M=1
  20  CONTINUE
  30  CONTINUE
      AVSAVE=SUM1/(NUMCARS)

C        WRITE STATEMENTS
      WRITE(32,997)H(1),H(2),H(3),H(4),H(5),H(6),H(7),H(8),H(9),
     CH(10),H(11),H(12),H(13),H(14),H(15),H(16),H(17),H(18),H(19),
```

```
    CH(20)
     WRITE(32,996)H(21),H(22),H(23),H(24),H(25),H(26),H(27),H(28),
    CH(29),H(30),H(31),H(32),H(33),H(34),H(35),H(36),H(37),H(38),
    CH(39),H(40)
     WRITE(32,993)AVSAVE,MINSAVE,MAXSAVE
 997 FORMAT( 20F6.0)
 996 FORMAT( 20F6.0)
 993 FORMAT( F16.1,2F18.1)
2000 STOP
     END
```

5. DRIVING DATA SMOOTHING PROGRAMME

This minitab command file is designed to operate on the raw speed and gradient driving data collected by the data logger. The raw data is smoothed so that there are no unrealistic changes in speed or gradient resulting from the collection process. The smoothing formula used is a prespecified MINITAB routine.

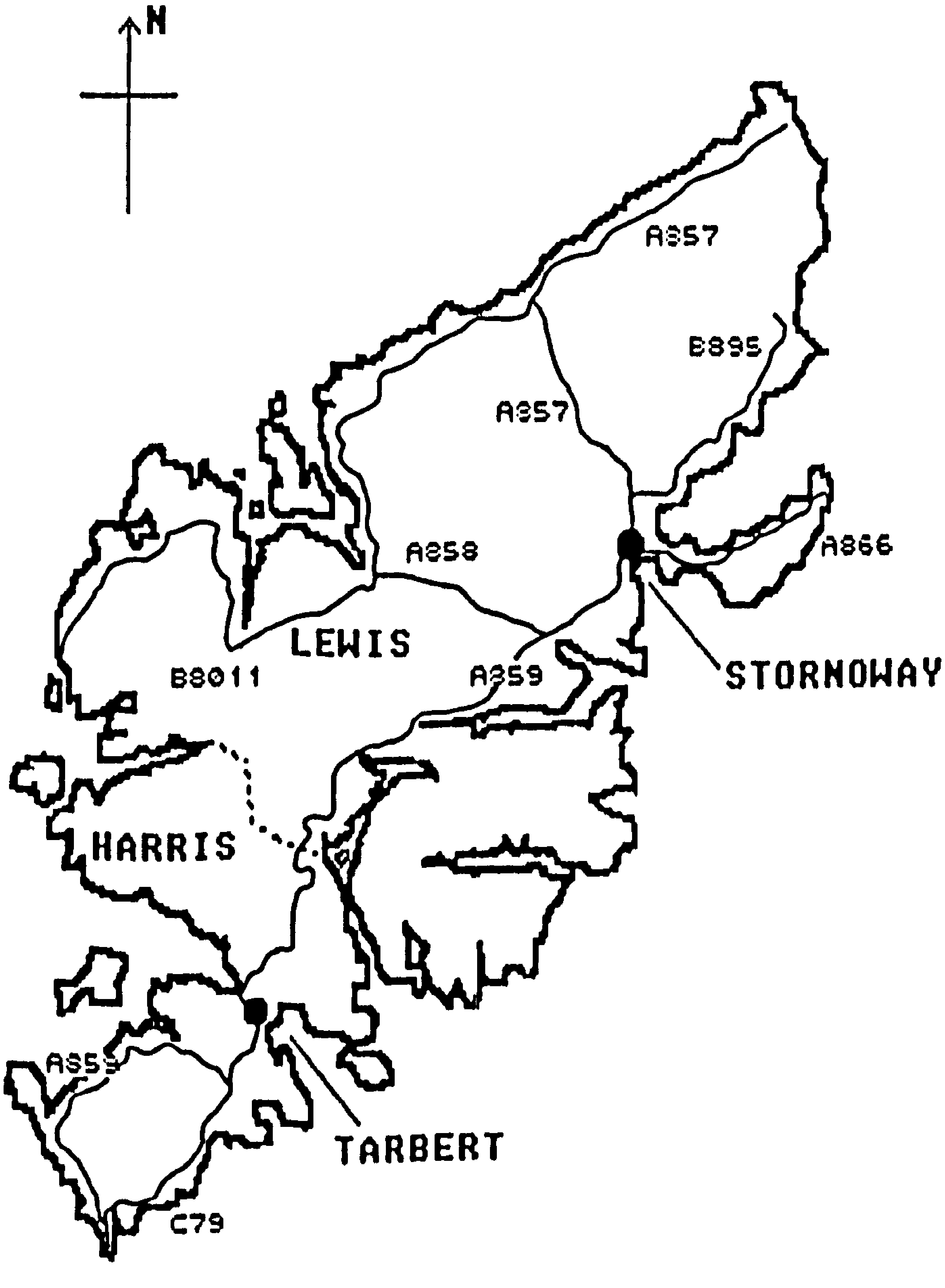
```
OH=0
READ 'filename' C1-C6
LET C4=C4+0.5
RSMOOTH C4,C5,C8            (smoothing the speed profile)
LET K1=0.0174533
LET K2=57.29578
LAG 1 C8,C9
LET C9=C5*K1
COS C9,C10
LET C9=(C10*C6)/9.81
ASIN C9,C11
LET C9=C11*K2
LET C10=C5-C9
RSMOOTH C10,C11,C12         (smoothing the gradient profile)
LAG 1 C8,C9
LET C13=(C8+C9)*1.15384615
LET C14=C12*K1                (calculation of the height of
SIN C14,C15                    the road at every stage as a
LET C14=C15*C13                check on the accuracy of the
END                            data)
```

APPENDIX 2

RESULTS OF PERFORMANCE SIMULATION MODEL

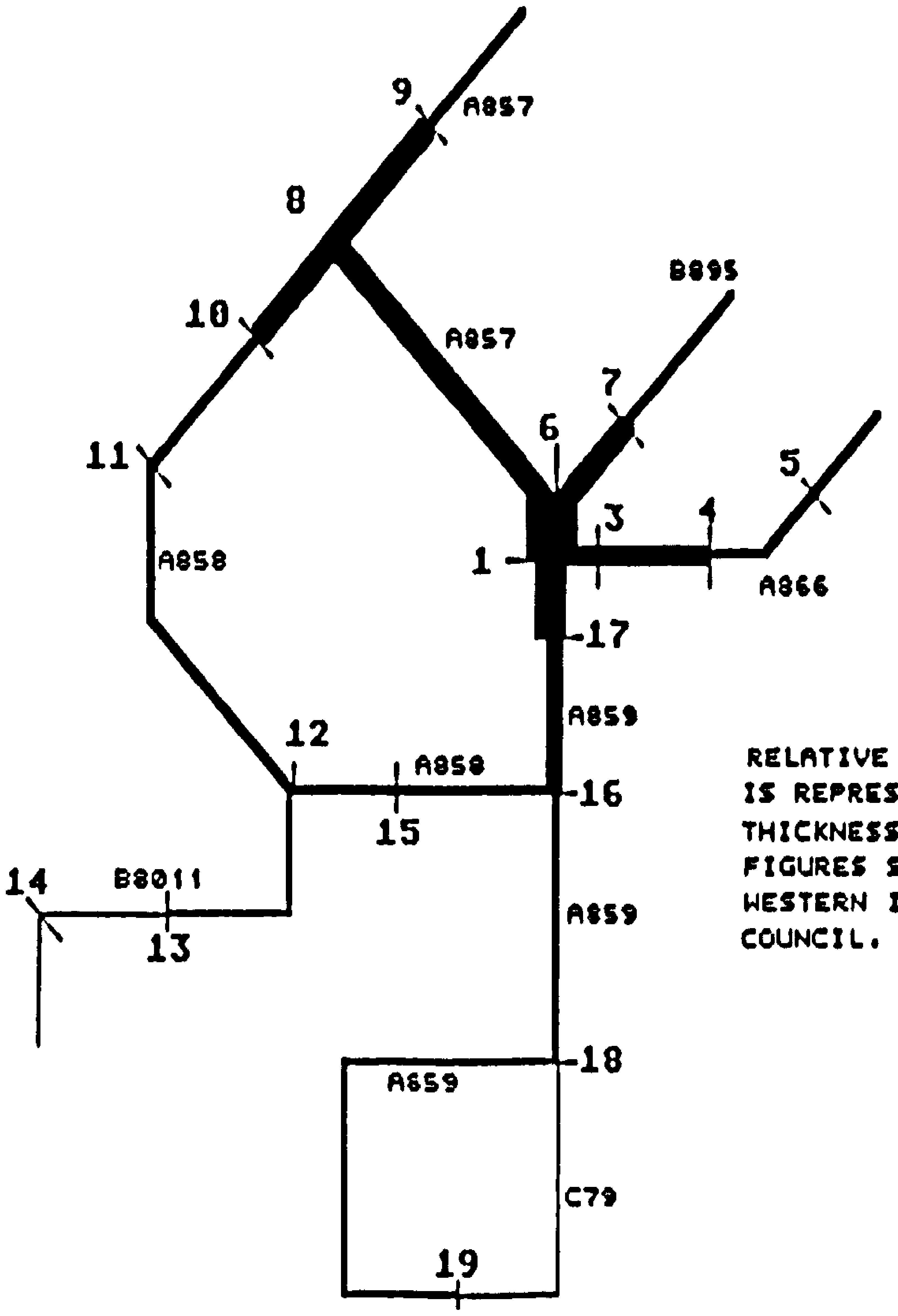
The portable data logger described in section 6.4 and appendix 12 was used in an ICE car to collect data on road gradients and vehicle speed over the island roads. The map below shows the principle roads in Lewis and Harris and the schematic traffic flow diagram shows relative traffic flows and the road sections over which data was collected. The detailed results from each section of road are given in this appendix and these results are weighted to give an overall island result.

PRINCIPAL ROADS IN LEWIS AND HARRIS



(Appendix 2 cont.)

SCHEMATIC TRAFFIC FLOW DIAGRAM FOR LEWIS AND HARRIS
(see table of road section weightings for flow figures)



RELATIVE TRAFFIC FLOW IS REPRESENTED BY THE THICKNESS OF THE LINE FIGURES SUPPLIED BY WESTERN ISLES ISLAND COUNCIL.

TABLE OF ROAD SECTION WEIGHTINGS

ROAD SECTION	SIMULATION NUMBER	TRAFFIC FLOW	SECTION LENGTH	WEIGHTING FACTOR	VEHICLE RANGE	WEIGHTED RANGE
3-5+	4	640	13.0	0.121	65.51	7.926
6-7+	5	528	12.6	0.097	48.11	4.657
6-8	6	904	10.2	0.134	59.72	8.002
8-9+	7	467	8.60	0.058	60.59	3.510
8-12	8	305	19.6	0.087	55.73	5.230
1-6	14	1128	2.00	0.033	52.71	1.740
1-17	9	1604	2.00	0.047	48.44	2.260
17-16	10	726	4.60	0.049	71.33	3.470
16-12	11	306	9.30	0.041	47.99	1.990
12-13	12	146	3.60	0.008	42.06	0.320
13-14	13	127	25.2	0.047	48.28	2.250
16-18	3	381	32.2	0.178	40.44	7.220
18-19W	1	230	22.7	0.076	39.85	3.028
19-18E	2	89	17.0	0.024	31.19	0.530
		TOTAL WEIGHTED VEHICLE RANGE				51.980

NOTES

Column 1 - The section of road as shown in the schematic diagram

Column 2 - Simulation number from tables below

Column 3 - Traffic Flow over 16 hour day as measured by the Western Isles Island Council in 1980. (Contained in Transport Policies and Programmes 1983-1988)

Column 4 - Length of road section in miles

Column 5 - Weighting factor. The fraction of total island vehicle-miles that each particular road section represents.

Column 6 - Simulated vehicle range for each road section (see tables of results)

Column 7 - Weighted range for each road section.

1 SIMULATION RESULTS FOR LEWIS AND HARRIS.

(see map and schematic diagram for details of road sections)

	SIMULATION NUMBER					
	1	2	3	4	5	6
RANGE (MILES)	39.85	31.19	40.44	65.51	48.11	59.72
RANGE (KM)	64.12	50.19	65.07	105.4	77.41	96.09
KWHRS USED/MILE	306.7	347.2	275.4	208.7	252.2	233.4
KWHRS USED/KM	190.6	215.8	171.2	129.7	156.8	145.1
TOTAL AHRS USED	52.86	48.28	49.32	57.91	52.61	58.90
AH REMAINING	137.1	141.7	140.7	132.1	137.4	131.1
TOT DRIVING TIME(MINS)	112.4	67.27	72.85	114.0	87.89	158.3
AV. BATT. CURRENT	116.4	151.1	133.7	88.89	113.3	79.41
MAX. BATT. CURRENT	457.9	567.6	530.1	319.9	426.6	235.6
AV. MOT. EFFICIENCY %	0.818	0.852	0.853	0.843	0.848	0.793
AV. TRANS. EFF %	0.903	0.897	0.865	0.836	0.857	0.859
AV. CONT. EFF %	0.768	0.835	0.876	0.896	0.887	0.803
AV. SYSTEM. EFF %	0.572	0.643	0.651	0.636	0.650	0.557
MAX. BATT. POWER (KW)	36.08	42.49	41.39	27.49	35.50	21.30
POWER EXCEEDED	10	59	77	0	23	0
REGEN ENERGY (WH/MILE)	112.1	104.1	51.48	22.37	45.60	60.88

FREQUENCY OF TIME INCREMENTS PER MILE WHERE REGENERATIVE POWER FALLS WITHIN THE FOLLOWING LIMITS

POWER RANGE (watts)						
0 TO 400 WATTS	14.1	6.06	6.90	6.11	6.07	15.8
401 TO 800 WATTS	10.1	4.74	3.51	2.32	3.06	5.12
801 TO 1200 WATTS	5.24	3.40	1.81	0.72	2.49	1.39
1201 TO 1600 WATTS	1.83	2.11	0.76	0.09	0.69	1.71
1601 TO 2000 WATTS	0.65	1.47	0.59	0.13	0.31	0
2001 TO 2400 WATTS	0	1.00	0.34	0.09	0.06	0
2401 TO 2800 WATTS	0	0.10	0.07	0	0.06	0
2801 TO 3200 WATTS	0	0.13	0	0	0	0
3201 TO 3600 WATTS	0	0.19	0	0	0	0
3601 TO 4000 WATTS	0	0	0	0	0	0

(LEWIS / HARRIS CONTINUED)

	SIMULATION NUMBER					
	7	8	9	10	11	12
RANGE (MILES)	60.59	55.73	48.44	71.33	47.99	42.06
RANGE (KM)	97.50	89.67	77.94	114.7	77.22	67.68
KWHRS USED/MILE	210.5	225.3	251.6	176.2	244.5	268.4
KWHRS USED/KM	130.8	140.1	156.4	109.5	151.9	166.8
TOTAL AHRS USED	54.68	53.99	52.82	54.08	51.15	49.79
AH REMAINING	135.3	136.0	137.2	135.9	138.9	140.2
TOT DRIVING TIME(MINS)	89.69	97.23	87.19	102.5	65.15	59.89
AV. BATT. CURRENT	107.5	111.7	112.2	108.8	136.3	140.8
MAX. BATT. CURRENT	347.8	369.7	411.9	395.8	483.8	473.2
AV. MOT. EFFICIENCY %	0.866	0.860	0.846	0.864	0.877	0.874
AV. TRANS. EFF %	0.833	0.857	0.853	0.830	0.857	0.870
AV. CONT. EFF %	0.942	0.900	0.893	0.945	0.967	0.956
AV. SYSTEM. EFF %	0.683	0.667	0.647	0.680	0.728	0.729
MAX. BATT. POWER (KW)	29.88	31.42	33.61	32.40	37.66	36.88
POWER EXCEEDED	0	3	40	46	24	20
REGEN ENERGY (WH/MILE)	19.12	41.59	58.52	36.52	33.92	36.80

FREQUENCY OF TIME
INCREMENTS PER MILE
WHERE REGENERATIVE
POWER FALLS WITHIN
THE FOLLOWING LIMITS

POWER RANGE (watts)						
0 TO 400 WATTS	5.59	7.70	6.44	7.42	3.25	2.64
401 TO 800 WATTS	1.27	3.77	2.87	1.93	0.98	1.14
801 TO 1200 WATTS	1.39	1.79	0.87	2.26	1.27	0.93
1201 TO 1600 WATTS	0	0.56	0.21	0.64	1.00	0.90
1601 TO 2000 WATTS	0	0.27	0.41	0	0.48	0.28
2001 TO 2400 WATTS	0	0.05	0.41	0	0.33	0.57
2401 TO 2800 WATTS	0	0	0	0	0	0.28
2801 TO 3200 WATTS	0	0	0	0	0	0
3201 TO 3600 WATTS	0	0	0	0	0	0
3601 TO 4000 WATTS	0	0	0	0	0	0

(LEWIS / HARRIS CONTINUED)

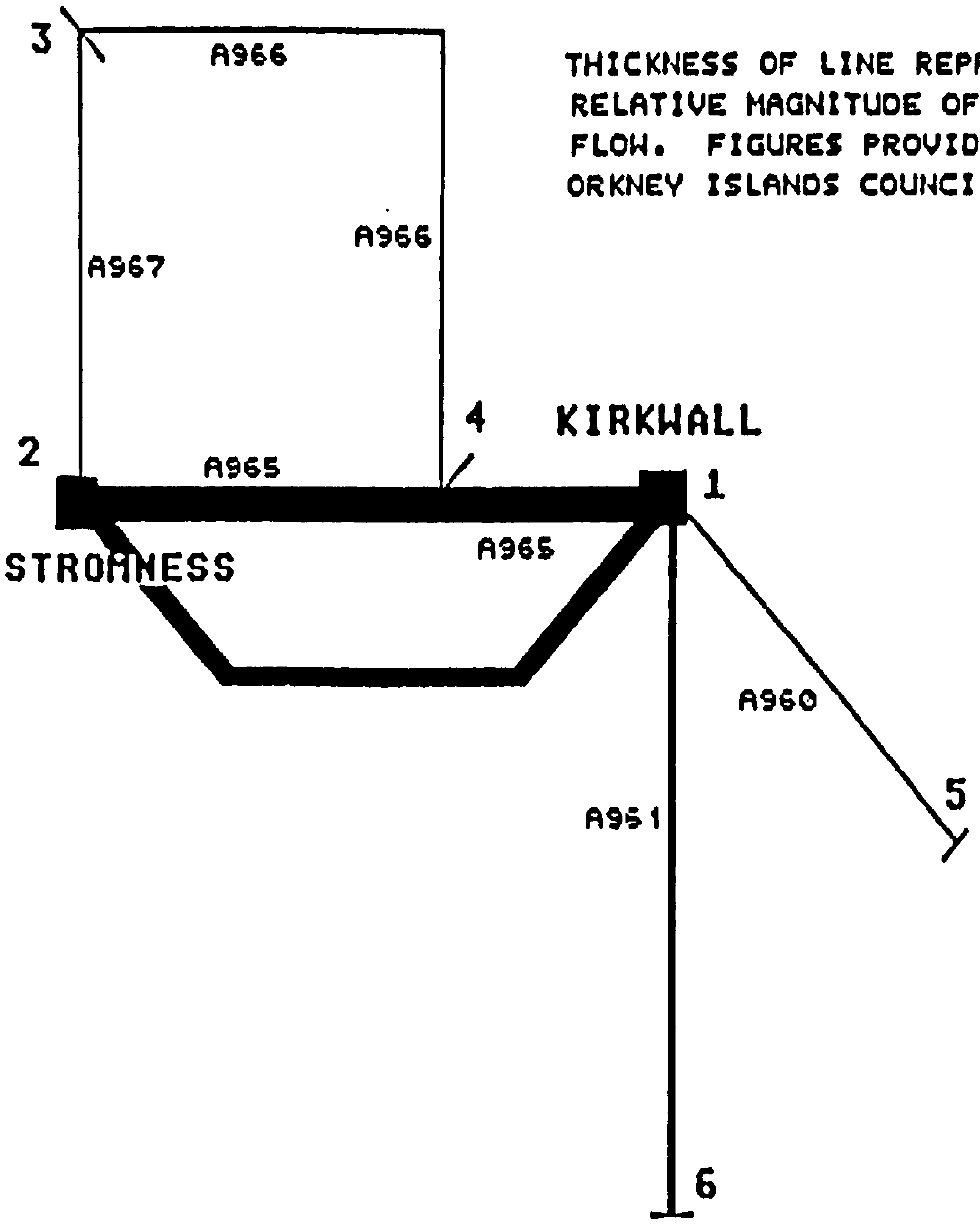
	SIMULATION NUMBER	
	13	14
RANGE (MILES)	48.28	52.71
RANGE (KM)	77.67	84.80
KWHRS USED/MILE	248.0	269.7
KWHRS USED/KM	154.2	167.6
TOTAL AHRS USED	52.06	60.06
AH REMAINING	137.9	129.9
TOT DRIVING TIME(MINS)	85.27	203.5
AV. BATT. CURRENT	118.8	66.43
MAX. BATT. CURRENT	412.4	443.9
AV. MOT. EFFICIENCY %	0.855	0.731
AV. TRANS. EFF %	0.857	0.855
AV. CONT. EFF %	0.881	0.739
AV. SYSTEM. EFF %	0.650	0.471
MAX. BATT. POWER (KW)	35.36	35.58
POWER EXCEEDED	22	12
REGEN ENERGY (WH/MILE)	56.07	70.03

FREQUENCY OF TIME INCREMENTS PER MILE WHERE REGENERATIVE POWER FALLS WITHIN THE FOLLOWING LIMITS

POWER RANGE (watts)		
0 TO 400 WATTS	5.37	27.4
401 TO 800 WATTS	3.75	9.99
801 TO 1200 WATTS	2.19	1.21
1201 TO 1600 WATTS	0.62	0
1601 TO 2000 WATTS	0.73	0
2001 TO 2400 WATTS	0.54	0
2401 TO 2800 WATTS	0.04	0
2801 TO 3200 WATTS	0	0
3201 TO 3600 WATTS	0	0
3601 TO 4000 WATTS	0	0

2 SIMULATION RESULTS FOR MAINLAND ORKNEY

SCHEMATIC TRAFFIC FLOW DIAGRAM - ORKNEY
(see table of road section weightings for figures)



THICKNESS OF LINE REPRESENTS RELATIVE MAGNITUDE OF TRAFIC FLOW. FIGURES PROVIDED BY ORKNEY ISLANDS COUNCIL.

TABLE OF ROAD SECTION WEIGHTINGS

1 ROAD SECTION	2 SIMULATION NUMBER	3 TRAFFIC FLOW	4 SECTION LENGTH	5 WEIGHTING FACTOR	6 VEHICLE RANGE	7 WEIGHTED RANGE
1-2N	1	1067	15.0	0.312	51.22	15.93
1-2S	2	864	18.5	0.311	59.70	18.51
1-6	3	457	21.0	0.187	43.10	8.103
1-5	4	206	10.0	0.040	51.35	2.105
2-3	5	271	13.0	0.069	72.30	5.061
3-4	6	230	18.0	0.081	68.49	5.180
		TOTAL WEIGHTED VEHICLE RANGE				54.880

NOTES

Column 1 - The section of road as shown in the schematic diagram
Column 2 - Simulation number from tables below
Column 3 - Traffic Flow over 16 hour day as measured by the Orkney Isles Island Council in 1980.

Column 4 - Length of road section in miles
Column 5 - Weighting factor. The fraction of total island vehicle-miles that each particular road section represents.
Column 6 - Simulated vehicle range for each road section (see tables of results)
Column 7 - Weighted range for each road section.

1 SIMULATION RESULTS FOR MAINLAND ORKNEY.

(see schematic diagram for details of road sections)

	SIMULATION NUMBER 1	2	3	4	5	6
RANGE (MILES)	51.22	59.70	43.10	51.35	72.30	66.49
RANGE (KM)	82.41	96.06	69.34	82.62	116.3	106.9
KWHRS USED/MILE	240.0	215.0	249.6	233.8	182.5	209.3
KWHRS USED/KM	149.2	133.6	155.1	145.3	113.4	130.1
TOTAL AHRS USED	53.16	54.99	48.18	52.09	56.19	58.64
AH REMAINING	136.8	135.0	141.8	137.9	133.8	131.4
TOT DRIVING TIME(MINS)	83.42	98.08	66.08	80.62	118.8	1.101
AV. BATT. CURRENT	112.5	104.2	139.7	122.5	99.50	95.69
MAX. BATT. CURRENT	475.9	465.1	698.7	369.9	304.8	215.9
AV. MOT. EFFICIENCY %	0.849	0.856	0.857	0.859	0.850	0.868
AV. TRANS. EFF %	0.848	0.844	0.864	0.858	0.850	0.857
AV. CONT. EFF %	0.906	0.929	0.932	0.926	0.903	0.953
AV. SYSTEM. EFF %	0.658	0.676	0.695	0.685	0.656	0.711
MAX. BATT. POWER (KW)	38.54	36.75	47.80	31.66	26.74	19.74
POWER EXCEEDED	30	12	72	5	0	0
REGEN ENERGY (WH/MILE)	35.30	31.89	45.34	38.03	46.86	21.27

FREQUENCY OF TIME
INCREMENTS PER MILE
WHERE REGENERATIVE
POWER FALLS WITHIN
THE FOLLOWING LIMITS

POWER RANGE (watts)						
0 TO 400 WATTS	4.80	5.53	4.64	3.66	6.87	2.71
401 TO 800 WATTS	2.17	3.65	2.80	2.30	4.59	2.17
801 TO 1200 WATTS	0.94	1.17	2.11	2.04	2.84	1.22
1201 TO 1600 WATTS	0.47	0.47	0.74	1.05	0.08	0.27
1601 TO 2000 WATTS	0.23	0.05	0.65	0	0.07	0
2001 TO 2400 WATTS	0.18	0	0.09	0	0	0
2401 TO 2800 WATTS	0.06	0	0	0	0.07	0
2801 TO 3200 WATTS	0.18	0	0	0	0	0
3201 TO 3600 WATTS	0.12	0	0	0	0.07	0
3601 TO 4000 WATTS	0	0	0	0	0	0

3 URBAN DRIVING IN DIFFERENT TOWNS

	ROAD SECTION			
	EDINBURGH	GLASGOW	STIRLING	STORNOWAY
RANGE (MILES)	53.01	53.79	50.66	52.71
RANGE (KM)	85.29	86.54	81.52	84.80
KWHRS USED/MILE	293.3	266.4	293.3	269.7
KWHRS USED/KM	182.3	165.5	182.3	167.6
TOTAL AHRS USED	64.82	60.22	62.18	60.06
AH REMAINING	125.2	129.8	127.8	129.9
TOT DRIVING TIME(MINS)	250.5	153.5	185.5	203.5
AV. BATT. CURRENT	53.05	77.63	68.43	66.43
MAX. BATT. CURRENT	311.4	265.4	242.2	443.9
AV. MOT. EFFICIENCY %	0.708	0.787	0.763	0.731
AV. TRANS. EFF %	0.876	0.874	0.886	0.855
AV. CONT. EFF %	0.717	0.803	0.751	0.739
AV. SYSTEM. EFF %	0.451	0.516	0.516	0.471
MAX. BATT. POWER (KW)	27.02	23.99	21.95	35.58
POWER EXCEEDED	0	0	0	12
REGEN ENERGY (WH/MILE)	80.16	45.42	76.78	70.05

FREQUENCY OF TIME
INCREMENTS PER MILE
WHERE REGENERATIVE
POWER FALLS WITHIN
THE FOLLOWING LIMITS

POWER RANGE (watts)				
0 TO 400 WATTS	13.2	13.9	17.4	27.4
401 TO 800 WATTS	4.77	4.09	8.76	10.0
801 TO 1200 WATTS	0.79	2.10	4.03	1.21
1201 TO 1600 WATTS	0.79	0.11	0.47	0
1601 TO 2000 WATTS	0	0	0	0
2001 TO 2400 WATTS	0	0	0	0
2401 TO 2800 WATTS	0	0	0	0
2801 TO 3200 WATTS	0	0	0	0
3201 TO 3600 WATTS	0	0	0	0
3601 TO 4000 WATTS	0	0	0	0

4 CONSTANT SPEED DRIVING AND SAEd CYCLE

	DRIVING SPEED OR CYCLE					
	20mph	30mph	45mph	55mph	60mph	SAEd
RANGE (MILES	101.7	103.1	81.53	59.68	50.65	39.58
RANGE (KM)	163.6	165.9	131.2	96.02	81.49	63.68
KWHRS USED/MILE	200.8	178.7	190.1	224.6	245.5	296.3
KWHRS USED/KM	124.8	111.1	118.2	139.6	152.6	184.1
TOTAL AHRS USED	191.0	173.5	148.3	130.8	123.0	118.3
AH REMAINING	-1.0	16.50	41.69	59.21	67.00	71.75
TOT DRIVING TIME(MINS)	707.7	478.8	252.3	151.1	117.5	85.55
AV. BATT. CURRENT	37.37	50.19	81.40	119.8	144.9	91.96
MAX. BATT. CURRENT	39.77	53.46	86.91	128.3	155.5	351.0
AV. MOT. EFFICIENCY %	0.722	0.822	0.884	0.906	0.912	0.806
AV. TRANS. EFF %	0.848	0.853	0.868	0.878	0.882	0.915
AV. CONT. EFF %	0.746	0.862	0.990	0.990	0.990	0.917
AV. SYSTEM. EFF %	0.457	0.604	0.760	0.788	0.797	0.687
MAX. BATT. POWER (KW)	3.99	5.33	8.51	12.28	14.65	29.50
POWER EXCEEDED	0	0	0	0	0	0
REGEN ENERGY (WH/MILE)	0	0	0	0	0	0

APPENDIX 3

RESULTS FROM APPLICATION POTENTIAL MODEL

The tables below show the calculated statistics for application potential and battery life for several different charging regimes and different assummed vehicle ranges. The figures show the average percentage of infeasible vehicle miles, days and journeys that will be experienced for any particular range and charging regime. Individual motorists may experience much less or much more inconvenience than the average, as can be seen from the 'maximum' and 'minimum' figures in the detailed results tables. Expected battery life in years is also given (Chloride battery life equation assumed) as well as statistics for the average magnitude of charge given to the batteries.

