THE TECHNOLOGICAL ECONOMICS OF COLLECTION AND LANDFILL DISPOSAL OF MUNICIPAL WASTE IN THE UNITED KINGDOM

by

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ABSTRACT

Accurate and detailed costs for individual municipal waste collection, treatment and landfill methods are not readily available. Neither is there a reliable means of comparing between two or more alternative options. However, before improvements to the management and planning of solid waste disposal can be achieved both are required. Currently, comparisons and planning in this field are highly ambiguous, often misleading, with individual operators using widely different accounting conventions and operating standards. The purpose of this work has been to establish accurate comparisons. Initially, detailed financial and technical information was collected from numerous operators, and then a standard basis for comparison (the "base case") was derived onto which the costs obtained were adjusted. Cost functions were also generated to interpret component costs for a range of sizes of operation.

The economics of five collection methods, four transfer methods, seven bulk transport vehicle types and several landfill disposal variations are considered. For each a detailed appraisal of the component capital and operating costs has been made so as to identify the largest expenditures. The effect of uncertainty on cost estimates was also emphasised and explicitly considered by sensitivity analyses on selected economic and physical parameters. These analyses have indicated those component costs which exert the most significant influence on the total costs, and as such should be the most closely monitored by a waste manager. One notable example is the sensitivity of total landfill costs to leachate treatment.

Six case studies are also presented. These are designed to demonstrate the versatility of the cost models derived and also the method developed for unambiguous economic comparison.

This research provides a large financial data base on all of the collection, transfer and landfill methods in common use in Britain. Use of this information and the principles for comparison put forward would enable waste managers to incorporate sound financial appraisals into both their operational and forward planning decisions. This should subsequently improve not only the quality of their decisions but ultimately the standard of service they offer too.

PHILIP RUSHBROOK April 1984

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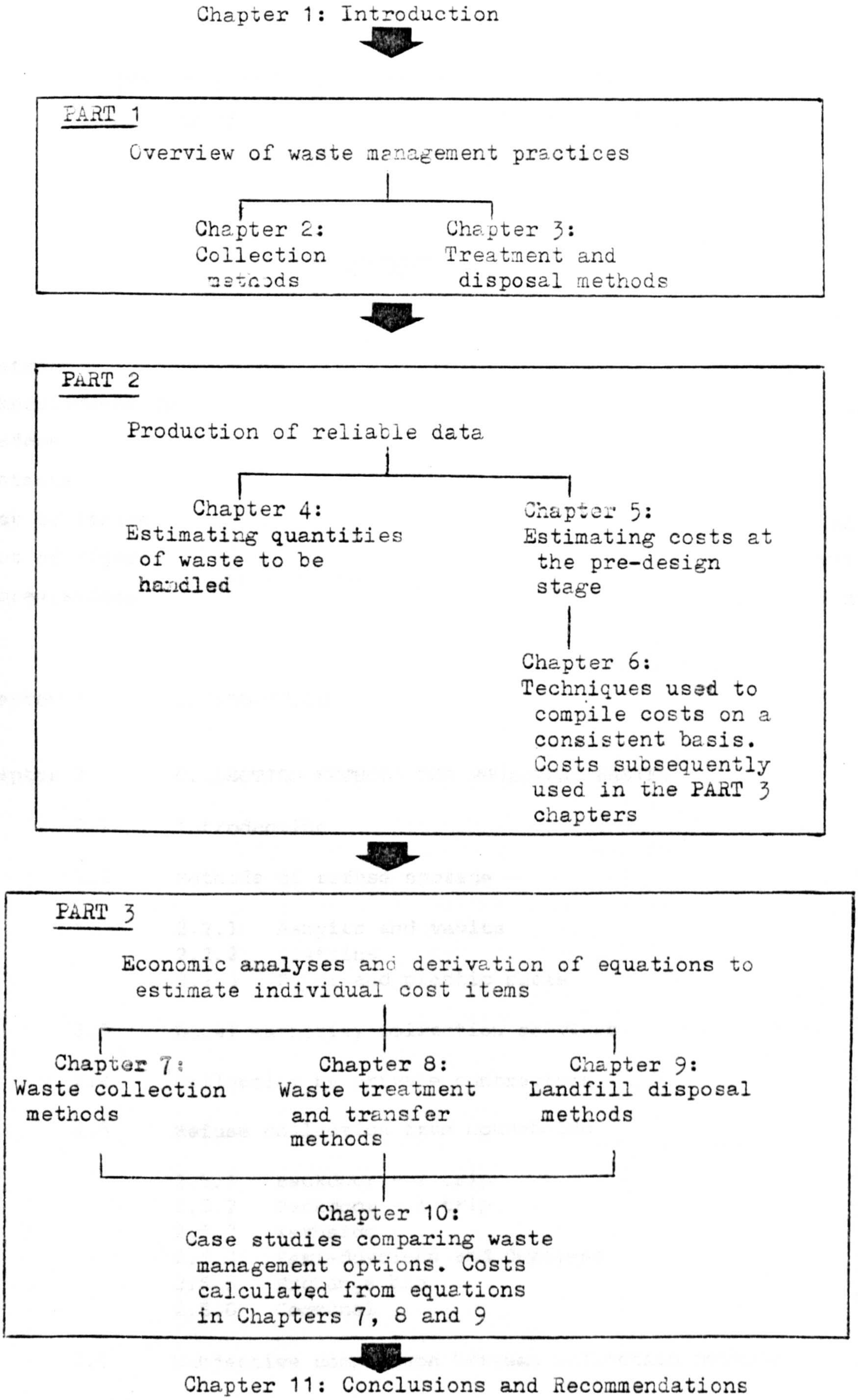
Preface

With the exception of the introductory and concluding chapters (Chapters 1 and 11 respectively) the remainder of this thesis has been divided into three distinct, but sequential parts. Part 1, incorporating Chapters 2 and 3, presents an overview of current waste management practices in the United Kingdom. It represents the collation of published information from an extensive literature review and the experiences of many waste managers interviewed during the course of this project.

Part 2, incorporating Chapters 4, 5 and 6, emphasizes the need for consistent data before reliable comparisons can be made in waste management. Chapter 4 outlines the problems in estimating waste tonneages and also presented is a new methodology for their calculation. Chapters 5 and 6 consider the existing methods for estimating costs and identifies a number of shortcomings. Also presented are two improved estimation techniques derived directly from the extensive cost data collected from approximately 50 local authorities. The first is useful in estimating costs before design work commences and the second provides detailed costs for use with planned operations at the design stage or the economic examination of existing ones.

Part 3 incorporates Chapters 7, 8, 9 and 10. The first three discuss the economic information gathered from local authorities, highlight the most significant financial outlays and derive cost equations to calculate individual items of expenditure. Collection costs are considered in Chapter 7, transfer and treatment costs in Chapter 8, and landfill costs in Chapter 9. Illustrative studies are presented in Chapter 10 demonstrating the use of the cost equations in waste management planning.

The diagram overleaf will be reproduced at the beginning of each chapter to remind the reader of the underlying structure to this thesis.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PART 2
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Chapter 5: Estimating costs at the pre-design stage
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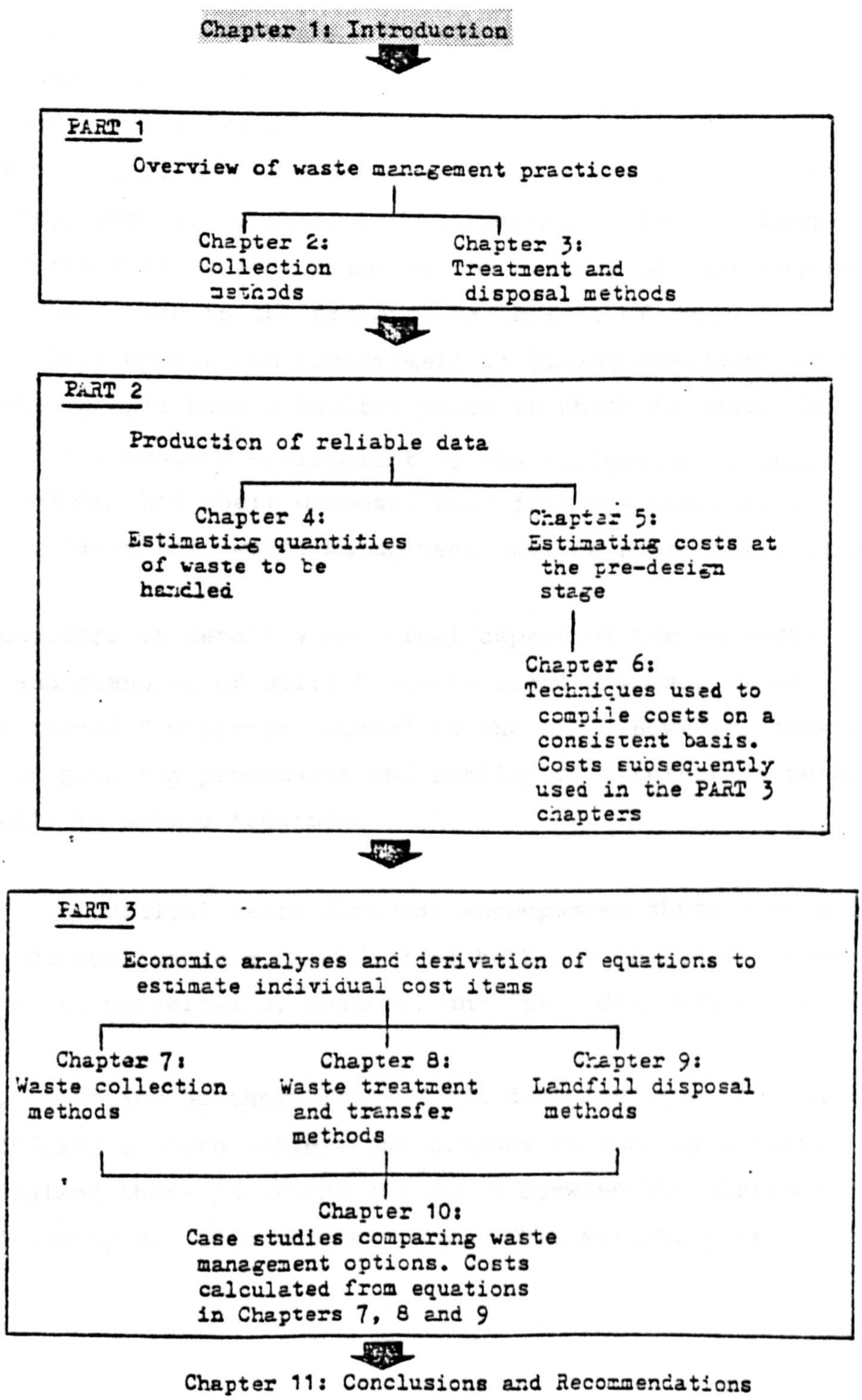
ABBREVIATIONS

Abbreviations used frequently in this thesis:

APWA	American Public Works Association
ASWS	Americal Solid Waste Systems
BC	Borough Council
CBA	Cost-Benefit Analysis
CC	County Council
CI	Confidence interval
CIPFA	Chartered Institute of Public and Finance Accountants
DC	District Council
DCF	Discounted Cash Flow
DOE	Department of the Environment (UK)
EPA	Environmental Protection Agency (USA)
INCPEN	Industry Committee on Packaging and the Environment
IWM	Institute of Wastes Management
kPa	kilo Pascal (unit of pressure)
LBC	London Borough Council
LAMSAC	Local Authorities Management Services Association
LGORU	Local Government Operational Research Unit
NCRR	National Center for Resource Recovery (USA)
NPC	Net Present Cost
NPV	Net Present Value
RDF	Refuse derived fuel
Rs	Relative sensitivity
SD	Standard deviation
t/d	tonnes per day
t/hr	tonnes per hour
t/r/y	tonnes per round per year
t/y	tonnes per year

CHAPTER 1

INTRODUCTION



Chapter 1

The production and consumption of any product results in the creation of residual materials not of immediate use at the place they arise. These are subsequently discarded as "waste". The organised collection and disposal of these wastes is fundamental to the development of a civilised society. Without organisation the ensuing squalor stifles all but the most primitive of life-styles. Consequently, wherever a population begins to concentrate in one locality, removal of their wastes becomes a major problem. Indeed, the first visible indication of the quality of life enjoyed by a town's inhabitants is the presence or absence of rubbish in the streets. Development and improvement in living standards only comes about when people have a healthy place in which to live. An integral part of a healthy environment is the collection of solid wastes and sewage, and their disposal away from the population centres. To achieve this waste management must be effectively planned.

This work considers in detail a principal aspect of the subject, the costing and planning of solid domestic waste disposal (more specifically termed " municipal waste" in the UK). However, general discussions on planning procedures and costing of alternative methods will also apply to sewage treatment.

The planning of municipal waste disposal encompasses three distinct operations: collection (e.g. backdoor or kerbside methods); treatment (e.g. compaction, pulverising, baling); and final disposal to landfill.

In Scotland, Wales and Northern Ireland the district councils have the responsibility to both collect and dispose of municipal waste, whereas in England these functions are split between the district councils and county councils respectively. This situation is a result of the 1974 local government reorganisation. The responsibility within an authority for the management of collection and disposal operations and the importance attached to it varies widely between authorities. In some, waste management is given equal status to departments such as Housing or Highways, while elsewhere it is treated as a "Cinderella" service and administered by a more junior official.

Responsible officials in different authorities include: Directors of Environmental Health, Directors of Technical Services, Cleansing Managers, Transport Managers, Waste Disposal and Waste Collection Officers. A further complexity inhibiting efficient waste management is that different individuals, often in different departments, deal with the operational and financial aspects respectively. Such confusion results nationally in wide variations in the resources allocated to collection and disposal and to the operational standards achieved.

The aims of the work undertaken are three-fold:

First, to bring together operational details of the most commonly used collection, treatment and landfill disposal techniques in the UK.

Second, to elucidate in detail the costs of each method. It should be appreciated that these costs, obtained for individual operations or landfills, are compiled using different conventions and direct comparisons are thus extremely ambiguous.

Third, to put the financial data collected onto a consistent basis. This overcomes the anomalies of individual operators using different accounting conventions, and provides reliable data for waste managers to make accurate comparisons between alternative methods. Economic comparisons can be made at several stages in the selection process and the subsequent design of the preferred option. The first economic evaluation undertaken would be to derive broad cost estimates ("pre-design" costs) for a number of suggested alternatives. This provides "order of magnitude" costs from which a smaller number of feasible options are identified. The second economic evaluation would be a more detailed costing exercise ("preliminary design" costs) carried out on the favoured alternatives established in the first evaluation. The final selection would no doubt take into account other, non-financial, considerations such as operational, social and environmental aspects of the proposed plan. The third evaluation undertaken at the "detailed design" stage would be the preparation of comprehensive cost estimates on larger items of capital and annual expenditures.

Managers rarely, if ever, possess operational experience or in-house financial details for all available alternative options. Consequently this study provides reliable methods of estimating the financial information they lack and presents a means of comparing alternatives on a standard basis. Without reliable economic data a manager's ability to prudently manage his/her existing operations and to select new ones is severely hampered.

Costs in this study have been derived predominantly for smaller disposal operations, below around 500t/d. A large proportion of treatment and landfill operations in Britain fall into this category although most economic research has been conducted on larger plants. This work consequently addresses an area of wide importance in waste management that has been neglected in earlier studies.

The Chapters of this thesis are laid out to develop sequentially the aims described above.

An extensive literature review (Chapters 2 and 3) has been conducted drawing from a broad range of technical and operational information relating to collection, waste treatment (specifically compaction, pulverisation and baling) and landfill disposal. This provides a comprehensive summary of the principal techniques available, together with their merits and disadvantages.

Landfill is the only disposal option considered in this work. It is the ultimate method of final disposal, since all of the other "disposal" and recovery methods, such as composting, incineration or refuse-derived fuel produce residues requiring landfilling. Constructive discussion on the relative merits of alternative methods of disposal are limited by the lack of understanding of the economics of landfill. It is therefore a purpose of this work to improve this understanding and to determine the effects produced by the many interacting variables on the constituent landfilling costs.

It became apparent during the course of the research that reliable estimates of the quantities of refuse handled are often not available. As a result the published literature contains many examples of plants being designed too large or too small for the quantity of waste arising. To remedy this situation a model has been developed (Chapter 4) which should prove attractive to waste managers. It produces accurate estimates of tonneages from only a very small, but representative, number of vehicle weighings.

Researchers in the waste management field have also recognised the ambiguities inherent in directly comparing the costs of collection, treatment or disposal alternatives using figures supplied by several operators. Significant variations in plant design, operating standards and site-specific expenditures frequently exist between operations, consequently producing highly dubious comparisons. Several methodologies and formulae have been proposed by other authors and these are discussed in Chapter 5. These are collectively known as "cost estimation techniques" and can be of use in some planning applications when pre-design costs are required to express a broad distinction between methods. Several shortcomings are highlighted in the published cost estimating formulae when applied to waste management, notably:

1. Many of the techniques are based on financial data not directly related to solid waste management.

2. Most ignore the fact that the original data used in their derivation originates from several sources, each compiled according to different costing conventions.

3. Many are based on very small sample sizes or calculate generalised values from operations ranging widely in size with no regard to economies of scale.

Consequently, several revised techniques are proposed based on the data gathered in this research.

As a practical development from cost estimation techniques the principal aim of the later stages of this work has been to derive more accurate and detailed component costs for each method, all on a standard basis for comparison (Chapter 6). To overcome the problem of small sample sizes data was gathered from over 50 authorities in the UK. From each authority detailed information was collected on both the technical and financial aspects of each operation they administer. By knowing the operational standards and plant designs of each operation, it was then possible to establish a standard basis onto which the costs from individual operations were adjusted. This standard basis is known as the "base case". In addition, different sizes of operation were analysed separately and cost functions established over a range of daily tonneages so that costs would be estimated for the intermediate sizes of plant. Further refinements were made for collection methods where a distinction was identified between the costs incurred in rural and urban operations.

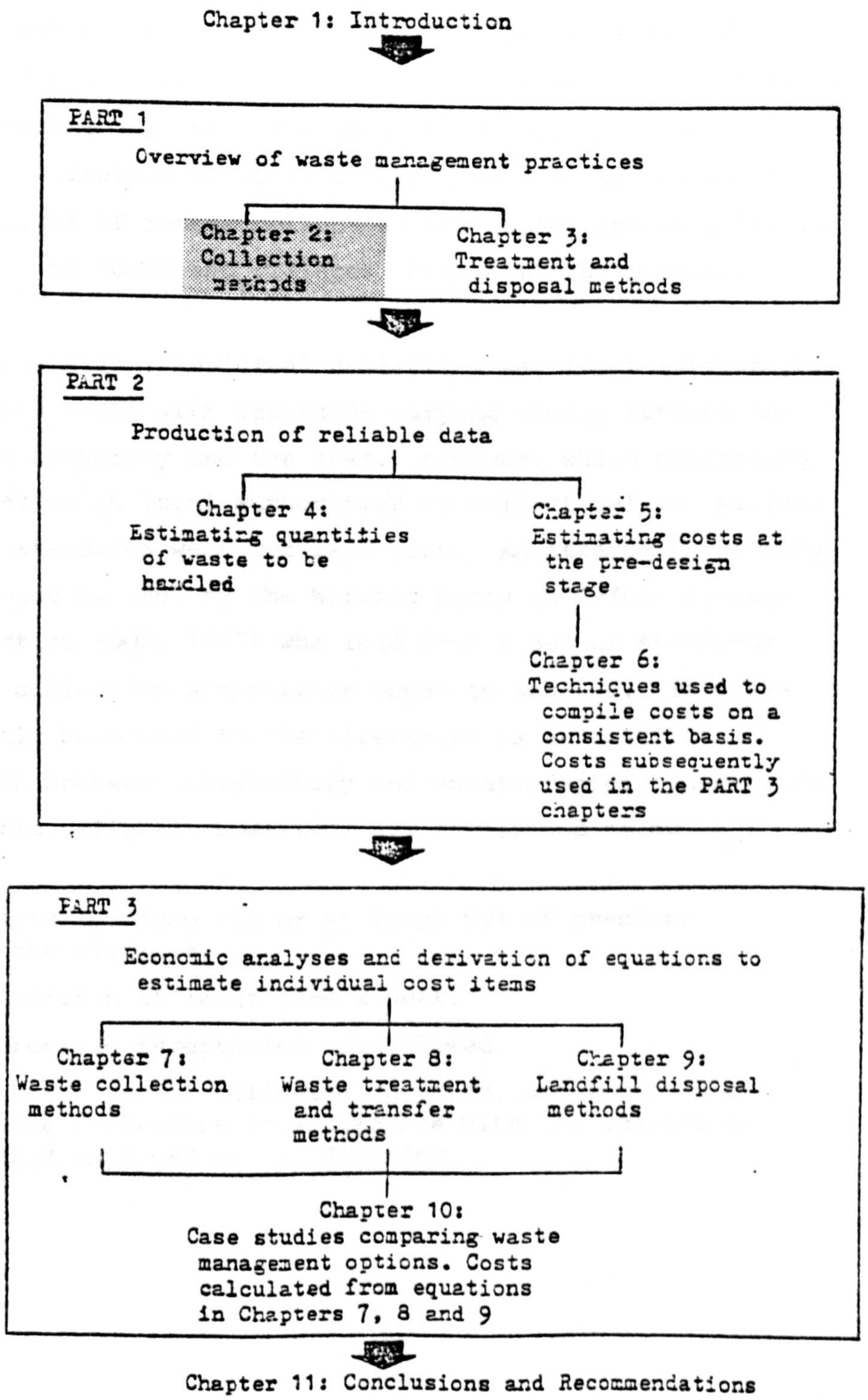
The practical use of this work to a waste manager is immense. Detailed discussions on individual capital and operating costs for each collection, transfer and landfill option are presented in Chapters 7, 8 and 9 respectively. Those component costs that dominate each method have been identified and some interesting results have been found. Cost models are also presented to provide cost estimates over a range of sizes of operations. In any economic evaluation uncertainty will always exist and accordingly several sensitivity analyses were undertaken in these chapters on selected costs and physical parameters.

Six hypothetical case studies are presented in Chapter 10 designed to demonstrate the versatility of the cost models developed. They also indicate the types of economic evaluation it is possible for waste managers to undertake which would enable them to more effectively plan and manage their operations.

In the planning of new operations or the modification of existing ones the economics of each feasible alternative is only one aspect in the selection of the most suitable method. The decision process also includes the assessment of inter-related operational, political and environmental considerations. Too often in waste management the economic aspect of a decision is given only cursory attention, the others being judged as over-riding. Frequently it is only after a method has been chosen that serious investigations into the economic implications are made. This is a poor reflection on management in the UK. Economic evaluations should form an integral part of the planning process at an early stage, with a subsequent appraisal of intangibles, before the final decision is made. This work can make a significant contribution towards a more systematic approach to decision-making in which proper financial appraisals are made.

CHAPTER 2

COLLECTION METHODS FOR MUNICIPAL WASTES



Chapter 2

2.1 INTRODUCTION

Municipal refuse collection incorporates the removal and carriage of wastes from their place of generation to a disposal site or treatment plant. The service is undertaken as a statutory obligation on local authorities and has led to the familiar sight of refuse collectors and collection vehicles in the streets of towns and villages throughout the country.

Before legislation, municipal collection was in an extremely disorganised state with standards varying widely between one collection authority and the next. However, while conferring the obligation on local authorities to collect refuse, minimum operating standards were not laid down. An attempt to rectify this was made in 1967 by the Working Party on Refuse Storage and Collection (DOE, 1967) who laid down a set of standards they felt collection authorities ought to achieve. This has subsequently been used in the literature as a "test" to distinguish between satisfactory and unsatisfactory operations. The criteria, slightly modified, are summarised below:

1. Collection from all or at least 99% of premises in the district.
2. Collection at least once a week.
3. Improvised receptacles not allowed.
4. Bins (or sacks) collected, emptied, and returned by refuse collectors in accordance with the collection method employed by the district.

5. Bulky household refuse collected free.

6. Provisions for commercial and garden waste collections.

7. The vehicle fleet should be composed of compacting vehicles for domestic, garden, and some commercial collections, and non-compacting vehicles for bulky waste.

Within a "satisfactory" operation wide differences in practice can still occur between authorities. Variations notably occur in the methods of storage employed prior to collection. Some authorities issue dustbins to householders, while others require householders to provide a bin themselves. The main problem with bins is not the type used but with the lack of subsequent maintenance. A standard metal dustbin has a life of approximately 8-10 years although many remain in use long after this period. As an alternative some authorities use plastic or paper sack collection schemes. The sacks are issued to householders and once filled are removed and replaced with a new one.