A. RESULTS FOR LEWIS/HARRIS

SUMMARISED RESULTS

1 CHARGING AT HOME OVERNIGHT ONLY

	VEHICLE RANGE (miles)				
	40	52	75	100	150
FEASIBLE CARS (%)	17.9	28.3	59.7	80.6	94.0
INFEASIBLE MILES (%)	21.5	12.8	5.25	2.64	1.70
INFEASIBLE DAYS (%)	26.9	15.5	5.27	2.31	0.93
INFEASIBLE JOURNEYS (%)	22.4	17.6	6.32	2.11	1.10

2 CHARGING AT HOME ANYTIME

	VEHICLE RANGE (miles)				
	40	52	75	100	150
FEASIBLE CARS (%)	23.9	37.3	68.6	80.6	95.5
INFEASIBLE MILES (%)	16.4	9.63	4.56	2.50	1.30
INFEASIBLE DAYS (%)	11.0	4.30	1.63	0.93	0.15
INFEASIBLE JOURNEYS (%)	16.5	7.50	2.70	1.50	0.37

3 CHARGING ANYWHERE ANYTIME

	VEHICLE RANGE (miles)				
	40	52	75	100	150
FEASIBLE CARS (%)	34.3	55.2	85.1	91.0	95.5
INFEASIBLE MILES (%)	10.1	5.78	2.77	1.48	0.30
INFEASIBLE DAYS (%)	7.93	2.86	0.78	0.56	0.15
INFEASIBLE JOURNEYS (%)	10.3	4.06	1.27	0.87	0.33

DETAILED RESULTS

1.1 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 40 miles)

FEASIBLE ISLAND CARS (%) - 17.9

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	21.5	14.6	0	63.4
INFEASIBLE DAYS (%)	26.9	24.5	0	100
INFEASIBLE JOURNEYS (%)	22.4	17.5	0	53.5
BATTERY LIFE (YEARS)	6.16	3.15	2.54	17.6
BATTERY CHARGE MAGNITUDE (%)	59.3	19.8	20.0	100

1.2 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 52 miles)

FEASIBLE ISLAND CARS (%) - 28.3

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	12.6	12.2	0	56.0
INFEASIBLE DAYS (%)	15.5	16.2	0	63.6
INFEASIBLE JOURNEYS (%)	17.6	10.2	0	45.6
BATTERY LIFE (YEARS)	7.37	3.61	2.69	22.3
BATTERY CHARGE MAGNITUDE (%)	50.5	18.9	15.4	90.2

1.3 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 75 miles)

FEASIBLE ISLAND CARS (%) - 59.7

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	5.25	8.70	0	43.3
INFEASIBLE DAYS (%)	5.27	9.06	0	42.9
INFEASIBLE JOURNEYS (%)	6.32	4.98	0	25.1
BATTERY LIFE (YEARS)	9.23	3.92	4.00	26.0
BATTERY CHARGE MAGNITUDE (%)	37.8	15.3	10.7	71.4

1.4 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 100 miles)

FEASIBLE ISLAND CARS (%) - 80.6

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	2.64	5.91	0	32.5
INFEASIBLE DAYS (%)	2.31	6.05	0	18.2
INFEASIBLE JOURNEYS (%)	2.11	4.50	0	18.2
BATTERY LIFE (YEARS)	10.7	3.95	5.13	28.1
BATTERY CHARGE MAGNITUDE (%)	29.2	12.1	8.00	55.8

1.5 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 150 miles)

FEASIBLE ISLAND CARS (%) - 94.0

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages)	
			MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	1.70	1.92	0	14.0
INFEASIBLE DAYS (%)	0.93	4.36	0	28.6
INFEASIBLE JOURNEYS (%)	1.10	3.91	0	12.8
BATTERY LIFE (YEARS)	12.4	4.20	6.08	30.0
BATTERY CHARGE MAGNITUDE (%)	20.0	8.75	5.30	44.3

2.1 CHARGING AT HOME ANYTIME (Assumed range = 40 miles)

FEASIBLE ISLAND CARS (%) - 23.9

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages)	
			MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	16.4	13.9	0	66.2
INFEASIBLE DAYS (%)	11.0	14.7	0	50.0
INFEASIBLE JOURNEYS (%)	16.5	15.1	0	50.0
BATTERY LIFE (YEARS)	5.90	2.97	2.41	17.1
BATTERY CHARGE MAGNITUDE (%)	44.8	17.7	13.3	94.8

2.2 CHARGING AT HOME ANYTIME (Assumed range = 52 miles)

FEASIBLE ISLAND CARS (%) - 37.3

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages)	
			MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	9.63	11.9	0	61.3
INFEASIBLE DAYS (%)	4.30	8.70	0	36.4
INFEASIBLE JOURNEYS (%)	7.50	8.84	0	38.5
BATTERY LIFE (YEARS)	6.83	3.22	2.80	18.6
BATTERY CHARGE MAGNITUDE (%)	37.3	15.8	10.3	83.9

2.3 CHARGING AT HOME ANYTIME (Assumed range = 75 miles)

FEASIBLE ISLAND CARS (%) - 68.6

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages)	
			MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	4.58	9.00	0	52.2
INFEASIBLE DAYS (%)	1.63	4.09	0	18.2
INFEASIBLE JOURNEYS (%)	2.70	4.80	0	22.6
BATTERY LIFE (YEARS)	8.14	3.46	3.81	20.2
BATTERY CHARGE MAGNITUDE (%)	27.5	11.9	7.10	58.8

2.4 CHARGING AT HOME ANYTIME (Assumed range = 100 miles)

FEASIBLE ISLAND CARS (%) - 80.6

			(Individual) motorist averages)	
VARIABLE	ISLAND MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	2.50	7.08	0	47.2
INFEASIBLE DAYS (%)	0.93	3.01	0	14.3
INFEASIBLE JOURNEYS (%)	1.50	3.90	0	17.9
BATTERY LIFE (YEARS)	9.08	3.59	4.04	21.0
BATTERY CHARGE MAGNITUDE (%)	21.1	9.23	5.30	44.1

2.5 CHARGING AT HOME ANYTIME (Assumed range = 150 miles)

FEASIBLE ISLAND CARS (%) - 95.5

			(Individual) motorist averages)	
VARIABLE	ISLAND MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	1.30	5.07	0	37.0
INFEASIBLE DAYS (%)	0.15	1.22	0	10.0
INFEASIBLE JOURNEYS (%)	0.37	1.82	0	11.8
BATTERY LIFE (YEARS)	10.1	3.81	4.23	21.7
BATTERY CHARGE MAGNITUDE (%)	14.3	6.31	3.60	29.5

3.1 CHARGING ANYWHERE ANYTIME (Assumed range = 40 miles)

FEASIBLE ISLAND CARS (%) - 34.3

			(Individual) motorist averages)	
VARIABLE	ISLAND MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	10.1	12.1	0	58.6
INFEASIBLE DAYS (%)	7.93	12.1	0	50.0
INFEASIBLE JOURNEYS (%)	10.3	11.6	0	48.7
BATTERY LIFE (YEARS)	5.00	2.36	1.63	14.0
BATTERY CHARGE MAGNITUDE (%)	33.9	14.3	10.0	70.9

3.2 CHARGING ANYWHERE ANYTIME (Assumed range = 52 miles)

FEASIBLE ISLAND CARS (%) - 55.2

			(Individual) motorist averages)	
VARIABLE	ISLAND MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	5.78	9.80	0	49.1
INFEASIBLE DAYS (%)	2.86	6.25	0	28.6
INFEASIBLE JOURNEYS (%)	4.06	6.30	0	26.3
BATTERY LIFE (YEARS)	5.63	2.55	1.72	14.8
BATTERY CHARGE MAGNITUDE (%)	27.5	12.1	7.70	57.1

3.3 CHARGING ANYWHERE ANYTIME (Assumed range = 75 miles)

FEASIBLE ISLAND CARS (%) - 85.1

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	2.77	6.64	0	37.1
INFEASIBLE DAYS (%)	0.78	2.93	0	14.3
INFEASIBLE JOURNEYS (%)	1.27	3.71	0	16.1
BATTERY LIFE (YEARS)	6.46	2.75	1.80	16.1
BATTERY CHARGE MAGNITUDE (%)	19.8	8.90	5.30	41.3

3.4 CHARGING ANYWHERE ANYTIME (Assumed range = 100 miles)

FEASIBLE ISLAND CARS (%) - 91.0

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	1.48	4.29	0	27.0
INFEASIBLE DAYS (%)	0.56	2.57	0	14.3
INFEASIBLE JOURNEYS (%)	0.87	3.22	0	15.8
BATTERY LIFE (YEARS)	6.98	2.94	1.84	17.1
BATTERY CHARGE MAGNITUDE (%)	15.2	6.90	4.00	32.5

3.5 CHARGING ANYWHERE ANYTIME (Assumed range = 150 miles)

FEASIBLE ISLAND CARS (%) - 95.5

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0.30	1.01	0	6.80
INFEASIBLE DAYS (%)	0.15	1.22	0	10.0
INFEASIBLE JOURNEYS (%)	0.33	1.68	0	11.8
BATTERY LIFE (YEARS)	7.50	3.12	1.88	18.0
BATTERY CHARGE MAGNITUDE (%)	10.3	4.88	2.70	25.1

B. RESULTS FOR ORKNEY

SUMMARISED RESULTS

1 CHARGING AT HOME OVERNIGHT ONLY

	VEHICLE RANGE (miles)				
	40	55	75	100	150
FEASIBLE CARS (%)	22.9	45.9	77.0	93.2	100
INFEASIBLE MILES (%)	17.6	9.01	3.25	1.03	0
INFEASIBLE DAYS (%)	19.6	11.6	3.30	0.99	0
INFEASIBLE JOURNEYS (%)	18.7	6.31	3.82	0.92	0

2 CHARGING AT HOME ANYTIME

	VEHICLE RANGE (miles)				
	40	55	75	100	150
FEASIBLE CARS (%)	32.4	63.5	86.5	95.9	100
INFEASIBLE MILES (%)	11.2	4.60	0.79	0.27	0
INFEASIBLE DAYS (%)	7.89	2.25	0.61	0.14	0
INFEASIBLE JOURNEYS (%)	9.31	3.52	1.28	0.32	0

3 CHARGING ANYWHERE ANYTIME

	VEHICLE RANGE (miles)				
	40	55	75	100	150
FEASIBLE CARS (%)	43.2	82.4	93.2	98.6	100
INFEASIBLE MILES (%)	5.48	2.04	0.69	0.06	0
INFEASIBLE DAYS (%)	4.39	0.92	0.24	0.02	0
INFEASIBLE JOURNEYS (%)	4.74	1.52	0.62	0.07	0

DETAILED RESULTS

1.1 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 40 miles)

FEASIBLE ISLAND CARS (%) - 22.9

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	17.6	11.8	0	53.6
INFEASIBLE DAYS (%)	19.7	23.2	0	100
INFEASIBLE JOURNEYS (%)	18.7	16.9	0	84.3
BATTERY LIFE (YEARS)	6.15	2.86	2.19	16.7
BATTERY CHARGE MAGNITUDE (%)	52.9	22.1	14.0	100

1.2 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 55 miles)

FEASIBLE ISLAND CARS (%) - 45.9

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	9.01	8.37	0	39.2
INFEASIBLE DAYS (%)	11.6	18.0	0	85.7
INFEASIBLE JOURNEYS (%)	6.31	12.1	0	71.2
BATTERY LIFE (YEARS)	7.46	3.15	2.30	17.8
BATTERY CHARGE MAGNITUDE (%)	42.6	20.5	10.2	98.5

1.3 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 75 miles)

FEASIBLE ISLAND CARS (%) - 77.0

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	3.25	4.75	0	28.8
INFEASIBLE DAYS (%)	3.30	9.83	0	57.2
INFEASIBLE JOURNEYS (%)	3.82	8.10	0	54.0
BATTERY LIFE (YEARS)	8.88	3.15	2.57	18.8
BATTERY CHARGE MAGNITUDE (%)	33.0	17.7	7.40	92.4

1.4 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 100 miles)

FEASIBLE ISLAND CARS (%) - 93.2

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	1.03	2.40	0	18.3
INFEASIBLE DAYS (%)	0.99	4.45	0	28.6
INFEASIBLE JOURNEYS (%)	0.92	2.90	0	14.1
BATTERY LIFE (YEARS)	10.0	2.97	3.45	19.9
BATTERY CHARGE MAGNITUDE (%)	25.2	14.4	5.60	79.0

1.5 CHARGING AT HOME OVERNIGHT ONLY (Assumed range = 150 miles)

FEASIBLE ISLAND CARS (%) - 100

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0	0	0	0
INFEASIBLE DAYS (%)	0	0	0	0
INFEASIBLE JOURNEYS (%)	0	0	0	0
BATTERY LIFE (YEARS)	11.3	2.68	5.08	21.0
BATTERY CHARGE MAGNITUDE (%)	16.9	9.93	3.70	57.4

2.1 CHARGING AT HOME ANYTIME (Assumed range = 40 miles)

FEASIBLE ISLAND CARS (%) - 32.4

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	11.2	9.32	0	48.4
INFEASIBLE DAYS (%)	7.89	12.6	0	71.4
INFEASIBLE JOURNEYS (%)	9.31	12.9	0	78.9
BATTERY LIFE (YEARS)	5.51	2.59	1.69	16.7
BATTERY CHARGE MAGNITUDE (%)	35.5	16.1	7.80	82.7

2.2 CHARGING AT HOME ANYTIME (Assumed range = 55 miles)

FEASIBLE ISLAND CARS (%) - 63.5

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	4.60	5.62	0	32.1
INFEASIBLE DAYS (%)	2.25	5.07	0	23.1
INFEASIBLE JOURNEYS (%)	3.52	8.32	0	63.2
BATTERY LIFE (YEARS)	6.41	2.89	2.01	17.8
BATTERY CHARGE MAGNITUDE (%)	27.9	14.1	5.90	80.0

2.3 CHARGING AT HOME ANYTIME (Assumed range = 75 miles)

FEASIBLE ISLAND CARS (%) - 86.5

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0.79	2.64	0	13.8
INFEASIBLE DAYS (%)	0.61	2.47	0	15.4
INFEASIBLE JOURNEYS (%)	1.28	5.75	0	47.4
BATTERY LIFE (YEARS)	7.23	3.01	2.63	18.8
BATTERY CHARGE MAGNITUDE (%)	21.2	11.7	4.40	74.7

2.4 CHARGING AT HOME ANYTIME (Assumed range = 100 miles)

FEASIBLE ISLAND CARS (%) - 95.9

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0.27	0.89	0	8.30
INFEASIBLE DAYS (%)	0.14	1.16	0	10.0
INFEASIBLE JOURNEYS (%)	0.32	1.63	0	10.5
BATTERY LIFE (YEARS)	7.83	3.09	3.02	19.9
BATTERY CHARGE MAGNITUDE (%)	16.2	9.41	3.30	63.5

2.5 CHARGING AT HOME ANYTIME (Assumed range = 150 miles)

FEASIBLE ISLAND CARS (%) - 100

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0	0	0	0
INFEASIBLE DAYS (%)	0	0	0	0
INFEASIBLE JOURNEYS (%)	0	0	0	0
BATTERY LIFE (YEARS)	8.43	3.16	3.50	21.0
BATTERY CHARGE MAGNITUDE (%)	10.9	6.37	2.20	43.6

3.1 CHARGING ANYWHERE ANYTIME (Assumed range = 40 miles)

FEASIBLE ISLAND CARS (%) - 43.2

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	5.48	8.28	0	39.7
INFEASIBLE DAYS (%)	4.39	7.82	0	42.9
INFEASIBLE JOURNEYS (%)	4.74	8.79	0	68.4
BATTERY LIFE (YEARS)	4.80	2.33	1.42	13.9
BATTERY CHARGE MAGNITUDE (%)	27.0	11.5	5.50	76.8

3.2 CHARGING ANYWHERE ANYTIME (Assumed range = 55 miles)

FEASIBLE ISLAND CARS (%) - 82.4

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	2.04	3.60	0	23.0
INFEASIBLE DAYS (%)	0.92	3.36	0	23.1
INFEASIBLE JOURNEYS (%)	1.52	6.46	0	52.6
BATTERY LIFE (YEARS)	5.40	2.54	1.64	16.6
BATTERY CHARGE MAGNITUDE (%)	18.7	8.39	1.40	33.7

3.3 CHARGING ANYWHERE ANYTIME (Assumed range = 75 miles)

FEASIBLE ISLAND CARS (%) - 93.2

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0.69	1.50	0	9.20
INFEASIBLE DAYS (%)	0.24	1.46	0	10.0
INFEASIBLE JOURNEYS (%)	0.62	3.74	0	31.8
BATTERY LIFE (YEARS)	5.87	2.70	1.93	19.0
BATTERY CHARGE MAGNITUDE (%)	15.3	8.03	3.00	62.9

3.4 CHARGING ANYWHERE ANYTIME (Assumed range = 100 miles)

FEASIBLE ISLAND CARS (%) - 98.6

	ISLAND	STANDARD	(Individual) motorist averages)	
VARIABLE	MEAN	DEVIATION	MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0.08	0.17	0	1.50
INFEASIBLE DAYS (%)	0.02	0.12	0	8.30
INFEASIBLE JOURNEYS (%)	0.07	0.62	0	5.30
BATTERY LIFE (YEARS)	6.19	2.80	2.11	19.9
BATTERY CHARGE MAGNITUDE (%)	11.6	6.35	2.20	50.7

3.5 CHARGING ANYWHERE ANYTIME (Assumed range = 150 miles)

FEASIBLE ISLAND CARS (%) - 100

VARIABLE	ISLAND MEAN	STANDARD DEVIATION	(Individual) motorist averages) MINIMUM	MAXIMUM
INFEASIBLE MILES (%)	0	0	0	0
INFEASIBLE DAYS (%)	0	0	0	0
INFEASIBLE JOURNEYS (%)	0	0	0	0
BATTERY LIFE (YEARS)	6.49	2.89	2.32	21.0
BATTERY CHARGE MAGNITUDE (%)	7.77	4.29	1.50	34.4

APPENDIX 4

RESULTS OF ECONOMIC ANALYSIS SIMULATIONS

This appendix documents the results from the economic analyses described in chapter 9. Three different models were used to examine the economic case for EVs in the islands and the results are listed in the following order.

1 A Monte Carlo type simulation was used to examine the spread of likely savings in the light of uncertainties surrounding the future value of economic parameters. The probability distributions used for each of these parameters are listed in appendix 1.

2 A scenario approach was used to examine the 'best' and 'worst' case for the expected annual savings under various different charging regimes and and assuming different battery lifetime equations.

3 A sensitivity analysis is used to examine the sensitivity of the distribution of annual expected savings to variations in each of the input parameters.

RESULTS OF ECONOMIC ANALYSIS SIMULATIONS

1 MONTE CARLO SIMULATION

Each motorist has his economic case assessed 1000 times and each time the calculations are made the values assigned to each of the economic variables is chosen at random from a pre-specified probability distribution (see appendix 1). The figures below represent the number of times the calculated annual saving falls within certain ranges. Various charge regimes were simulated and the model was used to examine the effects of assuming different battery cycle life characteristics (see section 9.2.7 for explanation). The various permutations of these two factors are numbered as follows,

1	Charging at home overnight only	-	semi-logarithmic cycle life eqn.
2	" " " " "	-	Chloride linear cycle life eqn.
3	Charging at home anytime	-	semi-logarithmic " " "
4	" " " "	-	Chloride linear " " "
5	Charging at home anytime but waiting until the battery is at least 20% discharged	-	" " " " "
6	Charging at home anytime but waiting until the battery is at least 40% discharged	-	" " " " "
7	Charging anywhere anytime	-	semi-logarithmic " " "
8	" " " "	-	Chloride linear " " "

1.A. RESULTS FOR LEWIS AND HARRIS

	CHARGE REGIME AND BATTERY CYCLE LIFE EQUATION USED							
RANGE OF SAVINGS (£)	1	2	3	4	5	6	7	8
Less than -1800	0	0	247	0	0	0	136	3
-1800 to -1700	0	0	100	0	0	0	53	1
-1700 to -1600	3	0	146	0	0	0	57	1
-1600 to -1500	4	0	203	0	0	0	77	8
-1500 to -1400	8	1	226	3	0	0	99	13
-1400 to -1300	9	2	357	8	1	0	118	25
-1300 to -1200	58	32	498	48	21	22	180	86
-1200 to -1100	129	110	717	118	92	85	297	171
-1100 to -1000	210	177	866	162	160	153	419	241
-1000 to -900	263	194	1128	221	192	188	565	306
-900 to -800	438	302	1558	350	265	266	831	532
-800 to -700	686	538	1946	599	471	434	1188	832
-700 to -600	1125	908	2565	952	801	762	1712	1268
-600 to -500	1655	1384	3368	1548	1247	1212	2420	1951
-500 to -400	2616	2201	4303	2369	1946	1910	3396	2900
-400 to -300	3943	3611	5418	3778	3214	3083	4644	4283
-300 to -200	5314	4867	6012	4942	4612	4494	5895	6544
-200 to -100	6417	6048	6646	6207	5673	5634	6649	6544
-100 to 0	7448	7201	7045	7271	6884	6800	7434	7497
0 to 100	8276	8219	6792	8090	8040	7873	7709	7958
100 to 200	8426	8500	6113	8284	8359	8344	7274	7857
200 to 300	7287	7691	4607	7346	8012	8078	6148	8715
300 to 400	5608	5990	2958	5663	6406	6531	4284	4918
400 to 500	3438	3993	1614	3762	4348	4589	4560	3236
500 to 600	1892	2314	827	2305	2740	2866	1319	1979
600 to 700	966	1356	394	1328	1566	1637	682	1125
700 to 800	450	724	199	817	955	994	381	633
800 to 900	219	387	91	447	539	550	228	320
900 to 1000	80	152	39	241	276	302	145	147
1000 to 1100	25	75	13	95	121	126	61	56
1100 to 1200	5	15	3	35	44	49	25	12
1200 to 1300	2	6	1	8	9	11	11	5
1300 to 1400	0	2	0	2	4	5	2	1
1400 to 1500	0	0	0	1	2	2	1	0
1500 to 1600	0	0	0	0	0	0	0	0
1600 to 1700	0	0	0	0	0	0	0	0
1700 to 1800	0	0	0	0	0	0	0	0
1800 to 1900	0	0	0	0	0	0	0	0
1900 to 2000	0	0	0	0	0	0	0	0

ANNUAL SAVINGS (Bracketed figs. are -ve)								
AVERAGE	12	52	(198)	44	80	89	(73)	(27)
MAXIMUM	1297	1340	1291	1413	1423	1445	1477	1351
MINIMUM	(1699)	(1411)	(2887)	(1478)	(1341)	(1296)	(2797)	(1860)

(Appendix 4 cont.)

1.B RESULTS FOR ORKNEY

	CHARGE REGIME AND BATTERY CYCLE LIFE EQUATION USED				
RANGE OF SAVINGS (£)	1	3	4	7	8
Less than-1800	3	384	0	157	0
-1800 to -1700	1	57	0	38	0
-1700 to -1600	2	86	0	58	0
-1600 to -1500	4	109	0	50	4
-1500 to -1400	4	176	3	53	4
-1400 to -1300	24	191	23	66	32
-1300 to -1200	61	318	62	109	110
-1200 to -1100	153	357	145	186	163
-1100 to -1000	211	475	172	269	197
-1000 to -900	293	640	245	328	294
-900 to -800	419	868	416	478	543
-800 to -700	664	1199	711	741	930
-700 to -600	1063	1756	1131	1114	1382
-600 to -500	1701	2523	1771	1656	2194
-500 to -400	2568	3571	2803	2582	3444
-400 to -300	3927	4782	4104	3778	4865
-300 to -200	5170	5746	5330	5007	5731
-200 to -100	6353	6719	6379	6052	7112
-100 to 0	7533	7470	7699	7130	8044
0 to 100	8260	7767	8050	8002	8031
100 to 200	8314	7029	7851	7867	7623
200 to 300	7405	5813	6666	7003	5929
300 to 400	5489	3983	5015	5305	4017
400 to 500	3620	2489	3321	3649	2625
500 to 600	2015	1381	2192	2456	1535
600 to 700	984	655	1258	1464	972
700 to 800	476	282	765	797	567
800 to 900	179	99	411	379	348
900 to 1000	70	39	251	147	189
1000 to 1100	28	19	133	50	90
1100 to 1200	4	1	58	27	49
1200 to 1300	2	1	25	6	18
1300 to 1400	0	0	9	1	2
1400 to 1500	0	0	0	0	0
1500 to 1600	0	0	0	0	0
1600 to 1700	0	0	0	0	0
1700 to 1800	0	0	0	0	0
1800 to 1900	0	0	0	0	0
1900 to 2000	0	0	0	0	0
ANNUAL SAVINGS (Bracketed figs. are -ve)					
AVERAGE	15	(105)	19	15	(31)
MAXIMUM	1271	1228	1538	1385	1442
MINIMUM	(1895)	(3415)	(1411)	(2870)	(1560)

2. RESULTS OF SCENARIO ANALYSES

The economic case for each motorist was calculated using a scenario approach where all the economic variables were set firstly at their most pessimistic estimates and then at their most optimistic estimates (see table 9.1 for values). Various charging regimes were used (see section 9.3.5) and the model was used to evaluate the effects of assuming different battery cycle life characteristics (see section 9.2.7 for explanation). The various permutations of these two factors are numbered as follows,

SCENARIO	'WORST'/'BEST'	CHARGE REGIME	CYCLE LIFE EQUATION
1	'Best'	Home-overnight only	Semi-logarithmic eqn.
2	"	" " "	Chloride linear eqn.
3	"	Home-anytime	Semi-logarithmic eqn.
4	"	" "	Chloride linear eqn.
5	"	Home-anytime but wait until battery is at least 20% discharged	Chloride linear eqn.
6	"	Home-anytime but wait until battery is at least 40% discharged	Chloride linear eqn.
7	"	Anywhere-anytime	Semi-logarithmic eqn.
8	"	Anywhere-anytime	Chloride linear eqn.
9	'Worst'	Home-overnight only	Semi-logarithmic eqn.
10	"	" " "	Chloride linear eqn.
11	"	Home-anytime	Semi-logarithmic eqn.
12	"	" "	Chloride linear eqn.
13	"	Home-anytime but wait until battery is at least 20% discharged	Chloride linear eqn.
14	"	Home-anytime but wait until battery is at least 40% discharged	Chloride linear eqn.
15	"	Anywhere-anytime	Semi-logarithmic eqn.
16	"	Anywhere-anytime	Chloride linear eqn.

The figures in the table represent the percentage of motorists making savings within each particular range of values. The results shown below are for the islands of Lewis and Harris.