Differences also occur in the methods of collection from households. Several systems are available and each of which has a different influence on the financial and operational aspects of manning levels, working efficiency and vehicle utilisation. The alternative methods can be classified as:

i) backdoor pick-up and return or some variant requiring participation by the householder
ii) kerbside collection
iii) exchange bin schemes
iv) bulk or communal (end-of-street) collection

Once the refuse has been collected there are a variety of vehicles into which it can be loaded, usually incorporating onboard compaction to improve payloads. Refuse containers are manually or mechanically emptied into side, front, or rear-end loading vehicles with a range of capacities to cope with any tonneage of refuse that is likely to be lifted during a collection round.

In the developed countries, including Britain, collection accounts for approximately 75% of the total cost of removing domestic refuse (Society of County Treasurers, 1979; Payne, 1975), but has received a great deal less scientific and technical study than the disposal aspects of waste management. Several reasons have contributed to this situation. Firstly, since disposal is a "point operation", it is more readily defined and easier to study than collection. Secondly, collection processes differ significantly from disposal. In the latter, physical, biological and chemical phenomena take place over many weeks or months. Collection, by contrast, is a more transient and short-term operation and some scientific disciplines may not appear to be easily transferrable. Thirdly, the area has become entrenched in "Work Study" principles or other quasi-optimisation techniques and researchers may have become blinkered into considering that this is the only topic in collection there is to study. Other possible collection-related research topics involving other disciplines are suggested in Appendix 2A.

The quantities and types of municipal waste are changing. The general rise in population and affluence have both increased the total quantity produced. Furthermore, the composition of refuse has undergone a significant change over the last few decades. A reduction in ash content (i.e. the switch from solid fuel to oil, electricity and gas for cooking and heating) and an increase in paper and plastics (due to the rapid expansion in the packaging of goods and the decline in open fires) have served to decrease the overall density of refuse and correspondingly increase the volume to be handled. (Table 2.1; Figures 2.1 and 2.2).

2.2 METHODS OF REFUSE STORAGE

The householder is responsible for the refuse he produced until it is collected and thus some means of acceptable temporary storage is generally required. "Continuous" removal methods based on water or air pipelines are not widely available and are not considered further in this work.

Table 2.1 A SUMMARY OF NATIONAL ANALYSES FOR HOUSEHOLD WASTE COMPOSITION BETWEEN 1935 and 1980* (% by weight)

Source/year

	Constituent (% by weight)	a 1935	b 1955	b 1960	a 1963	c 1965	a 1967	a 1968	a 1969	a 1970	a 1972	a 1973	a 1974	a 1975	a 1976	a 1977	a 1978	a 1979	a 1980
	Dust (<1.5cm)	39	45	43	28	24	22	17)	17	15	20	19	20	18	19	14	11	12	14
	Cinder (>1.5-5cm)	18	8	8	10	12	8	5)											
	Vegetable & Putrescible	13	12	12	14	17	16	18	20	25	20	18	21	20	19	25	29	24	25
	Paper & Cardboard	15	15	16	23	23	30	37	38	37	31	33	27	30	24	26	27	29	29
	Metal	4	6	6	8	7	8	9	10	9	8	9	8	8	8	9	7	8	8
	Textiles	2	2	3	3	3	2	2	2	2	3	3	4	3	4	3	4	4	3
	Glass	3	6	6	9	8	8	9	10	9	10	10	10	9	9	11	9	10	10
	Plastics	-	-	-	-	0.75	1	1	1.5	1.4	2	2	3	4	5	5	5	7	7
	Unclassified	6	6	6	5	5.25	5	2	1.5	1.6	6	6	7	8	13	7	8	6	4
1. 2.	Density / House of 3/ week (Kg/m^3)	318	272	259	200	186	160	157	143	146	153	152	161	164	152	126	141	141	147
	Volume / House of 3/ week (m^3)	0.065	0.054	0.057	0.069	0.065	0.079	0.083	0.090	0.092	0.076	0.076	0.066	0.073	0.067	0.080	0.077	0.078	0.076
3	Yield weight / House of 3/ week (Kg)	17.0	15	14.5	14.1	12	13.0	13.3	12.8	13.5	11.7	11.6	10.7	11.6	10.2	10.1	10.9	11.0	11.2

Sources: a - DOE (Private Communication) 1982; b - Flintoff and Millard, 1969; c - Higginson, 1965.

Notes: 1. Generally decreasing up to 1980.
2. The quantity of waste produced by a "household" is assessed for three occupants.
3. Yield: HIGH - 1935 - 1955; LOWER - 1963 - 1968; 1968 - 1980. Due to large quantities of ash. Since many homes switched to other fuel sources the yield of refuse generation is probably influenced by the overall increase in affluence and further decreasing density. It appears that since the early 1970s and contrary to earlier estimates the paper content has significantly decreased while the % of plastics has dramatically risen.

* The composition of refuse can vary widely between regions. Those national average values should only be used for the identification of major trends rather than detailed local purposes.

Fig 2.1 Density and volume changes in UK municipal refuse between 1935 and 1980.

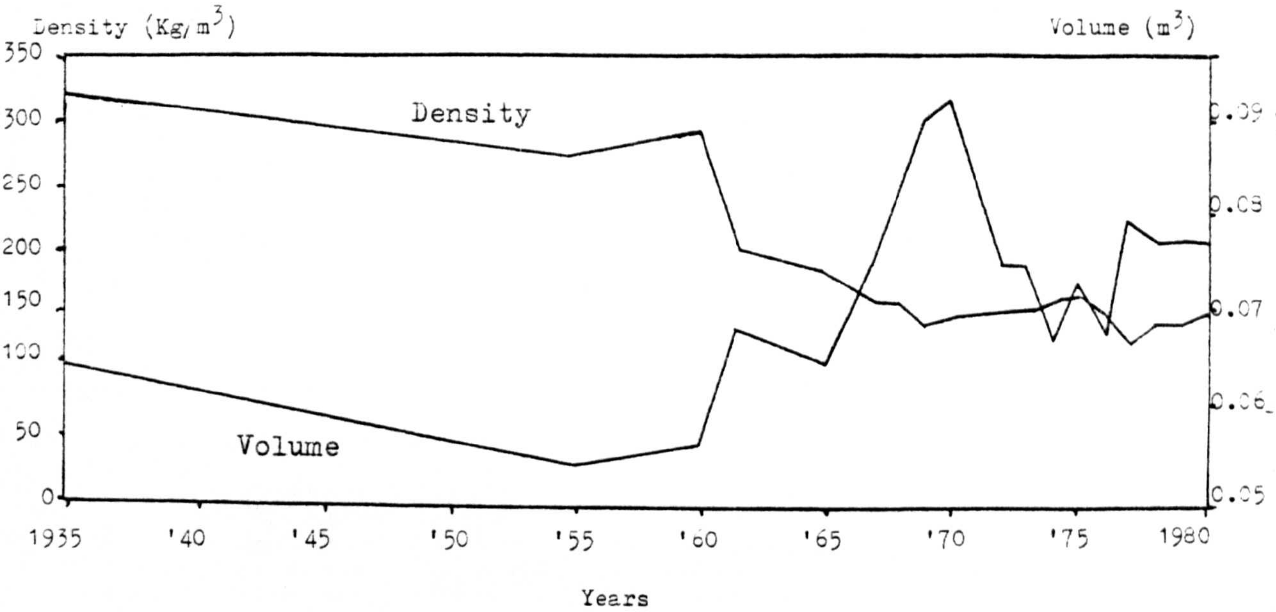
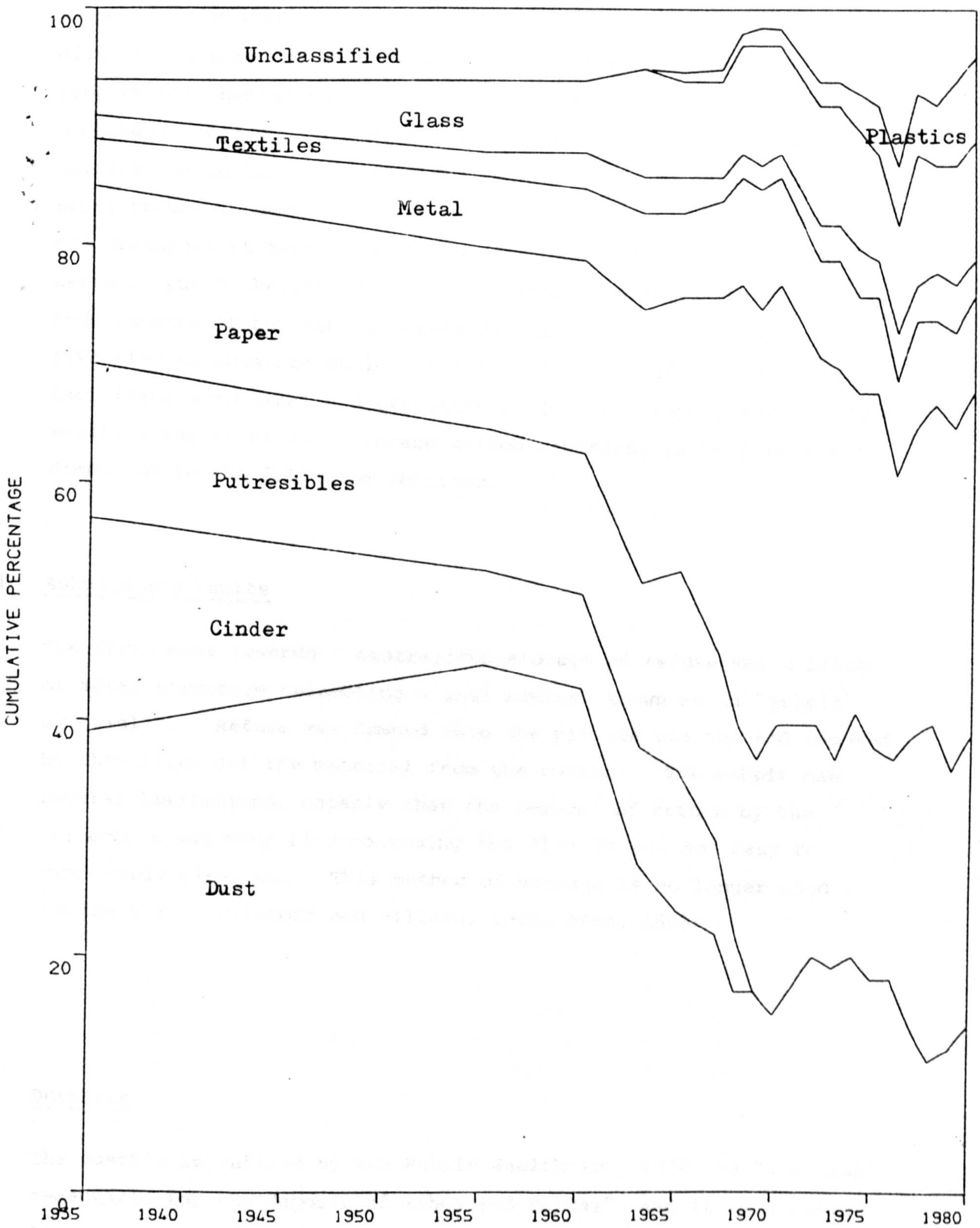


Fig 2.2 Composition of municipal refuse between 1935 and 1980 (Source;Table 2.1).



The storage of refuse has always created problems to man and the situation grew steadily more acute when urban areas began to develop. In former times rubbish was literally thrown into the streets indiscriminately or buried in a rubbish hole behind the house. These practices continued virtually unchanged until the Nineteenth century when eventually the householders and authorities perceived that it would be healthier to store refuse in one place at each house, then periodically collect and transport it away to a distant disposal site. Large improvements in public health were achieved from this development. The requirements of any storage place are that its contents should not give rise to nuisance while awaiting collection (DOE, 1967), and facilitate economical and effective collection (Payne, 1975). The relative merits of each storage method regarding these points are discussed in the following sections.

2.2.1 Ashpits and Vaults

The first move towards centralised storage of refuse was a brick or metal structure resembling a coal bunker, known as an "ashpit" or "vault". Refuse was dumped into the pit via the top and removed by shovelling out the material from the bottom. The ashpit has several limitations, notably that the removal of refuse by the collectors was very time-consuming and that it was not easy to completely clear out. This method of storage is no longer used in the U.K. (Flintoff and Millard, 1969; APWA, 1966).

2.2.2 Dustbins

The dustbin is defined by the Public Health Act, 1936, as "a moveable receptacle for the deposit of ashes and refuse", and it is a definition which also applies to paper and plastic sacks, with the exception that they are unsuitable of hot wastes.

The "mobile" dustbin developed as a natural progression from the ashpit method. It brought both a reduction in unit collection cost by speeding up the collection time per house and improved the environmental aspects of storage.

Dustbins can be constructed in galvanised steel, rigid plastic or rubber and are typically found in two standard sizes: $0.07m^3$ and $0.09m^3$ by volume. At present the "average" household is estimated to produce just under $0.08m^3$ of refuse per week. Bins larger than these are unwieldy for manual handling unless on wheels. Consequently either additional bins of standard size are supplied or the density is artificially increased by pushing down the contents. Uncompacted refuse in a bin has an approximate density of 0.05 to 0.08 t/m^3 (Flintoff and Millard, 1969) which can be subsequently increased to between 0.13 and 0.17 t/m^3 (DOE, 1967) by manually packing down. Furthermore, the bin size and number can vary with frequency of collection. For twice weekly collections the small size bin can be used satisfactorily while for once weekly collections the larger size is more suitable.

Not all authorities supply bins and consequently improvised containers have been used in the past. These awkward or overweight containers tend to slow collection and have been known to injure collectors. In the UK there are measures, enacted as national or local bye-laws, to standardise the bin size and refuse storage; these include:

1. Requiring householders to only use the bins supplied.
2. Requiring householders to supply and use only bins of specified standards (commonly conforming to the appropriate British Standards).
3. Prohibiting certain materials to be put into bins.
4. Setting a limit on the number of bins an authority will collect from a household without additional charge.

The DOE (1967) Working Party on Storage recommended that to overcome the vagaries of storing refuse all local authorities should supply a suitable bin to each household in their district financed by the general rate. This approach has several advantages over the hiring of bins or purchase by the householder as outlined by Flintoff and Millard (1969):

1. Collection efficiency.

   Collectors work faster when dealing with standard bins and fewer accidents are likely to arise. Bin replacement can be made quickly.

2. Hygienic storage.

   Maintenance of bins is more satisfactory when this is the responsibility of one body.

3. Administrative efficiency.

   The cost of administration is only a small proportion of that under a hire scheme or that required to serve statutory policies compelling householders to purchase bins.

Some authorities still do not conform to the recommendations of the Working Party while others have switched to sack collection which in themselves are a form of standardisation. Common criticisms of steel dustbins are that they are fairly heavy and extremely noisy when being emptied, difficult to thoroughly clean, corrode when left outdoors, and can become damaged due to mishandling. High density polyethylene and polypropylene bins do not suffer from these problems and several authorities have switched to these containers. Their apparent disadvantages are that they are unstable in windy weather when empty and cannot accept hot ashes, but with the trend away from open fires to central heating this latter problem is limited.

A variation on the standard bin with the detachable lid is the dustless loading bin. This has a hinged lid and is designed for use with mechanically operated loading equipment mounted on the back of collection vehicles. All other dimensions and characteristics of these bins are similar to the standard ones.

Multi-storey buildings use larger communal storage, one common type being "Paladins" equal in volume to ten standard 0.09m^3 bins. These are loaded by refuse chutes or direct by the residents and are wheel - mounted for easy transport to and from the collection vehicle. Loading into the vehicle is by mechanical loading equipment and is a form of "dustless loading". At least one authority in Scotland has found that there are significant savings in operating costs with this form of bulk container as opposed to a similar number of standard bins and are promoting their use wherever practicable (Dagg, pers. comm., 1980).

2.2.3 Paper and Plastic Sacks

The most recent development in refuse storage is the use of disposable paper and plastic sacks which are replaced by a new one when the refuse is collected. The sack is held by a free-standing or wall-mounted holder either indoors or outside at the back of the house. Paper sacks were first introduced in Sweden and have since gained popularity in Europe and North America. Most are made from one- or two-ply Kraft paper and can withstand bad weather between collections even if left continually outside.

Plastic sacks are not yet governed by a British Standard but in general they are made from medium or high density polyethylene, commonly black in colour, and used in the same way as paper sacks. Both types of sack have a volume of 0.1m^3, similar to the 0.09m^3 dustbins. The main advantages and disadvantages of sack collection schemes over bins are outlined below (modified from the DOE Working Party on Refuse Storage and Collection, 1967).

Advantages:

1. Clean and hygienic.
2. Very little noise when collected, and lightweight.
3. Less physical strain on the refuse collector.
4. Reduction in unit collection time (12% according to Payne, 1975).
5. Dustless or near dustless loading without the need for special loading devices.

6. Problems arising from collection delays minimised by issue of spare sacks.
7. Less wear and tear on vehicles during loading.
8. Elimination of complaints which occur with the use of bins, e.g. damage to paths, fences and gates, return of bins to the wrong house, with the wrong lids or without lids at all.
9. Refuse is not exposed to public sight.

Disadvantages:

1. Increase in total collection costs compared with most of the traditional systems, especially where householders require more than one sack or collections are more than once a week.
2. There is a risk of bursting the sack if the householder tries to compress the refuse within to make room for more.
3. Misappropriation of sacks.
4. Potential risk of sack failure from moisture (paper sack), broken glass, tins, hot ashes, animals, strong wind, or through production faults.
5. Authority dependant upon the continuity of the supply of sacks from an external source.
6. Possible injury to children or collectors from sharp, protruding objects.

With the recent rises in oil prices, plastic sacks have become more expensive and also the increasing cost of wood pulp has led to an even larger rise in the price of paper sacks. Consequently the cost of supplying sacks is a major expenditure to consider when comparing between sack and dustbin refuse storage methods.

2.3 LOCAL AUTHORITY COLLECTION SERVICES

The range of collection services offered by local authorities varies widely. While only domestic refuse collection is required by law, other collections are undertaken to provide a comprehensive range of services to the ratepayer. This is not only politically desirable but in practical terms reduces the quantity of waste discarded indiscriminately.

Urban and rural authorities collect domestic refuse from individual households and multi-storey dwellings "free of charge" (i.e. no additional cost is levied over the general rate). Other services also provided without additional charge are street sweeping, clearance of litter bins and municipal waste paper collections, although the latter are declining in number.

Further collection services are offered by virtually all local authorities though in some cases a charge is made. The levying of a reasonable charge is within the terms of the 1974 Control of Pollution Act. Those services where this may occur include bulky refuse collection, garden refuse (often collected with the domestic refuse) and commercial wastes (i.e. shops, offices and hospitals). Commercial premises are often serviced on a daily basis with charges sometimes made for the whole service, or the number of bins over the first one or two emptied.

Each collection service has quite distinctive economics. The scope of this work concentrates on domestic refuse collection although some quantities of garden and commercial wastes are also included where they are ordinarily collected on a domestic round.

2.4 COLLECTION BY PRIVATE CONTRACTORS

There has been a trend recently to consider, and in some cases opt for, collection services undertaken by private contractor. In many authorities the council workforce has become very powerful through the development of an organised and often inflexible trade union. Many restrictive practices exist such as: fixed manning levels, outdated bonus schemes, intolerance to productivity improvements, and high wage claims. All serve to increase the total cost of local authority collection.

The current economic and political climate in the UK has made conditions conducive for councils to appraise the cost of their collection operations against tenders from private contractors. However, the actual collection services contracted out vary widely. For example, some such as Southend

Borough Council have contracted out the entire cleansing operation with the contractor undertaking residential, commercial and bulky waste collections together with street cleaning and public conveniences; while others such as North Norfolk District Council, have only contracted out residential collection.

Where an authority has "gone private" the former restrictive practices are immediately removed and there are accounts of cost savings in the short-term. Southend BC estimates a saving of 20% per annum. However, this value is contested by some of Southend's own councillors. Apparently £278,000 of administration charges previously levied on the collection service and still incurred, were re-distributed over other departments. This sum was subsequently not considered in the savings estimate above (Hinchliffe, 1982).

By removing restrictive practices contractors will almost certainly achieve cost savings through better vehicle utilization and staff efficiency. Consequently fewer men and vehicles will be required to collect an area's waste. As a result fixed costs are reduced probably to a greater extent than any increase in variable costs, such as vehicle running expenses and staff overtime.

Unfortunately, public and private sector comparisons do not always compare like with like. Contractors often tender to provide a service which differs from that currently undertaken. To avoid ambiguity these tenders should only be compared against a local authority estimate for operating a similar level of service.

In the longer term several issues have been raised which suggest that savings achieved by an authority may not continue. One argument is that a local authority once it has contracted out the collection services will invariably have sold its collection fleet to the contractor and entered into a three to five year contract. At the end of this period the contract will be due for renewal, with no collection fleet of its own and the untransferrable legal obligation to collect refuse the authority could conceivably be in a poor bargaining position. The influence of fleet replacement costs must also be considered, particularly if only the former authority vehicles were used in the first contract period. An additional question of a contractor going bankrupt and the authority's legal requirement to maintain collections has still to be resolved. The trade unions argue that private companies are tendering at uncompetitive levels for the first contract period in order to make authorities dependant upon them, after which the short-term savings will be "repaid several times over" (Hutson, 1982). There is no evidence to support or deny this claim.

Some authorities (for example Rochford BC, Bracknell BC and Wandsworth LBC) have maintained their control over the collection operations by using the threat of "privatisation" to persuade the direct labour force to make productivity improvements and the desired financial savings.

Private collection will certainly increase throughout the UK over the next few years. It will most likely be centred on urban areas where a large number of waste producers are concentrated within a small area. As a result elements of the total operating cost are likely to be much lower than for rural authorities of similar size which are obliged to maintain country rounds, i.e. in areas of lower population density requiring longer hauls and probably smaller daily payloads. In the USA 61% of domestic refuse is collected by private firms and only 34% by municipal authorities (National Solid Wastes Management Association, 1970). The private companies are however noticeably concentrated in the cities and large towns.

2.5 REFUSE COLLECTION FROM HOUSEHOLDS

Currently six principal methods of collection are available in the UK and are classified subjectively according to their variation in handling requirements at each household. The methods are:

1. Backdoor - 2 trip.
2. Backdoor - 1 trip.
3. Kerbside.
4. Dustless techniques.
5. Exchange bin; and
6. Communal containers.

Within some of these methods above several operational variants exist (Figure 2.3).

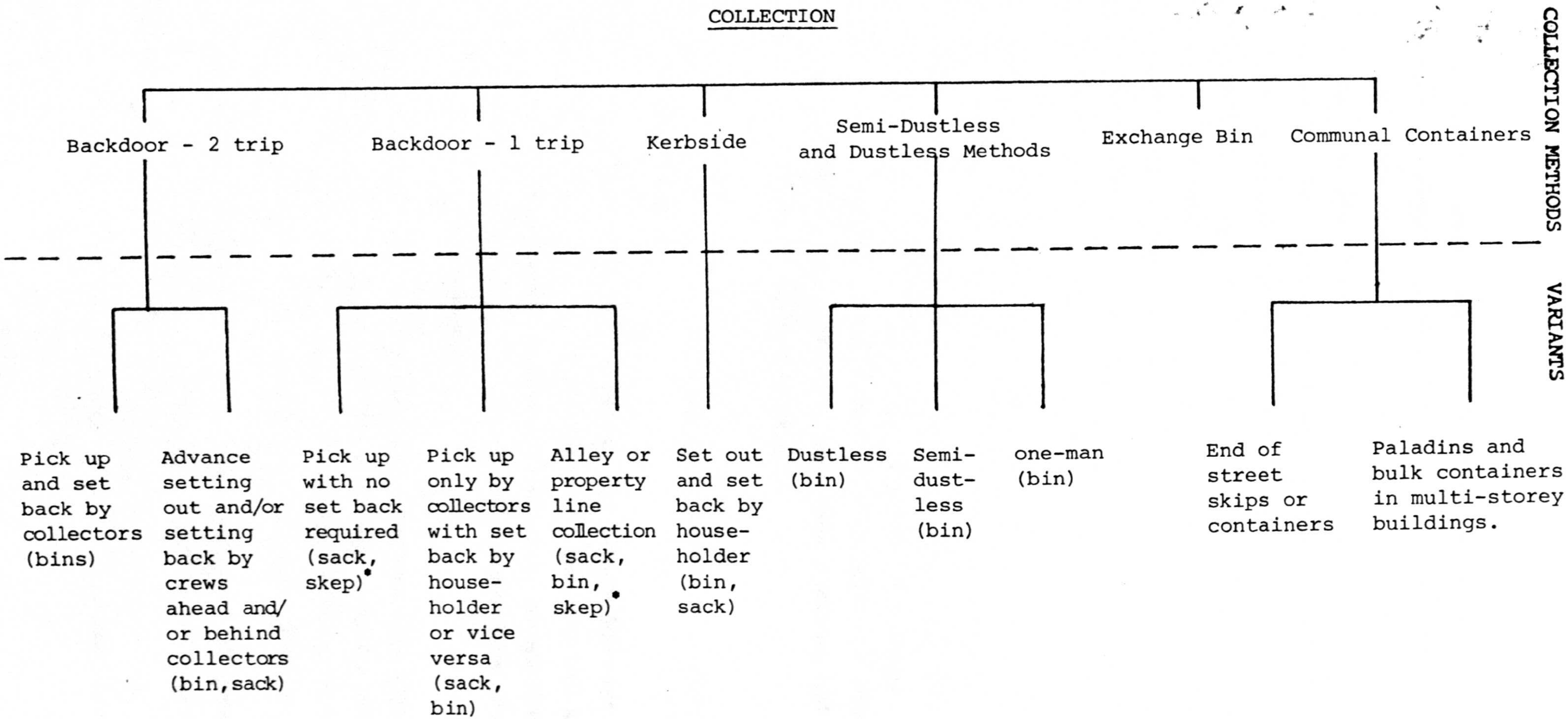


Figure 2.3 Diagram of the principal refuse collection methods and the variants found with each

• A skep is defined on page 33.