	SCENARIO							
RANGE OF SAVINGS (£)	1	2	3	4	5	6	7	8
Less than -1800	0	0	0	0	0	0	0	0
-1800 to -1700	0	0	0	0	0	0	0	0
-1700 to -1600	0	0	0	0	0	0	0	0
-1600 to -1500	0	0	0	0	0	0	0	0
-1500 to -1400	0	0	0	0	0	0	0	0
-1400 to -1300	0	0	0	0	0	0	0	0
-1300 to -1200	0	0	0	0	0	0	0	0
-1200 to -1100	0	0	0	0	0	0	0	0
-1100 to -1000	0	0	0	0	0	0	0	0
-1000 to -900	0	0	0	0	0	0	0	0
-900 to -800	0	0	0	0	0	0	0	0
-800 to -700	0	0	0	0	0	0	0	0
-700 to -600	0	0	0	0	0	0	0	0
-600 to -500	0	0	0	0	0	0	0	0
-500 to -400	0	0	0	0	0	0	0	0
-400 to -300	0	0	0	0	0	0	0	0
-300 to -200	0	0	0	0	0	0	0	0
-200 to -100	0	0	0	0	0	0	0	0
-100 to 0	0	0	0	0	0	0	0	0
0 to 100	0	0	0	0	0	0	0	0
100 to 200	0	0	0	0	0	0	0	0
200 to 300	0	0	1.5	0	0	0	1.5	0
300 to 400	0	0	1.5	0	0	0	0	0
400 to 500	1.5	1.5	10.5	3.0	1.5	1.5	3.0	6.0
500 to 600	7.5	7.5	19.5	7.5	7.5	7.5	12.0	12.0
600 to 700	18.0	18.0	21.0	21.0	15.0	16.5	21.0	19.5
700 to 800	19.5	16.5	25.5	16.5	19.5	16.5	25.5	16.5
800 to 900	28.5	21.0	7.5	18.0	21.0	22.5	15.0	16.5
900 to 1000	13.5	15.0	7.5	12.0	13.5	12.0	13.5	7.5
1000 to 1100	4.5	10.5	3.0	12.0	10.5	12.0	4.5	13.5
1100 to 1200	1.5	3.0	1.5	3.0	3.0	3.0	0	1.5
1200 to 1300	4.5	3.0	0	3.0	4.5	3.0	3.0	4.5
1300 to 1400	1.5	3.0	1.5	3.0	0	3.0	0	1.5
1400 to 1500	0	1.5	0	1.5	4.5	3.0	1.5	1.5
1500 to 1600	0	0	0	0	0	0	0	0
1600 to 1700	0	0	0	0	0	0	0	0
1700 to 1800	0	0	0	0	0	0	0	0
1800 to 1900	0	0	0	0	0	0	0	0
1900 to 2000	0	0	0	0	0	0	0	0

ANNUAL SAVINGS
(Bracketed figs. are -ve)

AVERAGE	822	847	690	842	865	870	768	812
MAXIMUM	1339	1403	1335	1456	1463	1458	1459	1415
MINIMUM	481	481	219	481	481	481	264	481

(Appendix 4 cont.)

RANGE OF SAVINGS (£)	SCENARIO 9	 10	 11	 12	 13	 14	 15	 16
Less than-1800	0	0	1.5	0	0	0	1.5	0
-1800 to -1700	0	0	0	0	0	0	0	0
-1700 to -1600	1.5	0	1.5	0	0	0	4.5	1.5
-1600 to -1500	0	0	6.0	0	0	0	0	1.5
-1500 to -1400	0	0	1.5	0	0	0	6.0	0
-1400 to -1300	1.5	1.5	10.5	1.5	0	0	7.5	1.5
-1300 to -1200	3.0	0	3.0	0	1.5	0	0	0
-1200 to -1100	4.5	1.5	12.0	1.5	0	1.5	15.0	3.0
-1100 to -1000	12.0	9.0	12.0	19.5	6.0	6.0	9.0	24.0
-1000 to -900	31.5	36.0	21.0	30.0	25.5	22.5	28.5	33.0
-900 to -800	28.5	31.5	10.5	28.5	42.0	39.0	16.5	24.0
-800 to -700	13.5	12.0	7.5	12.0	15.0	19.5	10.5	4.5
-700 to -600	1.5	3.0	1.5	3.0	4.5	6.0	1.5	6.0
-600 to -500	1.5	4.5	1.5	1.5	3.0	1.5	1.5	1.5
-500 to -400	0	0	0	3.0	3.0	3.0	0	0
-400 to -300	0	0	0	0	0	1.5	1.5	0
-300 to -200	0	0	0	0	0	0	0	0
-200 to -100	0	0	0	0	0	0	0	0
-100 to 0	0	0	0	0	0	0	0	0
0 to 100	0	0	0	0	0	0	0	0
100 to 200	0	0	0	0	0	0	0	0
200 to 300	0	0	0	0	0	0	0	0
300 to 400	0	0	0	0	0	0	0	0
400 to 500	0	0	0	0	0	0	0	0
500 to 600	0	0	0	0	0	0	0	0
600 to 700	0	0	0	0	0	0	0	0
700 to 800	0	0	0	0	0	0	0	0
800 to 900	0	0	0	0	0	0	0	0
900 to 1000	0	0	0	0	0	0	0	0
1000 to 1100	0	0	0	0	0	0	0	0
1100 to 1200	0	0	0	0	0	0	0	0
1200 to 1300	0	0	0	0	0	0	0	0
1300 to 1400	0	0	0	0	0	0	0	0
1400 to 1500	0	0	0	0	0	0	0	0
1500 to 1600	0	0	0	0	0	0	0	0
1600 to 1700	0	0	0	0	0	0	0	0
1700 to 1800	0	0	0	0	0	0	0	0
1800 to 1900	0	0	0	0	0	0	0	0
1900 to 2000	0	0	0	0	0	0	0	0

ANNUAL SAVINGS
(Bracketed figs. are -ve)

AVERAGE	(933)	(883)	(1196)	(894)	(848)	(838)	(1040)	(952)
MAXIMUM	(583)	(525)	(591)	(422)	(407)	(386)	(343)	(504)
MINIMUM	(1604)	(1315)	(2792)	(1383)	(1245)	(1165)	(2702)	(1698)

3. SENSITIVITY ANALYSIS OF ECONOMIC ANALYSIS RESULTS

The following tables show the results of the extensive sensitivity analysis that was performed on the results of the economic analysis model. The values chosen for each of the variables are discussed in section 9.2 of the main text and the 'BASE CASE' represents the cases where all values are set at the 'best estimate' (see section 9.3.2).

3.1 CHARGING AT HOME OVERNIGHT ONLY - SEMI-LOGARITHMIC BATTERY FORMULA

(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
		AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (see table 9.1)	-	344	788	67	100
Discount rate %	5	345	784	74	100
	9	263	702	(18)	99
Purchase price of ICE vehicle(£)	3000	292	731	16	100
	8000	325	764	49	100
ICE life (years) (EV life = 1.5*ICE life)	10	272	711	(4)	99
	5	346	785	70	100
Cost for ICE routine service(£)	40	278	664	9	100
	80	332	824	49	100
Electricity used per mile (Wh)	200	323	765	63	100
	350	258	691	(90)	99
Ratio of EV to ICE maintenance costs	0.3	333	776	65	100
	0.8	264	697	(76)	99
	1.0	236	665	(146)	94
Cost of petrol £/gallon	1.65	264	674	(49)	99
	2.0	361	838	68	100
	2.5	499	1073	89	100
	3.0	638	1369	111	100
Cost of electricity pence/Kwh	2.2	344	788	67	100
	5.2	254	687	(99)	99
	6.0	230	659	(160)	94
	7.5	186	609	(273)	93
Ratio of future battery costs to present costs	0.5	435	894	130	100
	1.0	176	594	(319)	91
Ratio of EV to ICE lifetimes	2.0	457	896	181	100
	1.2	150	589	(126)	87
	1.0	(6)	433	(282)	49
Ratio of EV to ICE capital cost	1.0	512	951	236	100
	1.6	99	538	(177)	76
	2.0	(176)	263	(453)	12

3.2 CHARGING AT HOME OVERNIGHT ONLY - CHLORIDE BATTERY FORMULA

(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
		AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (see table 9.1)	-	382	880	67	100
Discount rate %	5	383	860	98	100
	9	300	777	17	100
Purchase price of ICE vehicle(£)	3000	329	807	46	100
	8000	362	840	79	100
ICE life (years) (EV life = 1.5*ICE life)	10	309	787	26	100
	5	384	861	100	100
Cost for ICE routine service(£)	40	315	780	39	100
	80	369	867	79	100
Electricity used per mile (Wh)	200	360	847	63	100
	350	295	747	49	100
Ratio of EV to ICE maintenance costs	0.3	370	863	65	100
	0.8	301	756	50	100
	1.0	273	713	44	100
Cost of petrol £/gallon	1.65	301	729	52	100
	2.0	398	941	68	100
	2.5	537	1244	89	100
	3.0	675	1547	111	100
Cost of electricity pence/Kwh	2.2	382	890	67	100
	5.2	292	742	48	100
	6.0	268	705	43	100
	7.5	223	652	(57)	99
Ratio of future battery costs to present costs	0.5	460	983	130	100
	1.0	225	657	(31)	97
Ratio of EV to ICE lifetimes	2.0	494	971	210	100
	1.2	188	665	(98)	94
	1.0	31	509	(253)	57
Ratio of EV to ICE capital cost	1.0	549	1028	285	100
	1.6	136	614	(148)	78
	2.0	(139)	338	(423)	15

3.3 CHARGING AT HOME ANYTIME - SEMI-LOGARITHMIC BATTERY FORMULA
(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
		AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (see table 9.1)	-	107	738	(862)	76
Discount rate %	5	149	779	(809)	78
	9	63	696	(917)	72
Purchase price of ICE vehicle(£)	3000	94	725	(875)	75
	8000	127	758	(842)	78
ICE life (years) (EV life = 1.5*ICE life)	10	74	705	(896)	73
	5	148	779	(821)	78
Cost for ICE routine service(£)	40	80	658	(882)	73
	80	135	818	(842)	78
Electricity used per mile (Wh)	200	125	759	(817)	76
	350	60	685	(982)	72
Ratio of EV to ICE maintenance costs	0.3	135	770	(792)	78
	0.8	66	691	(968)	72
	1.0	38	660	(1038)	67
Cost of petrol £/gallon	1.65	67	668	(940)	72
	2.0	163	835	(758)	79
	2.5	301	1067	(497)	93
	3.0	440	1302	(235)	96
Cost of electricity pence/Kwh	2.2	146	783	(764)	79
	5.2	56	681	(990)	70
	6.0	33	654	(1051)	67
	7.5	(12)	603	(1164)	60
Ratio of future battery costs to present costs	0.5	303	890	(217)	94
	1.0	(88)	586	(1507)	54
Ratio of EV to ICE lifetimes	2.0	(204)	427	(1174)	16
	1.2	(48)	584	(1017)	48
	1.0	258	890	(711)	76
Ratio of EV to ICE capital cost	1.0	314	945	(655)	90
	1.6	(99)	532	(1069)	36
	2.0	(375)	257	(1344)	3

3.4 CHARGING AT HOME ANYTIME BUT ONLY IF THE BATTERY IS AT LEAST 20% DOD SEMI-LOGARITHMIC BATTERY FORMULA

(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	85	744	(859)	70
Discount rate %	5	126	784	(806)	78
	9	40	701	(914)	66
Purchase price of ICE vehicle(£)	3000	71	731	(872)	70
	8000	105	764	(839)	73
ICE life (years) (EV life = 1.5*ICE life)	10	51	710	(892)	70
	5	126	785	(818)	78
Cost for ICE routine service(£)	40	57	664	(879)	69
	80	112	824	(839)	76
Electricity used per mile (Wh)	200	102	764	(814)	73
	350	37	690	(979	66
Ratio of EV to ICE maintenance costs	0.3	112	775	(798)	75
	0.8	43	696	(964)	67
	1.0	15	665	(1035)	61
Cost of petrol £/gallon	1.65	43	673	(938)	67
	2.0	140	838	(755)	78
	2.5	279	1072	(493)	90
	3.0	417	1307	(232)	97
Cost of electricity pence/Kwh	2.2	124	789	(761)	78
	5.2	34	688	(988)	64
	6.0	10	659	(1048)	61
	7.5	(35)	608	(1161)	58
Ratio of future battery costs to present costs	0.5	289	894	(215)	93
	1.0	119	593	(1503)	48
Ratio of EV to ICE lifetimes	2.0	236	895	(708)	87
	1.2	(70)	589	(1041)	46
	1.0	(227)	432	(1171)	13
Ratio of EV to ICE capital cost	1.0	291	950	(653)	88
	1.6	(122)	537	(1066)	34
	2.0	(397)	262	(1341)	3

3.5 CHARGING AT HOME ANYTIME - CHLORIDE BATTERY FORMULA
(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	335	900	45	100
Discount rate %	5	375	940	84	100
	9	292	858	3	100
Purchase price of ICE vehicle(£)	3000	321	887	32	100
	8000	355	920	65	100
ICE life (years) (EV life = 1.5*ICE life)	10	301	867	12	100
	5	376	941	86	100
Cost for ICE routine service(£)	40	307	860	25	100
	80	362	940	65	100
Electricity used per mile (Wh)	200	352	927	51	100
	350	287	828	29	100
Ratio of EV to ICE maintenance costs	0.3	363	943	54	100
	0.8	293	836	31	100
	1.0	265	794	19	100
Cost of petrol £/gallon	1.65	293	809	34	100
	2.0	390	1021	59	100
	2.5	529	1324	89	100
	3.0	668	1627	111	100
Cost of electricity pence/Kwh	2.2	374	960	58	100
	5.2	284	822	28	100
	6.0	260	785	6	100
	7.5	215	717	(108)	97
Ratio of future battery costs to present costs	0.5	455	1037	130	100
	1.0	215	764	(98)	94
Ratio of EV to ICE lifetimes	2.0	486	1052	196	100
	1.2	180	745	(110)	90
	1.0	23	589	(267)	51
Ratio of EV to ICE capital cost	1.0	541	1107	251	100
	1.6	128	694	(162)	76
	2.0	(147)	418	(437)	18

(Appendix 4 cont.)

3.6 CHARGING AT HOME ANYTIME BUT ONLY IF THE BATTERY IS AT LEAST 20% DOD CHLORIDE BATTERY FORMULA

(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	369	911	59	100
Discount rate %	5	409	951	98	100
	9	327	869	17	100
Purchase price of ICE vehicle(£)	3000	356	898	46	100
	8000	389	931	79	100
ICE life (years) (EV life = 1.5*ICE life)	10	336	878	26	100
	5	410	952	99	100
Cost for ICE routine service(£)	40	342	871	39	100
	80	396	951	79	100
Electricity used per mile (Wh)	200	387	938	63	100
	350	322	838	49	100
Ratio of EV to ICE maintenance costs	0.3	397	954	65	100
	0.8	327	847	50	100
	1.0	299	804	44	100
Cost of petrol £/gallon	1.65	327	820	52	100
	2.0	425	1032	68	100
	2.5	563	1335	89	100
	3.0	702	1638	111	100
Cost of electricity pence/Kwh	2.2	408	971	67	100
	5.2	318	833	48	100
	6.0	294	796	43	100
	7.5	249	732	(4)	99
Ratio of future battery costs to present costs	0.5	478	1043	130	100
	1.0	261	778	(12)	99
Ratio of EV to ICE lifetimes	2.0	521	1062	210	100
	1.2	214	756	(96)	94
	1.0	58	600	(253)	57
Ratio of EV to ICE capital cost	1.0	576	1117	265	100
	1.6	163	705	(148)	86
	2.0	(113)	429	(423)	22

(Appendix 4 cont.)

3.7 CHARGING AT HOME ANYTIME BUT ONLY IF THE BATTERY IS AT LEAST 40% DOD CHLORIDE BATTERY FORMULA

(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
		AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (see table 9.1)	-	376	903	59	100
Discount rate %	5	417	943	98	100
	9	335	861	17	100
Purchase price of ICE vehicle(£)	3000	364	890	46	100
	8000	397	923	79	100
ICE life (years) (EV life = 1.5*ICE life)	10	344	870	28	100
	5	418	944	100	100
Cost for ICE routine service(£)	40	350	863	39	100
	80	404	973	79	100
Electricity used per mile (Wh)	200	395	930	63	100
	350	329	839	49	100
Ratio of EV to ICE maintenance costs	0.3	405	946	65	100
	0.8	335	845	50	100
	1.0	307	814	44	100
Cost of petrol £/gallon	1.65	335	822	52	100
	2.0	432	1024	68	100
	2.5	571	1327	89	100
	3.0	710	1630	111	100
Cost of electricity pence/Kwh	2.2	416	963	67	100
	5.2	326	835	48	100
	6.0	302	808	43	100
	7.5	257	757	33	100
Ratio of future battery costs to present costs	0.5	483	1038	130	100
	1.0	271	792	(12)	99
Ratio of EV to ICE lifetimes	2.0	528	1054	210	100
	1.2	222	748	(96)	94
	1.0	65	592	(253)	64
Ratio of EV to ICE capital cost	1.0	583	1109	265	100
	1.6	170	696	(148)	88
	2.0	(105)	421	(423)	22

3.8 CHARGING ANYWHERE ANYTIME - SEMI-LOGARITHMIC BATTERY FORMULA
(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	 MAXIMUM	 MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	225	925	(795)	92
Discount rate %	5	266	964	(742)	94
	9	182	883	(849)	88
Purchase price of ICE vehicle(£)	3000	212	911	(808)	91
	8000	245	945	(775)	93
ICE life (years) (EV life = 1.5*ICE life)	10	192	891	(828)	88
	5	266	966	(754)	93
Cost for ICE routine service(£)	40	198	845	(815)	90
	80	252	1005	(775)	93
Electricity used per mile (Wh)	200	243	945	(750)	93
	350	178	871	(914)	87
Ratio of EV to ICE maintenance costs	0.3	253	956	(724)	93
	0.8	183	877	(900)	87
	1.0	155	846	(970)	85
Cost of petrol £/gallon	1.65	183	854	(873)	87
	2.0	280	1018	(690)	93
	2.5	419	1253	(429)	99
	3.0	558	1488	(168)	99
Cost of electricity pence/Kwh	2.2	264	969	(697)	93
	5.2	174	867	(923)	85
	6.0	150	840	(984)	83
	7.5	105	789	(1097)	79
Ratio of future battery costs to present costs	0.5	381	1015	(172)	99
	1.0	68	835	(1417)	73
Ratio of EV to ICE lifetimes	2.0	376	1078	(643)	97
	1.2	70	770	(950)	69
	1.0	(86)	613	(1106)	34
Ratio of EV to ICE capital cost	1.0	431	1131	(588)	99
	1.6	18	718	(1001)	60
	2.0	(257)	443	(1276)	6

(Appendix 4 cont.)

3.9 CHARGING ANYWHERE ANYTIME - CHLORIDE BATTERY FORMULA
(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	291	839	(200)	95
Discount rate %	5	331	879	(155)	97
	9	249	769	(245)	95
Purchase price of ICE vehicle(£)	3000	278	826	(212)	95
	8000	311	859	(179)	97
ICE life (years) (EV life = 1.5*ICE life)	10	258	805	(232)	95
	5	332	880	(150)	97
Cost for ICE routine service(£)	40	264	799	(219)	95
	80	318	879	(179)	97
Electricity used per mile (Wh)	200	309	866	(170)	95
	350	244	766	(277)	94
Ratio of EV to ICE maintenance costs	0.3	319	881	(153)	95
	0.8	249	775	(268)	94
	1.0	221	732	(313)	94
Cost of petrol £/gallon	1.65	249	748	(249)	95
	2.0	346	960	(133)	99
	2.5	485	1263	(34)	100
	3.0	624	1565	111	100
Cost of electricity pence/Kwh	2.2	330	898	(135)	97
	5.2	240	761	(283)	94
	6.0	216	724	(322)	94
	7.5	171	655	(396)	92
Ratio of future battery costs to present costs	0.5	425	996	119	100
	1.0	157	682	(517)	86
Ratio of EV to ICE lifetimes	2.0	442	990	(48)	99
	1.2	136	684	(354)	77
	1.0	(20)	527	(510)	43
Ratio of EV to ICE capital cost	1.0	497	1045	(8)	99
	1.6	85	632	(405)	66
	2.0	(191)	357	(681)	14

RESULTS FOR ORKNEY

SUMMARISED RESULTS OF THE EFFECTS OF CHARGING REGIMES AND BATTERY CYCLE LIFE FORMULAE ON THE ECONOMIC CASE

CHARGING REGIME & BATTERY FORMULA USED	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (AT HOME ANYTIME-SEMI-LOGARTIHMIC	193	635	(1087)	89
AT HOME OVERNIGHT SEMI-LOGARITHMIC	337	770	25	100
ANYWHERE ANYTIME SEMI-LOGARITHMIC	297	792	(679)	97
AT HOME ANYTIME CHLORIDE FIGURES	299	946	(35)	97
ANYWHERE ANYTIME CHLORIDE FIGURES	253	884	(147)	96

1 CHARGING AT HOME OVERNIGHT ONLY - SEMI-LOGARITHMIC BATTERY FORMULA
(Island of Orkney)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	337	770	25	100
Discount rate %	5	339	758	59	100
	9	256	677	(23)	97
Purchase price of ICE vehicle(£)	3000	286	705	6	100
	8000	319	738	39	100
ICE life (years) (EV life = 1.5*ICE life)	10	266	685	(14)	97
	5	340	760	60	100
Cost for ICE routine service(£)	40	272	639	9	100
	80	326	799	29	100
Electricity used per mile (Wh)	200	316	742	22	100
	350	253	656	(108)	97
Ratio of EV to ICE maintenance costs	0.3	326	755	23	100
	0.8	259	664	(87)	97
	1.0	232	627	(188)	97
Cost of petrol £/gallon	1.65	261	659	(71)	97
	2.0	350	798	26	100
	2.5	478	1083	45	100
	3.0	606	1544	63	100
Cost of electricity pence/Kwh	2.2	337	770	25	100
	5.2	250	652	(120)	97
	6.0	227	620	(207)	97
	7.5	183	561	(370)	95
Ratio of future battery costs to present costs	0.5	418	921	90	100
	1.0	180	606	(479)	91
Ratio of EV to ICE lifetimes	2.0	450	870	171	100
	1.2	144	564	(136)	79
	1.0	(12)	407	(292)	45
Ratio of EV to ICE capital cost	1.0	506	925	226	100
	1.6	93	512	(187)	68
	2.0	(183)	237	(463)	14

(Appendix 4 cont.)

2 CHARGING AT HOME ANYTIME - SEMI-LOGARITHMIC BATTERY FORMULA

(Island of Orkney)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
		AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (see table 9.1)	-	193	635	(1087)	89
Discount rate %	5	234	679	(1026)	90
	9	150	589	(1151)	86
Purchase price of ICE vehicle(£)	3000	180	622	(1101)	89
	8000	213	655	(1068)	90
ICE life (years) (EV life = 1.5*ICE life)	10	160	602	(1121)	89
	5	234	676	(1046)	90
Cost for ICE routine service(£)	40	166	570	(1094)	90
	80	220	755	(1081)	89
Electricity used per mile (Wh)	200	210	673	(1035)	89
	350	147	535	(1228)	86
Ratio of EV to ICE maintenance costs	0.3	220	694	(1005)	90
	0.8	153	547	(1211)	89
	1.0	126	490	(1294)	84
Cost of petrol £/gallon	1.65	154	544	(1226)	89
	2.0	244	758	(903)	96
	2.5	372	1064	(442)	99
	3.0	500	1369	19	100
Cost of electricity pence/Kwh	2.2	230	717	(972)	93
	5.2	144	528	(1239)	86
	6.0	121	483	(1310)	84
	7.5	77	427	(1443)	77
Ratio of future battery costs to present costs	0.5	347	939	(145)	99
	1.0	38	459	(2030)	69
Ratio of EV to ICE lifetimes	2.0	344	787	(936)	95
	1.2	38	480	(1242)	61
	1.0	(119)	324	(1399)	23
Ratio of EV to ICE capital cost	1.0	399	842	(881)	97
	1.6	(14)	429	(1294)	51
	2.0	(289)	154	(1569)	8

(Appendix 4 cont.)

3 CHARGING ANYWHERE ANYTIME - SEMI-LOGARITHMIC BATTERY FORMULA
(Island of Orkney)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	297	792	(679)	97
Discount rate %	5	337	835	(621)	97
	9	254	748	(739)	96
Purchase price of ICE vehicle(£)	3000	284	779	(692)	97
	8000	317	812	(659)	97
ICE life (years) (EV life = 1.5*ICE life)	10	264	759	(712)	96
	5	338	833	(638)	97
Cost for ICE routine service(£)	40	270	684	(686)	97
	80	324	912	(672)	97
Electricity used per mile (Wh)	200	314	830	(626)	97
	350	251	692	(820)	97
Ratio of EV to ICE maintenance costs	0.3	324	851	(596)	97
	0.8	257	704	(803)	97
	1.0	230	645	(885)	96
Cost of petrol £/gallon	1.65	259	700	(817)	97
	2.0	348	915	(495)	97
	2.5	476	1220	(34)	99
	3.0	604	1526	63	100
Cost of electricity pence/Kwh	2.2	335	874	(563)	97
	5.2	248	685	(830)	96
	6.0	225	635	(901)	96
	7.5	181	576	(1034)	92
Ratio of future battery costs to present costs	0.5	417	1043	90	100
	1.0	177	626	(1485)	89
Ratio of EV to ICE lifetimes	2.0	449	944	(528)	99
	1.2	142	634	(834)	77
	1.0	(14)	481	(990)	41
Ratio of EV to ICE capital cost	1.0	504	999	(475)	99
	1.6	91	586	(885)	68
	2.0	(185)	311	(1161)	19

4 CHARGING AT HOME ANYTIME - CHLORIDE BATTERY FORMULA

(Island of Orkney)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve) AVERAGE	MAXIMUM	MINIMUM	% OF MOTORISTS MAKING SAVINGS
BASE CASE (see table 9.1)	-	299	946	(35)	97
Discount rate %	5	339	987	5	100
	9	257	902	(77)	95
Purchase price of ICE vehicle(£)	3000	286	933	(48)	97
	8000	319	966	(15)	99
ICE life (years) (EV life = 1.5*ICE life)	10	266	912	(68)	95
	5	340	987	6	100
Cost for ICE routine service(£)	40	272	835	(45)	97
	80	326	1066	(25)	97
Electricity used per mile (Wh)	200	316	983	(30)	97
	350	253	846	(47)	96
Ratio of EV to ICE maintenance costs	0.3	326	1005	(28)	97
	0.8	259	858	(45)	96
	1.0	232	799	(52)	96
Cost of petrol £/gallon	1.65	261	854	(44)	97
	2.0	350	1068	(23)	99
	2.5	478	1487	7	100
	3.0	606	1948	36	100
Cost of electricity pence/Kwh	2.2	337	1028	(25)	97
	5.2	249	838	(47)	96
	6.0	227	788	(53)	96
	7.5	183	693	(64)	92
Ratio of future battery costs to present costs	0.5	418	1146	67	100
	1.0	180	746	(137)	88
Ratio of EV to ICE lifetimes	2.0	450	1097	117	100
	1.2	144	791	(190)	76
	1.0	(13)	634	(346)	39
Ratio of EV to ICE capital cost	1.0	505	1152	172	100
	1.6	92	739	(241)	66
	2.0	(183)	464	(517)	19

5 CHARGING ANYWHERE ANYTIME - CHLORIDE BATTERY FORMULA
(Island of Lewis/Harris)

VARIABLE TO BE VARIED	VALUE	ANNUALISED SAVINGS (£) (Bracketed figs. are -ve)			% OF MOTORISTS MAKING SAVINGS
		AVERAGE	MAXIMUM	MINIMUM	
BASE CASE (see table 9.1)	-	253	884	(147)	96
Discount rate %	5	293	928	(107)	99
	9	211	839	(189)	93
Purchase price of ICE vehicle(£)	3000	239	871	(160)	96
	8000	273	904	(127)	96
ICE life (years) (EV life = 1.5*ICE life)	10	220	851	(180)	93
	5	294	926	(106)	99
Cost for ICE routine service(£)	40	226	878	(157)	96
	80	280	970	(137)	96
Electricity used per mile (Wh)	200	270	937	(142)	96
	350	207	749	(158)	95
Ratio of EV to ICE maintenance costs	0.3	280	967	(140)	96
	0.8	213	761	(157)	95
	1.0	186	703	(164)	95
Cost of petrol £/gallon	1.65	215	758	(155)	96
	2.0	304	1069	(135)	96
	2.5	432	1530	(105)	99
	3.0	560	1991	(75)	99
Cost of electricity pence/Kwh	2.2	291	1000	(137)	96
	5.2	204	742	(159)	95
	6.0	181	692	(165)	95
	7.5	137	597	(176)	91
Ratio of future battery costs to present costs	0.5	388	1170	(8)	99
	1.0	119	618	(286)	82
Ratio of EV to ICE lifetimes	2.0	405	1036	5	100
	1.2	98	730	(301)	65
	1.0	(58)	573	(458)	28
Ratio of EV to ICE capital cost	1.0	450	1091	60	100
	1.6	47	678	(353)	53
	2.0	(229)	403	(828)	9

APPENDIX 5

QUESTIONNAIRES USED

Several questionnaires were used to collect the data required for the analysis in this study and these are documented in this appendix.

1 DELPHI ROUND ONE QUESTIONNAIRE

Round 1 of the Delphi analysis questionnaire was circulated to 52 experts in the electric vehicle and related industries, 28 of whom responded.

2 DELPHI ROUND 2 QUESTIONNAIRE

Round 2 of the Delphi questionnaire was circulated to the same individuals as round 1 and 23 of them replied

3 DELPHI RESULTS

The results of the questions in the Delphi questionnaires which asked for quantified answers are given.