The relative importance of each method is not known at present although backdoor - 2 trip, backdoor - 1 trip, and kerbside, using either bins and sacks, were found to be widely employed in previous studies (Table 2.2). The choice of a particular method is apparently a subjective matter between the chief officer and the councillors composing the Environmental Health or Cleansing Committee. Their decision is likely to involve a trade-off between financial considerations and the levels of noise, spillage, visual intrusion and hygiene the ratepayers will tolerate. Typically an increase in environmental quality results in an increase in the cost of collection.

In the following sections operational details will be outlined and also a discussion of the literature is included regarding the costs and savings attributed to each method. Only five collection options are considered in the economic study of collection (Chapter 7). These are: Backdoor bin, backdoor skep, backdoor sack, kerbside sack, kerbside bin. No specific data was collected for any other variants and their costs are only appraised in this chapter.

2.5.1 Backdoor - 2 trip

This method of collection involves two return journeys to the rear of each house. The first is to collect the full bin and carry it to the collection vehicle, and the second is to return the emptied bin to its original position. The general arrangement of this operation is outlined in Figure 2.4.

The 2-trip collection is principally involved with refuse storage using bins, but it is conceivable that sack storage could also be included. The latter practice is a very inefficient use of labour and it is thought that very few authorities operate this method with sacks.

This backdoor-bin method is the most widespread in current use and is taken as the standard method against which the merits and disadvantages of other methods are compared (Section 2.6). It is also considered by the DOE to be the most convenient for the householder (DOE, 1967).

Table 2.2 RELATIVE IMPORTANCE OF EACH OF THE PRINCIPAL COLLECTION METHODS

	1964 (a)		1976 (b)	
Method	No. of Premises	% of Premises	% of Premises Bin	Sack
Backdoor - 2 trip	9,912,000	63	) 40	N/A
Backdoor - 1 trip	3,385,000	21	)	70
Kerbside	2,400,000	15	47	15
Exchange Bins	46,000	1	0	0
Communal Skips	0	0	4	0
Other*	0	0	9	15

Sources: (a) DOE, 1967

(b) Scottish Development Department, 1977

Notes: This survey excludes communal bins in multi-storey buildings.

N/A - not applicable.

* Indicates disposal on-site, dustless loading.

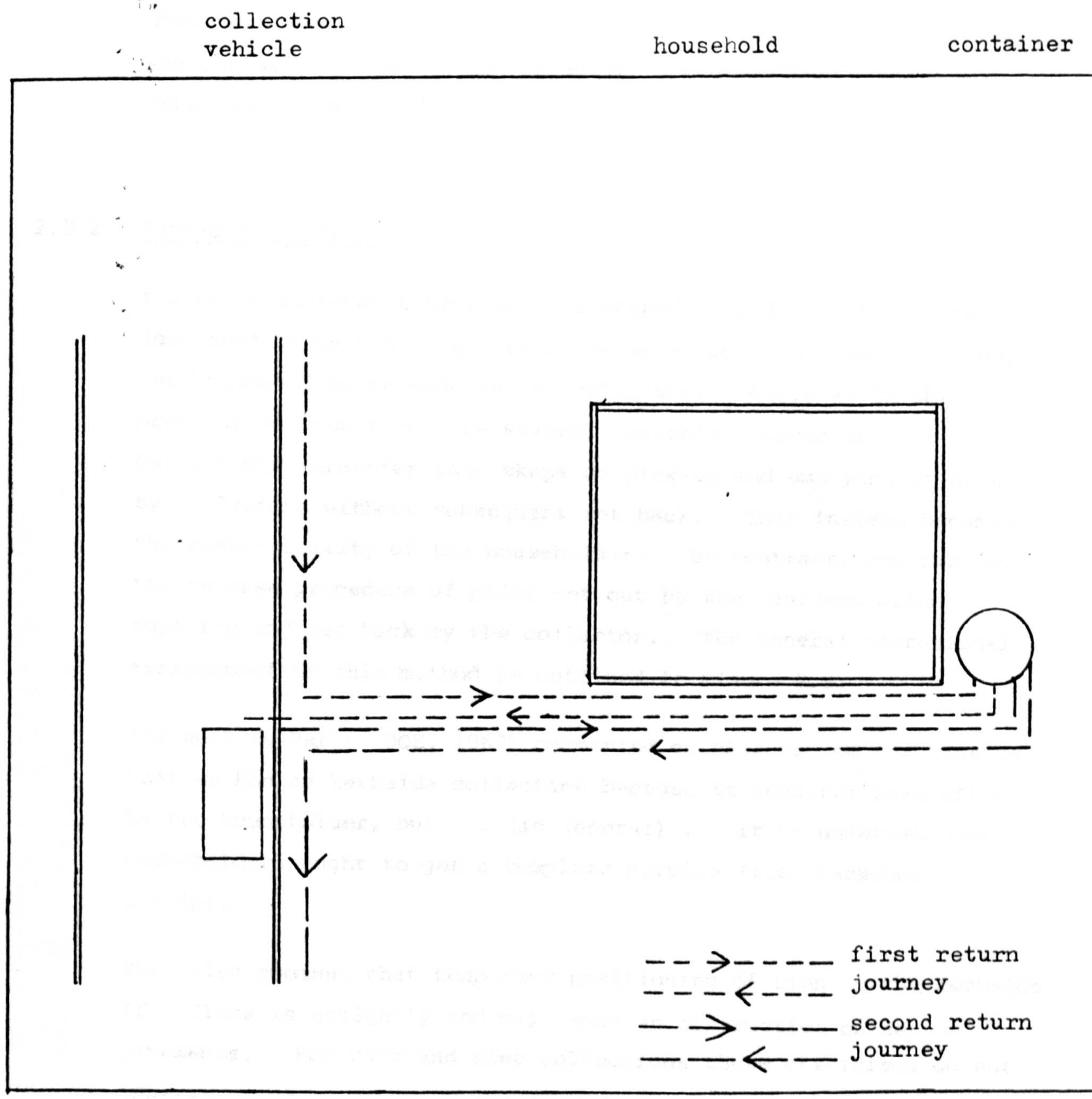


Fig 2.4 Backdoor - 2 trip collection

There are two variants of the backdoor - 2 trip collection method, pick up and set back by collectors, and advance preparation. These are compared in Table 2.3.

2.5.2 Backdoor - 1 trip

The basic difference between this method of collection and that described in Section 2.5.1 is it requires only one return journey per household to be made by the collector. Again as in the previous section there are several variants; backdoor sack collections, transfer into skeps or pick-up and emptying of bins by collectors without subsequent set back. This instead becomes the responsibility of the householder. By contrast, one can have the reverse procedure of prior set out by the resident with emptying and set back by the collector. The general operational arrangement of this method is outlined in Figure 2.5.

The Working Party (DOE, 1967) commented on this method for bins as "not as bad as kerbside collection because it requires less effort by the householder, but ... (in general) ... it is unsatisfactory. Householders ought to get a complete service (i.e. backdoor - 2 trip)."

They also comment that temporary positioning of bins at the kerbside if lidless is unsightly and may cause an obstruction on narrow pavements. For sack and skep collections these criticisms do not apply.

The three variants of the backdoor - 1 trip collection method are reviewed in more detail in Table 2.4.

2.5.3 Kerbside

In this method of collection the container is both set out at the kerbside on the day of collection and returned after emptying by the householder. No return journeys are made by the collectors and consequently the time available for loading is increased and less interrupted. The method is identical in operation for bins

Table 2.3 COMPARISON OF BACKDOOR - 2 TRIP COLLECTION VARIANTS

	Pick up and Set back by Collectors	Advance Preparation
1.	Same collector makes both trips to back of house.	Bin is brought to the kerb by a crew member working ahead of loaders and is returned by the second man. Possible additional labour costs over the other variant is a subject of debate.
2.	The bin is never left in the street, an important environmental benefit.	The bin is left out in the street for the short time between setting out and loading.
3.	This variant is highly convenient to householders. They are not required to carry bins at all.	As for the other variant.
4.	The collection operation produces very little visual intrusion to the general public.	More visual intrusion than the other variant due to its temporary position on the kerb.
5.	Has the disadvantage of a slow loading rate.	With experience collection crews set up a "rhythm" which can lead to a marginally faster rate of loading.
6.	Some risk of spillage during carrying to and emptying in the vehicle.	Risk of spillage increased by the bin spending some time at the kerbside, particularly if the lid is removed.

Sources: APWA (American Public Works Association), 1966
Tchobanoglous et al, 1977
Flintoff and Millard, 1969
DOE, 1967.

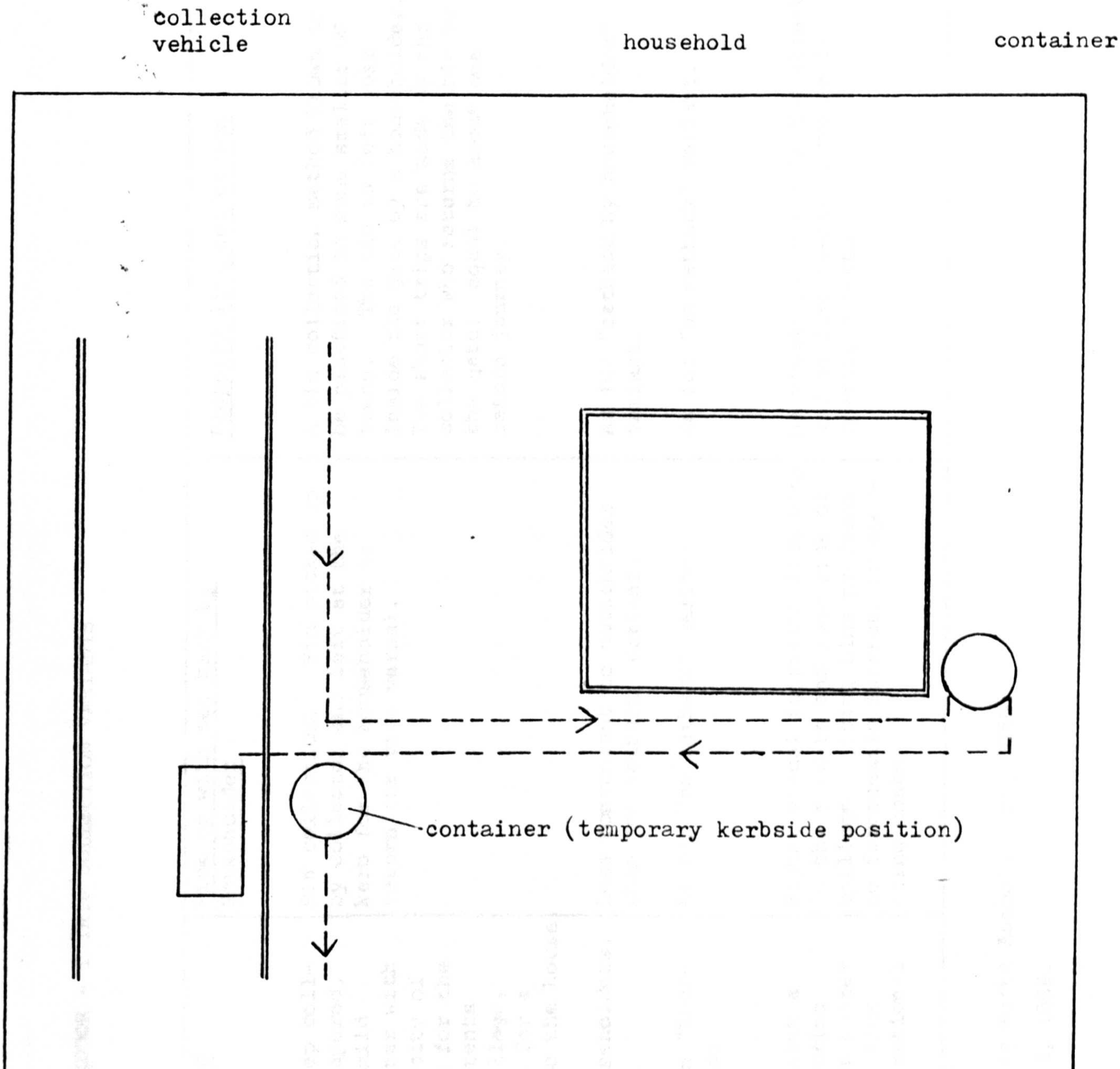


Fig 2.5 Backdoor - 1 trip collection

Table 2.4 COMPARISON OF BACKDOOR - 1 TRIP COLLECTION VARIANTS

	Pick-up with no required setback	Pick up with set back by Householder	Property line collection
1.	Disposable sacks and skep collection. A skep is a tapered, lightweight aluminium, mild steel or plastic container with a wide mouth and a capacity of $0.1m^3$. It is designed for the transfer of a bin's contents with the minimum of spillage, and eliminates the need for a second return journey to the house.	Bin collection, Bin picked up by collector and left at the kerb for the householder to return (or vice versa).	A bin collection method known to be practiced in some smaller US towns. The bin is left just inside the gate by a householder. Two short trips are made by the collector who returns the bin to the gate; equal to about one return journey.
2.	High convenience to householders.	Less convenient to householder than "no setback" variant.	As for "setback by householder" variant.
3.	Faster loading rate than "Backdoor - 2 trip" collection methods.	As for "no setback" variant.	As for "no setback" variant.
4.	Skeps are noisy and present a high risk of spillage during transfer. Sacks do not suffer from these problems but sack purchase is a major operational expenditure.	Higher visual intrusion from bins in the streets and some risk of spillage. Using bins produces no foreseeable increase in operating costs.	No visual intrusion in the streets and no foreseeable increase in operating costs.

Sources: APWA (American Public Works Association), 1966

Flintoff and Millard, 1969.

and sacks, and the level of participation by the householder in the collection procedure is higher than for either of the back-door methods. The operational arrangement of this method is described in Figure 2.6.

The Working Party on Refuse Storage (DOE, 1967) and APWA (1966) while admitting this method is "speedy and cheap" also found much evidence from local authorities that it is far from satisfactory:

1. They considered it unhygienic and untidy with bins and sacks frequently supplemented by improvised containers. Often these containers are left on the kerb for some time where they are vulnerable to animals, children and scavengers. Lids can be blown off bins or removed and subsequently the contents can become scattered across the street.

2. It passes the authority's responsibilities to the householder in a way which in general an authority has no power to require.

3. It creates hardship for older people, the handicapped, the infirm and the housewife. Furthermore, many old people are reluctant to ask for an exception to be made for them.

4. Householders often forget to put out their bins on the right day. Additionally, this method reduces the flexibility of the collection operations in that it dictates when a round must be made and minor problems have arisen when public holidays or vehicle breakdowns upset the usual routine.

Flintoff and Millard (1969) summarise the advantages of this method as a reduction in labour and vehicle costs but an increase in operating supplies costs where sacks are used will reduce the overall financial savings. The disadvantages are environmental, and difficult to quantify. They are: a high risk of spillage; visual intrusion; and inconvenience to the householder. These serve to make this method unpopular with some authorities. Kerbside collection however, is the only method possible where houses have no access to the rear, for example, back-to-back terraced housing.

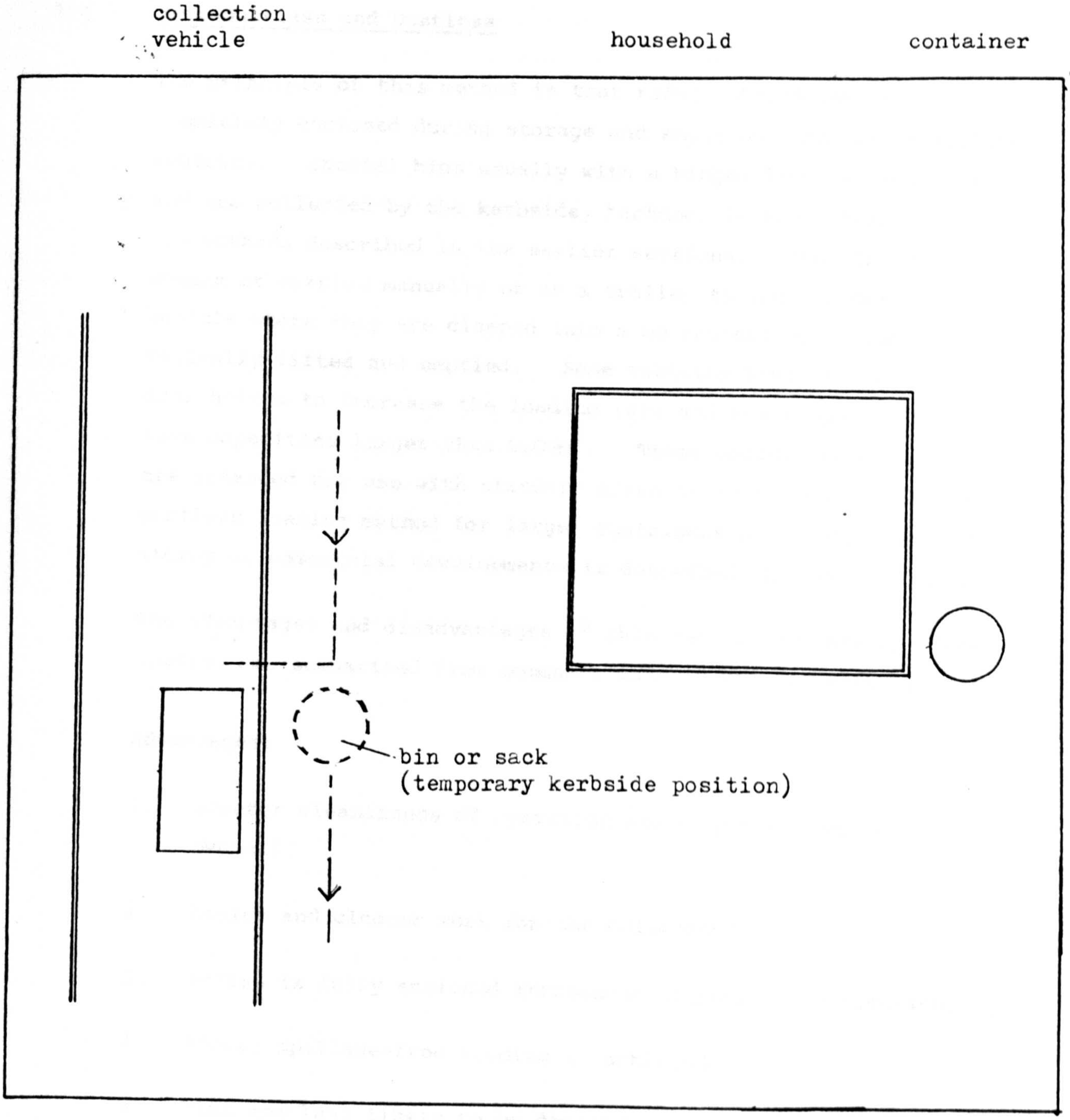


Fig 2.6 Kerbside collection

2.5.3 Semi-Dustless and Dustless

The principle of this method is that refuse should remain completely enclosed during storage and emptying into the collection vehicles. Special bins usually with a hinged lid are necessary and are collected by the kerbside, backdoor 1- and 2-trip collection methods described in the earlier sections. The bins are on wheels or carried manually or on a trolley to the collection vehicle where they are clamped into a mechanical hoist and automatically lifted and emptied. Some vehicles have independent dual hoists to increase the loading rate and new ranges of bins have capacities larger than $0.09m^3$. These collection methods are intended for use with standard sized bins; the use of the semi-dustless loading method for larger containers associated with multi-storey or commercial developments is described in Section 2.5.6.

The advantages and disadvantages of this method over non-dustless loading are summarised from comments made in the literature:

Advantages:

1. Greater cleanliness of operation and much more hygienic overall.
2. Easier and cleaner work for the collectors.
3. Refuse is fully enclosed throughout storage and collection.
4. Almost spillage-free loading is achieved.
5. Bins are less likely to be damaged during collection.
6. With trolleys or wheels there is a significant reduction in the carrying effort required by the loaders.

Disadvantages:

1. This method increases the unit collection time and probably the total labour requirement as compared to the previously described collection methods.

2. There is a corresponding increase in total collection costs, which are borne by the ratepayer, compared with other collection methods.

3. Noise from the lifting hoist, in addition to collection, compaction and engine noise.

4. Expensive, special bins and lifting equipment are required.

5. Bin trolleys or built-in wheels are difficult to use on uneven terrain. This is an important consideration where new bins well over the standard $0.09m^3$ are used, since manual carrying may prove impossible.

Dustless collection is not in widespread residential use and with the current economic constraints on local authorities the situation is not likely to change in the near future.

2.5.5 Exchange Bin

This is a very minor collection method, not used at all in Scotland (Scottish DD, 1977) and with local authority reorganisation it has probably now been discontinued in those places in England and Wales where it was once employed. The method involves the collectors taking to a household an empty bin and removing the full one. The full bin is then emptied, cleaned and the whole procedure repeated for the next house (Figure 2.7). This is not a favourable method with residents who object to having a neighbour's bin and experiments to clean the bins at the kerbside with a rotating brush have proved ineffective.

DOE (1967) consider that in theory this method could be satisfactory on environmental grounds if the bins were thoroughly clean and sterilised at a depot. However, this has not been undertaken in Britain although in the USA a few towns do physically collect and transport the bins to the disposal site (APWA, 1966). It is not known if they are subsequently cleaned. It is possible that minor

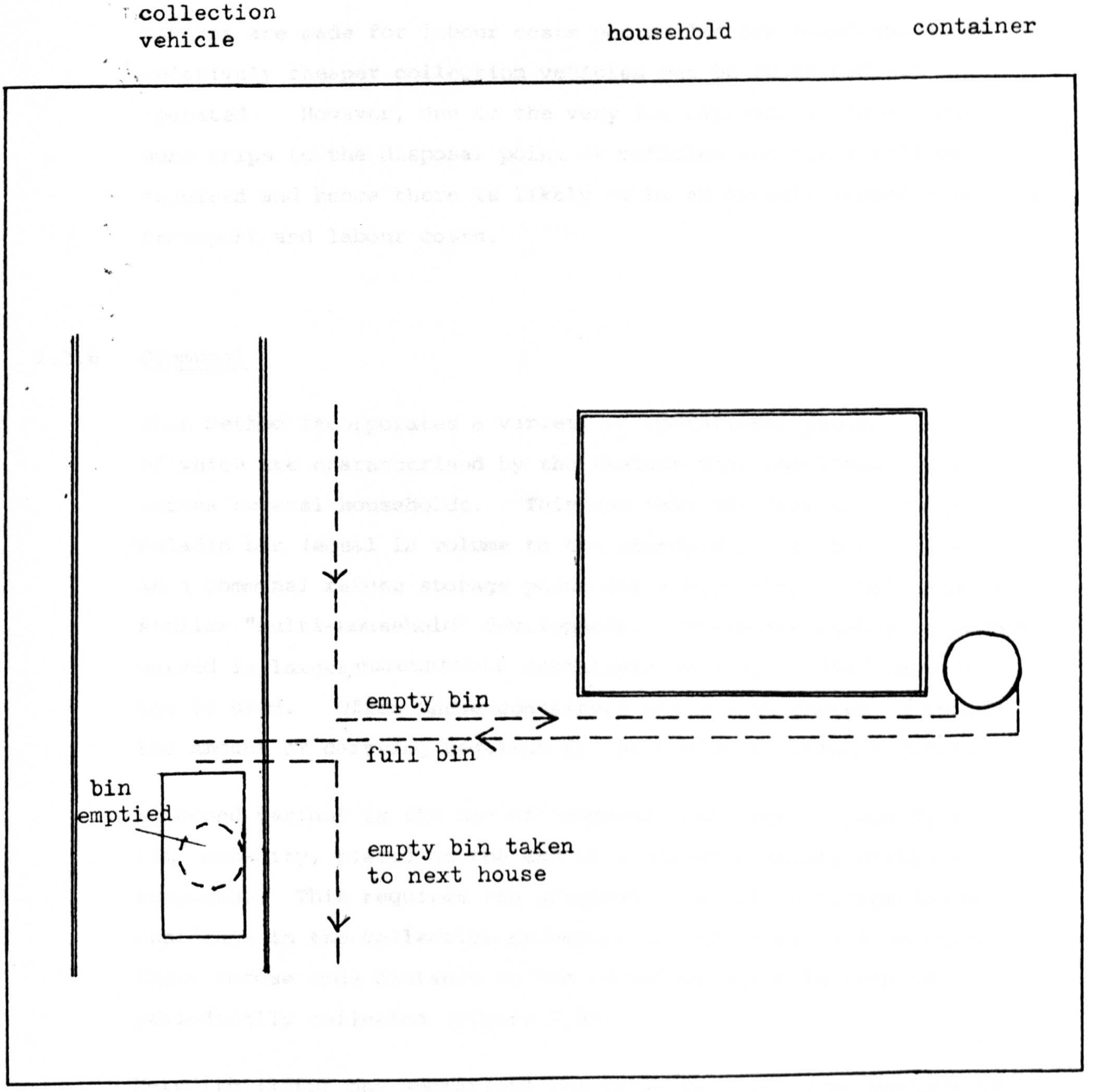


Fig 2.7 Exchange collection

savings are made for labour costs per collection round and also relatively cheaper collection vehicles can be purchased and operated. However, due to the very low payloads achieved many more trips to the disposal point or vehicles and crews will be required and hence there is likely to be an overall increase in total transport and labour costs.

2.5.6 Communal

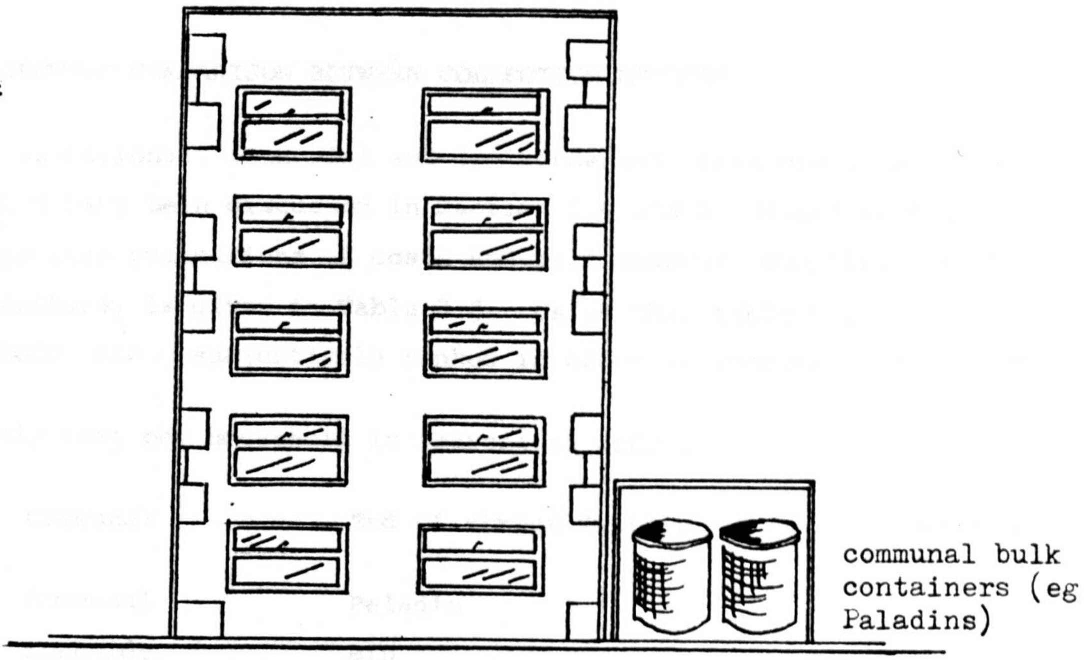
This method incorporates a variety of operational procedures, all of which are characterised by the feature that one large container serves several households. This can take the form of a large Paladin bin (equal in volume to ten standard $0.09m^3$ bins) acting as a communal refuse storage point for a multi-storey building or similar "multi-household" development. Where the number of people served is larger, demountable containers with up to $15m^3$ capacity can be used. Often these containers are fed by chutes to reduce the amount of carrying required by the residents (Figure 2.8a).

A second variant is the use of communal containers, again up to $15m^3$ capacity, placed at the end of a street probably within a compound. This requires the greatest level of participation by residents in the collection procedure in that they have to carry their refuse some distance to the container which in turn is periodically collected (Figure 2.8b).

Meredith (1980) has summarised the relative percentage savings in unit costs for the communal collection variants compared to backdoor - 2 trip. His values are based on cost figures from just one authority, the City of Westminster, and as such they cannot be directly extrapolated to other authorities since the basis of estimation is likely to be different. i.e.:

Backdoor - 2 trip:	Pick-up & set-back by collector:	100% unit costs on a m^3 basis:
Communal	Paladin	32% of the backdoor cost
Communal	Large container (uncompacted)	26.4% " " " "
Communal	Large container (compacted)	8.8% " " " "

A



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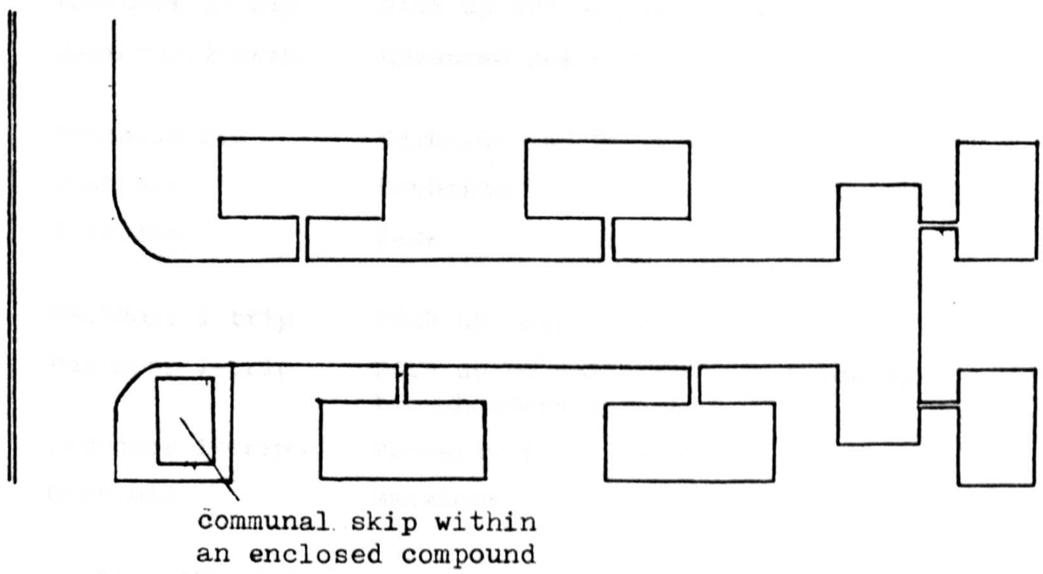


Fig 2.8 A & B Communal skips and Paladin collection methods.

2.6 SUBJECTIVE COMPARISON BETWEEN COLLECTION METHODS

The operational, financial and environmental considerations of each method have been discussed in Section 2.5 and a summary of their subjective evaluations of costs and performances, compiled from the literature, is given in Table 2.5. Using this table the collection methods are subjectively ranked in order of increasing unit cost:

Likely cost per household in increasing order:

1.	Communal	End of street (with or without compaction)
2.	Communal	Paladin
	Kerbside	Bin
3.	Backdoor 1-trip	Pick up by collectors, setback by householders - bin
	Backdoor 1-trip	Property line - bin
	Backdoor 1-trip	Pick up only - skeps
4.	Backdoor 2-trip	Pick up and set back - bin
	Backdoor 2-trip	Advanced set out - bin
5.	Exchange bin	Kerbside and Backdoor
	Dustless	Kerbside
	Kerbside	Sack
6.	Backdoor 1-trip	Pick up only - sack
	Backdoor 1-trip	Pick up by collectors, setback by householders - sack
	Backdoor 1-trip	Property line - sack
	Dustless	Backdoor

This ranking compares favourably with similar studies done with figures from individual authorities, notably by Flintoff and Millard (1969) and Whittocks (1975). The above ranking is based on different costing conventions from several authorities. Neither this method of compilation or the figures from the literature give meaningful comparisons and it is one of the purposes of this work to verify or discount the literature-derived cost ranking above. Costs gathered from many authorities have been reduced onto a common basis and are reported in Chapter 7.

Principally this study will concentrate on the backdoor - 2 trip, backdoor - 1 trip and kerbside collection methods and their variants.

Table 2.5 RANKING OF ECONOMIC AND ENVIRONMENTAL FACTORS AS EXPRESSED IN THE LITERATURE FOR EACH COLLECTION METHOD AND ITS VARIANTS

Collection Methods and Variants:	Backdoor - 2 trip		Backdoor - 1 trip						Communal	
Factors	Pick up and set back by Collectors	Advanced Set-out	Pick up with no setback required	Pick up by collectors, setback by householders	Property Line	KERBSIDE	DUSTLESS	EXCHANGE BIN	Paladin	End of Street
FINANCIAL FACTORS										
Labour cost (relative to Backdoor - 2 trip)	4	4-6	3	3	3	2-3	3	3	2	1
Transport cost (units as above)	4	3-4	3	3	3	3	5	5	3	2
Operating Supplies Cost (units as above)	4	4	Skep - 5 S - 6	B - 4 S - 6	B - 4 S - 6	B - 4 S - 6	5	4	4	B - 4 S - 6
Total Unit Cost - £ per household	4	4	Skep - 3 S - 6	B - 3 S - 6	B - 3 S - 6	B - 2 S - 5	Back - 6 Kerb - 5	Back - 5 Kerb - 5	2	WC - 1 C - 1
ENVIRONMENTAL FACTORS										
Rate of loading into Collection Vehicle	LOW	MOD	MOD	MOD	MOD	HIGH	Single H - LOW Dual H - MOD	MOD	HIGH	HIGH
Effort required by Collectors	HIGH	HIGH	Skep - HIGH S - MOD	B - HIGH S - MOD	B - HIGH S - MOD	B - HIGH S - MOD	MOD	HIGH	MOD	LOW
Number of Collectors Typically used	2-5	3-7	1-5	1-5	1-4	1-4	1-6	1-5	2-3	1-2
Risk of Spillage and Dust in Street and from Loading	MOD	HIGH	Skep - MOD S - LOW	B - HIGH S - LOW	B - HIGH S - LOW	B - HIGH S - LOW	LOW	HIGH	LOW	LOW
Visual intrusion of Containers in Street	LOW	MOD	LOW	MOD	LOW	HIGH	Kerb - HIGH Back - LOW	Kerb - HIGH Back - LOW	LOW	HIGH
Convenience of the Variant to Householder	HIGH	HIGH	HIGH	MOD	MOD	LOW	Kerb - LOW Back - HIGH	Kerb - LOW Back - HIGH	MOD	LOW

For Key, see next page

Table 2.5 RANKING OF ECONOMIC AND ENVIRONMENTAL FACTORS AS EXPRESSED IN THE LITERATURE FOR EACH COLLECTION METHOD AND ITS VARIANTS
(continued)

All financial factors are expressed as a ranking from 1 to 7 rather than absolute values, and relative to the Backdoor - 2 trip, pick up and return by collectors method. The approximate percentage cost range is:

	<STD			STD	>STD		
%	<50	20-50	<20	0	<20	20-50	>50
Rank	1	2	3	4	5	6	7

Environmental factors are ranked as: High, Moderate or Low effect.

Key to Abbreviations:

STD	Standard for comparison i.e. Backdoor - 2 trip, pick up and return
S	Sacks
B	Bins
Kerb.	Kerbside
Back.	Backdoor - 2 trip
WC	Without on-site compaction
C	With on-site compaction
MOD	Moderate
H	Hoist.

Sources:

DOE, 1967

Flintoff and Millard, 1969

Tchobanoglous et al, 1977

Payne, 1975

Meredith, 1980

Personal communications with several local authorities.

2.7 COLLECTION VEHICLES

The purpose of a collection vehicle is to transport refuse away from the places of generation to a point of disposal. Refuse has been collected in motorised vehicles since the beginning of the 1920s although at that time vehicles designed for other purposes were pressed into service. These vehicles were open-topped, non-compacting and had a high loading height. The conditions in which the collectors worked was unsatisfactory and vehicle capacities of around $4m^3$ were very small.

It was realised as early as 1922 that special adaptations would be necessary to improve loading conditions and subsequently the first purpose-built body and chassis was developed. Since then the manufacture and technology of collection vehicles has become increasingly complex and specialised. However, certain basic design features essential to satisfactory collection can be identified to assess the suitability of any new vehicle (modified from Hagerty et al, 1973; DOE, 1967):

1. The body must be leak-proof.

2. The body must be covered to reduce the uptake of water by the refuse (and hence increasing its weight) when collecting in wet weather.

3. The body must be easily emptied and cleaned, and the metal structure of suitable standard to prevent chemical attack and corrosion by the contained refuse.

4. The loading height should be as low as possible to ensure easy and convenient manual loading of refuse with the minimum of spillage and dust.

5. The vehicle should be fitted with a tipping body or an ejection plate hydraulically driven to enable straightforward discharge at the disposal point.

6. Facilities should be included in the design to enable oversized refuse to be collected; for example, large boxes and small items of furniture.

7. It should achieve a payload which is as near as possible to the legal maximum allowed for the particular size of chassis employed.

8. The vehicle should provide satisfactory cab space for the expected number of loaders to be used on a collection round.

9. The size (or range of sizes) of vehicle should be compatible with the width of the streets and quantity of arisings expected in the collection areas.

2.7.1 Non-Compacting Vehicles

Open top:

The most elementary vehicles are high-sided open-body trucks into which refuse is lifted up and thrown into the back. This type of collection vehicle has been virtually eliminated for residential collection from the UK except on some of the islands off the west coast of Scotland and for a few very remote rural collection rounds. The vehicles are usually no greater in capacity than $10m^3$ and suffer from poor payloads since compaction is not used. When loading, often one man is required to be inside the body to pack, the top man, with the second actually collecting from the households.

Open-topped vehicles are still used in the UK for bulky and garden waste, and other special collection services. Conversely, this type of vehicle is relatively cheaper than compacting ones and where labour is abundant, particularly in developing countries, open-topped collection trucks are most commonly used (White-Hunt, 1980) (Section 2.5).

Enclosed:

This type of vehicle represents a minor improvement on the open-top version by having the storage body completely enclosed thereby reducing littering and odours. Although possessing similar advantages, as for open top vehicles, of lower purchase and operating costs it has the same disadvantages, high loading height and low payloads.

Some models require the refuse to be "thrownback" from the loading doors by some form of mechanical raising of the body to achieve cursory compaction under the refuse's own weight (the so-called "fore and aft" vehicles). However, the intrinsically low density of refuse does not enable it to compact significantly.

Most vehicles of this form have been superceded by those with powered compacting devices, although some are still used for bulky collection services.

2.7.2 Powered Compacting Equipment

To achieve a larger, economic payload from intrinsically low density refuse there is a need to employ compaction. Figure 2.1 shows quite clearly that the density of refuse has fallen by over 60% in 45 years and personal discussions with local authority officials suggests an almost 100% use of compacting vehicles for domestic collection services in the UK.

There are two principal methods of compaction within the vehicle. The first is by using hydraulically operated pressure plates or rams which push the refuse from the loading hopper into the storage body. The second uses a mechanical screw feed which is situated at the bottom of the loading hopper and carries the refuse into the body of the vehicle. The screw is inclined upwards into the body from the loading hopper and tapers towards its upper end to improve the compaction achieved. The former method is currently the most popular and only one UK manufacturer produces screw-compaction equipment.

A further distinction between compacting vehicles is whether the compacting equipment operates continuously or intermittently, "continuous" and "intermittent" loaders respectively. In an intermittent compacting vehicle the loading hopper is first filled by the collectors who then operate the compacting cycle during which time no additional loading can take place. Often the vehicle cannot travel during this sequence thus with this type of equipment the loading routine may be held up. Modern designs, however, are continually reducing the packing time and on average it is now down to approximately 15 seconds per cycle.

Continuous compacting vehicles are those which can be loaded and packed at the same time with no consequent hold up in the collection operation. It also has the advantage of being able to compact while on the move and this type of equipment may be able to reduce collection times. However, their capital cost is larger and maintenance costs are estimated at being up to 40% greater than for intermittent loaders (personal communications with local authorities).

Compacting vehicles are available in several capacities to suit different characteristics of a collection area. The $20m^3$ capacity vehicle is the most popular for urban areas and smaller ones down to $13m^3$ for rural areas. In general compacting vehicles have a compaction ratio of 4:1 and local authorities usually budget for an expected life of seven to ten years. Compacting vehicles can be categorised into one of three forms depending on their position of loading: side, front- or rear-end loaders.

Side loading vehicles:

These are not generally used in the UK at the present time for domestic collections but a variety of designs are available in America and Canada where they are popular with small local authorities. Capacities up to $35m^3$ are available.

Side loading is also favoured in North America for the mechanical and one-man dustless collection methods whereas the UK predominantly uses hoists fitted to rear-end loaders described later. Side loaders are not considered further in this research study.

Front-end loading vehicles:

These vehicles are solely used for the pick-up of some types of bulk containers and are not used in the UK for domestic collection services.

Front-end loading vehicles require direct access to the container, at which the driver manoeuvers the vehicle so that the forks of its hoisting equipment interlock with the container. The container is then lifted above the cab, tipped into the body at the top, front end, and the refuse compacted. Since these vehicles are designed for bulk collection their capacities range up to 35m^3. They are used in some domestic communal collection operations in the US, but are not currently used for this purpose in the UK, and are therefore not evaluated further in this research.

Rear-end loading vehicles:

These are the most widely used vehicles in the UK. Collectors load refuse into the rear hopper which is intermittently or continuously compressed by the compacting equipment and pushed into the vehicle body. These vehicles have a low loading height of about 45cm and have been developed for both large volume urban use and low volume rural use. Most research and development effort has gone into rear-end loaders though no conclusive reasons are available as to why the UK should favour these over side loaders. Possibly it is the result of fixed operational ideas or an absence of marketing by side-loader manufacturers.

2.7.3 Skip Vehicles

For communal collections in addition to using front-end loaders other bulk containers such as those used at some multi-storey buildings require to be transported by a different type of vehicle. Two basic variations exist, the first involves the use of open or closed trapezoidal containers known as "skips". These are hoisted onto the back of the collecting vehicle's chassis by an overhead loading arm and chains attached to the container.

The second method employes a "roll-on, roll-off" technique whereby the containers have small wheels fitted to their ends and are uplifted by a variety of hoisting mechanisms, such as a spring-loaded bail hook, cable and winch, or a jib-mounted hook. When loading or unloading the chassis is tilted and once the hoisting operation is complete, it is lowered to the horizontal position for travelling.

The main limitation of this form of collection is that only one or two containers at a time can be hauled to the disposal point but by exchanging an empty container for a full one at each collection point the required travelling is reduced. Naturally this dictates the use of standardised containers.

2.7.4 Satellite Vehicles

This is a one-man operated, short-haul variation on the theme of open-topped non-compacting collection vehicles whereby refuse is picked up in small motor driven carts and then transferred to a centrally located "mother" compaction vehicle. Satellite vehicles as described have been specially developed to collect refuse from households with restricted road access or very long drive-ways. These vehicles typically hold between 10 - 20 bins and can operate in very confined areas. By working in conjunction with a larger compacting vehicle in such areas it is claimed that they save collection time (and hence labour and transport costs) as well as reducing the strain on collectors. Payne (1975) has suggested a 22% reduction in cost for a satellite system over a three-collector conventional system in areas where there are long carries to the collection vehicle.

2.9 Vehicle Routing

This research does not study in detail the optimisation of collection vehicle routing; however, it is useful in passing to include a discussion of the methods currently employed.

For the large majority of local authorities the routing systems used are not optimised to fulfill any particular objective, but instead have been developed on an ad-hoc basis over several years. Routings are usually produced from an Ordinance Survey map by tracing out a route to pass a pre-determined number of collection points so as to fill a collection vehicle or the working day (for rural areas). Each route is defined as a "collection round". The entire authority's area is divided up into rounds, then a nominal number of rounds/day/vehicle and days of operation are decided, from which the number of vehicles required is calculated. Finally, the authority's Work Study Officer would then adjust specific routings to ensure equal "work" is done by all the crews.

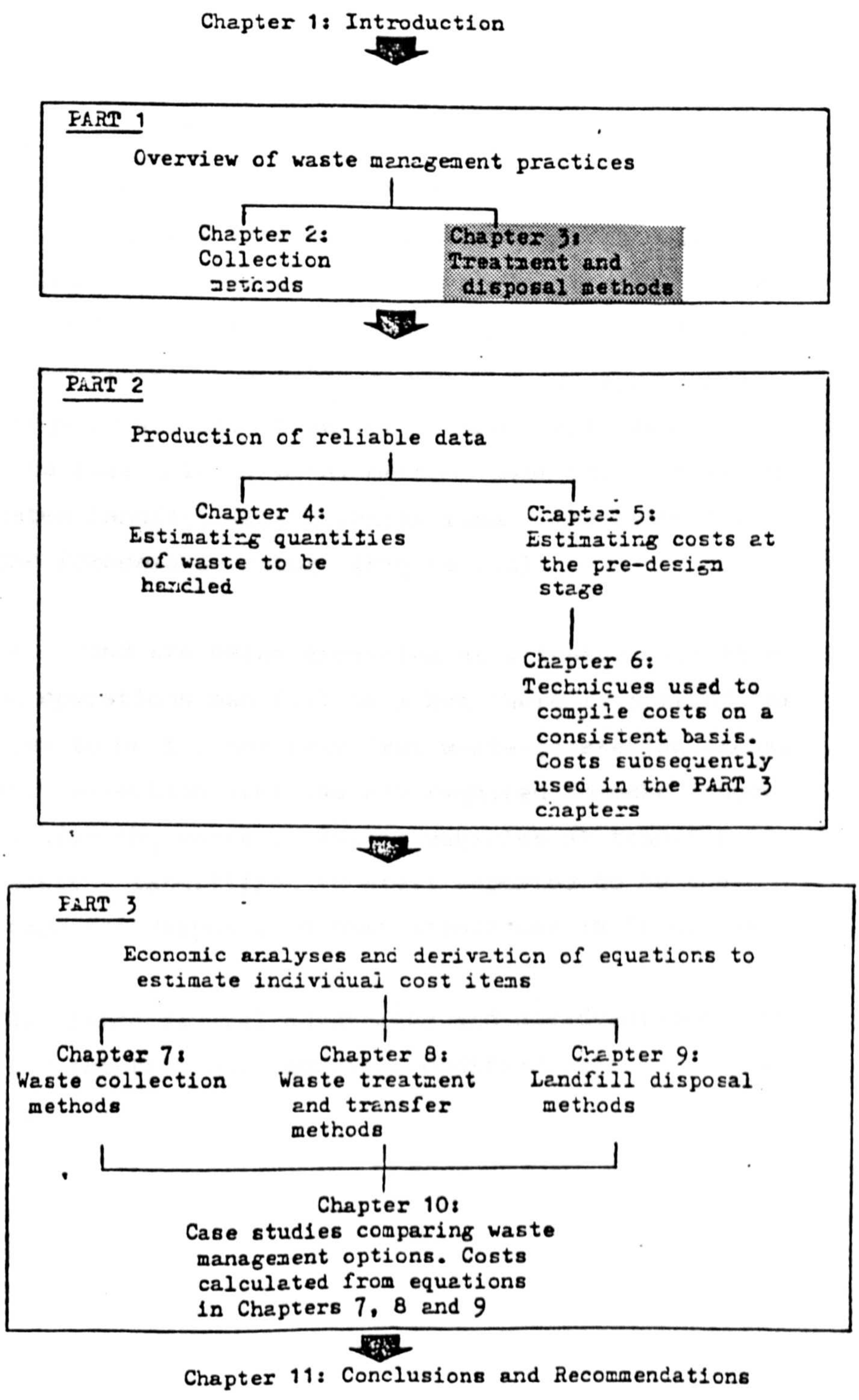
It should be noted that very few local authorities have had to start from the basis of no rounds but instead after reorganisation the new district councils inherited rounds from the previous local authorities. Modifications to these have been piece-meal and in many cases inertia has prevailed with routes remaining unaltered. These situations lead to large anomalies between actual and potential utilisation of labour and equipment especially where larger capacity vehicles, different compacting techniques and collection methods have been recently introduced.