4 QUESTIONNAIRE USED TO INTERVIEW ISLAND MOTORISTS.

A sample of island motorists were interviewed using a questionnaire (as described in section 5.3.3). A total of 214 motorists were questioned and were given a logbook to complete and return. 141 motorists returned this logbook and this is the basic size of the island sample used in this study.

5 JOURNEY LOGBOOK

A specimen logbook, in which motorists were asked to record details of every journey they made until it the logbook was complete, is shown in this appendix.

6 QUESTIONNAIRE FOR GROCERY VAN AND SCHOOL MINI-BUS OPERATORS.

All the grocery van and school mini-bus operators were sent a questionnaire to complete, asking questions about their vehicle use patterns.

1 DELPHI ROUND 1 QUESTIONNAIRE

Many of the questions in this questionnaire are quantitative in nature and demand either a projected timescale or a projection of relative costs. These projections should be made on the grids provided at the end of this questionnaire. However if you have any additional comments please supply these as well, either on the back of the sheet or on a new piece of paper. Some of the questions are not quantitative and in such cases I have left room for your comments. Throughout the analysis I am concentrating on high performance, traffic-compatible electric cars.

SECTION 1
This section deals with the possible time horizon of several events or developments in the EV industry.

VEHICLES
Q1 Many of the major car manufacturers have experimented with prototype battery-powered conversions of their i.c.e product, e.g Peugeot, Volkswagen, Ford. When do you think a major manufacturer will eventually get past the prototype stage and produce a commercially available high-performance electric car? *(Answer on Page 6, Timescale projection)*

Q2 When do you foresee continuous production line manufacture of high performance electric cars first beginning? *(Timescale P6)*

Q3 Typically quoted ranges for electric cars vary from 20 to 60 miles per recharge. When do you expect the electric car to have a range per charge in excess of 100 miles (160Km).
(Timescale projection, p6)

Q4 Do you think that the market for electric cars will be established by the existing large vehicle manufacturers or by specialised EV manufacturers? (Reasons for your answer would be welcome.)

Q5 What do you consider to be the main barriers to the commercially successful introduction of electric cars into the transportation fleet in your country?

Q6 There are many possibly beneficial developments or innovations which would significantly help the development of advanced electric vehicles. E.g more advanced energy sources, lighter construction materials and so on. What developments or innovations would be most advantageous or helpful for the success of the electric car in the following fields :-

a PERFORMANCE :-

b MANUFACTURE :-

c THE ECONOMIC CASE :-

d CONSUMER ACCEPTANCE :-

Are there any other major developments that might influence the development and adoption of electric cars?

Can you give any indication of what you expect the likely timescales of each of the developments you have mentioned to be?

(Please give your projections in the number of years from 1988. Write any projections next to your answers above)

BATTERIES.

Q7 Much is said about the potential contribution and success of alternative battery systems like the Sodium-Sulphur, Nickel-Iron and Aluminium-Air systems. When do you think each of these will be widely commercially available as EV energy sources? *(Timescale projection, P6)*

Q8 There have been great improvements in the traditional lead-acid battery and there seems to be a gradual edging forward in terms of its performance. When will a commercially available lead acid battery achieve a specific energy of :-
  a. 50 Wh/Kg
  b. 60 Wh/Kg
(Timescale projection, P6)

Q9 Which battery system do you think will eventually predominate for EV uses? (please give any reasons)

SECTION 2

The quantitative questions in this section relate to the costs associated with manufacturing, buying and operating electric road vehicles. Generally you will be asked to give estimates of costs RELATIVE to the nearest comparable i.c.e vehicle.

Q10 At present there is a cost disadvantage associated with the purchase price of an EV in comparison with an i.c.e vehicle of comparable size. The magnitude of this penalty can be expressed as the ratio of the EV price to the equivalent i.c.e vehicle price. At present, this ratio varies from just over 1 to a factor in excess of 3, depending upon the level of production and type of vehicle.

a In your opinion, what are the main reasons for this cost penalty?

b Do you think that this initial cost penalty could ever be eliminated?

c Taking a fairly standard car (like a Volkswagen or Ford), how small do you think this cost factor <u>could</u> be? (If you wish, state an associated scale of production)
(Answer on Page 7, Cost ratio estimate)

Q11 It is claimed that the maintenance costs associated with EVs are substantially less than those for similar i.c.e vehicles. What do you consider to be the ratio of costs for EV versus i.c.e vehicle under the following maintenance regimes :-

a Following manufacturers recommendations. *(cost estimate P7)*

b Following a policy of maintaining or repairing only when necessary. *(Cost ratio estimate P7)*

Q12 Similarly, the useful life of an EV is recognised as exceeding that of the i.c.e vehicle. Again, what do you consider to be the ratio? *(Relative estimate P7)*

BATTERIES

Q13 The traction battery represents a large proportion of the purchase price and subsequent operating costs of an EV. Do you foresee any potential cost reductions in the Lead-Acid battery system? If so, how can these be achieved?

If the cost-reducing measures you have mentioned are exploited, can you predict the resultant battery cost as a fraction of the present cost along with any assumptions or necessary conditions. *(Cost ratio estimate P7)*

Q14 It is often stated that the raw material costs of the Sodium-Sulphur battery are lower than that of the Lead-Acid system but that the production of a safe operable Sodium-Sulphur battery is more problematic. How do you foresee the ratio of costs between Na-S and Lead-Acid? Again state any assumptions, related volumes of production or timescales. *(Cost ratio estimate P7)*

Q15 By what factor do you anticipate the Na-S battery will increase typical EV range? *(Ratio estimate P7)*

Q16 What do you think are the greatest potential areas for cost reduction in EVs? (Please try to give some indication of the potential magnitude of these cost reductions)

THANK YOU

2. DELPHI ROUND 2 QUESTIONNAIRE

(Participants were asked to comment on the results of the first round and to modify their estimates in the light of the consensus of opinion if they felt that they should)

QUESTION 1
Several respondents mentioned the Sodium-iron chloride battery in their answers. Do you think that this battery system will ever be developed to the stage of being widely commercially available and if not why not? If Yes, when do you think it will become commercially available?

QUESTION 2
Several references were made to the lack of incentives for developers and potential EV users although the UK does have the advantage of several legislative and tax incentives that other European countries do not yet have. Do you think that the UK Government should be more actively involved in stimulating the industry and if so, how should it be involved and what should be the nature of its interest? What legislative or financial incentives should be given?

QUESTION 3
Some doubts concerning the inherent safety of electric vehicles, charging facilities and their energy source have been expressed in the past by laymen and experts on the subject. The safety of the battery system in particular has been the object of concern whether it is a well known battery system like the lead-acid or a less common or well developed system like the high temperature sodium-sulphur battery.

Do you think that the perceived safety of electric vehicles will affect consumer acceptance and confidence in EVs and/or affect willingness to buy? In what way? What do you think will be the source of these concerns? (i.e batteries, charging facilities, vehicle design and stability, electronics etc?)

What do YOU consider to be the RELEVANT safety issues and the REAL potential hazards if any?

QUESTION 4
Undoubtedly, the commercial development of electric vehicles and in particular electric cars, will be a slow process that will be dependent on many factors outside the influence of the EV industry. It is even quite possible that the electric car will never play a significant role. However, much of its success does lie in the hands of the EV industry and the measures that are within its control. The electric car still has a 'laboratory image' and at some point the technology will have to be taken out of the laboratory and developed into a saleable product.
How do you see the future progression of EV development? What should the EV and related industries be doing to further the cause of electric transport and what areas of research or development should predominate?

THANK YOU

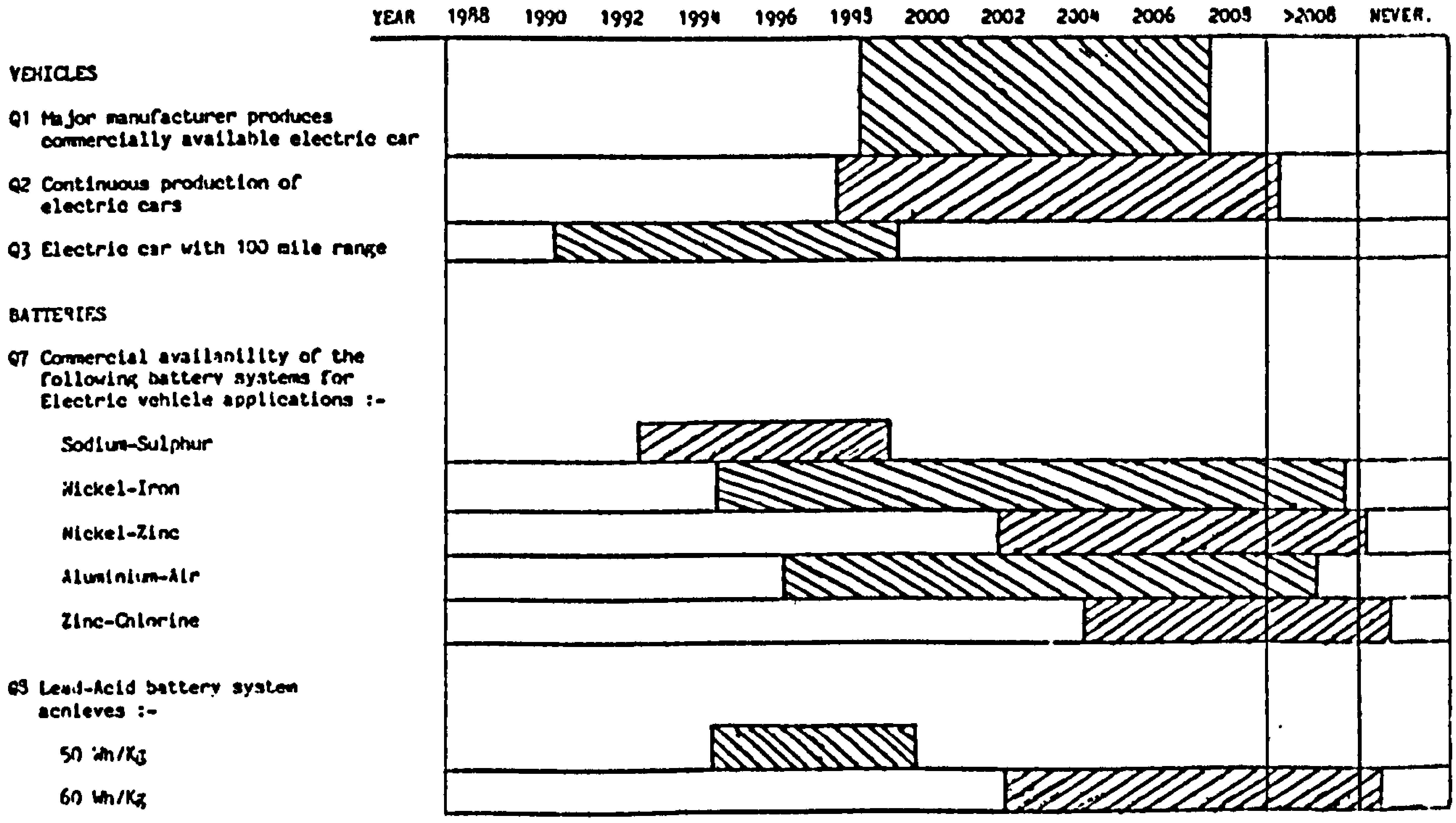
(Appendix 5 cont.)

3 QUANTIFIABLE RESULTS FROM DELPHI ANALYSIS

- Shaded areas represent the INTERQUARTILE RANGE of the answers received.

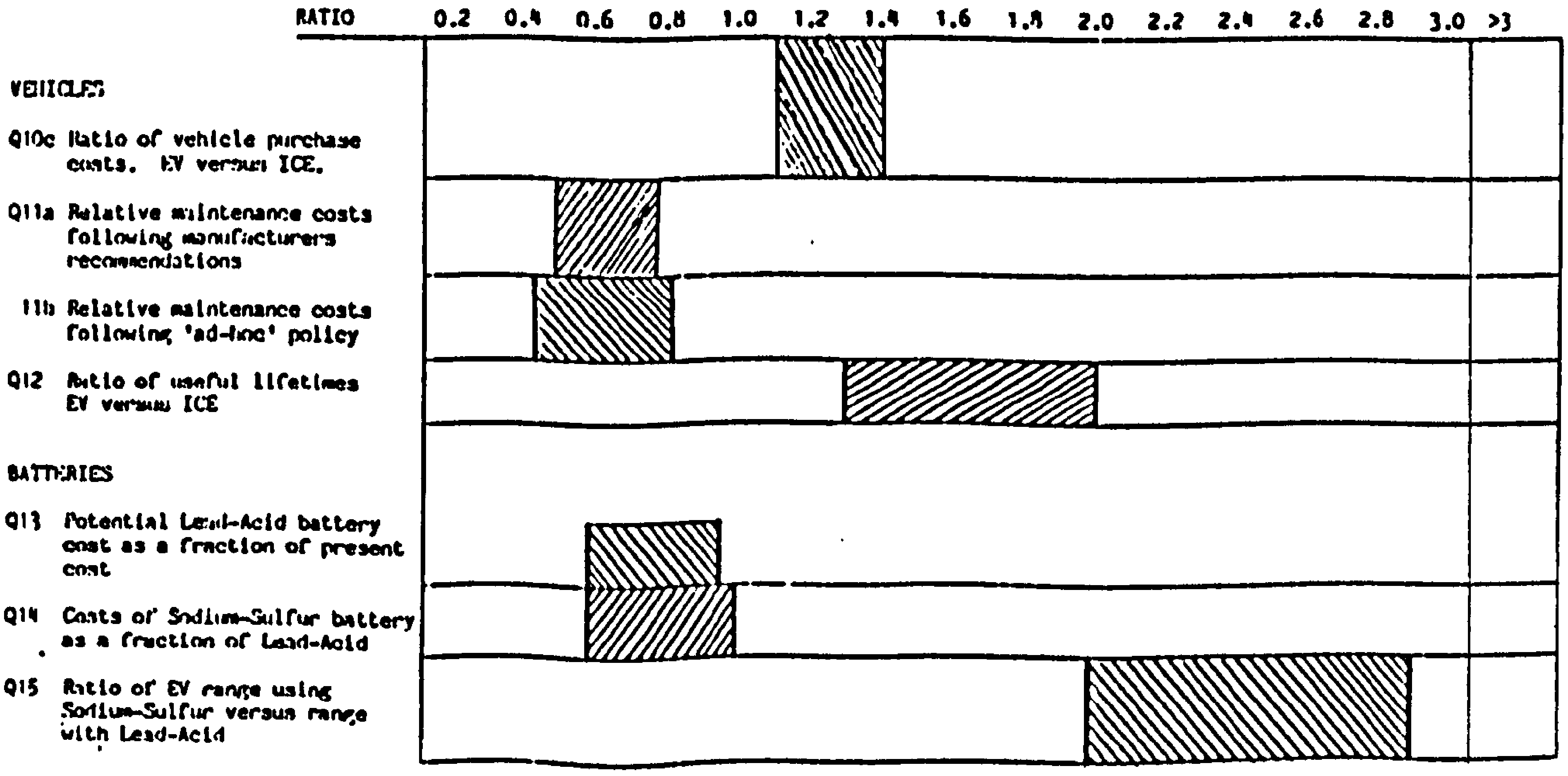
ESTIMATED TIMESCALES OF VARIOUS DEVELOPMENTS.

SECTION 1



SECTION 2

COMPARISON OF EV WITH ICE IN RATIO FORM.



4 QUESTIONNAIRE USED AS THE BASIS OF INTERVIEW WITH ISLAND CAR OWNERS

A GENERAL USE PATTERN INFORMATION

1 When you are buying a car, what features do you look for (please tick relevant boxes :-

HIGH PERFORMANCE
APPEARANCE
RELIABILITY
ECONOMY
OTHER (please specify)________________

2 How many cars are there in your household? ________
Make and model ________________

3 Did you buy your car new or second hand? ________

4 Do you normally buy new/secondhand cars? ________

5 How many miles has your car done in the last year? ________

6 Do you ever take your car to the mainland? (yes or no) ____
If "YES", how many times a year? ________

7 Is there a regular 8 hour period during the night when your car is not in use? (yes or no) ________

Where do you normally park your car at night? (please tick)

GARAGE
STREET
DRIVE
OTHER (specify) ________________

Is this location within easy reach of an electricity supply?

8 Do you have your car serviced regularly according to manufacturers recommendations? (yes or no) ________

How often do you have it serviced? ________

9 If there are two or more cars, is one regarded as a 'second' vehicle? ________________

Is it possible to organise their use so that one car is never taken to the mainland and is used for shorter trips? (yes or no) ________________

10 How often does your car travel more than 50 miles in one day
How often does your car travel more than 75 miles in one day
How often does your car travel more than 100 m in one day

11 Do you use your car for regular trips to work? ________
What is the return distance from your home to work? ________
What would you say was the car's average daily mileage?

B INFORMATION ON ATTITUDES AND OPINIONS

12 Would you consider buying a car which had ACCELERATION similar to a van or diesel car? ______ REASONS

Would you consider buying a car with a TOP SPEED of 70mph? ______________ REASONS

Would you consider buying a car which had to be connected to a power supply over-night? ______ REASONS

Would you consider buying a car which had a daily range of say 60 miles? _______ REASONS

If this range could be extended to 100 miles, do you consider this to be :-

FULLY SUFFICIENT
ONLY JUST SUFFICIENT
INADEQUATE

What would have to be the daily range of a car in order to be suitable for your needs?

Would you consider buying a vehicle with this daily range?

13 An average car costs about £30 per week to operate. Would you consider buying a car with the above characteristics if it cost £25 per week?

How much would you have to save each week before you would consider buying one?

14 When considering the costs involved in your next car, which do you consider to be MOST important?

THE RUNNING COSTS AND THE ECONOMY OF THE VEHICLE
THE INITIAL PURCHASE PRICE
BOTH EQUALLY IMPORTANT

Would you consider buying a more expensive vehicle if the running costs were low enough to pay back the difference?

15 How much did your present car cost?
How long have you had it?
What age is it?

INFORMATION PROVIDED ON ELECTRIC VEHICLES

A modern electric car would be capable of performance characteristics which are similar to a diesel van in terms of acceleration. Top speeds would be in the range 60-70 mph. They are usually built with a conventional car body and look identical to the petrol equivalent. Current prototype models include the VW Golf, Peugeot 205 and Renault 5 electric cars. They have a limited range of about 60 miles, after which they have to be recharged from an electricity socket. A full recharge takes about 8 hours but partial recharges can be given. Advantages include :-

No road tax or MOT certificate is required
Maintenance costs are very low because there are fewer parts
Electricity costs are lower than petrol costs (about 1/4)
Electric cars tend to last nearly twice as long as petrol ones.
They can be refuelled at home and are not dependent on oil supplies or prices.

16 Were you aware that such vehicles existed?

17 What is your general response/attitude towards the idea of electric cars?
POSITIVE
NEGATIVE
INDIFFERENT

18 Would you consider buying an electric car if there were savings available instead of buying a conventional car?

Would you consider to be your main reasons for not buying an electric car?

<u>THANK YOU</u>

5 SPECIMEN JOURNEY LOGBOOK

	DAY	TIME am/pm	DETAILS OF JOURNEY	MILEOMETER READING	
				START	END
E.g	Mon 9th	3.13 pm	Kirkwall to Finstown	315	322

THANK YOU.

(Appendix 5 cont.)

8 QUESTIONNAIRE CIRCULATED TO GROCERY VAN AND SCHOOL MINI-BUS OPERATORS

ISLAND TRANSPORT SURVEY
QUESTIONNAIRE

1. Please list below the details of any vans that you operate for whatever purpose.

	FIRST VAN	SECOND VAN	THIRD VAN
MAKE	-	-	-
MODEL	-	-	-
AGE	-	-	-

2. This question is concerned with your mileage patterns. I am trying to establish the variation in the daily mileages of your van(s).

Please try to estimate the following.

AVERAGE YEARLY MILEAGE	-	-	-
AVERAGE DAILY MILEAGE	-	-	-
MAXIMUM DAILY MILEAGE	-	-	-

How often does each of your vans exceed the following daily mileages.(ie how many days per week or year)

MORE THAN 50 Miles per day	-	-	-
MORE THAN 75 Miles per day	-	-	-
MORE THAN 100 Miles per day	-	-	-

3. If the number of miles that your van(s) could travel each day was limited, (e.g like a battery powered vehicle or due to petrol rationing), how far would it have to be able to travel in a day to be suitable for your needs?

-	-	-

4. Are your vans ever taken to the mainland?

YES/NO	-	-	-
If yes, how often?	-	-	-

5. The following questions relate to the costs of operating your vehicles

BOUGHT NEW OR SECONDHAND ?	-	-	-

APPROXIMATE PRICE - - -

Do you service your vehicles according to manufacturer's recommendations?

YES/NO - - -

SERVICE INTERVAL - - -

When buying a vehicle would you consider buying a more expensive vehicle if the running costs were low enough to pay back the difference over the life of the vehicle?

YES/NO

6. When you are buying a van what features do you regard as being most important (please tick)

HIGH PERFORMANCE
APPEARANCE
RELIABILITY
ECONOMY
OTHER (Please specify).......................................

7. In the space below could you give a brief summary of the daily or weekly routine of your grocery vans and supply vehicles. The daily mileages are very important.

THANK YOU

APPENDIX 6

SOME RECENT AND CURRENTLY AVAILABLE ELECTRIC VEHICLES

This appendix shows some examples of the electric vehicles which have become available in the course of the last 10 years. There have been many other prototype vehicles built by companies such as Ford, Volkswagen, Renault and Fiat which are not shown here, however the vehicles presented in this appendix show the variety and potential of the current technology.

ELECTRIC VEHICLES

1 BEDFORD CF ELECTRIC VAN (one tonne payload)

2 FREIGHT ROVER ELECTRIC SHERPA VAN (950 Kg payload)

3 HOPE 'WHISPER' ELECTRIC CAR

4 HIL ELECTRIC QT50 RANGE

5 DODGE 50 SERIES ELECTRIC VAN

6 LEYLAND ELECTRIC ROADRUNNER

7 DUNBAR DEAN ELECTRIC UTILITY VAN

8 PEUGEOT 205 ELECTRIC PROTOTYPE CAR

9 A LOW-PERFORMANCE EV

1 BEDFORD CF ELECTRIC VAN. (See section 1.4.2)

This vehicle was backed by Bedford and Lucas Chloride Electric Vehicle Systems Ltd (LCEVS). The drivetrain was built by LCEVS with the support of a government subsidy on each drivetrain sold. The vehicle shell was built by Bedford Commercial vehicles and is the same as the one used for the petrol and diesel versions. In 1985 it was sold at a price of £10,280 (inclusive of battery and charger).

SPECIFICATIONS

MOTOR - Type - Lucas CAV MT 305 separately excited 216 V DC traction.
- Power - 40 Kw.

BATTERY - 36 x 6 volt Chloride tubular plate, lead-acid (216 V).
- Mounted via quick-release pins under the floor.

CHARGER - Chloride Spegal S1P 108/30. Input voltage 240 V, single-phase AC. Input current rating 45 amps, output current 30 amps.

CONTROLLER - Lucas thyristor electronic controller with regenerative braking, mounted together with ancilliary equipment on subframe in the under-bonnet are

VEHICLE WEIGHT (GVW) - 3,500 Kg

PRIMARY DRIVE - Chain and sprockets

PERFORMANCE

MAXIMUM SPEED - 50-60 mph.

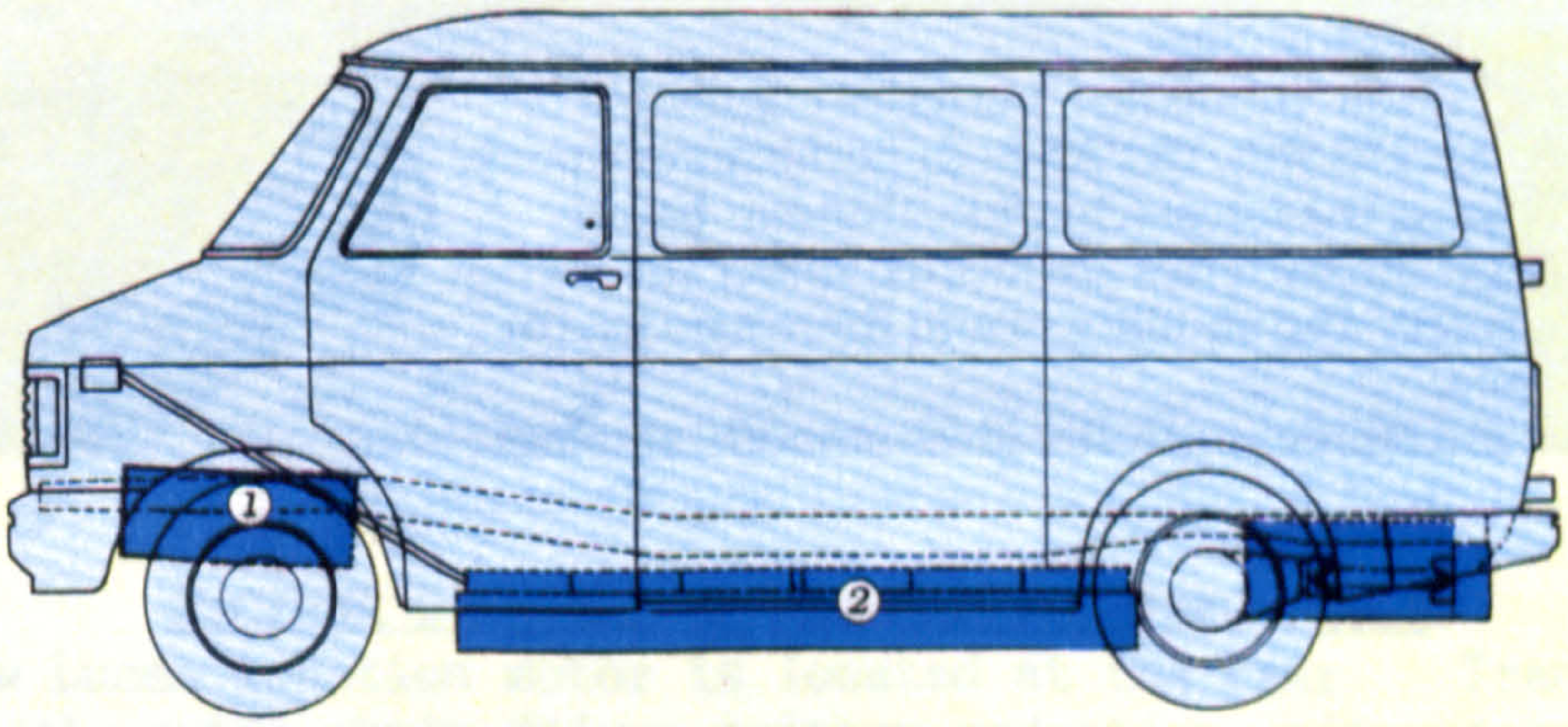
RANGE - 50-60 miles.

ACCELERATION - 0-30 mph, 11 secs.

MAXIMUM GRADIENT - 16% restart, laden.

BEDFORD CF ELECTRIC DRIVE SYSTEM

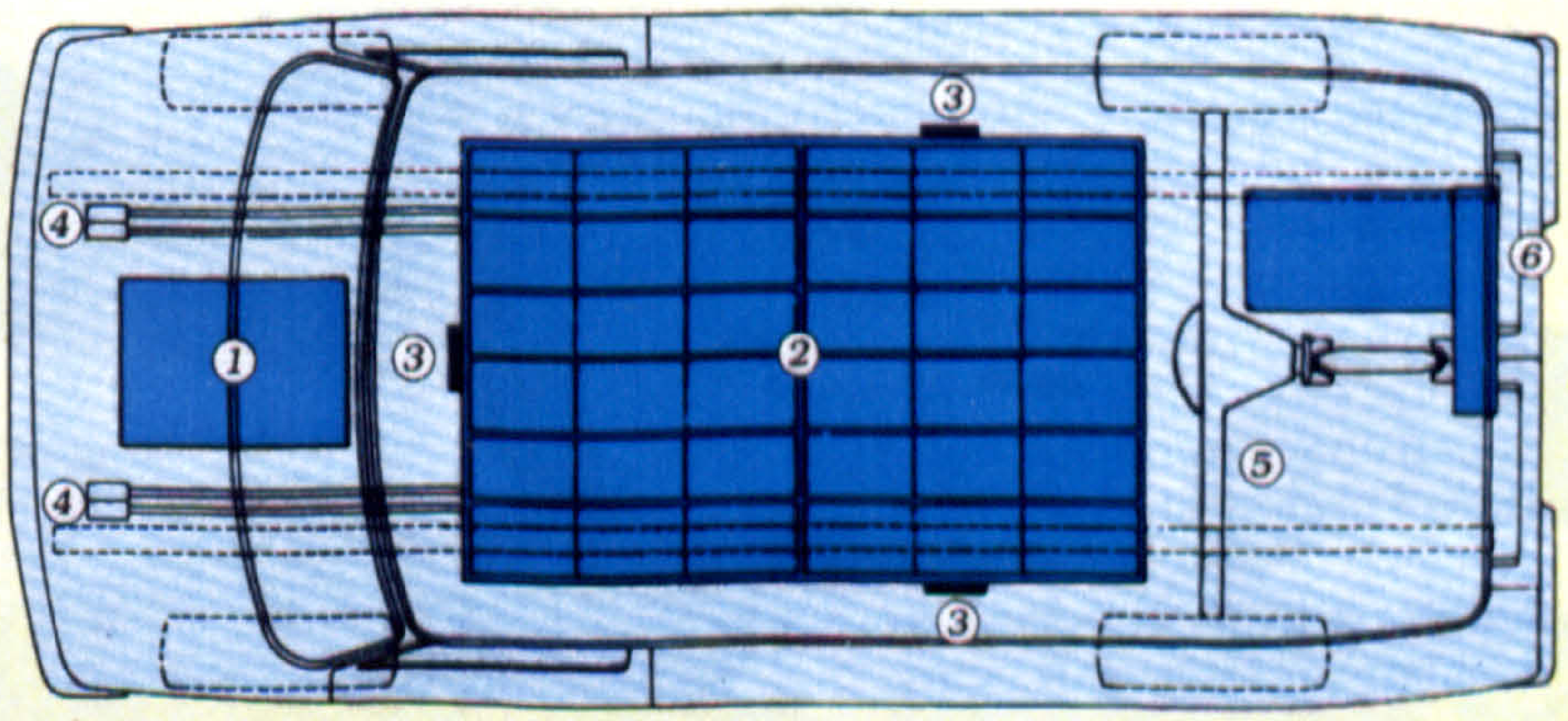
Bedford CF Electric Drive System.