The economics of collection methods are strongly influenced by the distance to the initial discharge point. However, the relationship between cost and distance is very complex. An approximate linear cost function was discussed by Wilson (1981) whereby the unit collection cost rises as the number of trips to the disposal point decreases. Minimising the distance of haul by collection vehicles should be an important consideration when planning waste disposal. Flexibility in the collection organisation (e.g. length of working day, turnaround time, number of loaders etc) reduces the dependance of cost on distance. Unfortunately, the organisation of municipal cleansing is often relatively inflexible.

There are a number of optimised routing procedures available from bodies such as LAMSAC and LGORU, although one should first determine what is to be optimised. Is it the overall collection cost; or "work" performed by a crew (e.g. tonneages collected, premises serviced, etc) in a given time period; or the smallest route; or the least equipment and manpower required to collect from a given area? It is also unclear as to the value of optimised collection vehicle routings since a very strong, and possibly over-riding, constraint is to get equal workloads between crews. At the heart of this is Work Study, whose measurements are both inflexible and difficult to calculate correctly for each of the collection tasks.

CHAPTER 3

TRANSFER, TREATMENT and LANDFILL DISPOSAL METHODS FOR MUNICIPAL WASTES



Chapter 3

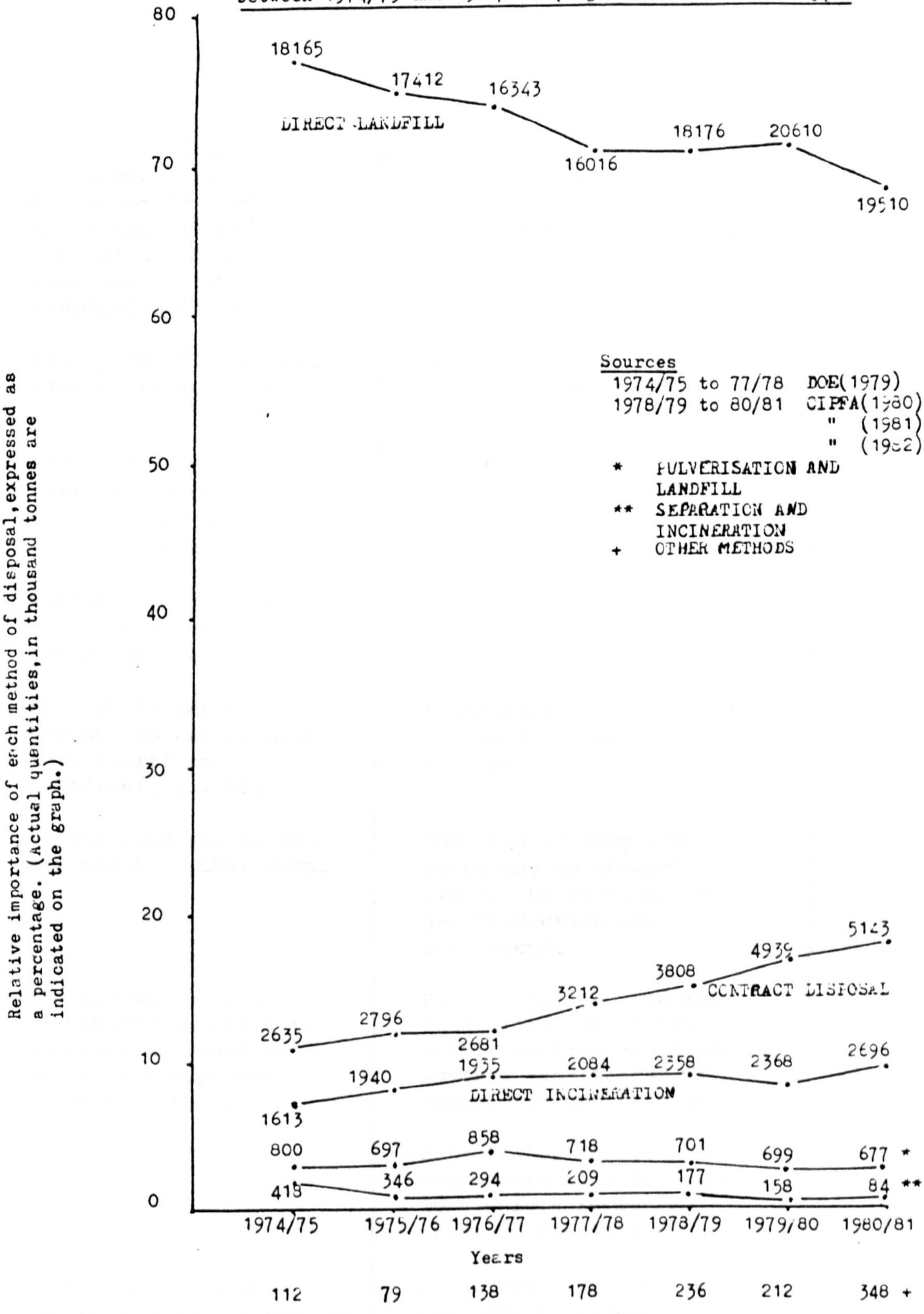
3.1 INTRODUCTION

Landfill is the disposal of wastes by deposition onto land away from their places of generation. It is the most widely used disposal method for domestic and commercial wastes in the UK (also termed "municipal refuse"), accounting for approximately 85% of arisings by weight. A review of the quantities handled by the available disposal methods over the last seven years indicates landfill will probably remain the principal option in the foreseeable future (Figure 3.1).

Holes in the ground are being excavated at a faster rate than land-filling operations can fill them but there is a trend for suitable sites to be further away from waste-generating areas. Consequently, collection vehicles are required to make longer hauls or transfer the waste to larger vehicles at transfer stations. However landfilling is still reported to be the cheapest method for disposal in most situations (Wilson, 1981).

Nelson (1974) listed several advantages and disadvantages with a well-managed (controlled) landfill, modified version is given in Table 3.1.

Fig 3.1 Waste tonneages treated by the principal disposal methods between 1974/75 and 1980/81. (English authorities only)



'DIRECT LANDFILL' refers to local authority operated sites, 'CONTRACT DISPOSAL' refers to private sector sites. Together these landfilling options account for the disposal of between 85 and 90% of waste arisings.

Table 3.1 Advantages and Disadvantages of Landfilling

	Arguments for	Arguments against
1.	Lower capital and operating costs in relation to other disposal methods.	Haul distances and costs will increase after nearby sites have been filled.
2.	All types of municipal wastes are acceptable.	Bad weather may hinder operations to an unacceptable degree.
3.	All refuse including bulky items can be accommodated without the need to sort.	
4.	Variations in waste arisings can be easily handled.	
5.	A landfill can be engineered and brought into operation relatively quickly.	Protection of ground water may be difficult or costly.
6.	Filled land can be reclaimed for other uses.	The uses of completed sites may be severely limited by problems of gas production and settlement.
7.	The operation of a controlled landfill is a proven and environmentally acceptable disposal method.	Public feelings towards landfilling are often highly emotive and based on adverse experiences with improperly operated sites.
8.		Potentially recoverable components in refuse are lost unless recovered prior to emplacement.
9.	Most commonly only derelict or wastelands are used for landfill sites.	Large areas of land are required in relation to other methods and suitable land may be difficult to obtain.

3.1.1 Principal Variants of Disposal by Landfill

Figure 3.2 indicates the different kinds of landfill disposal available. The most basic is the landfilling of untreated refuse carried directly to the landfill in collection vehicles and often termed as "direct landfill". This can be subdivided by the alternative methods available for emplacing refuse, that is, either dumped without compaction or covering (termed as insanitary, uncontrolled, crude or cascade landfilling), or emplaced in an ordered manner, compacted and covered during the day of deposition so as to reduce the likelihood of nuisance from fires, flies or vermin (termed as sanitary or controlled landfilling).

All the other methods are considered "indirect". Refuse is transferred and in some cases treated prior to deposition. The primary aim of treatment is to reduce the volume of airspace that a unit mass of refuse occupies and thereby to increase the payload of the transporting vehicle and potentially to increase the life of a landfill site. The secondary aim of treatment is to reduce the quantity of refuse disposed to landfill by undertaking separation and recycling. The transfer and treatment methods can be defined in four broad categories.

1. The simplest in practice is the transfer of refuse from low payload collection vehicles to higher payload bulk transporters. High payloads are obtained by compacting the refuse into a bulk haulage vehicle. Some operators argue that the legal payload limit can be reached without the need for compaction.

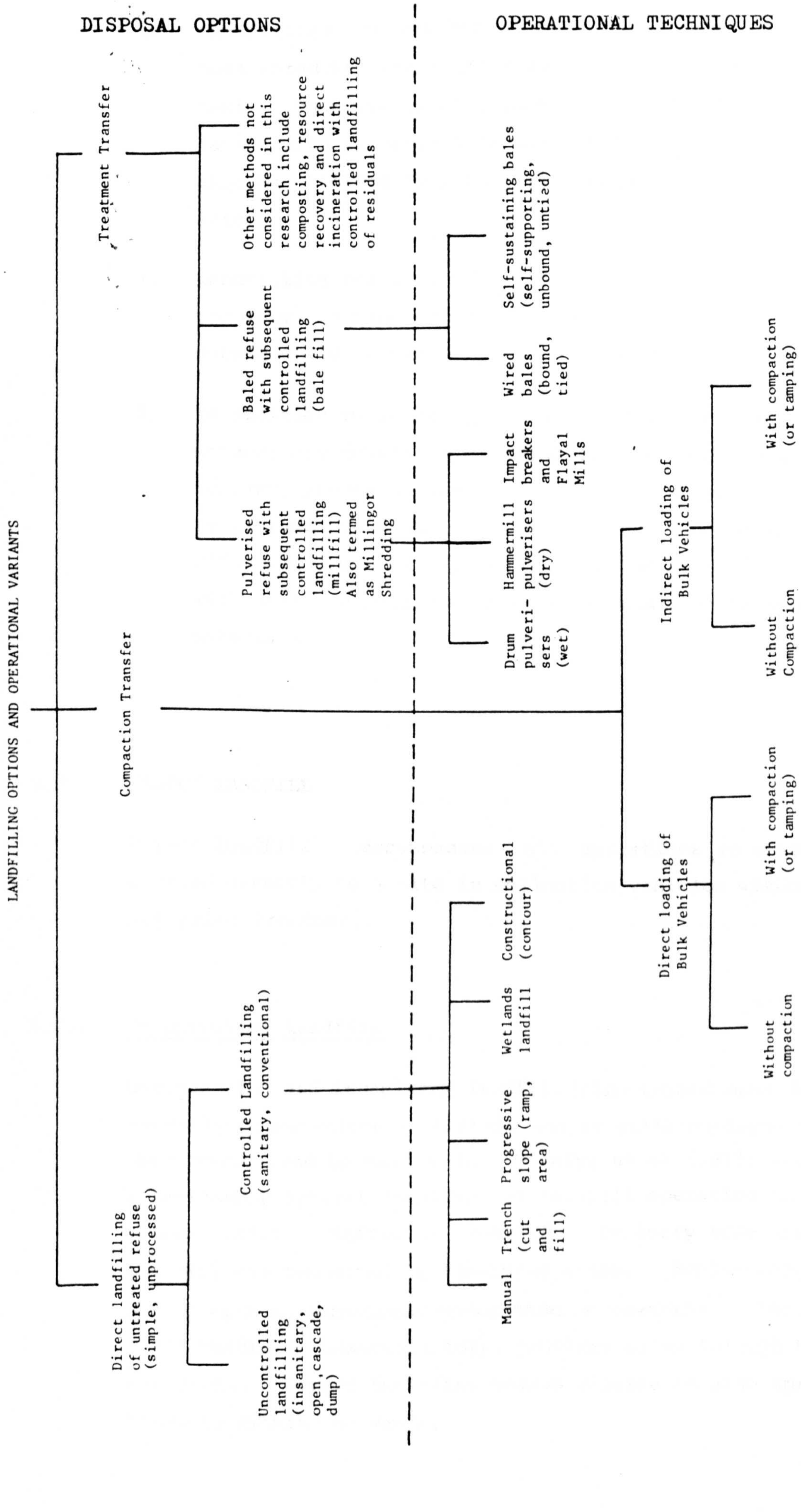


Figure 3.2 Diagram of the methods of refuse disposal involving landfill and the operational techniques available.
(The terms in brackets denote alternative names found in the literature for that particular technique or method.)

2. Landfilling pulverised refuse, i.e. waste which has been shredded into small fragments, before emplacement. Recovery of materials is often undertaken in association with pulverisation and refuse treated in this way can also be utilised as a fuel to heat boilers for steam generation.

3. Landfilling baled refuse. Waste, after possible resource recovery, is compressed into rectangular bales, and subsequently transported to and stacked in a landfill.

4. In addition to landfilling wastes, various other disposal methods are available. These include composting, resource recovery processes and incineration. (A more extensive list is included in Wilson, 1981). However, no matter how effective a method may be the availability of a landfill will still be required to take the residual or unprocessable materials.

3.2 DIRECT LANDFILL

Direct landfill encompasses all operations in which waste is carried directly to a site in collection vehicles without undergoing any prior treatment.

3.2.1 Uncontrolled Landfill

Uncontrolled and insanitary landfill (also termed open dumping) was until recently common-place in Britain and is still employed in parts of Europe, North America, and the Third World. Olaniya et al (1977) have described a reasonably typical uncontrolled landfill operation in the city of Jaipur, India. Refuse is carried by lorry some distance from the city and deposited in low-lying areas. Emplacement is haphazard with no subsequent compaction or covering. The site is environmentally unsatisfactory, problems arise through burning, odours and vermin. During the rainy season disease is also spread by flies breeding within the waste.

The leachate produced from the wastes at such sites is much more concentrated than at controlled landfill, due to the speed and type of decomposition processes operating. Pollution of surface and ground water is often more serious since it is unlikely that any anti-pollution engineering has been undertaken when preparing the site.

3.2.2 Controlled Landfill

All municipal landfilling in the UK is "controlled", and operations are expected to be conducted in accordance with the provisions of government legislation, most notably the Control of Pollution Act 1974.

Several definitions of controlled landfilling can be found in the literature. The standard definition adopted by the US Government's Environmental Protection Agency (EPA) is given below:

> "Sanitary (controlled) landfilling is a method of disposing of refuse on land without creating nuisances or hazards to public health or safety by utilising the principles of engineering to confine the refuse to the smallest practical volume, and cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary." (Nelson, 1974).

The site equipment, operations and techniques employed in controlled landfilling are described in subsequent sections.

3.2.3 Principles of Landfill Management

On controlled landfills refuse is deposited in discrete "segments" separated by cover material on all sides from previously emplaced refuse. This is to reduce the likelihood of problems from odour, vermin, insects, birds, fire, wind-blown litter, and visual intrusion.

Each segment corresponds to one day's refuse. Cover materials are commonly sands, clays, pulverised fuel ash, and occasionally sewage sludge. Both the refuse and cover material are compacted by mobile plant to increase the density achieved so minimising the airspace used. On some sites to improve site operations and further reduce the risk of fire and vermin, the refuse is emplaced in "cells". Large bays are built up from soil or other softfill and are capable of taking between three and six months refuse (Figure 3.3). Cover is also still used at the end of each day to seal off each segment. A layer of adjoining segments of accordant height is termed a "lift" and a completed landfill commonly contains two or more lifts. Throughout a site's lifetime measures are taken to minimise water pollution and gas problems, and to prepare it for a pre-determined after-use.

3.2.4 Site Selection Criteria

Landfill sites fall broadly into one of three categories (Baum and Parker, 1973; Anon, 1979a), these being:

1. Flatlands
2. Depressions
3. Constructional.

These categories are not mutually exclusive. Operations often incorporate two or all three of these categories during a site's lifetime.

Flatland sites include marshlands, tidelands, foreshore, moorland or marginal lowlands and are situations where a site is not appreciably below the level of the surrounding land. They are found in areas where there is no suitable or available hollows or in areas where a particular flatland requires stabilisation. The site depth is shallow and refuse tends to be laid down in only one or two lifts.

Depression sites utilise natural depressions or man-made irregularities in the terrain and include quarries, gravel pits, valleys cuttings, and subsidence areas. Refuse at these sites can be laid in several lifts each successively compacted and covered until the site level has been built up to the general level of the surrounding landscape. This is the most important category in the UK.

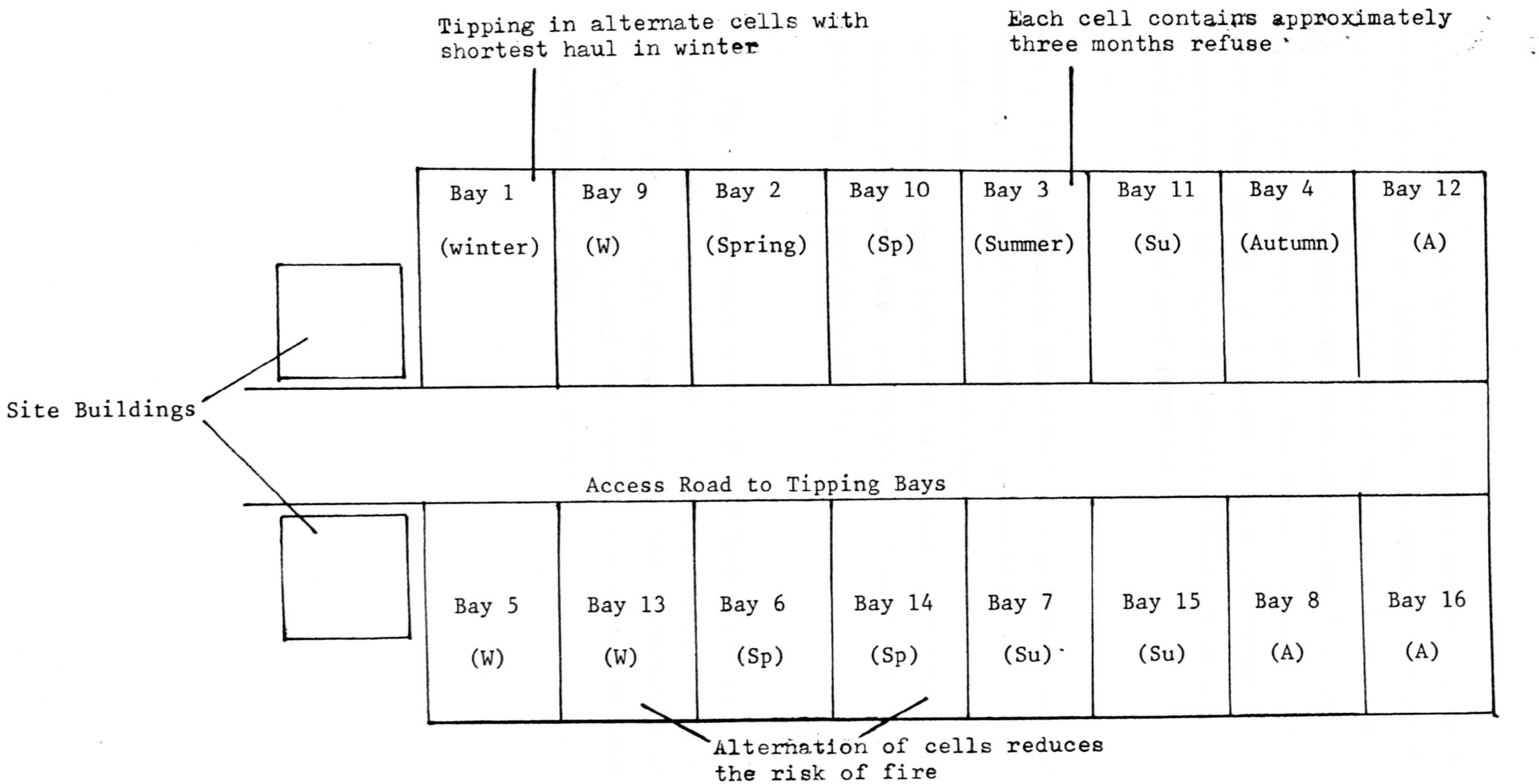


Fig. 3.3 An arrangement of cells and their period of use. A similar compartmental system has been in operation since the earliest days of controlled landfilling. (After Flintoff and Millard, 1969).

Constructional landfilling is a recent departure from the traditional type of landfills and is basically an extension of the flatlands form or the final stage of a depression landfill. This category encompasses those schemes which include the tipping of refuse well above the general level of the surrounding ground, in association with landscaping and contouring, to produce aesthetically pleasing artificial hills usually for recreational purposes.

Not all land initially identified as a possible location for a landfill is actually suitable. Hydrogeological, public health, social and political considerations must be taken into account. Often only a small number of favourable areas from a large initial list meet the conditions laid down by the various planning and regulatory bodies.

The EPA has described a set of "minimum criteria" on environmental aspects against which a selected site should conform (Table 3.2). While some of the criteria in this table are not directly relevant to the United Kingdom it represents a useful starting point.

Table 3.2 US Environmental Protection Agency Minimum Environmental Criteria for Landfills (modified after Manko and Katcher, 1978)

1.	Environmental Constraints: The EPA has identified areas of delicate environmental sensitivity and no disposal site should be located in or near these areas. The areas are:
a.	Wetlands
b.	Floodplains unless they do not restrict the natural usefulness of the floodplain and are floodproofed.
c.	Permafrost
d.	Critical habitats defined by the US Endangered Species Act, 1973
e.	Sole-source acquifer recharge zones. Additional sensitive areas to this list include fault zones, karst terrains, and areas of special scientific interest.
2.	Surface Water: Sites should not adversely affect surface water quality and permission is required for any discharges to watercourses.
3.	Ground Water: Sites should not adversely affect ground water quality.
4.	Air Pollution: Sites should be located and operated so as not to adversely affect air quality.
5.	Other criteria defined by local planning and regulatory bodies. For example, minimum distance from residential houses, relationship to local planning zones, proximity to airports.

Within any of the three site categories, flatland, depression or constructional, the water pollution potential (criteria 2 and 3 above) of a landfill is strongly influenced by the surrounding rock strata. Mather (1976) distinguishes between three types of site on the basis of the relative movement and attenuation of leachates (produced from the emplaced refuse) by the underlying strata.

Class 1 Sites

Sites which provide a significant element of containment for leachates, i.e. situated on relatively impermeable strata such as shales and clays.

Class 2 Sites

Sites allowing slow leachate migration and significant attenuation, termed "dispersal sites". A typical site would be one in fine sand or silt strata, glacial tills or loess with some depth of unsaturated rock beneath.

Such sites need to be located well away from groundwater abstraction points to enable the maximum possible dilution to proceed. Nelson (1974) estimates a minimum distance of 150m.

Class 3 Sites

This is concerned with those sites which allow rapid leachate migration and insignificant attenuation thus representing a high risk of pollution of the groundwater. Such sites could be located on gravels or other terrace deposits, limestones eroded by solution and virtually any highly fissured igneous or metamorphic rock such as granite, basalts and schists.

3.2.5 Site Operations

Landfill sites are valuable assets. Replacement sites are becoming more difficult to obtain and are invariably further from the areas generating wastes. Therefore a landfill should be managed by its operator to contain as much refuse as practical. To achieve this methods of emplacement have been developed to ensure the refuse is compacted into the smallest practicable volume by site machinery. There exists much confusion over the densities achieved in landfill sites and a detailed review of the literature for both untreated and treated refuse using different site vehicles and appropriate emplacement methods is discussed in Section 3.8.