1 Controller and E.V. auxiliary equipment subframe.

2 Detachable underfloor battery with no intrusion into body.

3 Attachment points for battery pack.



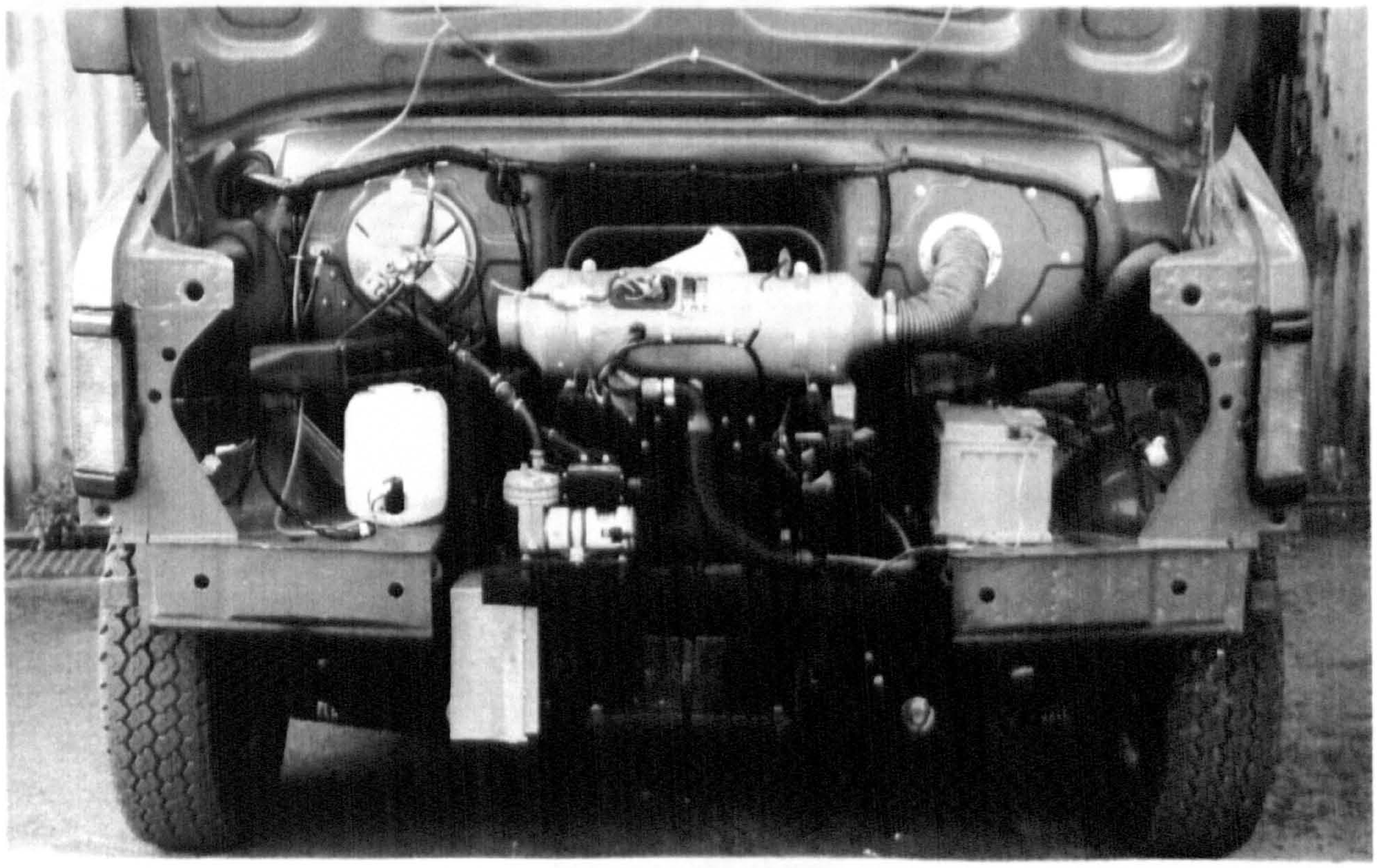
4 Automatic watering and venting points.

5 Conventional rear axle.

6 Motor and first stage reduction.

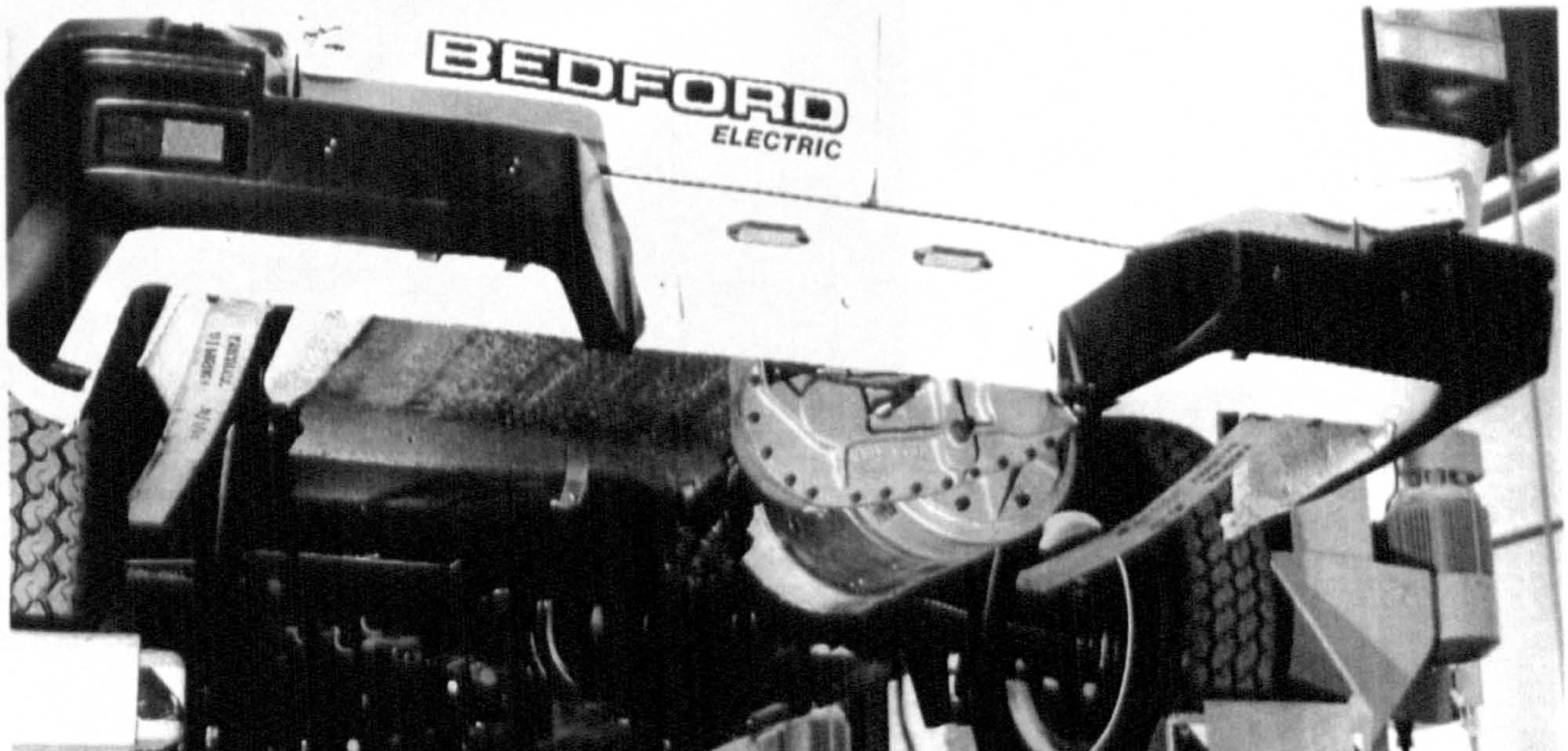
PICTURE 1 UNDER THE BONNET OF THE BEDFORD CF ELECTRIC VAN

The controller unit and auxiliary equipment such as the parafin heater and an auxiliary 12 volt battery are packaged in a subframe which fits into the same space as the normal petrol or diesel engine of the ICE version. For assembly, this subframe unit is simply bolted in in place of the engine.

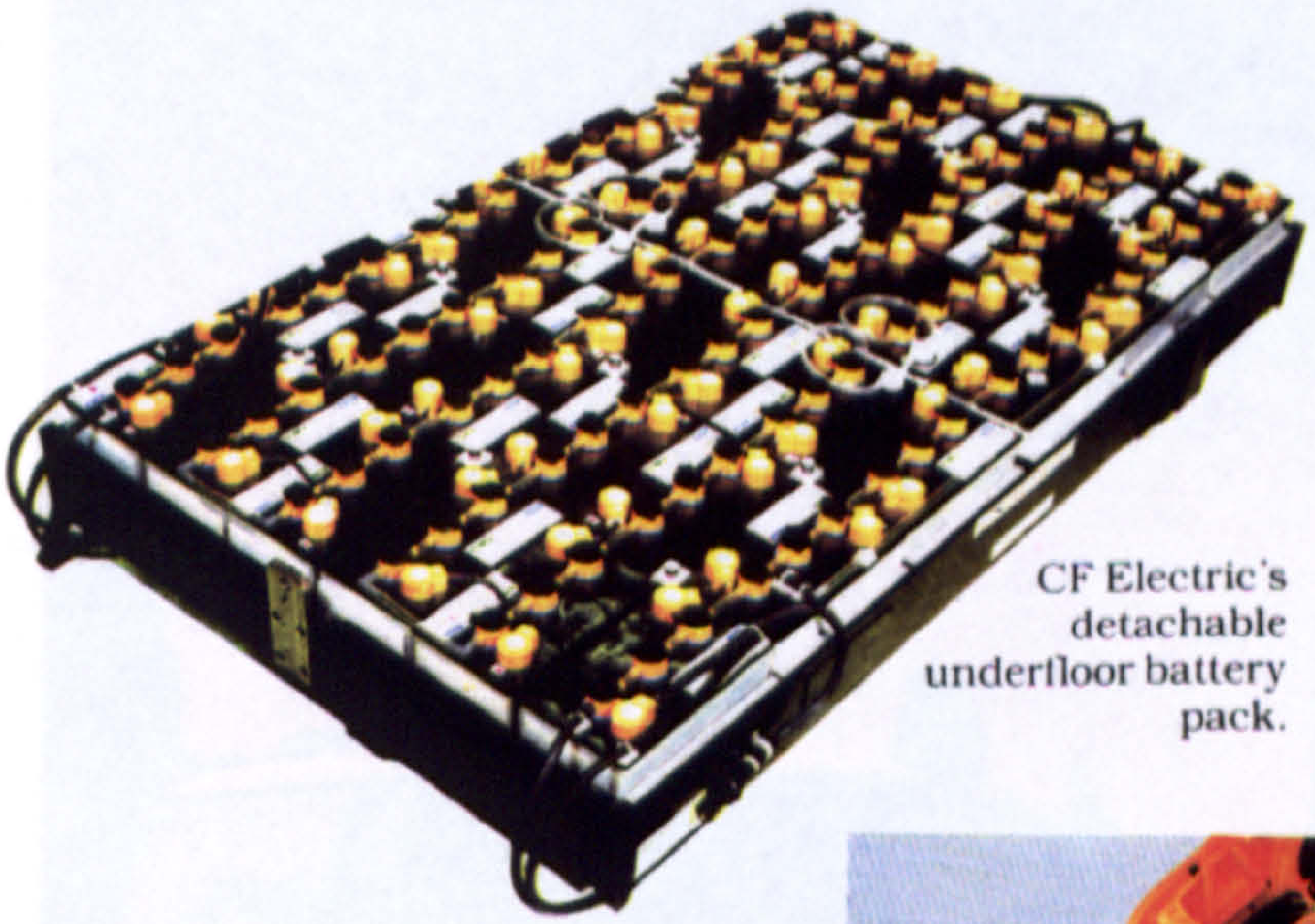


PICTURE 2 THE BEDFORD CF ELECTRIC MOTOR

The 40 Kw Lucas traction motor is located at the rear. Transmission is via a single ratio chain-driven primary reduction unit which is integral with the motor. A short propshaft connects with the rear axle

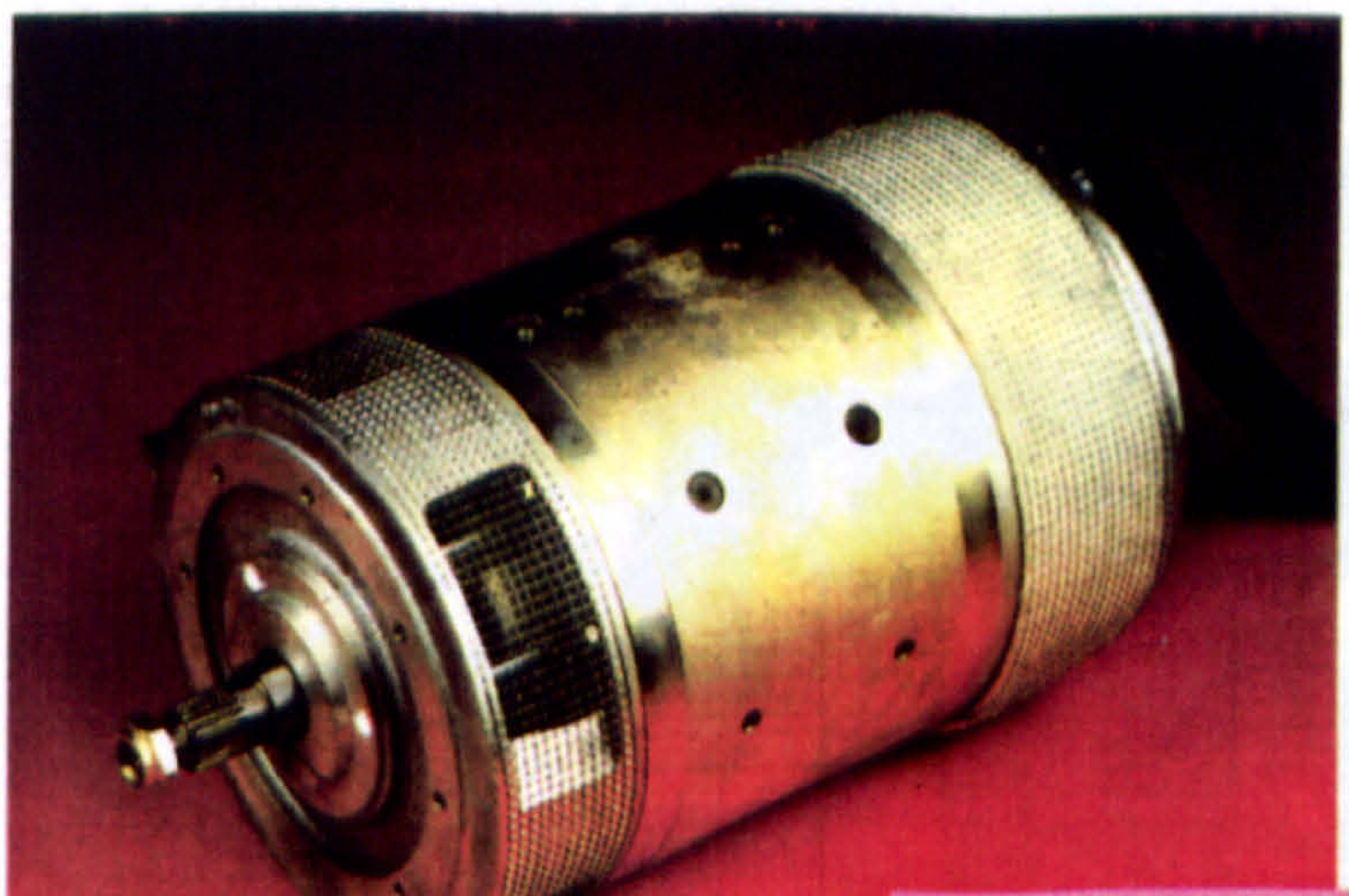


THE MAJOR COMPONENTS OF THE BEDFORD CF



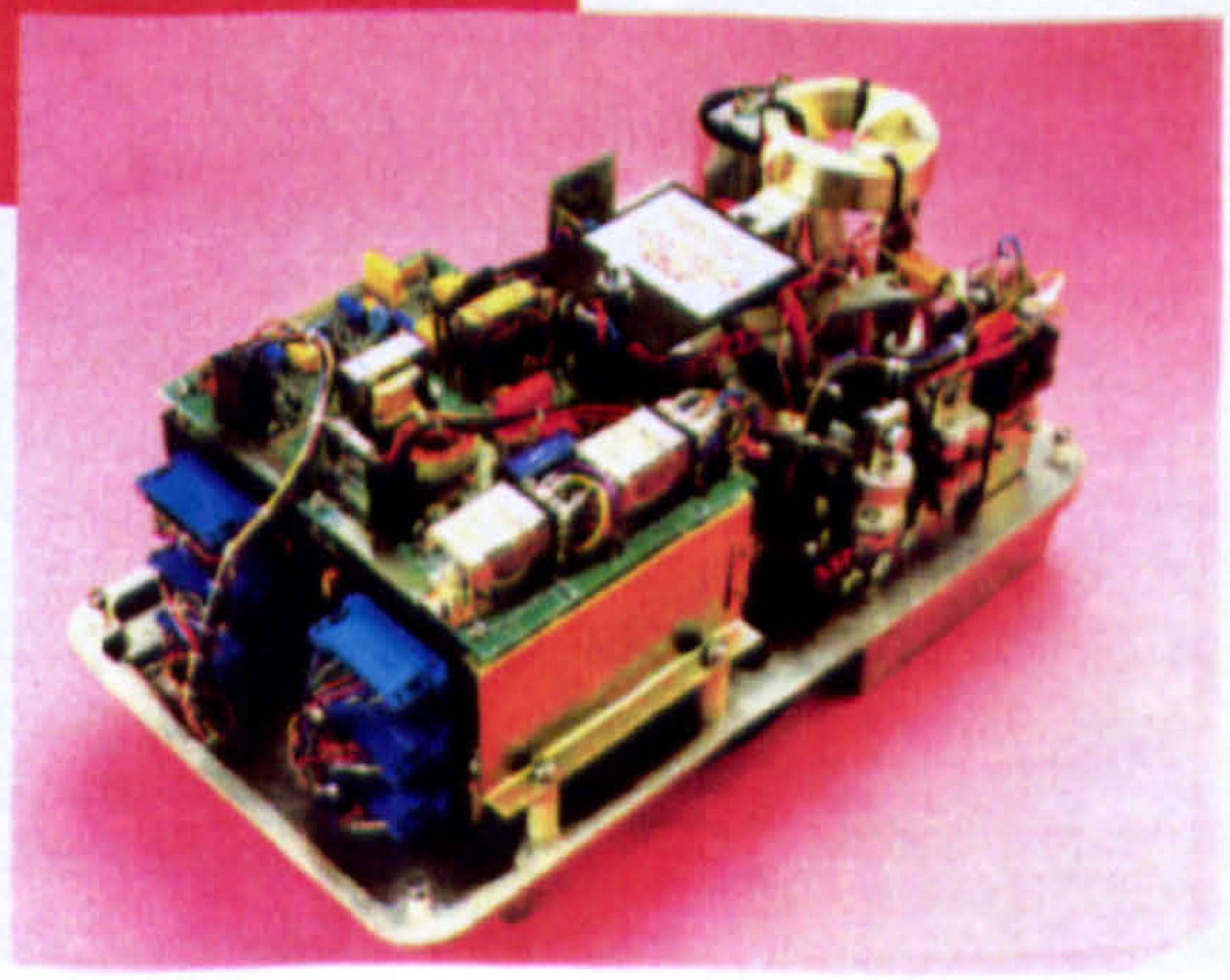
CF Electric's detachable underfloor battery pack.

Charger unit.



The Lucas-CAV traction motor fitted to the CF Electric. It is housed neatly under the van floor at the rear.

Electronic controller provides smooth, progressive acceleration and controls the regenerative braking action.



A number of Bedford CF Electrics were exported to the US. They were bought by GM and the EPRI. They were renamed the "GRIFFON" and proved to be very successful.

A BEDFORD CF ELECTRIC IN SERVICE WITH THE SOUTHERN ELECTRICITY BOARD.

Southern Electricity has pioneered the everyday use of advanced, traffic compatible, electric commercial vehicles in commercial fleet use. Now, with the world's largest fleet of this type of vehicle, they are reaping the benefits of low running costs, high reliability, smooth, quiet operation and freedom from pollution.

2. FREIGHT ROVER ELECTRIC SHERPA VAN (see section 1.4.2)

As with the Bedford van, the sherpa electric used the same basic vehicle shell as the conventional models. The drivetrain was supplied by LCEVS.

SPECIFICATIONS

MOTOR - Lucas CAV, 216 volt, 40 Kw, DC motor

BATTERY - 36 x 6 volt tubular "monoblock" units, 216 volts, 184 Ah, Mounted underfloor.

CHARGER - Chloride Leg S1P108/30, 30 amp single phase with Spegal control.

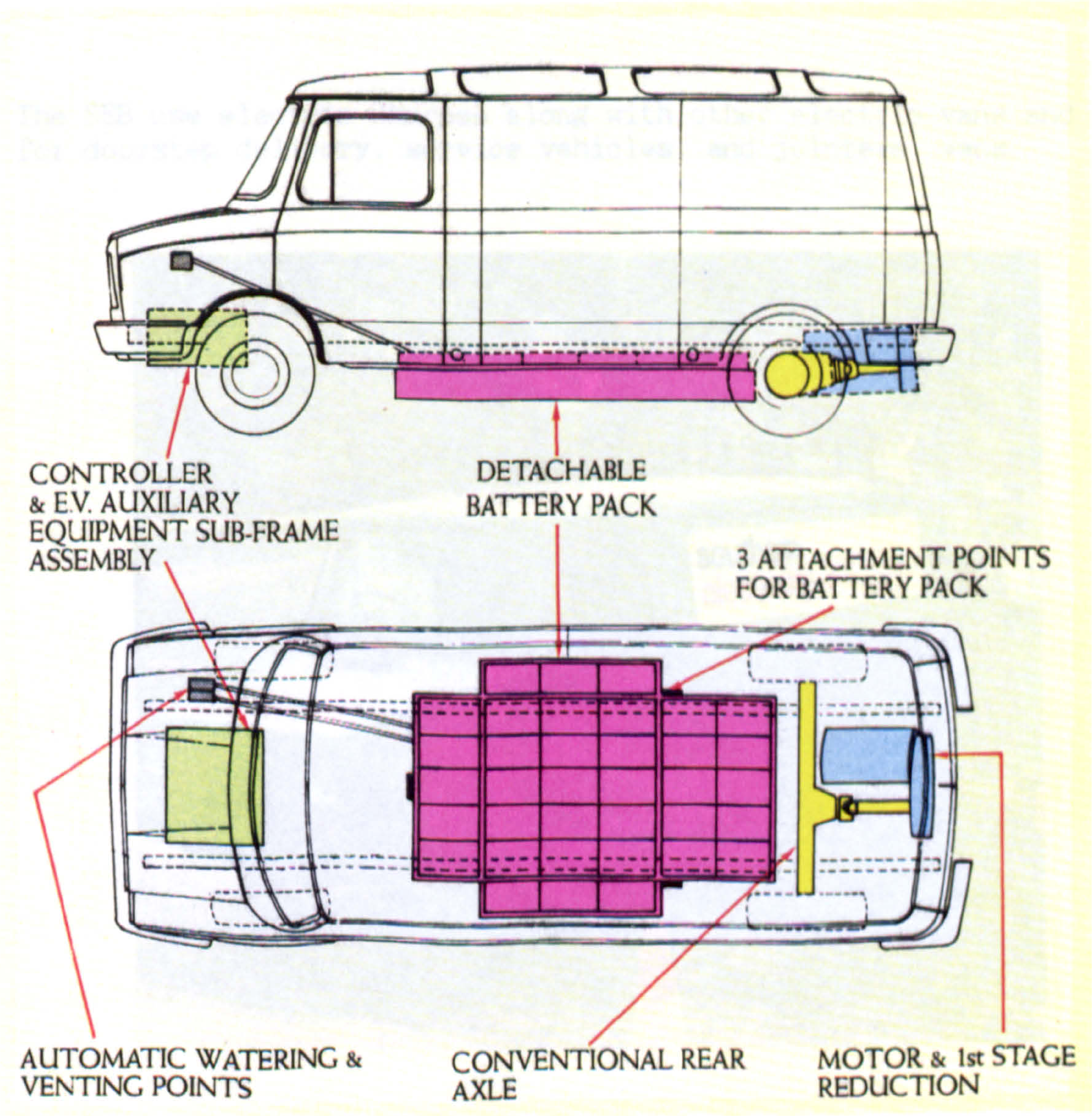
DC/DC CONVERTER - Lucas 25 amp.

CONTROLLER - Lucas thyristor electronic with regenerative braking

GVW - 3,500 Kg, PAYLOAD - 950 Kg.

PERFORMANCE - Same as Bedford CF electric.

FREIGHT ROVER SHERPA ELECTRIC DRIVE SYSTEM



ELECTRIC SHERPAS IN OPERATION

A The Post Office bought 80 electric vans for testing with the intention of replacing many of their diesel vans if tests were successful.

B The SEB use electric Sherpas along with other electric vans and trucks for doorstep delivery, service vehicles, and jointers´ vans.

3. DANISH HOPE WHISPER ELECTRIC CAR (see section 1.4.7)

This vehicle, built by the Hope Motor Company in Denmark, was to be imported and distributed in this country by HIL Electric Ltd but Hope eventually concentrated on getting into the American market. It was priced in 1985 at £4,500 (inclusive of battery and charger).

SPECIFICATIONS

MOTOR	- Series wound DC, 6 Kw. Front-wheel drive.
BATTERY	- 12 x 6 volt deep cycle lead-acid, 6 in front and 6 in rear. Battery charger included.
CHASSIS & BODY	- Rust and corrosion proof glass fibre body. Longlife, coated steel chassis with integral rollbar passenger protection system
CHARGER FUSE RATING	- 10 Amps
SEATS	- 2 + 2
CARGO VOLUME	- In van version 700 litres (24.7 ft^3) 1 back seats in use 400 litres (14.12 ft^3) 2 back seats in use 100 litres (3.53 ft^3)

PERFORMANCE

CRUISING SPEED	- 44 mph
TOP SPEED	- 50 mph
MAXIMUM RANGE	- 62 miles
ENERGY CONSUMPTION	- 0.27 Kwh/mile (net) = 0.38 Kwh/mile
ACCELERATION (250 Kg load)	- 0 - 37.3 mph in approximately 20 seconds

DIMENSIONS

WEIGHT	- 984 Kg (including battery of 380 Kg)
OVERALL LENGTH	- 346 cm.
OVERALL HEIGHT	- 145 cm.
OVERALL WIDTH	- 156 cm.

The Danish Hope Whisper Electric Car

5. DODGE 50 SERIES ELECTRIC VAN

The Dodge 50 series electric van is an electric conversion of the conventional diesel vehicle built by Karrier Motors Ltd. The van can be fitted with a variety of different body types including integral van, box van, Luton head van, PSV, personnel carrier or demountable body systems. The vehicle has been developed as a joint venture with LCEVS under the same scheme as the Bedford and Sherpa vans.

SPECIFICATIONS

MOTOR - EDC Separately wound DC motor rated at 50 Kw.
CONTROLLER - Transistor electronic controller with regenerative braking.
BATTERY - Chloride lead-acid 160 volts, 240 amp hour (5 hour rate)
CHARGER - Spegal SPT80/80 three phase
GVW - 4,200 Kg.

PERFORMANCE

RANGE - 45-55 miles (stop start driving)
ACCELERATION - 0-30 mph in 19seconds.
MAX SPEED - 40 mph.

THE DODGE 50 ELECTRIC CHASSIS CAB VEHICLE

6. LEYLAND VEHICLES ELECTRIC ROADRUNNER

Jointly developed by Leyland Vehicles Ltd and W & E Vehicles Ltd, the Electric Roadrunner is a larger vehicle than the others previously mentioned. Again it is an electric conversion of a diesel vehicle.

SPECIFICATIONS

MOTOR - EDC compound wound separately excited DC, 55 Kw.
BATTERY - Oldham or Chloride 160 volts.
CONTROLLER - Chloride Leg Transistor electronic or equivalent.
CHARGER - Speigal or Westinghouse 3 phase automatic

PERFORMANCE

RANGE - 50 miles (Laden - stop start driving)
MAX SPEED - 45 mph
ACCELERATION - 0-30 mph in 25 seconds.

THE LEYLAND ELECTRIC ROADRUNNER

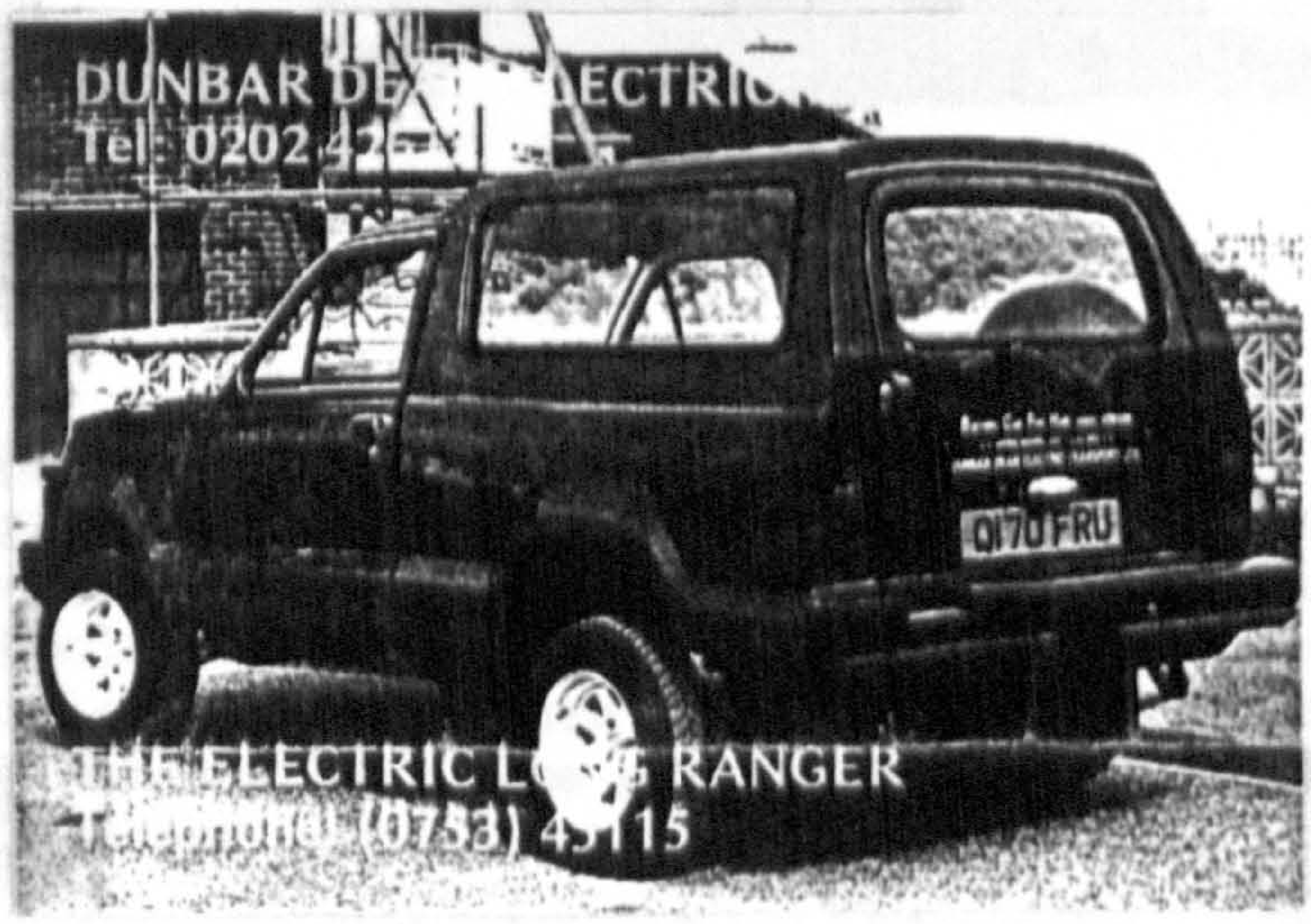
7. DUNBAR DEAN ELECTRIC UTILITY VAN

This vehicle has been developed by a small company in Bournemouth and is similar to the Ford or Bedford 5 cwt. vans. It is hand built on a very small scale and there are no prospects for volume manufacture. It has been marketed at £10,000 plus car tax and VAT. Only a few have been sold.

SPECIFICATIONS AND PERFORMANCE

BASIC RANGE - 50-80 miles (110 maximum)
PAYLOAD - 5 cwt (plus 2 passengers)
CARGO VOLUME - 50+ cubic feet
TOP SPEED - 50 mph
CONTROLLER - Custom built by Dunbar Dean
CHARGER FUSE RATING - 13 amps
ENERGY CONSUMPTION - 0.89 Kwh/mile

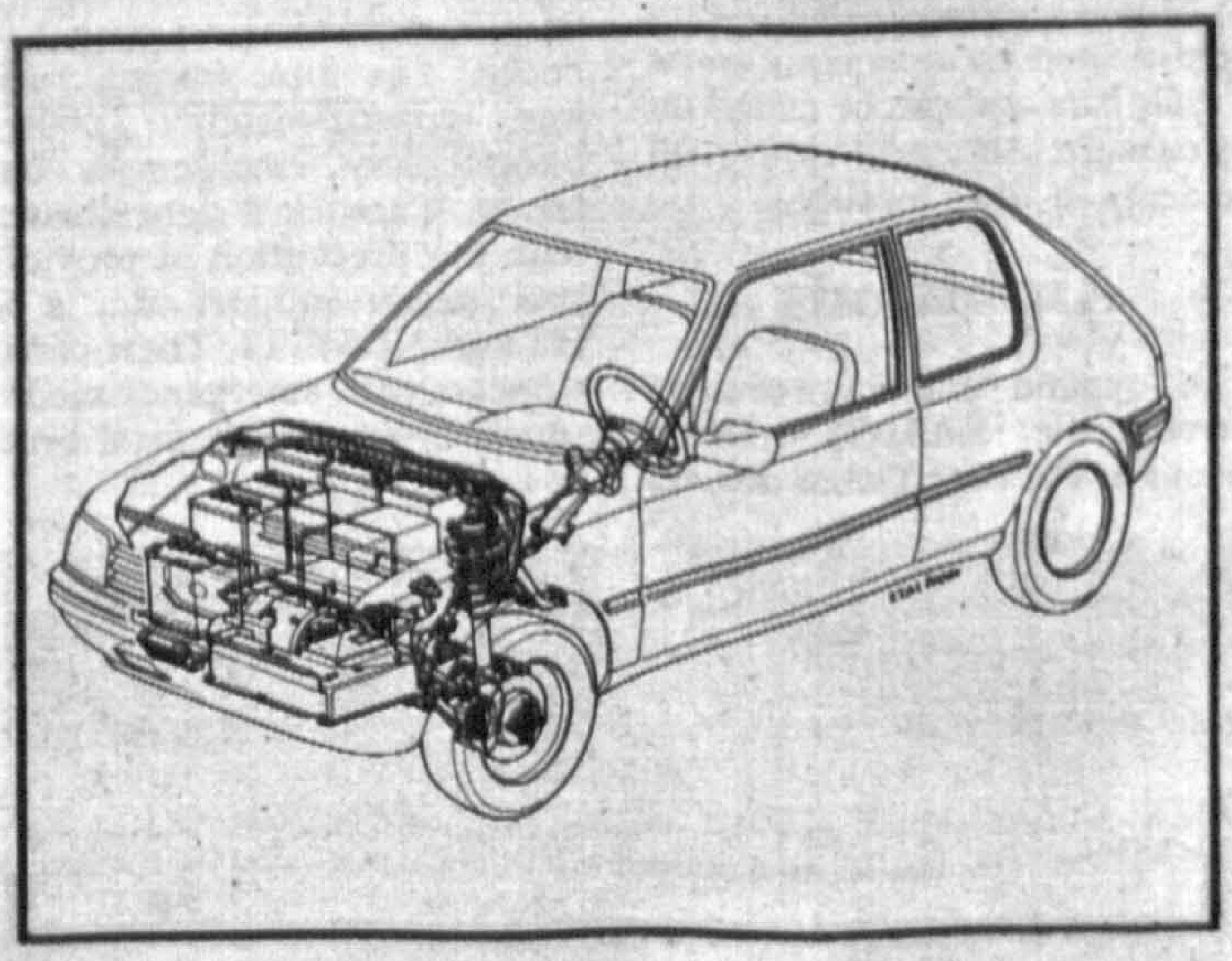
THE DUNBAR DEAN ELECTRIC "LONG RANGER"



7. PEUGEOT 205 ELECTRIC CAR (see section 1.4.6)

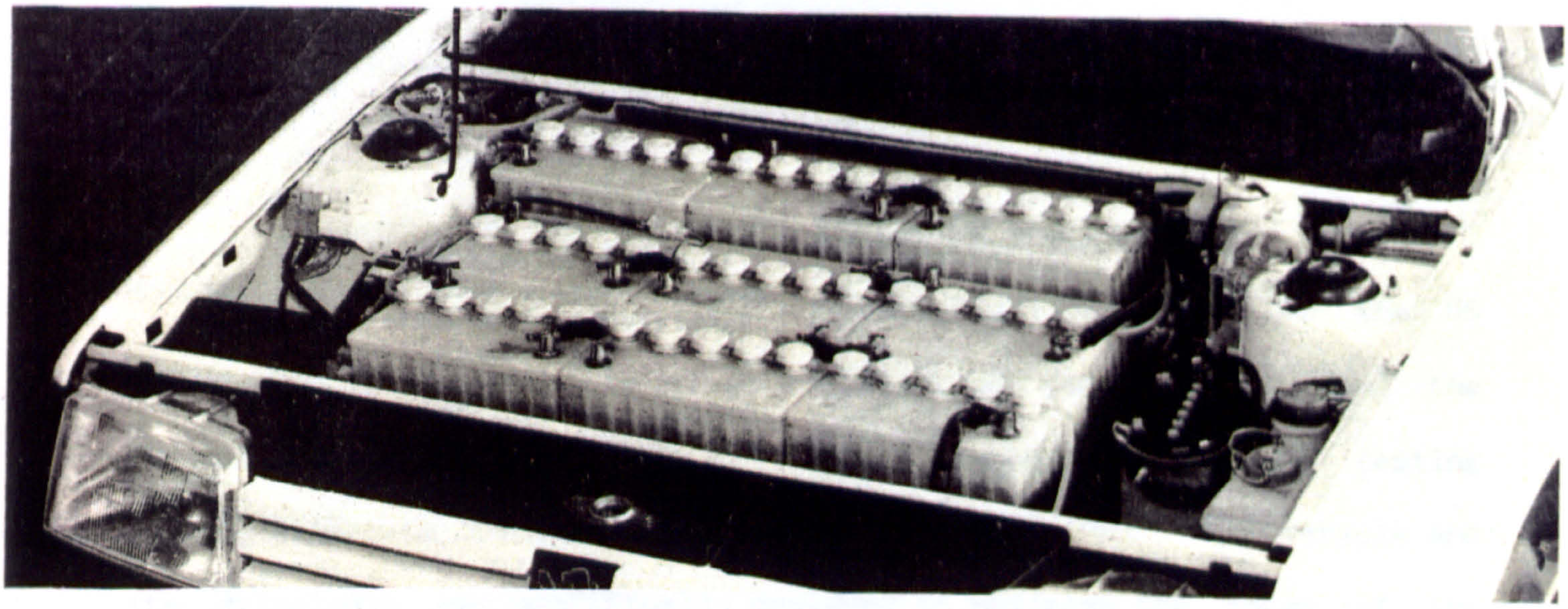
Peugeot have developed an electric conversion of the popular 205 petrol or diesel car using nickel-iron batteries. However it has not been developed with near-term commercialisation in mind but rather as a test vehicle for further research and development by Peugeot who have been experimenting with EVs for nearly 20 years. It has a top speed of 62 mph and a claimed range of 87 miles.

Located in the engine bay of an unmodified Peugeot 205 are rank upon rank of extra-powerful batteries. The cutaway drawing above shows the location of the motor underneath them.



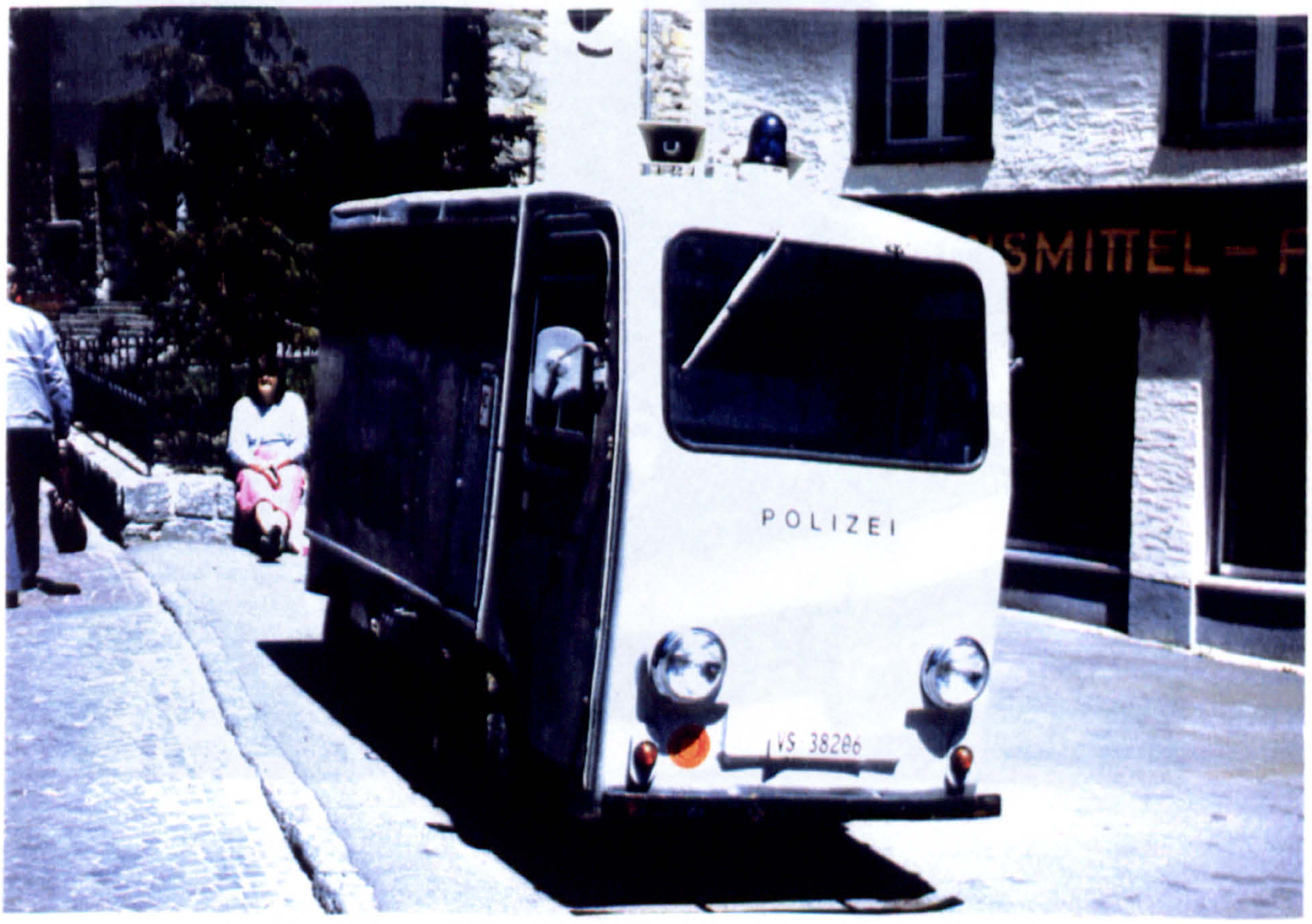
UNDER THE BONNET OF THE PEUGEOT 205 ELECTRIC CAR

The nickel-iron batteries are located in the engine compartment of the vehicle with the motor placed beneath.



8. LOW-PERFORMANCE EVs

There is a great variety of low-performance electric vehicles in use for many different applications. These include milk floats, golf carts, hospital vehicles, industrial materials handling vehicles and street clensing vehicles. The picture below shows a rather unusual application for a low-performance EV. The picture was taken in Zermat in Italy where ICE vehicles are not permitted to enter the town.



APPENDIX 7

DESCRIPTION AND SPECIFICATIONS OF THE ETV-1 VEHICLE

The Electric Test Vehicle (ETV-1) (see fig 1) was built for the US Department of Energy by the General Electric Company (USA) and the Chrysler Corporation. Work on the vehicle commenced in 1978 and testing was undertaken by the Jet Propulsion Laboratory in 1981. The vehicle and its drivetrain was specifically designed to maximise the range of the vehicle under SAE J227A (D) driving cycle conditions.

THE GENERAL ELECTRIC/CHRYSLER DOE ETV-1 TEST VEHICLE

(Appendix 7 cont.)

The separately excited DC motor is controlled by transistor armature and field choppers which are commanded by the propulsion control microcomputer. The microprocessor is the interface between driver demands and the electronic components. The control strategy calls for armature control for vehicle speeds from 0 to 30 mph and field control from 30 to 60 mph. When the vehicle is stationary, the field chopper circuit is used as an on-board battery charger utilising a 115 V, 60 Hz AC power line.

VEHICLE CHARACTERISTICS

Total Vehicle Weight (Kg)	1795
Drag Coefficient	0.32
Frontal area (m^2)	1.875
Coefficient of rolling resistance	0.01
Wheel radius (m)	0.28
Overall length (m)	4.30
Overall height (m)	1.31
Overall width (m)	1.67

MOTOR SPECIFICATIONS

Type - General Electric DC shunt, force ventilated
Power rating - 15 Kw, continuous
Maximum power - 30 Kw
Voltage - 108 (modified to 96)
Maximum speed - 5000 rpm
Approximate weight - 100 Kg

CONTROLLER SPECIFICATIONS

Type - Transistorised, armature chopper, field chopper, microprocessor controlled

Armature chopper

Continuous rating
Motoring: +200 amps
Generating -100 amps
Transient rating (1 minute)
Motoring: +400 amps
Generating: -200 amps
Switching frequency = 100 Hz - 2 kHz

Field chopper

Continuous rating
Field supply: 10.6 amps, 53 Volts
Switching frequency = 9.5 kHz
Charging: 24 amps, 132 Volts (30 amp line)
8 amps, 132 Volts (15 amp line)
Switching frequency = 5 - 15 kHz   Cooling - forced air

TRANSMISSION SPECIFICATIONS

Type - 2 stage chain reduction
Overall final drive ratio - 5.48:1
Differential - Omni/Horizon, modified production model

BATTERY SPECIFICATIONS

Type - Globe-Union EV2-13, Lead-acid
Voltage - 108 V (18 - 6V modules)

Capacity (claimed)

Specific energy - 37.5 Wh/kg (3 hour rate)
Specific power - 181 W/kg (peak)
Capacity - 174 amp-hours (3 hour rate), 190 ah (5 hr rate)
Life - 500 cycles to 70% DOD

Dimensions

Cell size
Length (cm) - 26.35
Width (cm) - 18.26
Height (cm) - 28.26
Battery weight - 495 kg

APPENDIX 8

AN INTRODUCTION TO ELECTRIC VEHICLE MOTORS AND MOTOR CONTROLLERS

1 MOTOR CONTROLLERS

1.1 RESISTANCE TYPE

The resistance type controller has the advantage of simplicity and low cost and is seen in electric golf carts, a low-performance use. An inserted resistance limits the initial current by the equation,

$$I = V/(R_a+R_i),$$

where I is current to the motor, V is applied battery voltage, R_a is resistance of the motor armature, and R_i is the value of the inserted resistance. V is in volts, I is in amperes and R is in ohms. An important disadvantage of this method is the loss of energy dissipated in the inserted resistance. It represents energy lost from the battery, which in turn decreases the potential range of the vehicle. In driving a vehicle of greater curb weight, this loss in range can be prohibitive. Thus high-performance electric vehicles rarely use this method of current control.

1.2 VOLTAGE SWITCHING TYPE

While voltage switching is not as simple as the resistance type control, voltage switching is still a reasonably inexpensive means of limiting start-up current to a motor, depending on the number of contactors employed. The starting current to the motor is limited by the application of a low initial voltage being impressed on the motor contacts. Under such conditions the initial current is limited only by the low armature resistance. As the rotor gains in speed, successively higher back emf is generated in the armature, serving to limit the current. As the accelera- tion pedal is depressed further, a successively higher voltage from the battery is switched on until finally the full voltage from the battery is impressed on the motor. The disadvantage of this voltage switching system for current limitation can be the somewhat jerky acceleration of the vehicle, the clicking sound as the interlocks close, and the maintenance associated with good operation of the interlocks. In addition, there is always the latent possibility of battery voltage imbalance, almost inherent in voltage switching. This imbalance can cause uneven battery life, or the presence of unequally charged batteries in the set.

1.3 VOLTAGE SWITCHING AND RESISTANCE INSERT TYPE

This is a technique combining both of the above features. While it is more complex than either of the above methods, the current to the motor is better controlled. Not only is there step application of voltage, but between the steps use is made of resistance insert. This combination of control yields a smoother start. The disadvantages are described in the two methods above.

1.4 SOLID-STATE "CHOPPER" CONTROLLER

With modern electric road vehicles where the emphasis is on range, at start-up the trend is to use a control device known as a chopper. As its name implies, this solid-state control device chops the power from the battery into discrete time blocks. The solid-state chopper controller limits initial current to the motor primarily by the time duration of the impressed battery voltage across the motor. A lightly depressed accelerator results in relatively few pulses being generated and these pulses are short in duration. As the accelerator is further depressed, the pulses become longer in duration and more frequent thus applying a higher average voltage to the motor. This system has the advantages of allowing a continuously variable voltage to be applied and of being more efficient than the above methods; typical energy efficiencies are in the region of 95-99%. In addition, there are no moving parts so it is highly reliable.

2 ELECTRIC VEHICLE MOTORS

2.1 DC SERIES MOTORS

This type of motor is still the most commonly used in electric vehicle drive systems because its torque characteristic is maximum at stall and falls off gradually as speed is increased. There is normally no possibility of overspeeding the motor in an EV.

2.2 DC SHUNT MOTORS

Because of their approximately constant speed characteristics these are generally less suitable than series motors for propulsion of EVs unless used with a mechanical variable transmission.

2.3 DC SEPARATELY EXCITED MOTORS

When a sophisticated control system is used it is possible to obtain very high efficiency on almost any desired characteristic by controlling the armature and the field separately. For this reason this type of motor is used in some of the most advanced EVs.

2.4 AC MOTORS

An AC motor is cheaper to manufacture than equivalent DC motors because it has no brush gear or commutator and it requires less maintenance. However for propulsion use it must be driven from a variable frequency supply which can be expensive to achieve from a normal DC battery.

2.5 RELUCTANCE MOTORS

This motor utilises the advantages of the AC motor that have been mentioned above such as low cost etc. and is controlled by the use of a pulsed DC supply. At present the cost of the equipment required to generate this supply is greater than the saving on the motor plus the saved cost of the DC controller, but new semi-conductor devices are now being utilised thus combining the benefits of the AC motor with the advantages of DC speed control.

APPENDIX 9

HOUSE OF LORDS SELECT COMMITTEE ON SCIENCE AND TECHNOLOGY
SESSION 1979/80 1st REPORT ELECTRIC VEHICLES

SUMMARY OF RECOMMENDATIONS

(a) EVs must eventually stand or fall on their commercial viability. There is however a national interest in their production, on energy, environmental and industrial grounds, and the Government are right to support RD&D. Electric transport must be seen as a serious long term option. Support should continue at not less than its present level in real terms but does not have to be greatly increased.

(b) The Government's objective should be to allow the EV to prove whether it can compete with the ICE vehicle on equal terms before oil supplies actually run down.

(c) Some extra funding should be given to test hybrid vehicles.

(d) Within current investment programmes, drive-trains should receive particular support.

(e) Special attention should be paid to testing and field trails of EVs; evaluation schemes, assisted by public money, are important.

(f) Government support should reflect manufacturers' investment. The future of EVs lies with larger companies prepared to invest heavily rather than with the small companies now engaged in building specialised EVs.

(g) Product-launch money, to get over the volume-production hump in the next few years, will be required. The Committee commend battery leasing schemes; extra support, repayable in part by levies on future sales, should be considered.

(h) The Committee endorse the applications for continuation of industrial support from Chloride and Lucas. A similar application by a major vehicle manufacturer would call for support.

(i) Public authorities should undertake bulk purchases of specialised EVs built to their own specification.

(j) The Electricity Council should take a greater part in promoting EV's publicity.

(k) The existing battery research programme should continue. There is no need for additional expenditure, and effort should be concentrated on a few projects. A critical review of these projects should be undertaken before long in case they outlive their usefulness.

(l) Preferential parking regulations for EVs in town centres should be considered.

(m) If manufacturers of EVs are inhibited by legislation or other regulations, they should bring this to the Government's notice.

(n) Manufacturers must do what they can to make a specialised recharging infrastructure for EVs unnecessary

(o) The Committee recommend no change in the organisation of R&D of EVs.

APPENDIX 10

REVIEW OF WORLD OIL RESERVES, PRODUCTION AND CONSUMPTION

1 PRINCIPAL ESTIMATES OF ULTIMATE WORLD OIL RESOURCES (Since 1940)

DATE	SOURCE	THOUSAND MILLION TONNES
1942	Pratt, Weeks and Stebinger	82
1946	Duce	55
1946	Progue	76
1948	Weeks	183
1949	Levorsen	205
1949	Weeks	138
1953	MacNaughton	136
1956	Hubbert	171
1958	Weeks	205
1959	Weeks	273
1965	Hendrix (USGS)	338
1967	Ryman (Esso)	285
1968	Shell	246
1968	Weeks	300
1969	Hubbert	184-286
1970	Moody (Mobil)	146
1971	Warman (BP)	164-273
1971	Weeks	312
1971	US National Petroleum Council	364
1972	Linden	402
1972	Weeks	498
1972	Moody, Emerik (Mobil)	246-259
1975	Adams and Kirby (BP)	273
1975	WPC (Tokyo)	270
1975	Moody (Mobil)	177
1976	Klemme (Weeks)	159
1977	Delphi survey, WEC (Istanbul)	240-600
1978	Nehring-Giant Oilfields & World Oil Resource	232-315
1979	WPC (Bucharest)	304
1980	WEC (Munich)	350
1982	Arab Oil and Gas	180-300
1982	Colitti (Agip)	285
1982	Petroleum Economist	300
1983	WPC (London)	213-369

(Source - Despraires P C, Boy de la Tour X, Lacour J J, 1985.
"Progressive mobilisation of oil resources - A factor in ensuring moderate price rises"
Energy Policy Dec 1985 pp511-523.

(Appendix 10 cont.)