There are two principal methods of emplacing refuse at the tip face:

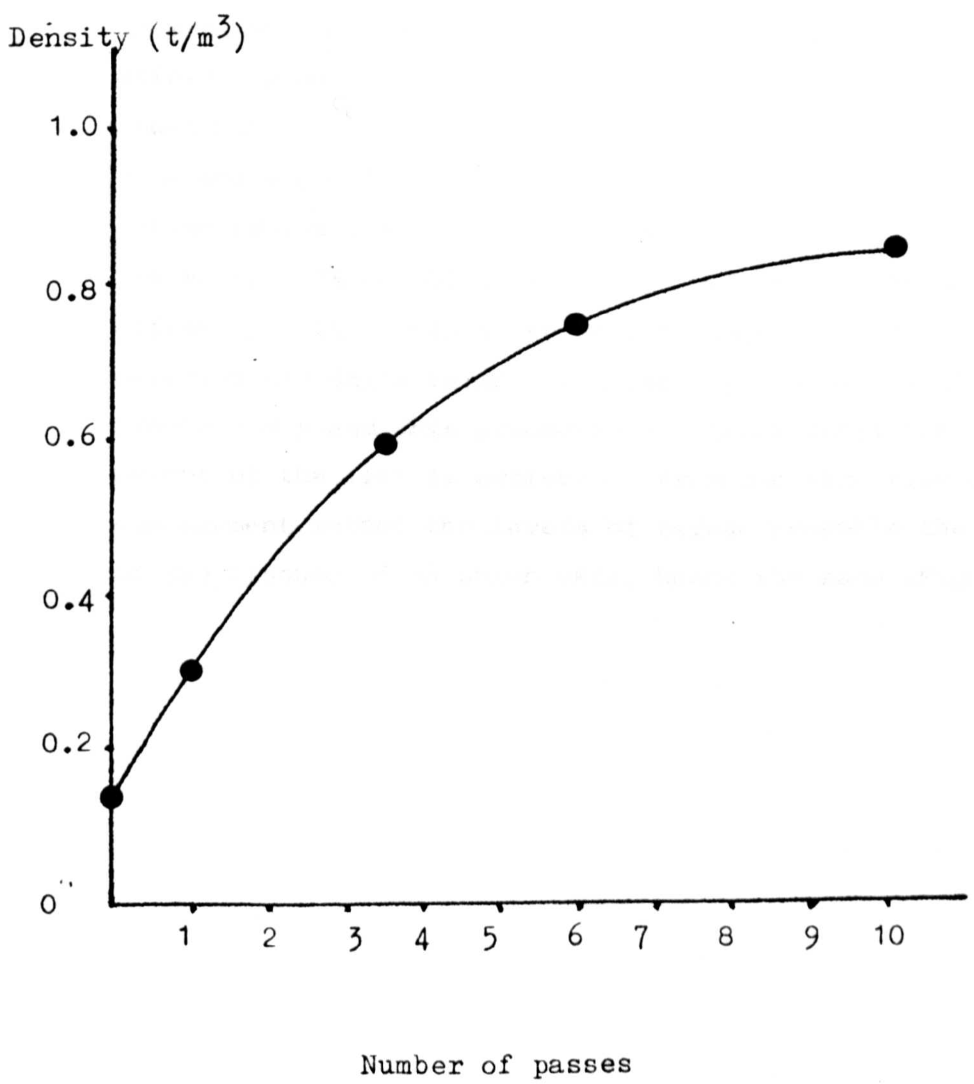
1. In Britain, the "over-the-top" method (or the US counterpart, "bottom-tipping" method) is the most widely used.

2. Thin layering methods.

Over-the-top

Refuse is emplaced by pushing it over and down the extending tip face. Consequently, newly arrived refuse is only compacted under the action of the emplacement vehicles when the lift is approximately 2m thick. This has the effect of preventing the entire mass from being compacted as fully as possible since only about the top 1m will become highly compacted with the remainder still relatively poorly compacted. However, by increasing the number of passes made by the emplacement vehicle the compacting pressure exerted rises significantly (Figure 3.4).

Fig 3.4 Refuse density with number of passes by emplacement vehicle (After Reindl,1977).



Thin-layering

These methods are based on the concept of depositing refuse in thin layers and building them up to the height of a lift. Two variants are described in the literature; onion skinning, and horizontal layering.

Onion skinning:

This method was first demonstrated by Bratley, (1976) and is gaining in popularity. Retaining banks are constructed of inert material to 2m in height and at one site bays 12m wide and approximately 20m long are produced. Incoming refuse is deposited at the base of the bay just in front of the working face (Figure 3.5). A compactor then pushes the refuse up 1 in 7 this slope in thin layers. In onion skinning one day's refuse is spread up and over that of the previous day and this procedure continues until the full 2m height of the lift is achieved. From the side view of this emplacement method the layers of refuse resemble the layering of the tissues of an onion skin, hence the name (Figure 3.6).

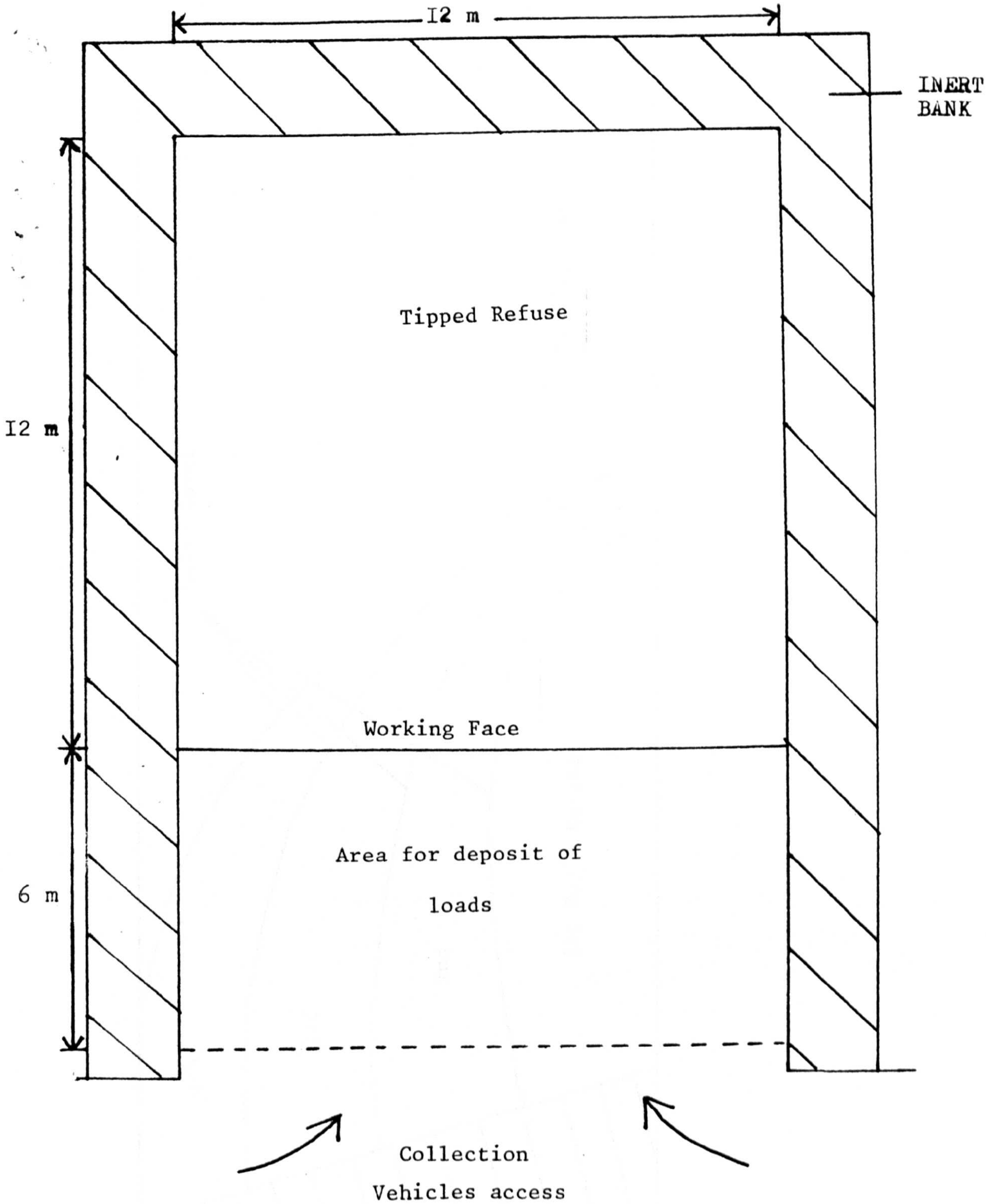
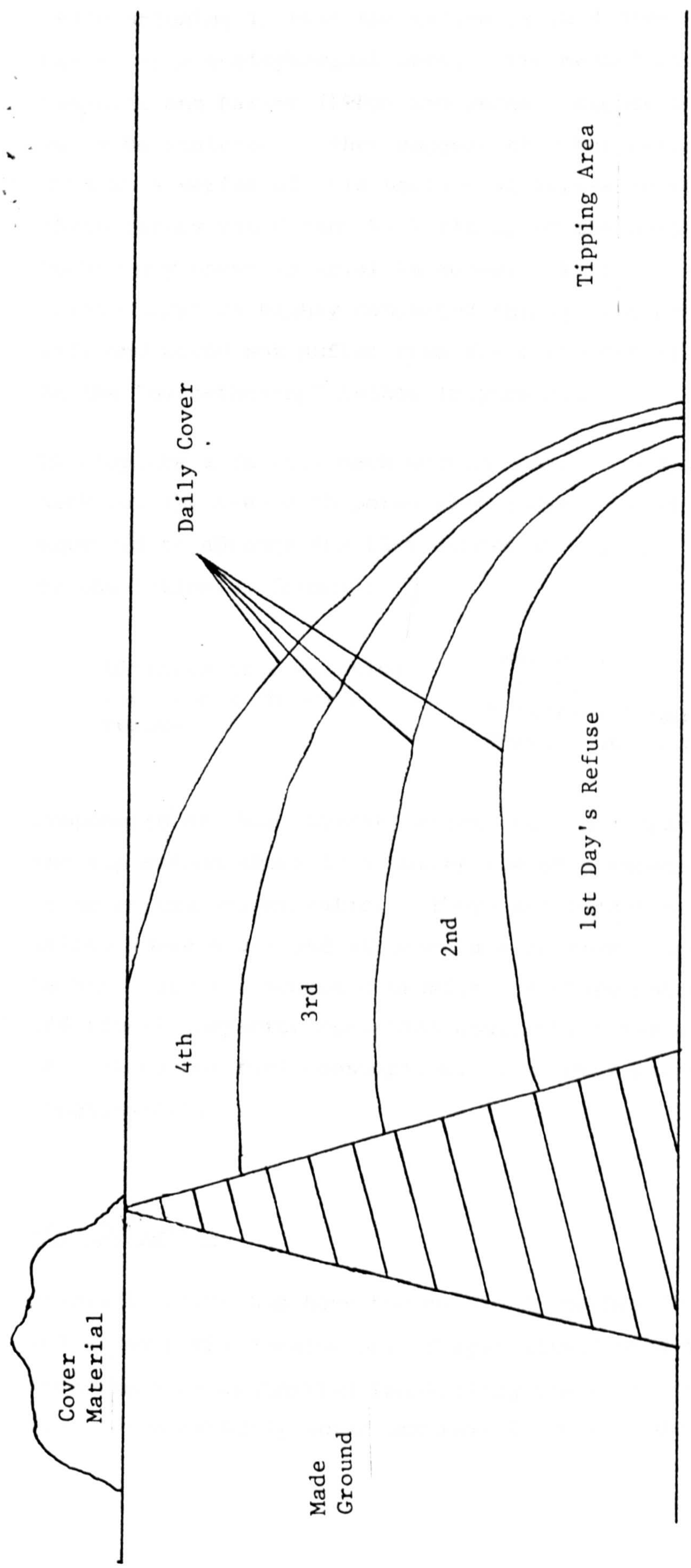


Fig. 3.5 Plan View of a Bay (After Bratley, 1976).

Fig 3.6 Side view of refuse emplacement using the onion skin method. (after Bratley, 1976)



Horizontal Layering:

This is a variant of thin layering which differs from onion skinning in that the refuse is laid down in horizontal bands rather than hemispherical ones. The method was first proposed by Campbell and Parker (1980) who suggest higher inputs of refuse would be achieved. They suggest that the refuse would be laid down in a series of thin horizontal layers approximately 0.5m thick. These layers would then be built up to the height of a 3m lift before any cover material is added. It is argued that the refuse would be highly compacted through the entire depth of the lift and would not suffer from the differential densities outlined in the "over-the-top" method (Figure 3.4).

To complete a 3m lift each working day, it would be necessary to mark out the area with poles that a day's arisings could be expected to advance the lift across the site. This is calculated by the following formula:

$$\text{Distance from existing face for each day's refuse} = \frac{\text{Refuse input rate per day}}{\text{Effective density} \times \text{Terrace width} \times \text{Terrace depth (i.e. refuse + cover)}}$$

Proponents of thin layering argue that in comparison to the over-the-top method there is a better use of airspace producing a lower cover refuse: weight ratio. These are important economic considerations where cover and airspace are in short supply. Campbell and Parker argue the economic benefits of these points outweigh any additional compactor operating costs which may accrue (i.e. increases in: compactor fuel consumption, compactor maintenance, and site supervision).

3.2.6 Site Equipment

Disposal operations have become highly mechanised in recent years and without the development of specialised site machinery the general acceptance of controlled landfilling practices or high throughput operations probably would not have been possible.

The variety of tasks on site requiring mobile machinery has been listed by McCartney (1980) and such equipment can be involved from the early stages of site preparation to the latter stages of site closure and restoration. The principal duties as considered by McCartney are:

1. Levelling and preparation of the site.
2. Preparation of access roads and manoeuvring areas.
3. Digging and carrying cover material.
4. Initial handling and segregation (if necessary) of incoming refuse.
5. Spreading and emplacing refuse in the landfill.
6. Spreading the cover material.
7. Final levelling and spreading topsoil.

Principally three types of machine are available, distinguished by their methods of traction: rubber tyred, tracked, and steel wheeled. The degree of compaction achieved by each vehicle type is an important factor in the choice of machine, but not the only one. Other criteria must also be considered:

The quantity of waste to be handled

The availability of cover

Reliability - susceptability to punctures or wheel damage

Other duties - e.g. site clearing, site maintenance, excavation and possibly off-site uses.

Each type of machine is discussed in more detail with regard to the criteria outlined above.

<u>Tracked Vehicles</u>

This type of vehicle was most popular in the early years of mechanised refuse disposal. It is extremely stable on sloping ground and not subject to punctures. This type of equipment usually has a dozer blade suitable for levelling, or a shovel which can dig and carry cover material. Major disadvantages are its low ground pressures (40-60 kPa), which do not produce a particularly high density in the emplaced refuse; and its slow travelling speed.

Rubber-tyred Vehicles

These four-wheeled drive vehicles are very mobile over the site terrain and when fitted with a standard or four-in-one loading shovel they can perform all of the daily routines on site. The narrow contact area of the tyres with the ground produces a high compacting pressure, approximately 200 kPa. These machines are not particularly manageable on steep slopes and get "bogged down" more easily than tracked vehicles on unconsolidated material or in wet weather. In the past this type of vehicle suffered from poor reliability due to punctures but now solid or fluid-filled tyres have been developed to alleviate this problem.

Steel-wheeled Compactors

Steel-wheeled compactors are a recent development. They are much more expensive than tracked or rubber tyred vehicles, but are able to produce higher refuse densities. They are said to compact by the action of the steel protrusions (cleats) from the wheels. However, in practice these cleats become clogged with refuse, especially on clayey or wet sites and as a result, compacting probably tends to be by deadweight spread over the contact area of the wheels.

Compactors are usually fitted with a specialised dozer blade, a "landfill blade", and it is chiefly used to emplace refuse at the tip face. Compactors are designed to handle far larger quantities of refuse than other types of site vehicles. However, it is not practicable for them to win or carry cover across site. Consequently, they must be used in conjunction with support vehicles which undertake the other tasks around the site.

The use of a particular type of machine can be summarised for different sizes of landfill. One machine (e.g. tracked or rubber tyred) can perform all of the functions necessary on a small site but on larger ones a division of labour improves efficiency and unit costs. Compactors are becoming increasingly used on sites with inputs above about 150t/d along with rubber tyred support vehicles. Baum and Parker (1973) and Nelson (1974) have suggested the numbers and types of machinery required for landfill sites on an average daily tonneage basis (Table 3.3).

Table 3.3 GENERALISED EQUIPMENT REQUIREMENT FOR LANDFILL SITES

Daily Refuse Tonneages (tonnes)	No. of Refuse Emplacement Machines		Types of Emplacement and Ancillary Equipment		Weight range of machinery (tonnes)	
	BP	N	BP	N	BP	N
0 - 25	1	1	Tracked or rubber tyred front end loader 1-2m^3. Also a landfill blade attachment.	Tracked dozer. Tracked or rubber tyred loader.	4.5 - 13.5	4.5 - 14
25 - 140	1	1	Tracked or rubber tyred front end loader with landfill blade. Also possibly: scraper, dragline, water truck.	Tracked or rubber tyred front end loader plus speciality machinery (i.e. scraper, dragline, water truck)	13.5 - 27	14 - 27
140 - 270	1-2	1-2	As above but including steel wheeled compactors.	As above but including steel wheeled compactors.	13.5+ each	14+ each
270+	2+	2+	Tracked, rubber tyred or steel wheeled compactor with landfill blade. Front end loader, dragline, scraper, water truck.	As BP	20.5+ each	18+ each.

Sources: (both American) BP - Baum and Parker, 1973; N - Nelson, 1974.

Notes:
- In UK where hot, dry conditions are not generally prevalent the suggested requirement for a water truck can be ignored.
- Draglines and scrapers are only used in Britain on very large sites (approx 1000t/d or more).
- General observations of UK operations closely resemble the number of emplacement machines recommended by these American authors.

3.3 INDIRECT LANDFILLING

Indirect landfilling describes those methods of landfill disposal which involve the transfer of refuse from collection vehicles to higher payload bulk transporters, prior to its emplacement at a disposal site.

3.3.1 Transfer Stations and Treatment Plants

The transferal of refuse via a transfer station can take a variety of forms with some stations incorporating treatment of the refuse namely, sorting, pulverisation or baling; while others simply transfer untreated refuse.

The more modern plants employ compaction to improve the bulk transporter's payload and loads are frequently achieved up to the legal road weight or rail operating limits. Some would say however, compacting is not necessary to achieve these limits.

Transfer stations are favoured when available landfills are some distance away from the areas of refuse generation, thus by constructing a centralised transfer point collection vehicles need not make excessively long journeys to the landfill and instead can return to collecting much sooner. Furthermore, the fixed location of a transfer station means that collection vehicle routings do not have to be reorganised every time a new landfill is established (Wilson, 1981).

The decision to establish a transfer operation is largely an economic one, based on a situation where the total cost of transfer and bulk handling is less than that incurred by direct haulage with collection vehicles, providing it is still below the estimated cost of the next cheapest disposal method. The relative economic advantage of direct and transferred haul varies with haul distance (Figure 3.7). The distance at which break-even occurs is open to debate; it will vary regionally as well as upon the mode of bulk haulage used; that is, road, rail or river. For road haulage, Palmer (1979) suggests transfer is more economical for landfills over 20 - 25 km away when considering operational experience in Suffolk. In Norfolk it is estimated

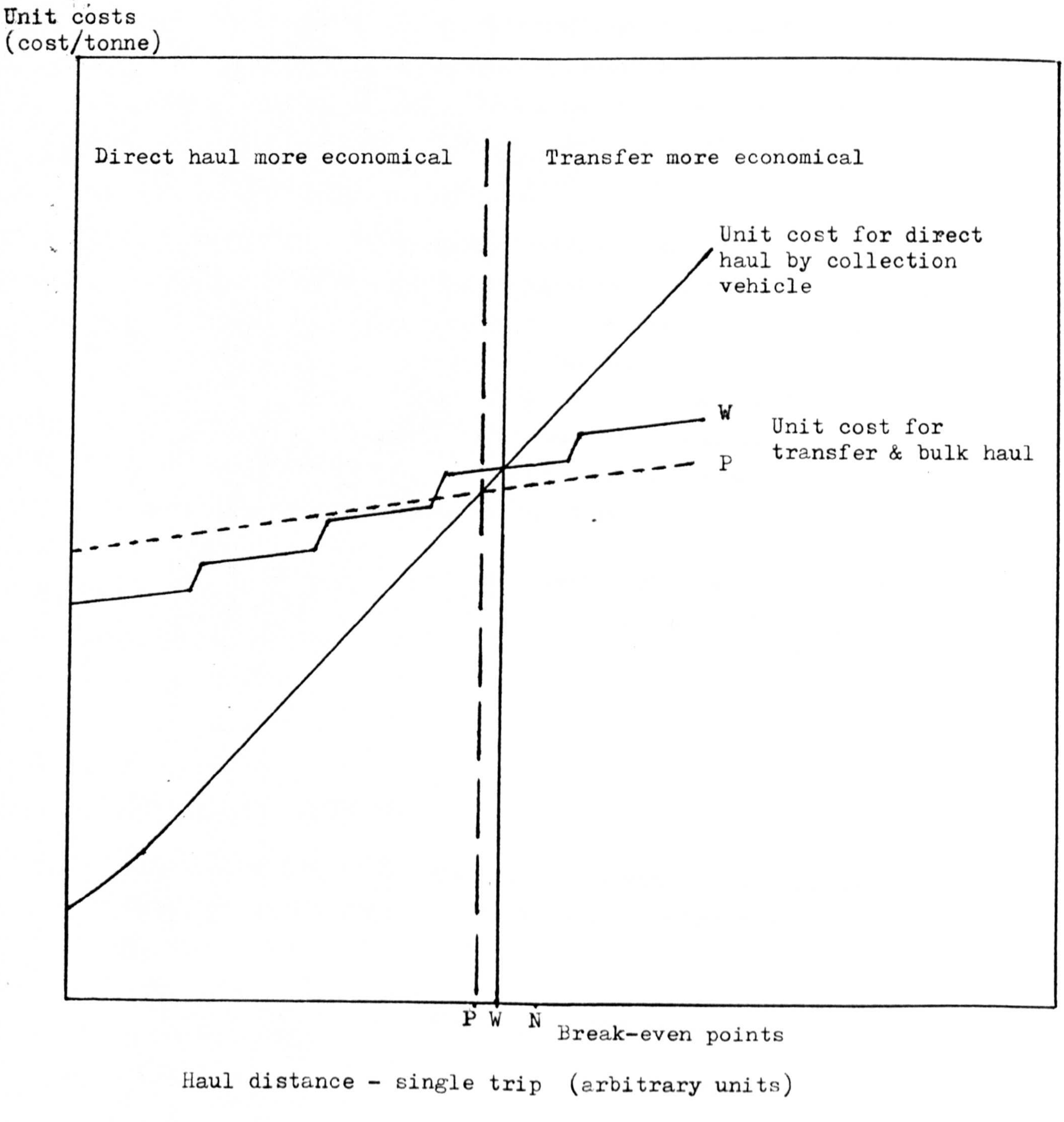


Fig 3.7 The economic relationship between direct and bulk haul of refuse to a distant disposal point.
(after Palmer, 1979 (P); Norfolk CC, 1980 (N); Wilson, 1981 (W))

as 30km. Wilson (1981) using empirical figures suggests the transfer component in bulk haulage is stepwise increasing with tonneage and that there is a periodic requirement for additional vehicles as tonneages rise. Furthermore, he has shown that the break-even point is dependant on the relative speeds at which collection and bulk vehicles operate.

Wilson found that if the speeds of the bulk and collection vehicles are similar then direct haul is cheaper for sites up to 30 km away (the upper distance in his analysis). However, it is reasonable to expect that collection vehicles actually travel slower than bulk transporters. Thus, assuming bulk vehicles travel at 20 - 30 km/h then transfer becomes cheaper for sites 20 - 30 km away when collection vehicles travel at 15 km/h, and for sites 10 - 20 km away at speeds of only 10 km/h (Table 3.4).

It is emphasised however that individual studies are required for each particular case since Wilson's figures are based on hypothetical data.

3.4 TRANSFER WITHOUT TREATMENT

The simplest methods of transfer are those which do not involve treatment and four operational techniques are identified (Figure 3.8):

1. Direct transfer from collection to bulk vehicles without compaction.
2. Direct transfer from collection to bulk vehicles with compaction.
3. Indirect transfer from collection to bulk vehicles without compaction.
4. Indirect transfer from collection to bulk vehicles with compaction.