2 PROVED OIL RESERVES AT END 1986

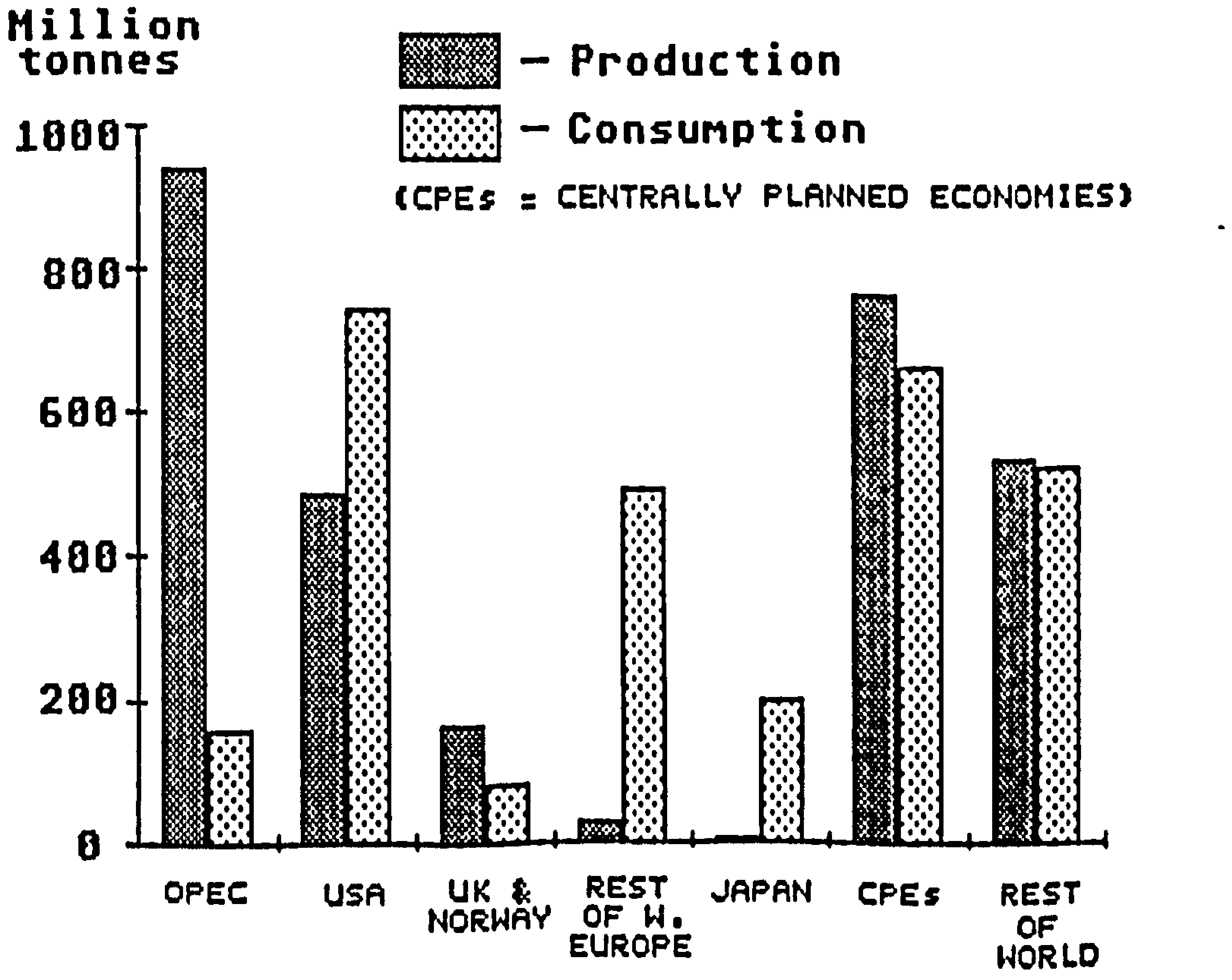
(source - BP Statistical Review of World Energy 1987)

AREA	THOUSAND MILLION TONNES	SHARE OF TOTAL (%)	R/P RATIO
North America			
USA	4.1	4.6	8.5
Canada	1.0	7.9	12.3
TOTAL NORTH AMERICA	5.1	5.7	9.0
Latin America			
Argentina	0.3	0.3	14.4
Brazil	0.3	0.3	10.1
Ecuador	0.2	0.2	16.7
Mexico	7.6	7.8	56.3
Venuzuela	3.6	3.6	38.7
Others	0.4	0.4	10.9
TOTAL LATIN AMERICA	12.4	12.6	37.7
Western Europe			
Norway	1.4	1.5	31.2
United Kingdom	0.7	0.8	5.5
Others	0.3	0.3	13.3
TOTAL WESTERN EUROPE	2.4	2.6	12.2
Middle east			
Abu Dhabi	4.1	4.4	80.6
Dubai	0.2	0.2	9.7
Iran	6.7	6.9	71.1
Iraq	6.3	6.7	74.7
Kuwait	12.7	13.1	>100.0
Neutral Zone	0.7	0.7	43.3
Oman	0.6	0.6	19.8
Quatar	0.4	0.5	25.0
Saudi Arabia	22.7	23.7	90.3
Syria	0.2	0.2	19.2
Others	0.2	0.2	31.1
TOTAL MIDDLE EAST	54.8	57.2	85.5
Africa			
Algeria	1.1	1.3	26.9
Angola	0.2	0.2	11.7
Egypt	0.5	0.5	12.1
Lybia	2.8	3.0	55.1
Nigeria	2.2	2.3	30.2
Tunisia	0.2	0.3	46.1
Others	0.3	0.4	13.6
TOTAL AFRICA	7.3	8.0	29.3
Asia and Australasia			
Japan	<0.05	<0.05	14.0
Brunei	0.2	0.2	25.6
Indonesia	1.1	1.2	16.7
Malaysia	0.4	0.4	15.0
Other South East Asia	<0.05	<0.05	2.8
India	0.6	0.6	18.0

(Appendix 10 cont.)

Other South Asia	<0.05	<0.05	8.0
Australia	0.2	0.2	8.8
New Zealand	<0.05	<0.05	21.2
TOTAL ASIA & AUSTRALISIA	2.5	2.8	14.3
TOTAL NON COMMUNIST WORLD	84.5	88.7	39.1
Centrally Planned Economies (CPEs)			
China	2.4	2.6	18.5
USSR	8.0	8.4	13.1
Others	0.3	0.3	11.0
TOTAL CPEs	10.7	11.3	14.0
TOTAL WORLD	95.2	100.0	32.5
Of which OPEC	65.0	67.9	68.7

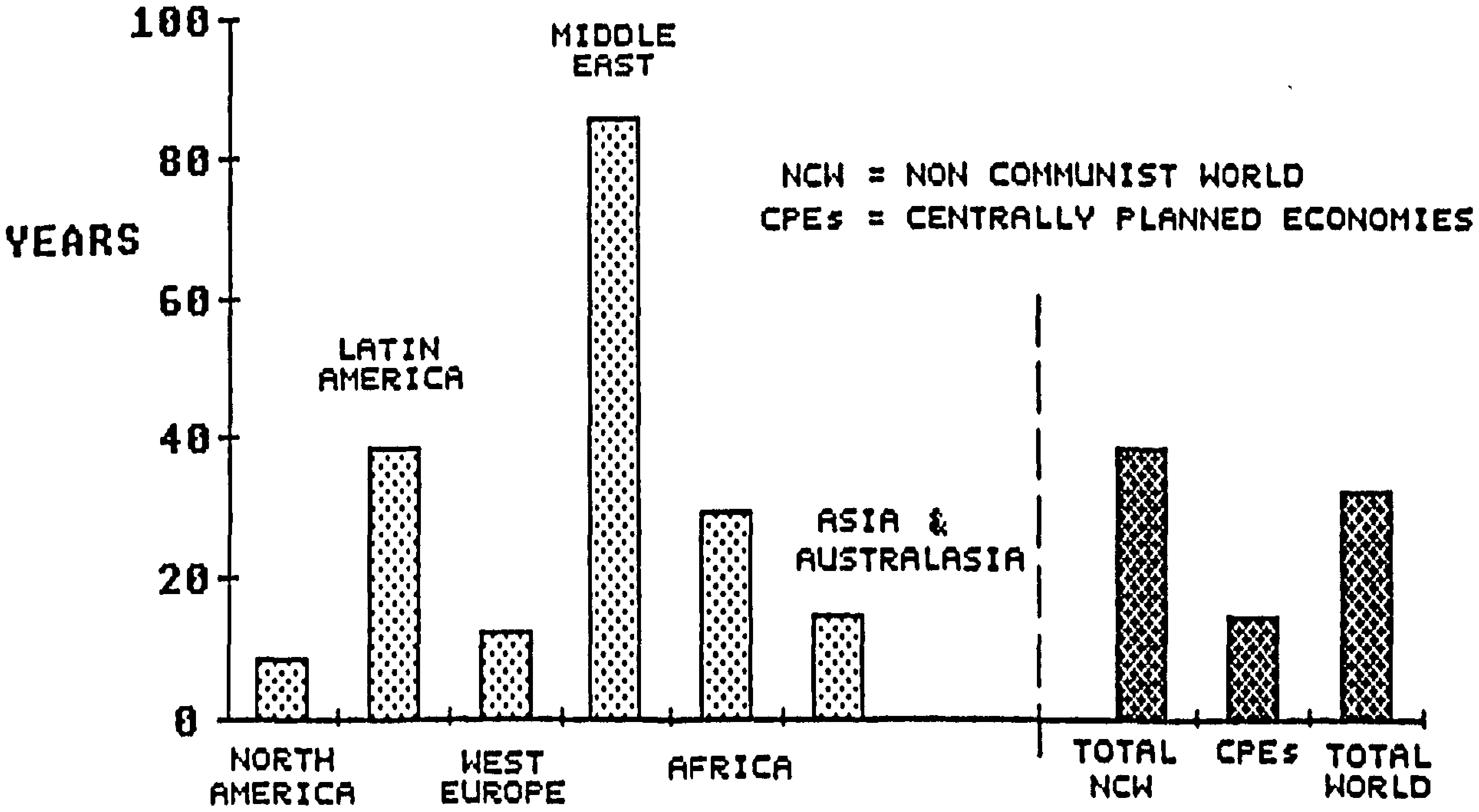
OIL PRODUCTION AND CONSUMPTION IN 1986



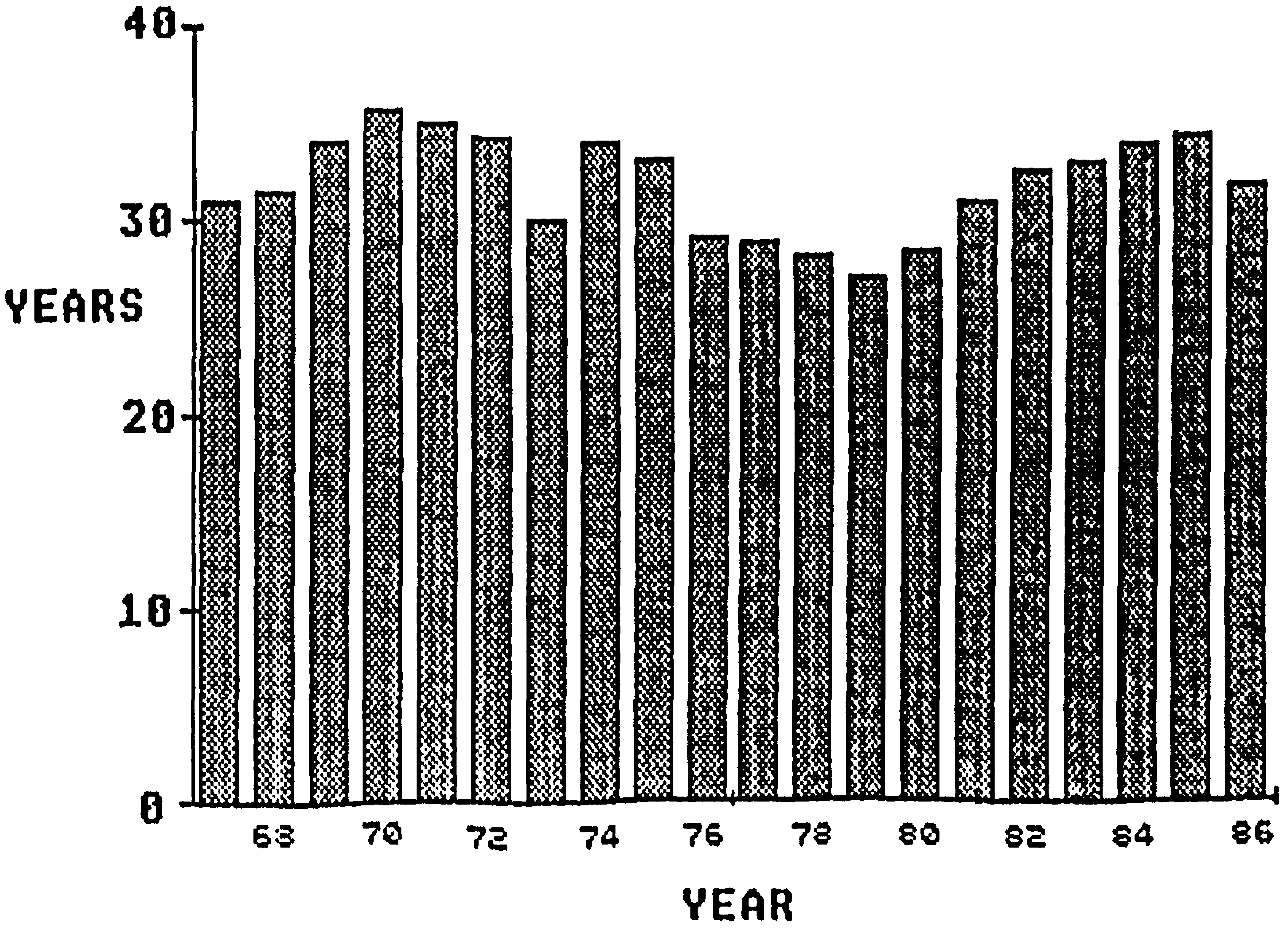
3 RESERVES TO PRODUCTION (R/P) RATIOS BY AREA AND TOTAL WORLD

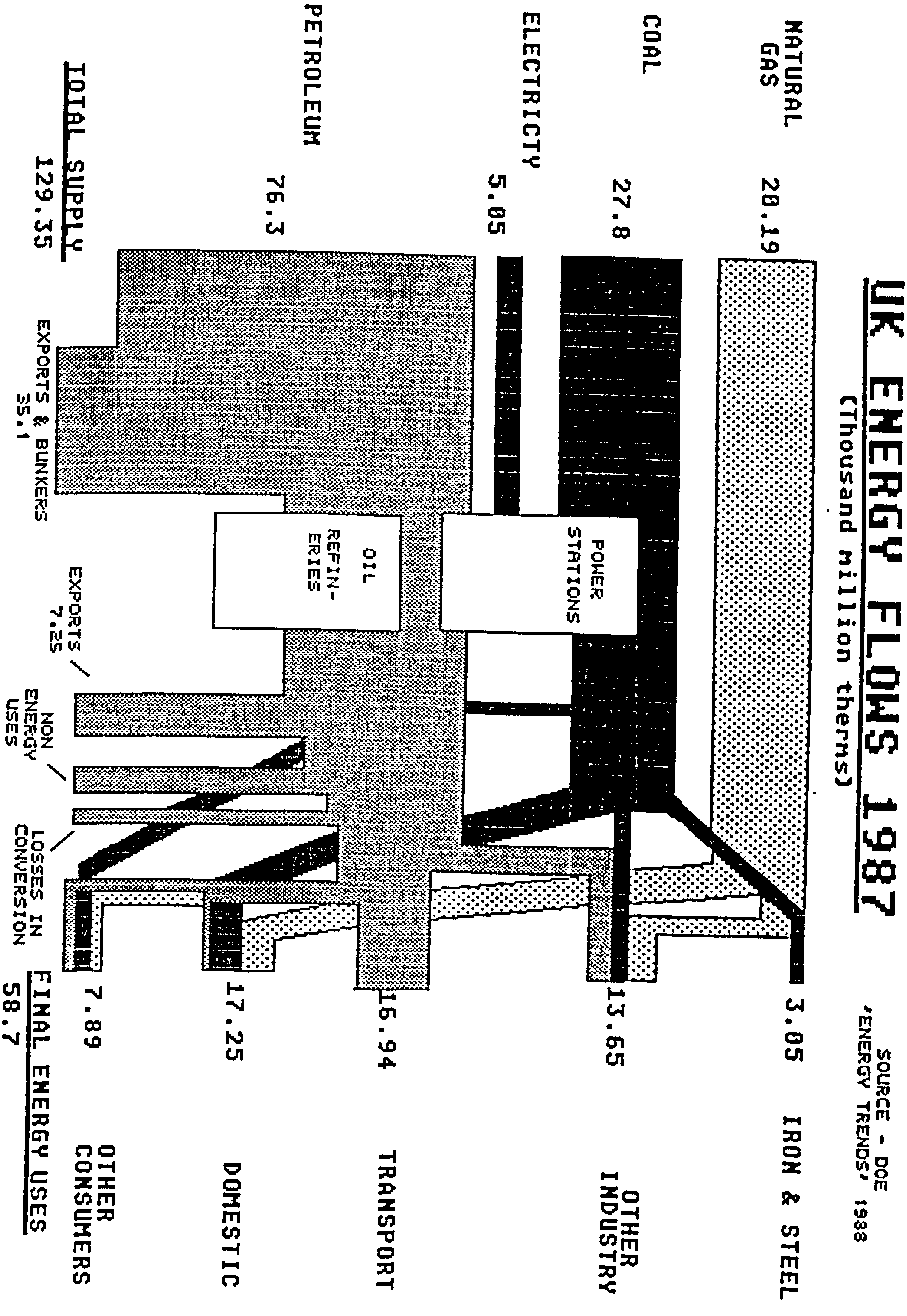
The R/P ratio is a measure of the number of years that production at current levels could be continued before all proved reserves are depleted.

R/P RATIO 1986 BY AREA - YEARS OF RESERVES REMAINING
(source - BP Statistical Review of World Energy)



WORLD R/P RATIO :- YEARS OF RESERVES REMAINING
(source - BP Statistical Review of World Energy 1987)





UK ENERGY FLOWS 1987

(Thousand million therms)

SOURCE - DOE 'ENERGY TRENDS' 1988

APPENDIX 11

DIRECTIONS FOR RESEARCH AND DEVELOPMENT OF LEAD-ACID TRACTION BATTERIES

The following is a list of the areas where further research and development efforts could help to improve the performance and life cycle costs of lead-acid traction batteries. (Source - Jnl of Power Sources, Vol 5(1980) p221-234.)

AIM	DEVELOPMENT AREAS	RESEARCH AREAS
Improved energy density	1 Reduced batt. weight & vol. -lower weight container -low density grids -minimum battery hardware	1 Increased utilisation of active materials. -structural aspects, e.g particle morphology, porosity, surface area, electrical isolation -morphological changes on cycling -phase transformations, -electrochemical inactivity.
	2 Alternative cell configurations -improved grid design -more efficient plate geometery and arrangement -decreased internal resistance	2 Effect of dopants -plate additives, e.g, expanders:$BaSO_4$, lignin -electrolyte additives, e.g, H_3PO_4, Co^{2+}
Increased cycle life	3 Improved separator materials -reduced attack by active materials, metal dendrites, temperature	3 Stability of active mats. -cohesion and adhesion and particle morphology -electrolyte action, e.g, erosion, dissolution -new grid alloys.
	4 Control of temperature -heat exchangers -circulating electrolyte	4 Effect of contaminants -dissolved grid metals, especially Sb -trace impurities in mats.
	5 Control of electrolyte concentration -circulating electrolyte	5 Reduced grid corrosion -new alloys -effect of additives -control of self discharge
		6 Effect of high temperature operation.

(Increased cycle life continued)		7 Effect of variable load -pulsed high-rate discharge -regenerative and boost charging -rest periods -recharging rate
Reduced maintenance	6 Control of gas evolution	8 Decreased gassing -new grid materials, e.g, Pb-Ca-Sn alloys
	7 Control of self-discharge	
	8 Charger optimisation	9 Improved charge acceptance

APPENDIX 12

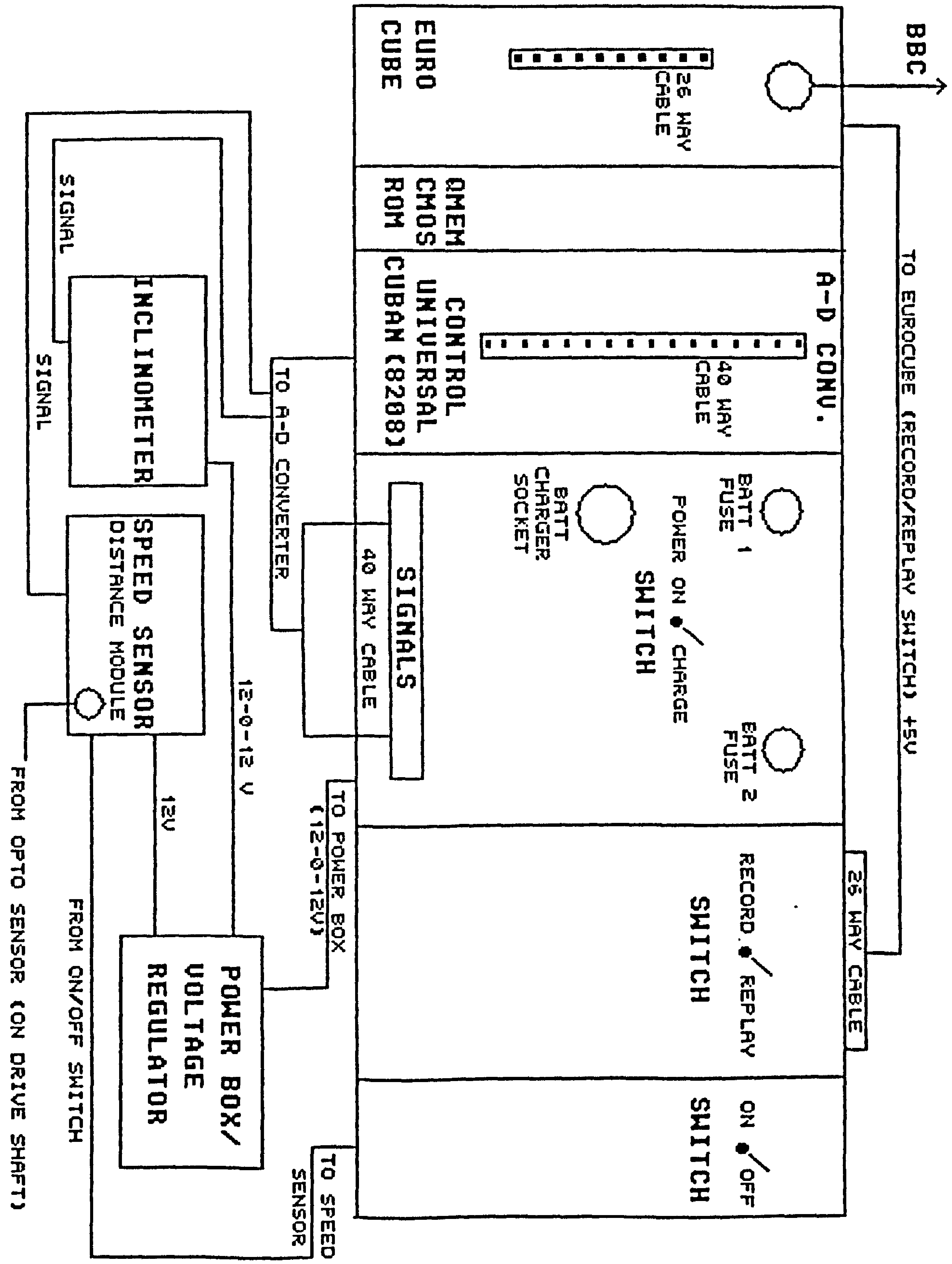
DETAILS OF PURPOSE BUILT DATA LOGGER TO COLLECT VEHICLE DRIVING DATA

The data logger was used to record data on vehicle speed and road gradient at regular intervals of time as the vehicle was driving. This data was used in the performance simulation model described in section 6.3 and the data collection process is described in section 6.4. The data logger was purpose built at Stirling University and this appendix documents the logger specifications as follows,

1 SCHEMATIC DIAGRAM OF LOGGER UNIT
2 PICTURES OF COMPLETE LOGGER UNIT
3 SPECIFICATIONS OF INCLINOMETER SENSOR
4 DETAILS OF SPEED SENSOR
5 PICTURES OF THE CONSTRUCTION AND USE OF THE LOGGER
6 CIRCUIT DIAGRAM OF DATA LOGGING SYSTEM

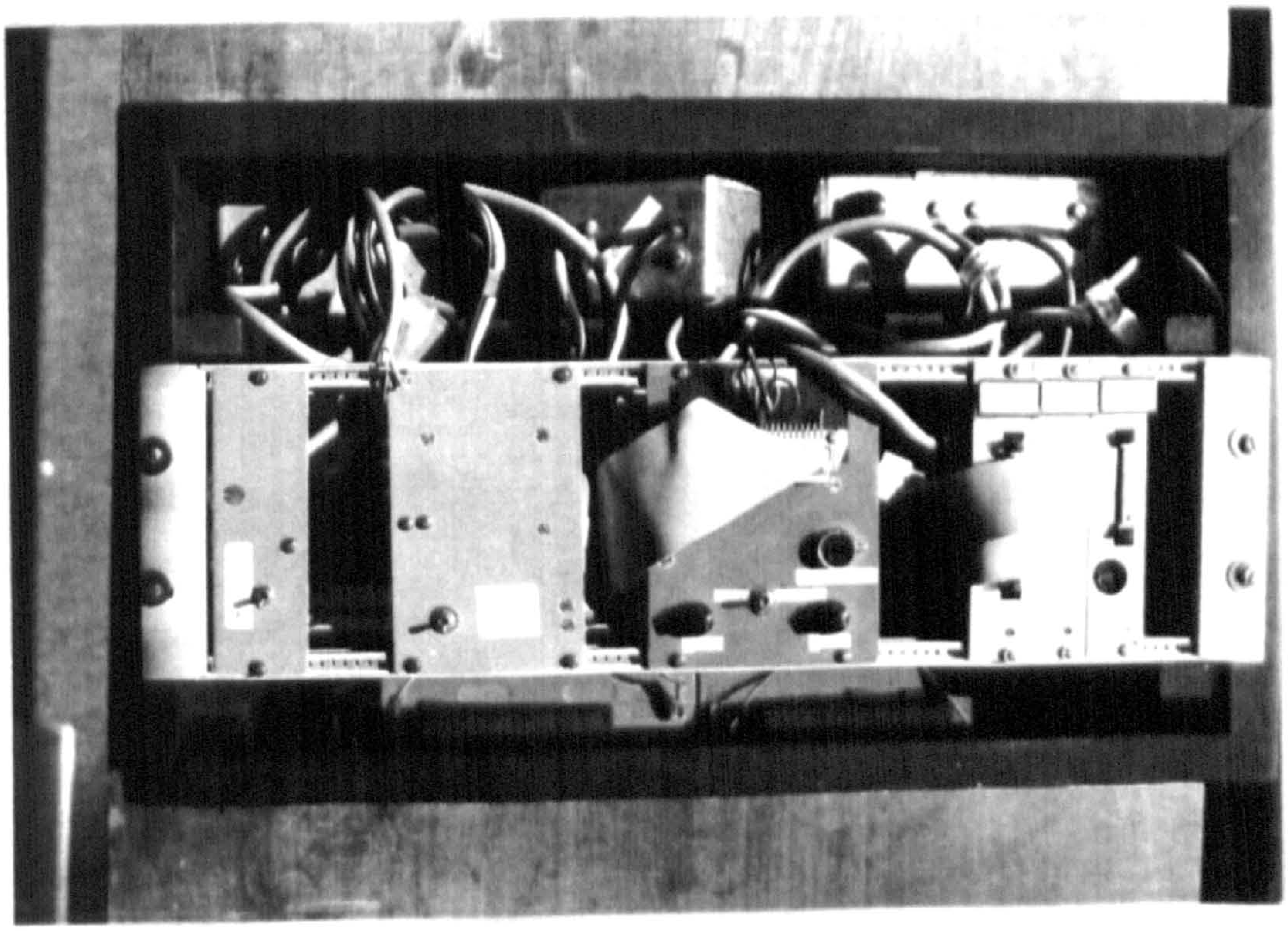
(Appendix 12 cont.)

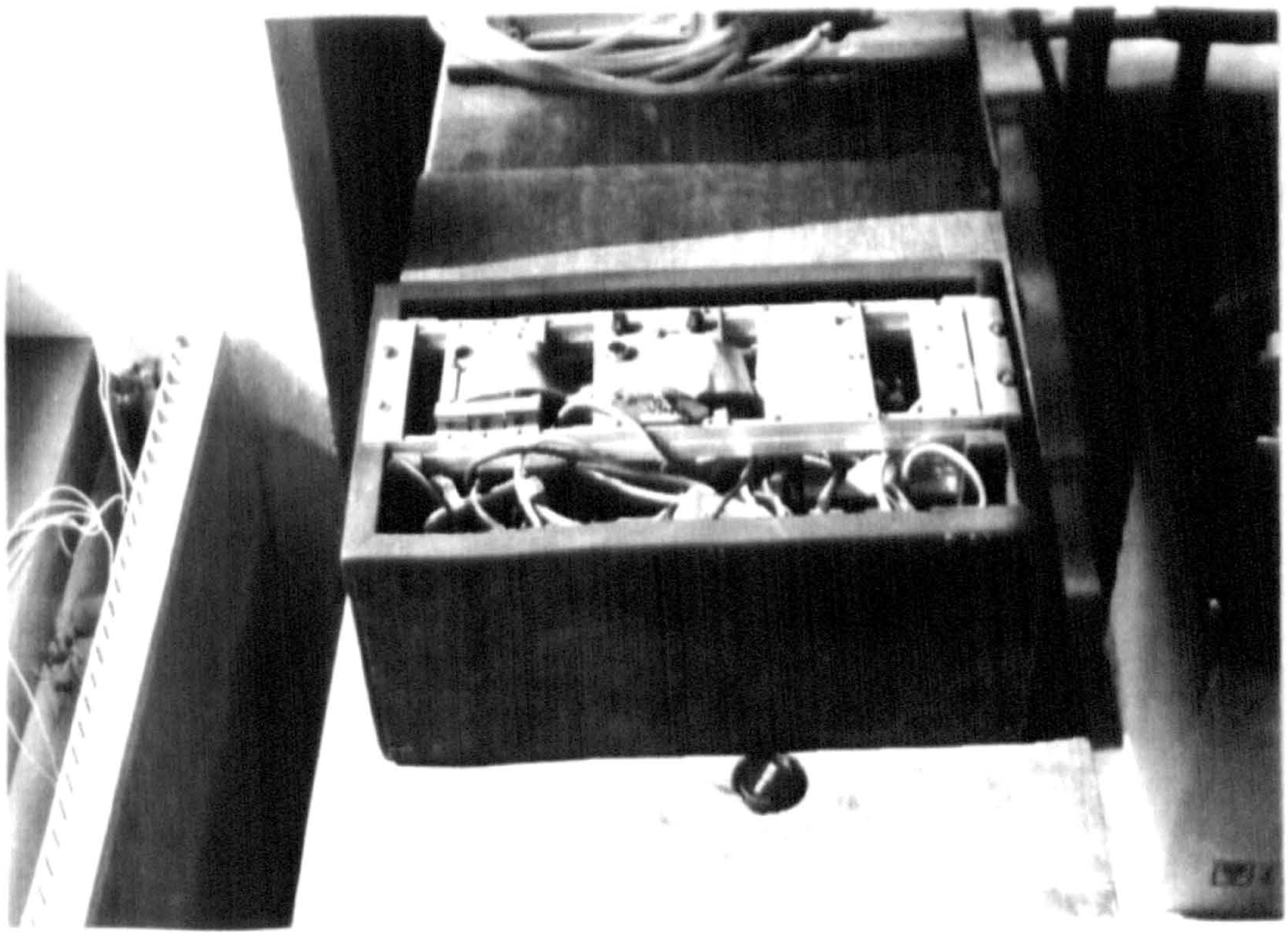
SCHEMATIC DIAGRAM OF DATA LOGGING SYSTEM



THE COMLETE UNIT IN ITS BOX

The inclinometer is contained within the box which was carried in the vehicle. The signal from the speed sensor was also fed into the data logger. (see schematic diagram for comparison)





SPECIFICATIONS OF THE INCLINOMETER USED IN THE DATA LOGGING EQUIPMENT

Inclinometer Specifications

Performance

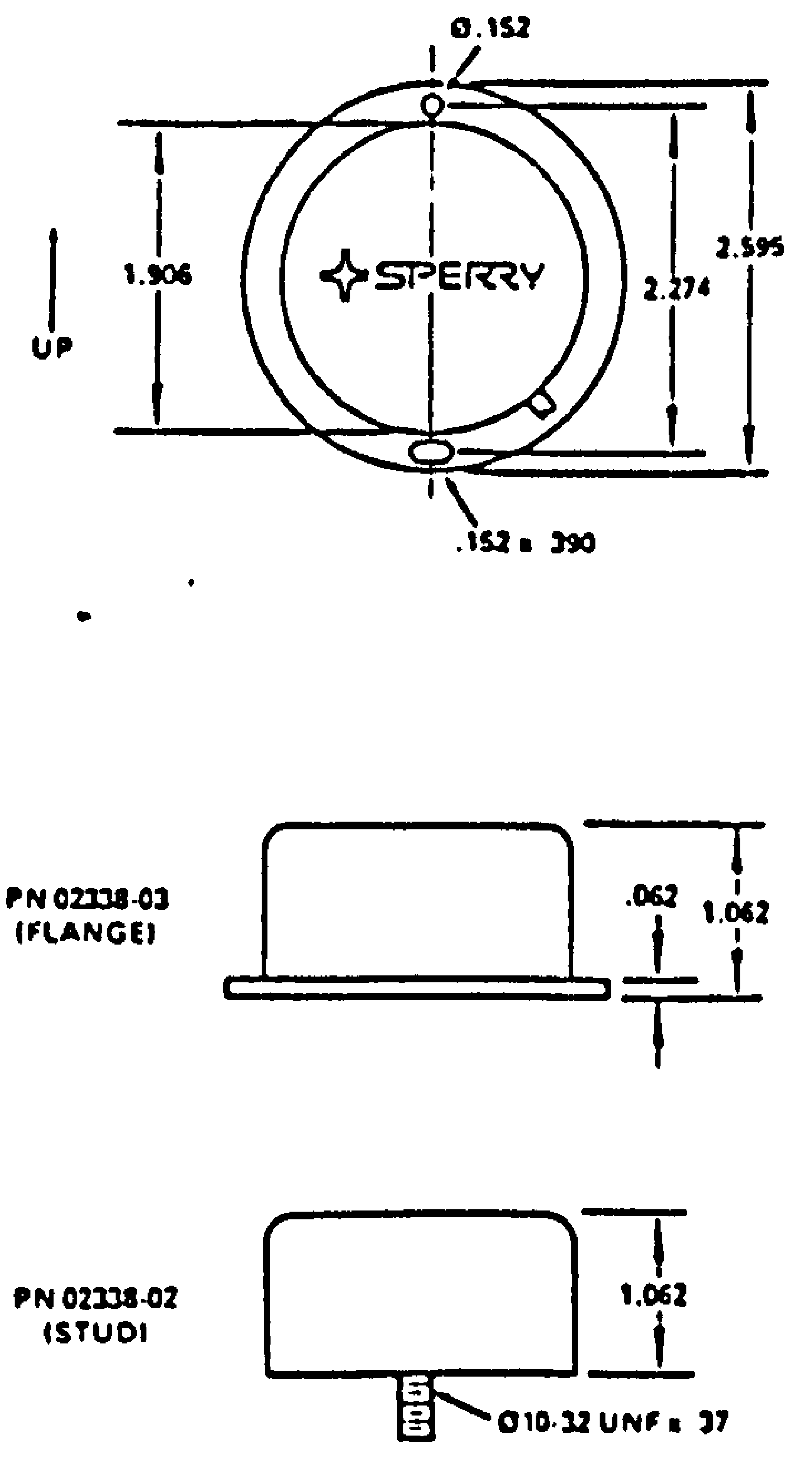
Total range	± 60 deg.
Linear range	± 45 deg.
Threshold and resolution	.001 deg.
Linearity–null to 10 deg.	± .1 deg.
–10 to 45 deg.	± 1 percent angle
–45 to 60 deg.	Monotonic
Null repeatability	.05 deg.
Cross axis error to 25 deg.	<1 percent
Time constant	.3 second
Frequency Response	1.0 Hz

Electrical

Voltage supply–nominal	± 12 VDC
Voltage supply range	± 8 to + 20 VDC
Current–each nominal supply	5 milliamps
Scale factor–to linear range	60 millivolts/deg. (analog) 100 microseconds/deg. (digital PW)
Load resistance–minimum	10K ohms

Environmental

Temperature range–Operating	– 40 to + 65°C
–Storage	– 55 to + 65°C
Temperature coefficient of null	.008 deg. per °C
Temperature coefficient of scale factor	.05 percent per °C



DIMENSIONS IN INCHES

WEIGHT 4 OUNCES

Miniature Electronic Inclinometer Applications

Integrate as a component or install as a stand-alone device:

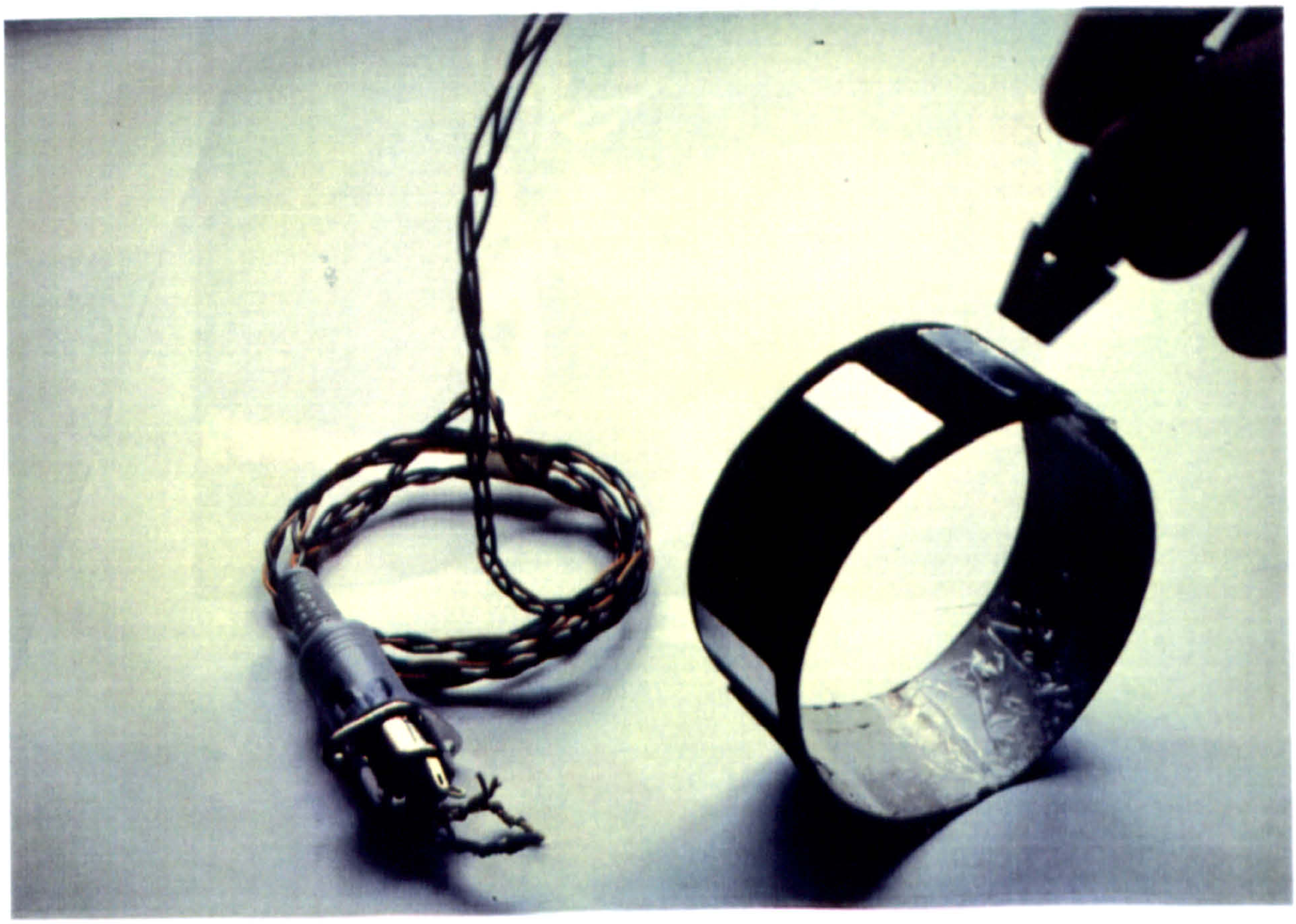
- Robotics
- Cranes
- Antenna
- Construction
- Aircraft
- Manufacturing
- Automotive
- Military
- Security
- Marine
- Medical
- Agriculture

SPERRY CORPORATION
AEROSPACE & MARINE GROUP
P.O. BOX 21111
(SENSING SYSTEMS–MS DV-2)
PHOENIX, ARIZONA 85036-1111
(800) 545-3243

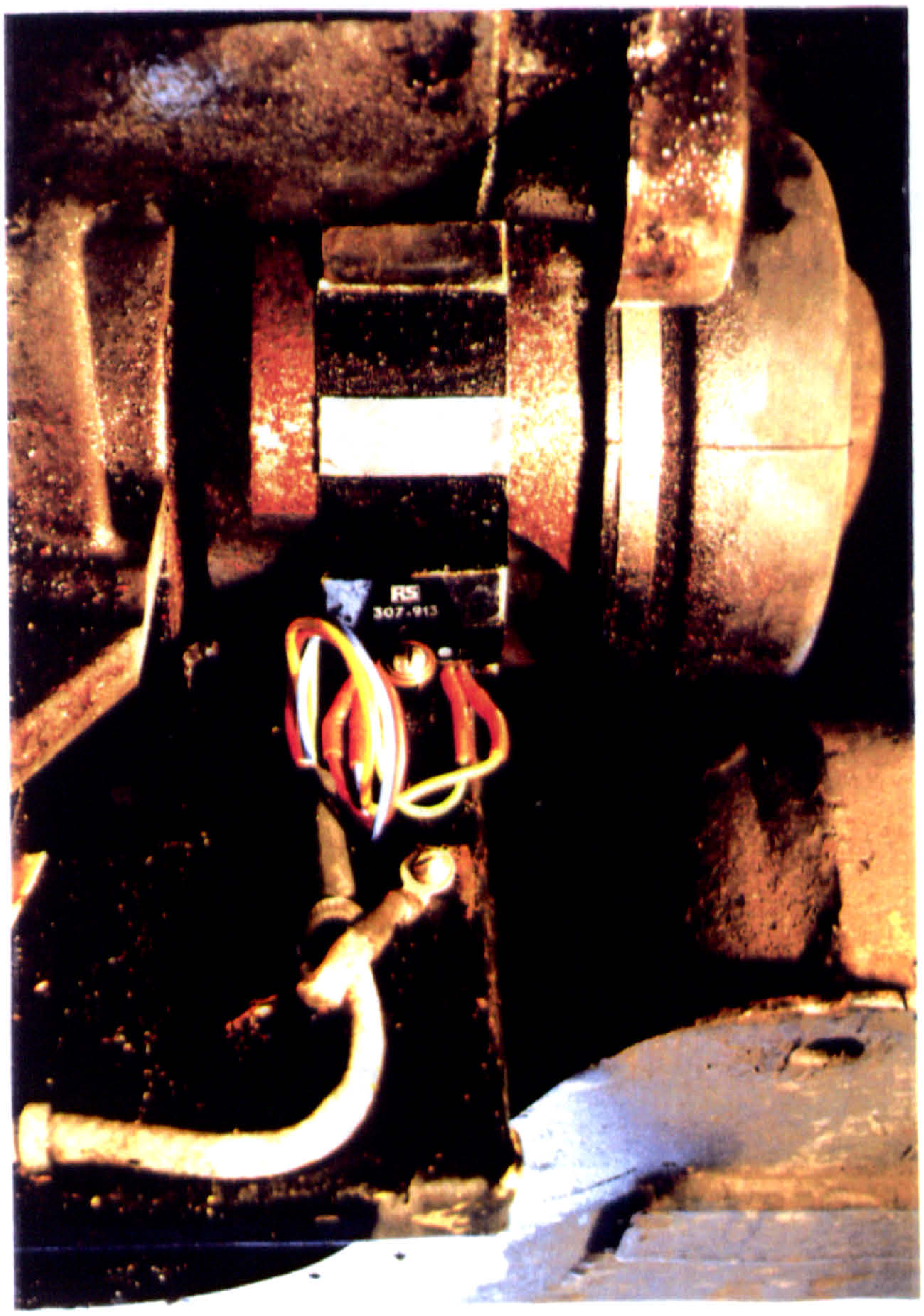
61-5740-01-01
May 1985
Printed in U S A

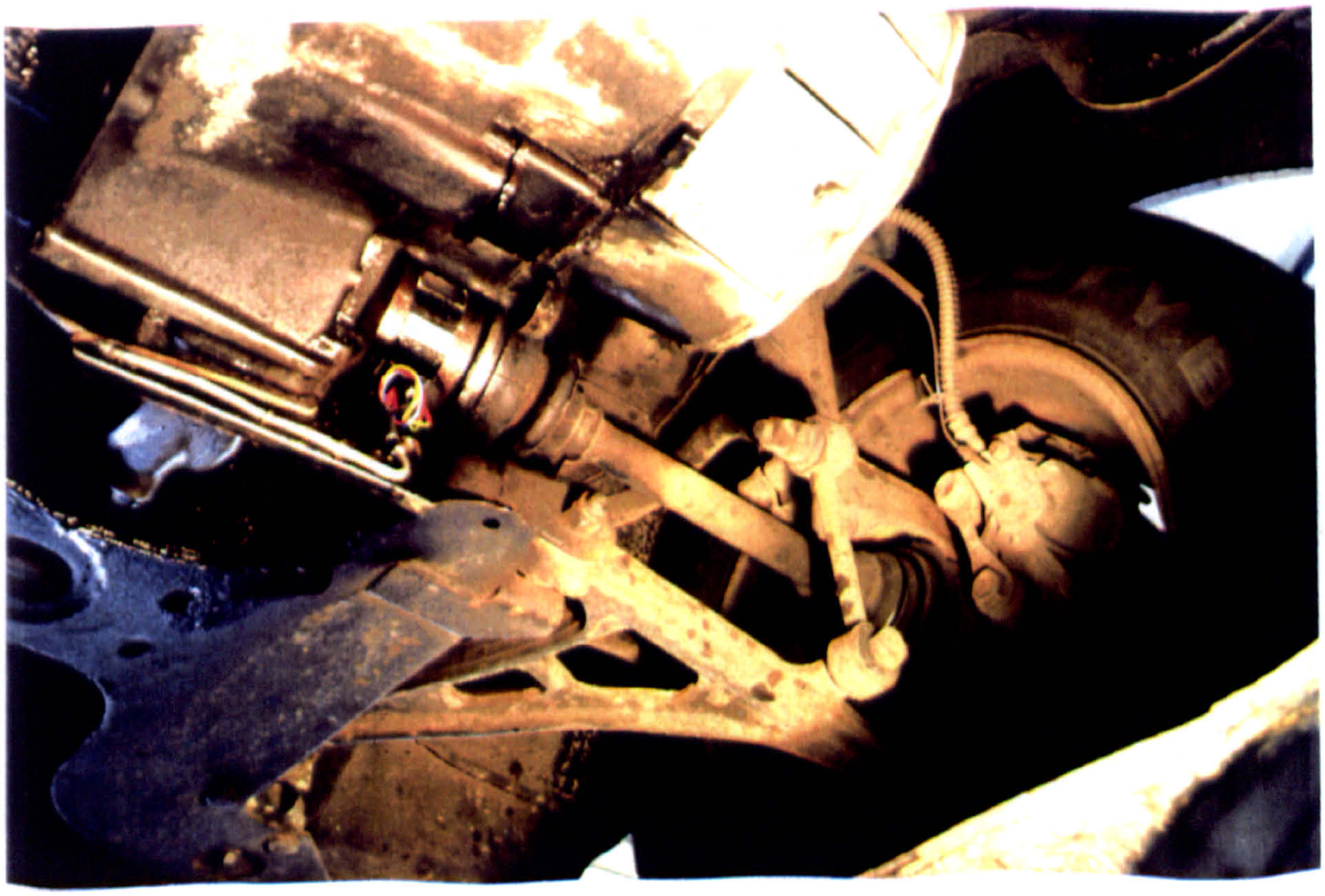
THE SPEED SENSOR UNIT

The speed was recorded using an opto-head sensor which shone a beam of light at the band encircling the driveshaft. The opto-head records the fequency of the reflections from the reflective patches, the voltage of the signal being proportionate to vehicle speed (see section 6.4).

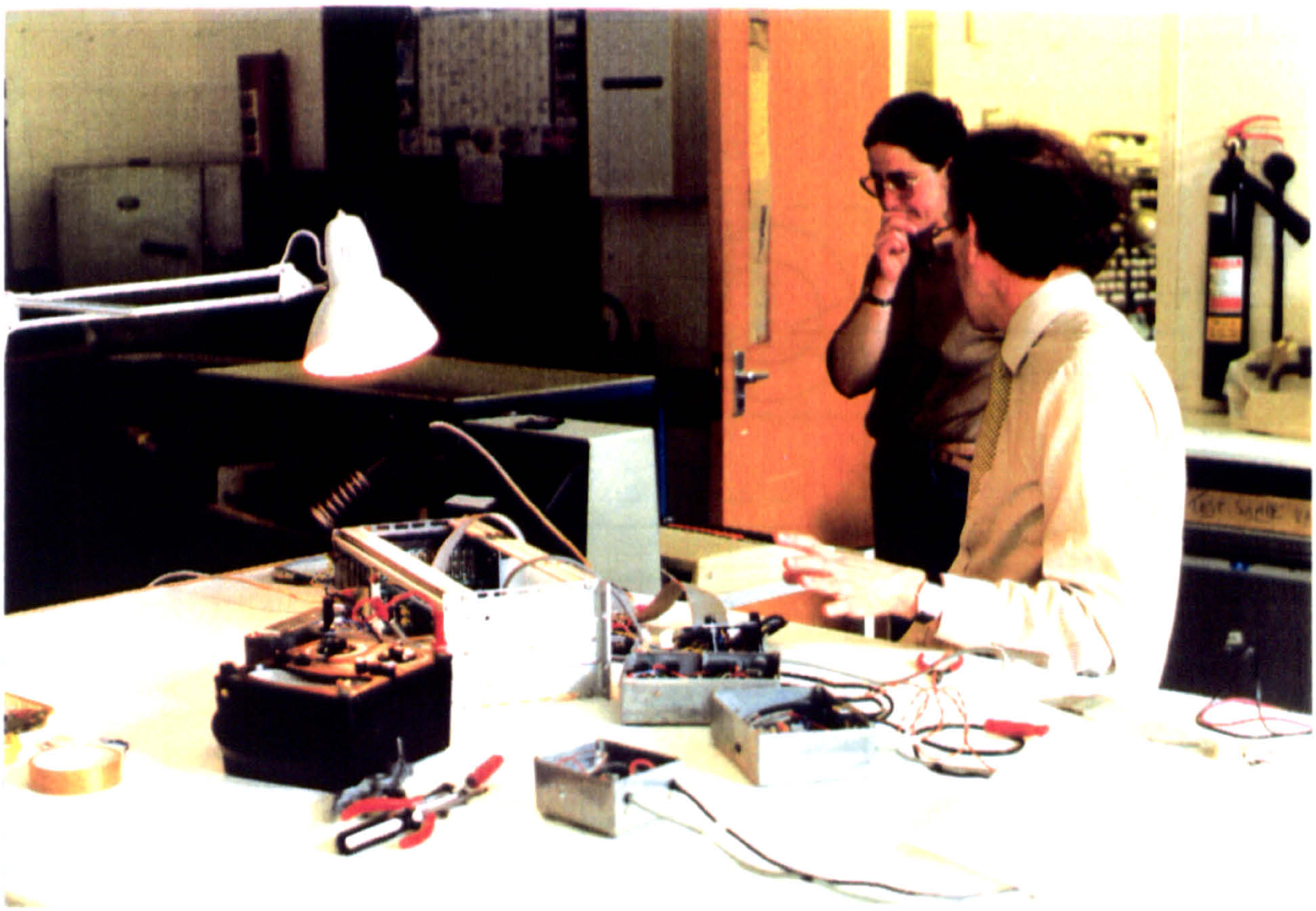


THE SPEED SENSOR SYSTEM ATTACHED TO THE DRIVESHAFT





THE DATA LOGGING SYSTEM BEING CONSTRUCTED



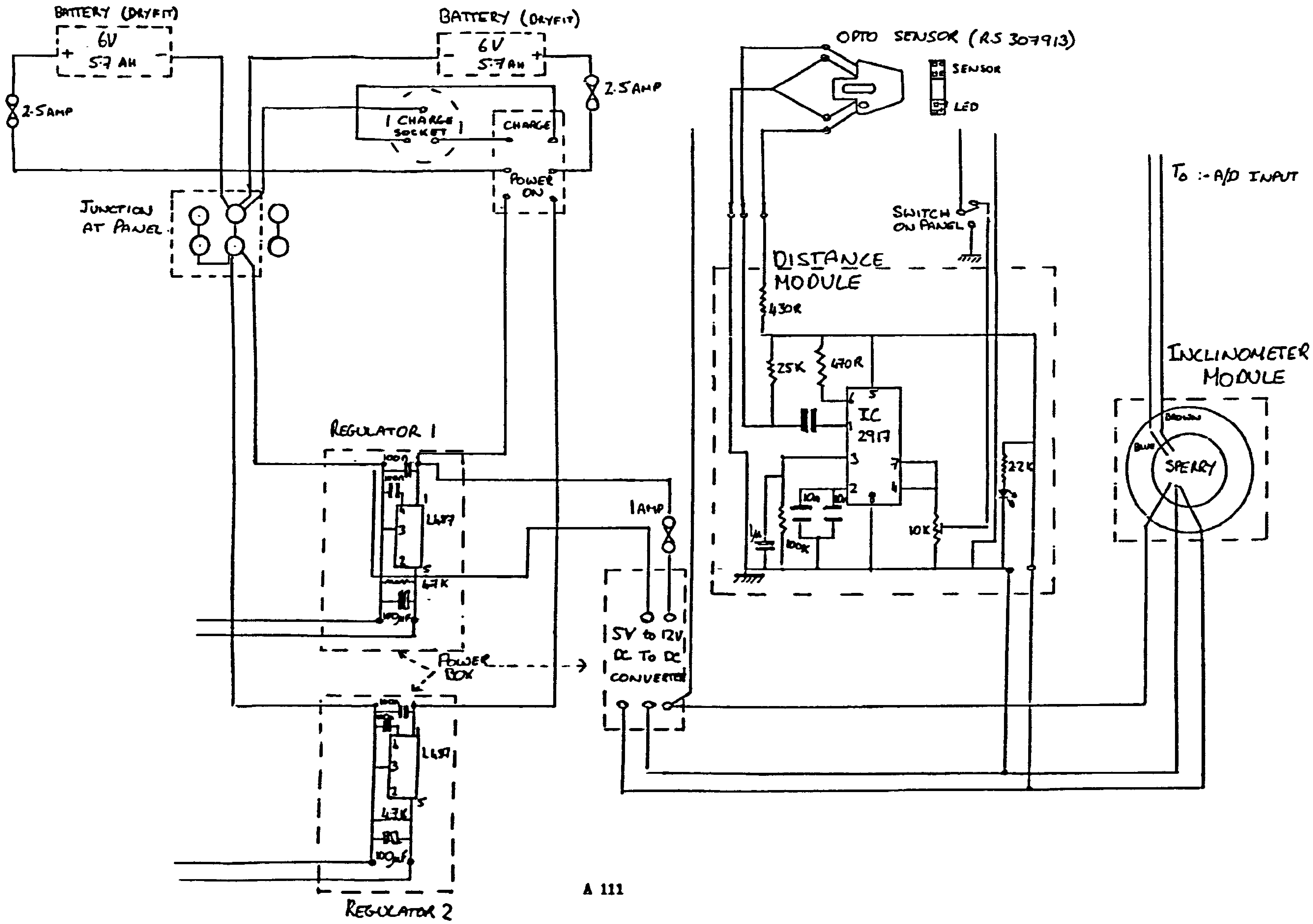
THE EQUIPMENT IN THE CAR

The data logger, the battery charger, and a BBC computer were carried in the car for the duration of the fieldwork in the islands. The trip was also used to collect information from islanders on their journey patterns and attitudes.

(Appendix 12 cont.)

CIRCUIT DIAGRAM OF DATA LOGGING SYSTEM

DISTANCE SENSOR - OPTO HEAD WITH ELECTRONICS (Opto -head Part No. RS-307-913)
INCLINOMETER SENSOR - "SPERRY" Part No. 02338-03



APPENDIX 13

BODIES INVOLVED IN EV RESEARCH IN BRITAIN

The main attempts at development of a viable electric vehicle in this country have already been described in chapter 1, but in addition to development efforts there is also a considerable amount of basic and applied research effort. The Electric Vehicle Association (EVA) is an association of companies and organisations whose common interest is the use of battery power for "moving things on wheels". Its purpose is to promote the interests of its members in the UK and overseas, and it facilitates the flow of information amongst its members and to other interested parties. One of their publications, "Trade Counter", lists the various organisations in its membership and their respective areas of expertise, production, testing, research and so on. The following additional list is not intended to be an exhaustive summary of current research but to provide a general background to and understanding of the situation in the UK with regards to research in the public sector.

1 UNIVERSITIES

Durham	Vehicle performance computer simulation Hybrid electric vehicles Testing laboratories Contract research
Warwick	Hybrid electric vehicles Disk motors
Leeds	Switched reluctance drives
Manchester	Hybrid electric vehicles (Report commissioned by SERC)
Swansea	Computer simulations Hybrid electric vehicles

Bristol Detailed technical aspects

2 ASSOCIATIONS AND RESEARCH BODIES

Electric Vehicle Association (EVA) - see above

Motor Industry Research Association (MIRA)
- contract research
- market research
- testing laboratories
- Vehicle design services

Electric Vehicle Development Group
- organisers of international conferences

Lead Development Association
- battery research
- metals advisory service.

Electrical Research Association (ERA)
- mainly monitoring role
- testing laboratories
- contract research
- market research
- electrochemical research
- truck efficiency testing

Transport and Road Research Laboratory
- energy consumption,
- refuelling infrastructures

Electricity Council
- monitoring of all aspects
- testing of electric vehicles
- development of sodium-sulphur battery
- electricity utilisation advice