Table 3.4 BREAK-EVEN DISTANCES QUOTED IN THE LITERATURE

Source		Approximate break-even distance at which transfer becomes cheaper than direct haul (single trip) Km
Palmer (1979)	Suffolk operating experience	20 - 25
Wilson (1981)	Collection and bulk same speeds	Undetermined
	Bulk 20-30 Km/h Collection 15 Km/h	20 - 30
	Bulk 20-30 Km/h Collection 10 Km/h	10 - 20
Norfolk County Council (1980)	Norfolk Waste Disposal Plan calculation	30

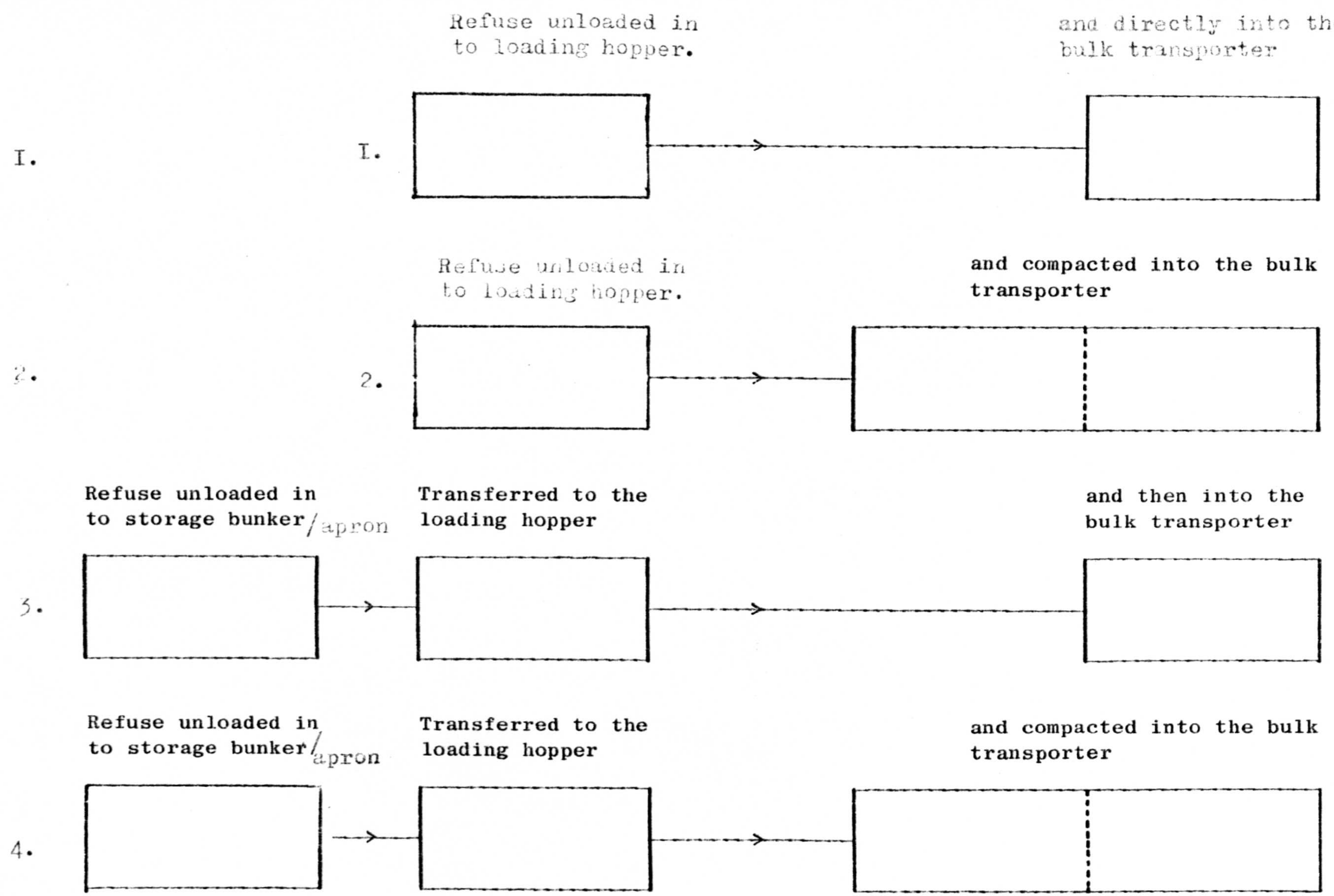


Fig 3.8 Summary of the operating techniques possible for transfer stations

3.4.1 Direct transfer from collection to bulk vehicles without compaction

The concept of transfer is not new; direct transfer without compaction was operating at the turn of the century in some US cities when collection vehicles were still horse-drawn (Hagerty et al, 1973). This transfer technique is very straightforward in design and as with each of the other techniques the operational layout of a site is specific to each station.

Wilson (1981) has summarised two general layouts for such a transfer station:

1. The least sophisticated is an open concrete apron probably bounded by an earth bank. Refuse is tipped on to this apron and then directly loaded into an open top lorry by a front-end loader. This method is unlikely to be acceptable in urban areas.

2. To remove the need for handling by loaders the refuse can be tipped directly into the waiting vehicle or container beneath. This arrangement requires the construction of a raised apron for the collection vehicles to discharge from. To further improve its acceptability the whole operation can be enclosed within a building. Usually the upper level is about 5.5m above the lower and the tipping aperture approximately 9m long by 1.8m wide (Ferguson, 1971).

Direct transfer has been used in conjunction with road, rail and river haulage at one time or another but generally this technique is not favoured at present. Frequently, it is difficult to obtain large enough payloads in a bulk transporter for economic operation.

3.4.2 Direct transfer from collection to bulk vehicles with compaction

Essentially the station has a similar layout to (2) above, however, refuse does not just pass from one vehicle into another but instead is acted upon by a compactor at some stage in the transferal.

The aim behind compaction is the elimination of void space and the expulsion of air from the bulk transporter thereby enabling higher tonneages to be carried. It also has the advantage of an aesthetic benefit over non-compaction methods by reducing littering. Tamping was the first method of compaction involving nothing more than the use of a crane's grab or loader's shovel to push down the refuse in an open-topped bulk transporter. Flintoff and Millard (1969) described a case where this procedure was used at a former rail transfer station in Islington, London, and also a modification at the river transfer stations at Grosvenor Dock and Walbrook Wharf, London. At Walbrook an overhead travelling compaction ram compressed the refuse into the barges beneath. Compaction within barges is of only limited effectiveness since part of the compressive force is lost through displacement of the floating barge itself.

In recent years there has been a trend not only to enclose the transfer stations but also the bulk transporters, by using containers or covered trailers. With it has come the use of enclosed stationery compactors to form an integrated transferal system rather than the exposed methods with tamping. Refuse is fed first into a hopper before being pushed into the charge box of the compactor. A compacting ram pushes the refuse into a container unit clamped against the discharge aperture of the compactor. Loading continues until electronic or mechanical weight or volume indicators signal the container to be full. At the rear of the container large double doors are closed or alternatively tarpaulins are tied down to prevent any possible spillage. The container is then ready for road haulage or for manoeuvering and lifting on to a railway wagon. Harrison (1980) has noted that compacted, containerised refuse could also be transported by river on barges or larger self-powered vessels. He goes on to state that compaction ratios are typically 1:3 to 1:5 and occasionally as high as 1:9 with light refuse.

Transfer stations can vary in size from one compactor up to ten. The larger number enables a higher throughput to be handled as well as allowing for some spare capacity. Ferguson (1971) as a rough rule of thumb suggests approximately one compactor per 100 tonnes of daily refuse. This applies to direct transfer only, where sufficient compacting equipment and containers are necessary to deal with peak throughputs. Filled containers therefore provide temporary buffer storage prior to hauling to the landfill.

3.4.3 Waste Handling on Reception

The arrival of collection vehicles is not uniform but tends to peak at one or more times of the day. Some provision is therefore made at the transfer station for buffer storage to prevent long queues. In recently commissioned small plants (up to 500t/d) apron storage is employed. This form of storage is less expensive to construct and operate than bunkers but equally effective in buffering peak arrivals of incoming refuse. For larger throughputs (above 500t/d) Lisiecki (1976) suggests bunker storage is more appropriate especially where peak arrivals account for a large proportion of the total daily tonneage.

The simplest storage is to discharge the refuse onto a concrete apron adjacent to the loading hopper into which it is then subsequently loaded by mechanical shovel. In more sophisticated designs storage bunkers are constructed whose depths are related to the peak tonneages arriving. The desired storage capacity can range from peak only to over one day.

There are a number of possible handling systems using overhead cranes with grab attachments or "in-bunker" conveyor systems. However, the use of bunkers as buffer storage to cope with peak throughputs is not favoured by everyone in the waste management field. Cheyney (1980) suggests two reasons against the use of this method of storage.

His criticisms are:

1. The size of a bunker to cater for all likely fluctuations in input would need to be large in size and construction costs and would result in double handling the refuse.

2. If a bunker is constructed, it cannot be cleaned out very frequently; a feature which could lead to increased problems of smell, vectors and fires.

Apron storage has been favoured over bunker storage in virtually all recent developments handling below about 750t/d primarily on economic grounds. Bunker construction adds considerable extra capital expenditure to the project cost (approximately £200,000/100t of storage volume - 1981 prices).

3.4.4 Indirect transfer from collection to bulk vehicles without compaction

The indirect transfer of refuse usually incorporates compaction equipment. Flintoff and Millard (1969) commented that some river transfer stations were designed for collection vehicles to discharge into a reception bunker on the dockside and then a grab crane transferred the refuse directly into a waiting barge. Some tamping was often incorporated with an experienced operator able to handle approximately 200 tonnes in an eight-hour shift. This is the closest example of indirect transfer without compaction in the UK.

3.4.5 Indirect transfer from collection to bulk vehicles with compaction

This operational technique is the most sophisticated of the four alternatives described and undoubtedly the most expensive to construct and operate. Such transfer stations incorporate not only buffer storage but also compaction equipment and are operationally the most flexible. They are able to cope with peak demands without an excess of redundant equipment as well as attaining high payloads by compaction. There are at present many plants of this type in existence, e.g. Whetstone in Leicestershire.

3.4.6 Transporting Transferred Refuse

Waste can be transferred effectively by three distinct modes: road, rail, and river.

Road

An extensive range of road vehicles and containers are available for bulk transport.

Principally there are two basic designs; demountable containers, and covered or flatbed trailer units. The first type, demountable containers, are carried on a rigid chassis between disposal site and transfer station. A tipping mechanism allows each loading and discharge of refuse. In the loading operation the container is demounted, manoeuvered and clamped to the compactor. When full a container is hoisted onto the lorry chassis by means of a hook and jib or drag-line arrangement.

This method of bulk transport is the most popular in the UK and a range of capacities for open topped and covered ISOcontainers are available. Two common container sizes are 10t and 16t carrying capacity.

The second type of road transport are articulated trailer units complete with their own rear axle(s). Trailers are loaded in a similar manner to demountables but discharge is usually by on-board ejection ram rather than tipping mechanisms. Covered trailers are used for all refuse except baled which employs cheaper flat beds, or half-sided trailers. Trailer sizes used are commonly 12, 14, 16 or 22t carrying capacity, although until recently the UK gross vehicle weight of 32 tonnes did not allow the full capacity of the 22t trailer to be realised.

Rail

All current rail transfer in Britain is by container, a feature introduced by the establishment of "liner trains" whereby the containers and rolling stock are owned by a local authority or private haulier rather than British Rail. British Rail has an upper operating limit of 1,400 tonnes per train and hauling costs are on a per-train-load basis. Therefore it is in the best interests of the local authority to maximise the payload in its containers. A freight train usually has a deadweight of approximately 500 - 600 tonnes so enabling refuse loads of 900 - 800 tonnes to be transported. There are currently five rail transfer stations in Britain; three are situated in London, at Brentford, Hendon, and Hillingdon. Refuse from the first is carried to a landfill in Oxfordshire; from the second to Bedfordshire; and the third to a site in Northamptonshire. The other two stations are operated in Manchester.

Loading and unloading of all containerised equipment is by forklift or overhead crane and provisions for these will be required on site. Rail transfer is only economic in the UK where loads of about 800t can be produced in a day, where the rail head is directly adjacent to the landfill and where a return trip can be completed by the railway staff within one shift.

River

River transfer is at present solely operated in London and with the exception of Cringle Dock, Westminster, (which carries pulverised refuse) the other four stations handle tamped, untreated refuse. A typical barge has a registered tonneage of approximately 140 tonnes and a carrying capacity of 290 tonnes. It is likely that even with tamping, loads will not exceed 115 tonnes (Flintoff and Millard, 1969). The pulverisation of refuse at Cringle Dock has enabled the payload of a barge to be improved to around 200 tonnes (Ferguson, 1973).

When filled the barges are marshalled together in twos, fours or sixes, and towed by tug to a riverside disposal point 70 km away on the Pitsea Marshes in Essex.

3.5 TRANSFER WITH TREATMENT - PULVERISATION

Pulverisation has been a common method of waste treatment for the last twenty years particularly where operators consider the refuse requires some form of processing before it is acceptable for landfill. This process involves a milling, shredding or grinding action designed to break down the larger components in the waste and so reduce the average particle size. Pulverising refuse is said to produce a product in which putrescible matter becomes thoroughly mixed.

It is believed by some to be impossible to landfill municipal waste properly in an untreated state no matter how rigidly site licensing conditions are applied (Skitt, 1979; Porteous, 1981). The reason for this opinion is that the composition of domestic refuse has changed in the past years and now includes a larger proportion of low density materials, notably paper and plastics. These can easily become airborne when discharged from a vehicle or blown off of the tip face. There has also been a steady decrease in the proportion of ash and denser materials (DOE, 1971). Skitt adds that obtaining cover material in sufficient quantities is becoming difficult, a problem alleviated by pulverised refuse which is claimed to require no daily covering. However, in reality most UK pulverised refuse is covered daily in just the same way as untreated refuse.

The practice of pulverising refuse began in the last century in Southwark, London. However the technique has only become established in the last 25 years following development work carried out on the Continent. The method was developed from the industrial practices of crushing quarried stone and the milling of grain. Originally the earliest pulverisers were low capacity units designed to break-down bulky items prior to composting, but subsequent designs have concentrated on higher throughput equipment primarily as a preparation for landfilling. Due to the mixed nature of the treated refuse pulverisation prior to resource recovery is claimed to be a necessary pre-requisite and as such gained further popularity. Conversely, others have argued that screening (and thus recovery) ought to be undertaken before pulverisation since potentially non-reducible or explosive materials can be removed before damaging the plant (Nollet and Sherwin, 1979).

3.5.1 The Location of Pulverisers

The location of the pulverising equipment must be considered in the context of the subsequent destination of the product. It is a common practice to site a pulverisation plant centrally within a waste collection area for the same reasons discussed under compaction in Section 3.3.1. Occasionally pulverisers are located at landfill operations, such as those at Aberdeen and Harlech in Wales. However this should only occur where a site is centrally located to its catchment and once landfilling is completed, and more distant landfills are being utilised, that site converts to the role of a transfer station.

The location and nature of pulverised refuse enables a much more flexible disposal plan to be devised than that possible with untreated refuse, and is more readily adapted as trends in disposal philisophy and practice change (Figure 3.9). Ham (1975) has argued that one of the main reasons for the interest in pulverisation is that it is usually the first step in "advanced processing schemes".

Pulverisation however is a more expensive option to construct and operate than direct landfill or compaction transfer. Authorities in the UK frequently do not have the necessary finance to make this first step to keeping open future options. Ham proposes the contrary however for the United States, where saving money is often less important than the ultimate quality and public acceptability of the chosen disposal method.

Ultimately pulverisation operations involve landfilling for the comminuted product and the unprocessible or residual materials.

3.5.2 Advantages and Disadvantages of Pulverisation

Several lines of argument have been proposed supporting or criticising pulverisation and these are discussed in depth in Appendix 3A. In this section only the generally quoted, although not always substantiated, advantages and disadvantages are listed (Table 3.5); reference to Appendix 3A is urged for a fuller understanding of the complex arguments surrounding pulverisation.

Direct Landfill of Untreated Refuse

Collection ——————> Landfill

Collection ——> Transfer (Possible crude resource recovery) ——> Landfill

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Pulverised landfill (Treated Refuse)

Collection ——> Pulverisation at Transfer ——> Landfill

Collection ——> Pulverisation and resource recovery ——> Landfill

Collection ——> Pulverisation ——> Incineration ——> Ash) ——> Incombustibles) To landfill

Collection ——> Pulverisation (necessary pre-requisite) ——> RDF ——> Incombustible material to landfill

Collection ——> Pulverisation (necessary pre-requisite) ——> Composting ——> Incompostible material to landfill

Collection ——> Pulverisation (necessary pre-requisite) ——> Experimental Disposal Processes of Pyrolysis, Acid Hydrolysis ——> Rejected material to landfill

Fig. 3.9 Comparison between disposal alternatives for direct landfill and pulverisation

Table 3.5 Advantages and Disadvantages of Pulverisation

Arguments for	Arguments against
1. The comminuted nature of pulverised waste reduces the presence of void spaces in the landfill and so produces savings in the daily volume used.	Disputed
2. The reduction in voids increases site lifetime and reduces the fire risk.	
3. No daily cover required.	The Control of Pollution Act 1974 implies that all landfills require daily cover.
4. Food wastes are rendered unpalletable to vermin and consequently reduces the presence of pests at a landfill.	Not proven.
5. The smaller particle size is less likely to become airborne and create litter.	Disputed
6. No perceivable odours are said to eminate from pulverised refuse.	Not found to be the case in practice.
7. The smaller particle size is susceptible to an increased rate of decomposition and final settlement of the landfill is sooner.	The smaller particle size in accelerating decomposition is likely to produce a stronger leachate than non-pulverised wastes.
8. Reduced problems with gas.	Not found to be the case in practice.
9. A technologically sound method of treatment.	Pulverisers have a poor record of reliability.
10. Reduces the need for land-fill site.	Landfill is still required to take the pulverised waste and irreducibles, and to cover during plant breakdowns.
11. Pulverisation can be used by any authority.	Pulverisation is not suitable for disposal authorities with small daily arisings.
12. Any increase in disposal costs is small compared to the improvements made in handling waste.	More expensive than direct landfill and provides no reduction in bulk transport over compaction transfer.

3.5.3 Pulverisation Techniques

The most detailed study of pulverisation techniques published was that of Reindhart and Ham (1974) who conducted a seven-year project at Madison, Wisconsin. Their findings are widely quoted in the literature on this subject along with Marsden (1973) who described a pulverisation scheme at Holes Bay, Poole, Dorset. The salient points of their articles are quoted throughout this chapter.

An estimate of the number of pulverisers in operation in the UK was derived as 74 from a survey conducted by Loram (1976) but this figure is now dated and unreliable. Ham (1975) following a similar survey put the number at 60 in the US although he noted that the figure was steadily rising but is now probably just as unreliable as the UK figure.

All pulverisation plants, unless located adjacent to the landfill, are indirect transfer operations. The basic plant consists of a reception area, a feed system carrying refuse to the pulveriser and a second transport mechanism to carry the pulverised product direct to a waiting vehicle or product storage hopper.

There are basically two types of pulveriser; those which breakdown refuse by pounding it with spinning hammers; and those which reduce it by attrition or abrasion within a rotating drum. They are known as the hammermill and drum methods respectively and since water is commonly added to the latter method they are also termed as dry or wet pulverisation.

The pulverised waste can be discharged directly into open topped lorries (e.g. Caister, Norfolk) or routed through a compactor and packed into covered containers (e.g. Millhouses, Sheffield).

3.5.4 Comparison between rotary drum and hammermill methods

Little scientific work has been published on comparisons between wet and dry pulverisation. A survey of the literature provides several subjective evaluations based on authors' experiences.

1. A more accurate control of product size is possible with hammermills and the proportion of rejects is smaller (Skitt, 1979).
2. The peak power demand is greater for hammermills but the mean power consumption per tonne is virtually the same (Reinhardt et al., 1974)

3. A wet pulverised product is argued to be more suited to landfilling since there is virtually no litter problem during transport or landfilling.
(Loram, 1976).

4. In contrast to (3) the wet product increases the weight of refuse to be bulk hauled and consequently transport costs are marginally higher than the dry, hammermill product (Loram, 1976).

5. In drum pulverisers the formation of "ropes", a roll of matted material running along the length of the machine, is a recurrent problem which requires manual removal.

6. The dry pulverised product from hammermills is more commonly used for subsequent resource recovery although resources can also be recovered during pre-screening prior to pulverisation. (Loram, 1976).

3.5.5 Impact breakers and Flail Mills

Impact breakers are designed to break up bulky items such as cookers and furniture prior to landfilling. If left intact these can create voids within landfill sites and handling problems at incinerators. Feed openings are up to 1.5m x 3m and the items are broken up by impact between fixed hammers on the rotor arm and blow bars. The product is visually fairly coarse, i.e. greater than 12.5cm in diameter, however, certain recent advances in hammermill design now enable these to cope with both "normal" and bulky items. This has eliminated the need at some stations for separate machines.

Flail mills can accommodate both bulky and normal refuse. They produce a coarse product which requires less power than pulverisers and are arguably more suited to resource recovery.

3.5.6 Landfilling Pulverised Refuse

The statement by Ham (1975) following a survey of sites in the US and Europe serves to put this aspect of pulverisation into context.

> "It was interesting to observe the lack of uniformity of experience or knowledge with respect to shredded solid waste landfills."

This lack of uniformity stems from the conflicting views laid out in the advantages and disadvantages of pulverisation discussed earlier and disagreements between suitable methods of landfilling also exist between its proponents. An example of this is the use of daily cover. Rimberg (1975) states it is not necessary but others suggest that it should be applied so as to suppress odours (DOE, 1971) and to prevent excessive infiltration (Ham, 1975).

The emplacement of pulverised refuse and the site equipment resemble that discussed for the landfilling of untreated wastes. Pulverised landfills can be established on flatland, depression and constructional sites, and the site preparations are identical to those required at direct landfills.

3.6 TRANSFER WITH TREATMENT - BALING

Baling is the application of pressure to "loose" waste within a confined volume; this action produces a compacted, rectangular bale. To maintain the integrity of a bale where "low" or "medium" compaction pressures are used it is bound with wire, plastic or netting. Where "high" pressures are involved the bale is typically self-supporting. The relevance of these differences in pressure will become apparent in later sections.

Baling has only recently become commercially available as a treatment method for wastes prior to landfilling. Its primary objective as with the other treatment methods are to increase refuse density thereby increasing bulk transporter payloads and site lifetimes.

The first application of baling was in Japan in 1960; however development did not increase in pace until the Americans studied the technique. In the US baling was originally seen as an extension to the practice of bulk hauling by rail. In the mid-1960s one major study on this method was conducted by the APWA in Chicago (General Electric, 1975). By the end of that decade three full-scale plants were in operation built with the aid of development grants at San Diego, California; Cambridge, Massachusetts; and St Pauls, Minnesota. It is from these plants that much of the operational and technical information quoted in the literature is derived.

The technique of baling domestic refuse, like pulverisation, has evolved from equipment designed for industrial uses. Manufacturers strong in specific fields adapted their equipment to handle domestic refuse and currently three companies manufacture equipment for this purpose: The American Hoist and Derrick Company (Amhoist), known in the UK as Harris-Economy Limited; Lindemann (W. Germany) and Vickers - Logemann (UK). Two convergent lines of development can be traced. The first system produces a wired bale and was developed from paper baling equipment. The second produces self-sustaining bales and originated from scrap metal balers.

The end product of a baling operation is a rectangular bale which can be subsequently carried to landfill by lorry or railway wagon.

It is the ease of handling baled waste both at the transfer station and the landfill which is frequently stressed as an innovation unique to the method.

In Britain only a few plants are operational, the first in Glasgow, only began operations in 1976. Consequently, operational experience of the equipment and landfill methods is limited.

3.6.1 Advantages and Disadvantages of Baling

As discussed in Section 3.5.1 for pulverisation, baling also has its supporters and opponents. Since there is very little reliable and independent information published there is frequently no scientific backing to substantiate the merits or disadvantages of baling as a waste treatment method. The more commonly cited pros and cons are listed in Table 3.6 and supplemented by a more detailed discussion in Appendix 3B.

Table 3.6 Advantages and Disadvantages of Baling

Arguments for	Arguments against
1. The physical crushing of waste reduces the voidage enabling site volume to be saved.	Springback occurs in self-sustaining bales soon after production. This results in a significant loss in waste density. Furthermore the poor stacking of bales in the landfill is inevitable under normal operating conditions and leads to no overall improvement in site density compared with untreated waste emplaced by a steel wheel compactor.
2. Void reduction reduces the risk of fire.	
3. No daily cover required.	Daily cover is likely to be required as a planning requirement.
4. Cheaper, less sophisticated machinery can be used to emplace bales.	Insufficient information on the reliability of balers.
5. Decomposition within the bale will be slow and consequently leachate and gas production are likely to be lower.	Not found to be the case in practice.
6. Baled wastes do not release any odours.	Disputed.
7. Potential problems from wind blown litter are reduced.	Disputed.
8. Food wastes are rendered unpalatable to pests.	
9. High vehicle payloads are achieved.	No improvement in bulk transporter payloads over compaction transfer.
10. Any increase in disposal costs is small compared to the improvements made in handling waste.	More expensive than direct landfill compaction transfer and pulverisation. Landfill sites are still required to take baled waste, incompressibles and to cover during plant breakdowns.

3.6.2 Baling Techniques

There are two mechanisms by which bales are formed. The first is a single stroke continuous baler, forming a bale against an end plate and then subsequently ejects it by a second ram. The bales produced by this method are usually bound in some way since the compacting pressures and hence the density at formation is lower than those of the second method. Throughputs are in the order of 10 to 50t/hr and consequently equipment can be selected for use in areas of both moderately high and low daily arisings.

The second method employed produces discrete bales from pre-weighed loads. These are formed by compressing a waste load in three mutually perpendicular directions. Higher pressures are used in this method and consequently providing moisture is no more than about 30% by weight (Shepard, 1979) the bales will retain their form without the need for binding. However, subsequent springback will decrease this high formation density. This is a high volume method and unsuitable for sites below about 300t/d (50t/hr).

Currently there are only a handful of balers operating in the UK; at Leeds, Glasgow, Bradford (producing self-sustaining bales), Musselburgh, Stafford, Colnbrook, Hull, Fort William (wire balers), and a small number planned or under construction: Lytham St. Annes and Thornley (Durham CC). Balers are most usefully classified by whether the bales are "tied" or "self-sustaining" and not according to the density since by virtue of spring-back the high pressure (self-sustaining) method actually produces lower density bales at emplacement than the medium pressure (wire-tied) method.

The operational technique is similar for both types of baler and is closely analogous to the plant layout detailed under pulverisation. Refuse is discharged from the collection vehicle onto a covered apron where it is mixed to produce a relatively uniform moisture content by a loading shovel before being pushed onto a receiving conveyor. Since an even moisture content is crucial to producing stable bales storage bunkers are not suitable for baling plants. From the first conveyor refuse is transferred into the baler directly. The bales produced are ejected from the baling press and can be loaded directly onto trailers using diverter rams, or carried by overhead crane or fork lift to the waiting bulk transporters.

3.6.3 Comparison between wire-tied and self-sustaining balers

The two types of baler are essentially designed for different users and as such the two techniques are not in competition with one another as is the case between wet and dry pulverisers.

1. The wire balers generally operate on lower daily throughputs than self-sustaining ones, therefore they are more suited to medium-sized and smaller authorities.

2. The operating pressures with wire balers are lower and therefore are cheaper to operate than self-sustaining models but where throughput is large the use of wire balers would incur the penalties of a longer working day and higher variable costs.

3. The densities achieved by each method are comparable and the landfilling practices identical.

4. Pre-sorting is more likely to be necessary for the less robust wire balers than for the self-sustaining ones.

5. Although individual operations vary, the manpower requirements for wire balers is probably less due to the smaller arisings and the lower complexity of this equipment.

6. Wire-tied bales are possibly more durable over excessively long hauls than self-sustaining bales (Chapman, 1980).

3.6.4 Landfilling baled refuse

The operational techniques of emplacement at a baled landfill site are simpler than those for a direct landfill site. Since the refuse is already highly compacted landfilling is reduced to the straightforward handling of the bales by forklift and stacking them along the working face. The working face can be very narrow, 10 - 15m wide (Middleton Broom, Leeds) or very broad, 90 - 150m (St Paul, Minnesota). The width is dependant on the configuration of the site and the area required for one or more site vehicles to operate unhindered.

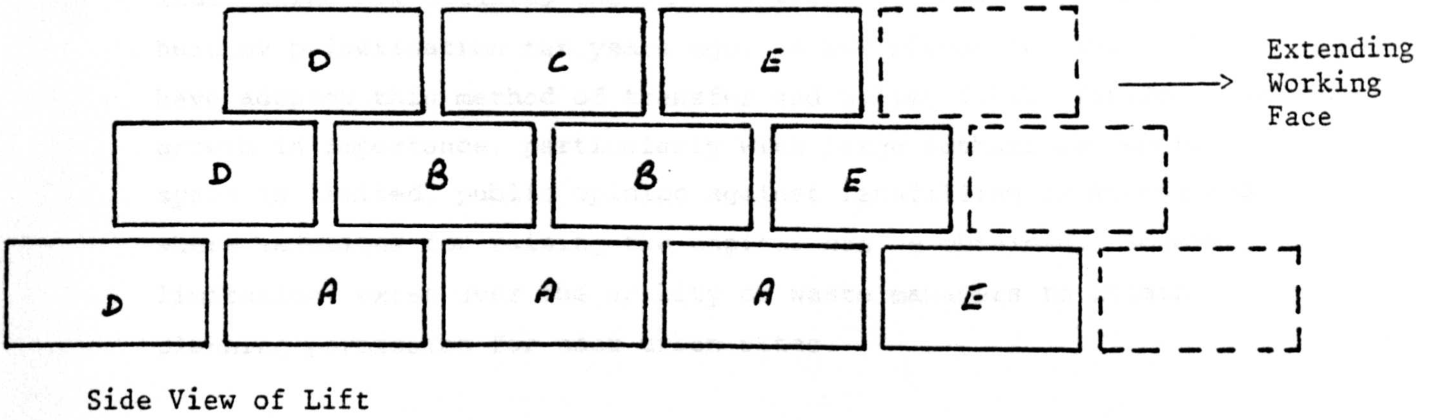
Bales are typically stacked two (Omaha, Nebraska) or three (Middleton Broom, Leeds; Polmadie, Glasgow; St Paul, Minnesota) high in each lift depending upon the operators choice and the site equipment's lifting height limitations. A lift is generally no more than 3m in height. The bales can be stacked with each row interlocking over the joints of those above or below (Figure 3.10), i.e. resembling a brick wall, or emplaced in columns with no interlocking (Figure 3.11). The first arrangement is considered to produce a firmer structure upon which to support subsequent lifts.

A further variation in landfilling and following a similar argument to that for pulverisation, is whether baled landfills should be covered daily. At St Paul, Minnesota, the operator does not use daily cover since the bales produce a firm base and the refuse is considered in an unutilisable form to pests (Stone, 1975). Furthermore, the vertical face does not enable easy covering. However, practices at Leeds, San Diego and Musselburgh are all required to spread between a 7.5 and 15 cm layer of daily cover, mainly for aesthetic reasons and to minimise possible problems from scavenging birds or rainfall ingress.

Baled landfills can be established in any of the three geomorphological categories: flatlands, depressions or constructional sites; and the site preparations are identical to those required for direct landfilling.

3.7 FUTURE TRENDS IN PULVERISATION AND BALING

Up until the mid-1970s many of the writers on solid waste topics confidently predicted that pulverisation would be the next step in landfilling practices (Flintoff and Millard, 1969; Marsden, 1973). They saw the need for treatment of refuse to enable a more favourable public acceptance of landfilling thereby enabling potential disposal sites closer to urban areas to be utilised, and also enable larger tonneages of refuse to be emplaced at each site. Currently, few observers consider this to be the case.



At the beginning of each row 3 bales are placed on the ground (A), then two on top of these to produce a 2nd tier (B) and finally one on top of this (C). The bales of each successive tier overlap those below giving an interlocking appearance. This arrangement is the starting point and against this sets of three bales (D and E) are placed as the row extends along the width of the working face.

Fig. 3.10. Interlocking arrangement of bales along the working face (modified after Stone, 1975).

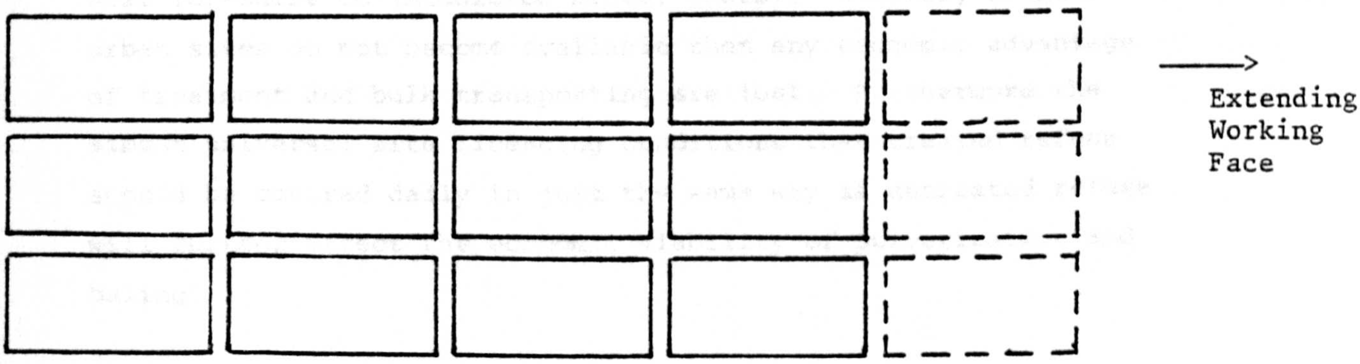


Fig. 3.11 Columnar arrangement of bales along the working face.

Baling is still in its infancy and the potential advantages and disadvantages have yet to crystallise in the minds of waste managers. Thus baling now occupies the same position of "high expectations" held by pulverisation ten years ago. A few pioneering authorities have adopted this method of transfer and Gulley (1979) foresees its growth in importance, particularly with large authorities where space is limited, public opinion against landfilling is strong and where sanctions for raising the capital can be obtained. However, limitations exist over the ability of waste managers to obtain planning permission for near urban sites.

The initial reaction by the general public to a new landfill site for treated or untreated refuse is one of reticence; however the literature on this topic (Marsden, 1973; Ham, 1975; NCRR, 1974; Loram, 1976) suggests that near-urban sites may become preferentially accessible to pulverised or baled refuse. This "advantage" is not automatically applicable; residents will still oppose a pulverised or baled landfill site with the same ferocity as a direct landfill, and nowhere in the literature (except for a passing reference in Loram, 1976) is this reason cited by authorities in their decision to commence pulverisation. Two authorities do claim this as a major reason for selecting baling, i.e. Humberside CC (Hull) and West Yorkshire CC (Middleton Broom, Leeds). However, if near-urban sites do not become available then any economic advantage of treatment and bulk transporting are lost. Furthermore the almost universal site licencing conditions that treated refuse should be covered daily in just the same way as untreated refuse will further affect the economic viability of pulverisation and baling.

Since it is not certain that either near-urban sites or densities higher than direct landfilling will materialise only the aesthetic (a politically useful) advantage remains. However, the costs of treatment, with limited exception for dry pulverisation, are more heavily dominated by the plant's capital cost than untreated methods:

	Capital charges (% of total operating cost) 50t/d site	250t/d site
Direct landfill	27	40
Compaction (without storage)	40	50 approx.
Wire tied baling	43	64
Dry pulverisation	45	43
Wet pulverisation	76	70

(See chapters 8 and 9 of this work)

In the present period of strict financial control on local authority capital projects it is unlikely that the externality of "tidy refuse" could be used to justify the sanctioning of many plants.

In the view of many operators nowadays, pulverisation for landfilling has lost favour and many of its potential advantages have not materialised. For the purpose of processing waste prior to resource recovery or RDF production its future appears more encouraging. The future of baling is still debateable and it is not likely to be resolved without a few more years of operational experience, economic evaluation and consideration of the relative stringency of future site licencing conditions.

Detailed economic appraisals for wire-tied baling and wet and dry pulverisation are included in subsequent chapters. Direct landfill and compaction transfer methods are also analysed up to operations around 500t/d in size.

3.8 VARIATIONS IN LANDFILL DENSITY

A principal objective of good landfill management is to compact refuse as tightly as possible. However data on the densities achieved by individual methods is very confused. Variations in measurement, calculation, refuse composition, moisture content, experience of driver, number of compacting passes and quantities of cover material are some of the factors contributing to the ambiguities. One further noteable source of complication is the method of calculation of densities.

"In-place density" is commonly used by engineers, i.e.

$$\text{In-place (or actual) density} = \frac{\text{weight of refuse + weight of cover}}{\text{volume of refuse + volume of cover}} \quad (3.2)$$

However this density value can produce a misleading conclusion about the effectiveness of a particular emplacement method since by combining the weight of cover and refuse it is not clear what is the actual density of the refuse alone in any given volume of airspace. Consequently, it has been argued (Wilson, 1981) that the "effective density", where only the weight of the refuse is compared against the volume of refuse and volume of cover, is a more informative figure, i.e.

$$\text{Effective density} = \frac{\text{weight of refuse}}{\text{volume of refuse + volume of cover}} \quad (3.3)$$

Effective densities are used throughout this work. It should be appreciated that an effective density value is critically dependant on the quantity of cover used. The provision of cover, like airspace is an expensive operating cost and should be kept to the minimum necessary.

The refuse density achieved by a machine on the working face is a major factor (though not the only one) in equipment choice. Bratley (1976) investigated this for machines using different tractions. He used the onion skin method and found no correlation between the deadweight or wheel widths of machines and the resulting density. However, a general ranking of different tractions and their effective density can be derived; i.e.

Tracked vehicles < Rubber tyred < Steel wheeled compactors

Bratley attributes this to the different actions of emplacement, however his ranking has not been entirely supported by later work (Table 3.7). It has been suggested that there may be no difference in effective densities between the methods except on very large sites since onion skinning requires an inert bank. If this is added to the "volume of cover" figure in the effective density calculation then a reduction in the difference between the density values for the landfill methods will result.

Another factor that will reduce the differences in effective densities for each type of site machine from those values suggested in Tables 3.7 and 3.8 is the effect of discharging vehicles. The passage of collection vehicles over the refuse will compact the material down further, although the magnitude of their effect is not known.

The preceeding discussion on densities concerns the density on emplacement (i.e. the initial density). Theoretically, irrespective of the initial density, if given sufficient time the final density of decomposed refuse (approximately 0.8 - 1.0 t/m^3) will be the same for all emplacement methods (Figures 3.12 and 3.13). The function of emplacement vehicles is to reduce the size of the difference between the initial and final values. Very high initial densities are only achieved by employing expensive mobile plant.
Thus it is only on those sites where high initial densities are crucial that they should be operated. Such sites are those confined to small surface areas but receiving large intakes of refuse (approximately 200 tonnes/day or more). By handling large volumes it is likely that

Table 3.7 IN-PLACE AND EFFECTIVE DENSITY OF UNTREATED REFUSE WITH VARIOUS TYPES OF SITE MACHINERY

(Modified after Bratley, 1976; Campbell and Parker, 1980).

Vehicle Traction	Bratley (1980) Effective Density (t/m^3)	Campbell and Parker (1980) Effective Density (t/m^3)	
	ONION SKINNING	ONION SKINNING	OVER-THE-TOP
Tracked Vehicles	0.47	-	0.58
Rubber-tyred Vehicles	0.56	-	-
Rubber-tyred Vehicles (with puncture-resistant tyres)	0.67	0.73	0.46
Steel-Wheeled Vehicles	0.63 - 0.99	0.63	0.52, 0.67 - 0.69

Table 3.8 SUMMARY OF QUOTED EFFECTIVE DENSITIES FOR EACH METHOD OF LANDFILL EMPLACEMENT

Landfill Emplacement Method		EFFECTIVE DENSITY (t/m^3): Range of Values found in the Literature[2]	EFFECTIVE DENSITY (t/m^3): Approximate value expected from good management and used in subsequent analyses[3]
DIRECT LANDFILLING			
Uncontrolled		0.45[1]	0.45
Controlled - Over the Top:	Tracked	0.25 - 0.60	0.50
	Rubber-tyred	0.40 - 0.60	0.55
	Steel wheeled	0.50 - 0.70	0.65
Onion Skin:	Tracked	0.47	0.50
	Rubber-tyred	0.55 - 0.75	0.65
	Steel wheeled	0.60 - 1.00	0.85
Horizontal Layering:	Tracked	N/D	N/D
	Rubber-tyred	0.95[1]	0.95
	Steel wheeled	0.95 - 1.2	0.95
INDIRECT LANDFILLING			
Pulverisation - Wet Product:	Tracked) Rubber-tyred)	0.80 - 1.00	0.90 wet weight
	Steel wheeled	N/D	N/D
Dry Product:	Tracked	0.45 - 0.70	0.55
	Rubber-tyred	0.60 - 0.70	0.65
	Steel wheeled	0.76	0.75
Baling - Wire tied Bale:	Rubber-tyred forklift	0.60 - 0.70	0.65
Self-sustaining Bale:	Rubber-tyred forklift	0.60 - 0.90	0.80

Notes:
1 - Only one value found in the literature.
2 - Literature sources are listed overleaf.
3 - $\pm$ say, 0.05 t/m^3
N/D - No data.

Table 3.8 SUMMARY OF QUOTED EFFECTIVE DENSITIES FOR EACH METHOD OF LANDFILL EMPLACEMENT

(continued)

Sources

1. Lyle (1980)
2. Bratley (1976)
3. Campbell and Parker (1980)
4. Reindhart et al (1974)
5. Dumbarton District Council (1980)
6. Anon (1976). Figures modified assuming 25% (by weight) cover material.
7. Anon (1979)
8. Skitt (1979)
9. DOE (1971)
10. Shepard (1979)
11. Holmes (1975)
12. Cheyney (1980)
13. NCRR (1974)
14. Stone and Kable (1977)
15. Campbell, personal communication (1981)
16. City of San Diego (1973). Implied figures from text.
17. Manufacturer's literature.
18. Biddell, personal communication, $1.2 t/m^3$

Fig 3.12 Theoretical compaction curve for refuse.

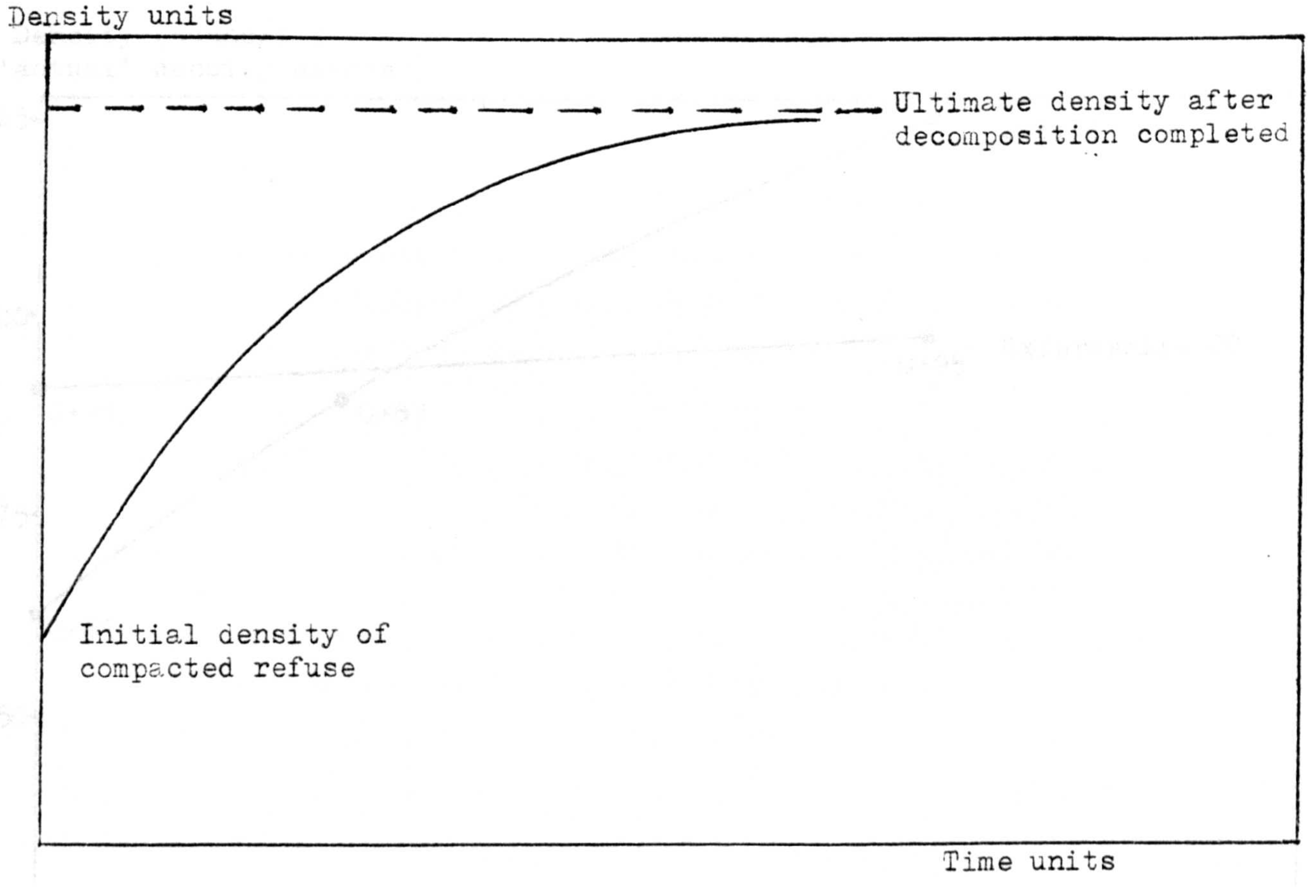
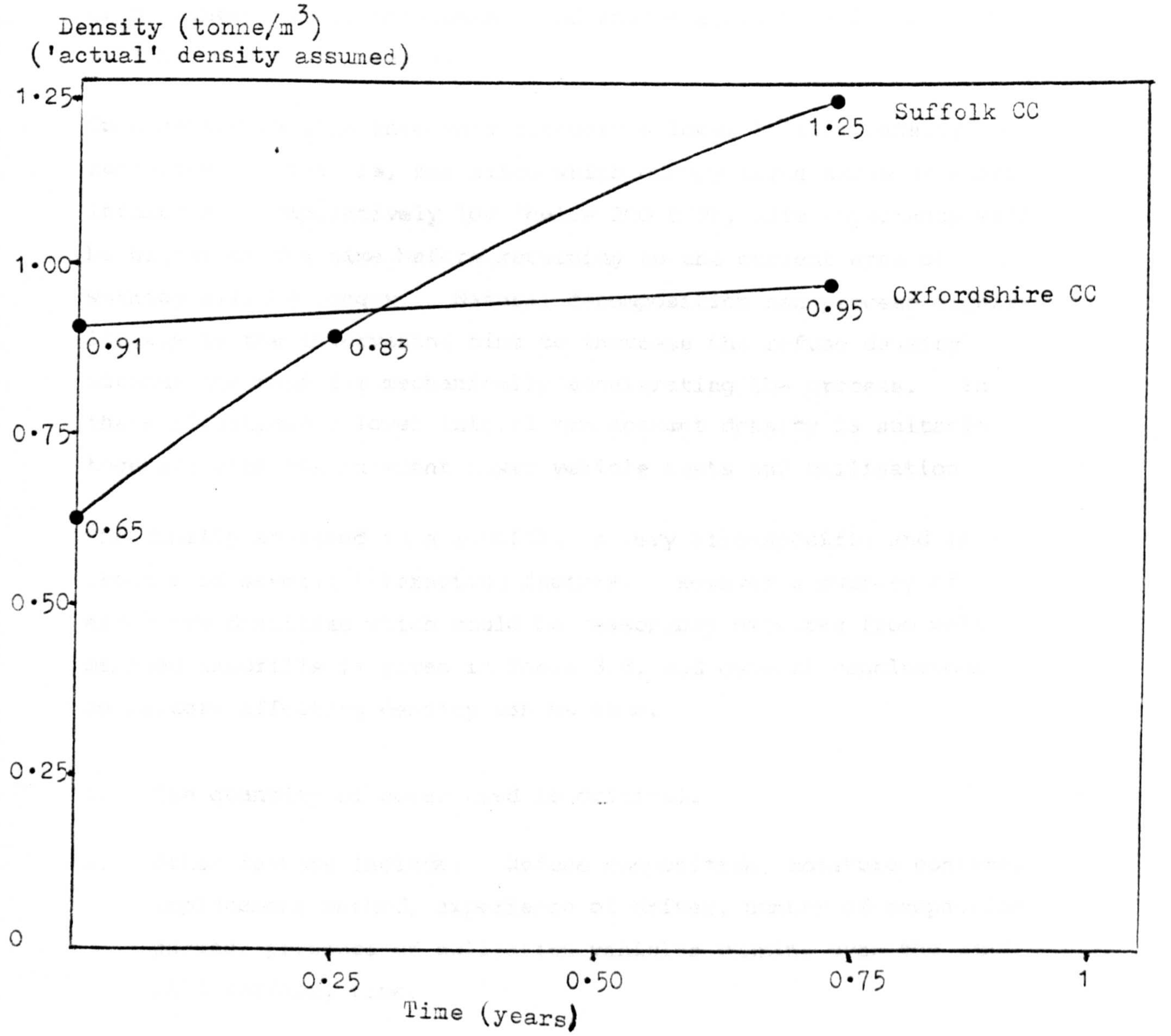


Fig 3.13 Compaction curves derived from experiments in Suffolk and Oxfordshire. (after Holmes, 1975)



these sites have only a short life expectancy or that emplacement of the next lift at the point currently being worked will be fairly rapid, therefore decomposition in the intervening period will be minimal. A high initial density is necessary to make the best use of the available airspace under the prevailing time constraint. To achieve higher initial compaction involves a larger expenditure on machinery, fuel, maintenance and spares since vehicle utilisation will be relatively greater.

On sites not falling into this category a lower initial density is sufficient. That is, for sites which occupy large areas or where intakes are comparatively low (below 200 t/d), life expectancy will be higher or the time before returning to the current area of working will be longer. Natural decomposition can proceed significantly in the intervening time to increase the refuse density without the need for mechanically accelerating the process. In these situations a lower initial emplacement density is suitable together with the inherent lower vehicle costs and utilisation.

The density achieved in a landfill is very site-specific and is a product of several interacting factors. However a summary of effective densities which could be reasonably expected from well-managed landfills is given in Table 3.8, and general conclusions on factors affecting density can be made.

1. The quantity of cover used is critical.

2. Other factors include: Refuse composition, moisture content, emplacement method, experience of driver, number of compaction passes, presence of collection vehicles running over the landfill surface, time.

3. For each emplacement method (see Table 3.8) the ranking on emplacement density of Tracked < Rubber-tyred < Steel wheel compactors, generally applies.

4. Controlled landfilling gives superior densities than uncontrolled.

5. Within controlled landfilling thin layering methods give superior densities than the over-the-top method.

6. Dry pulverisation gives densities comparable to onion-skinning.

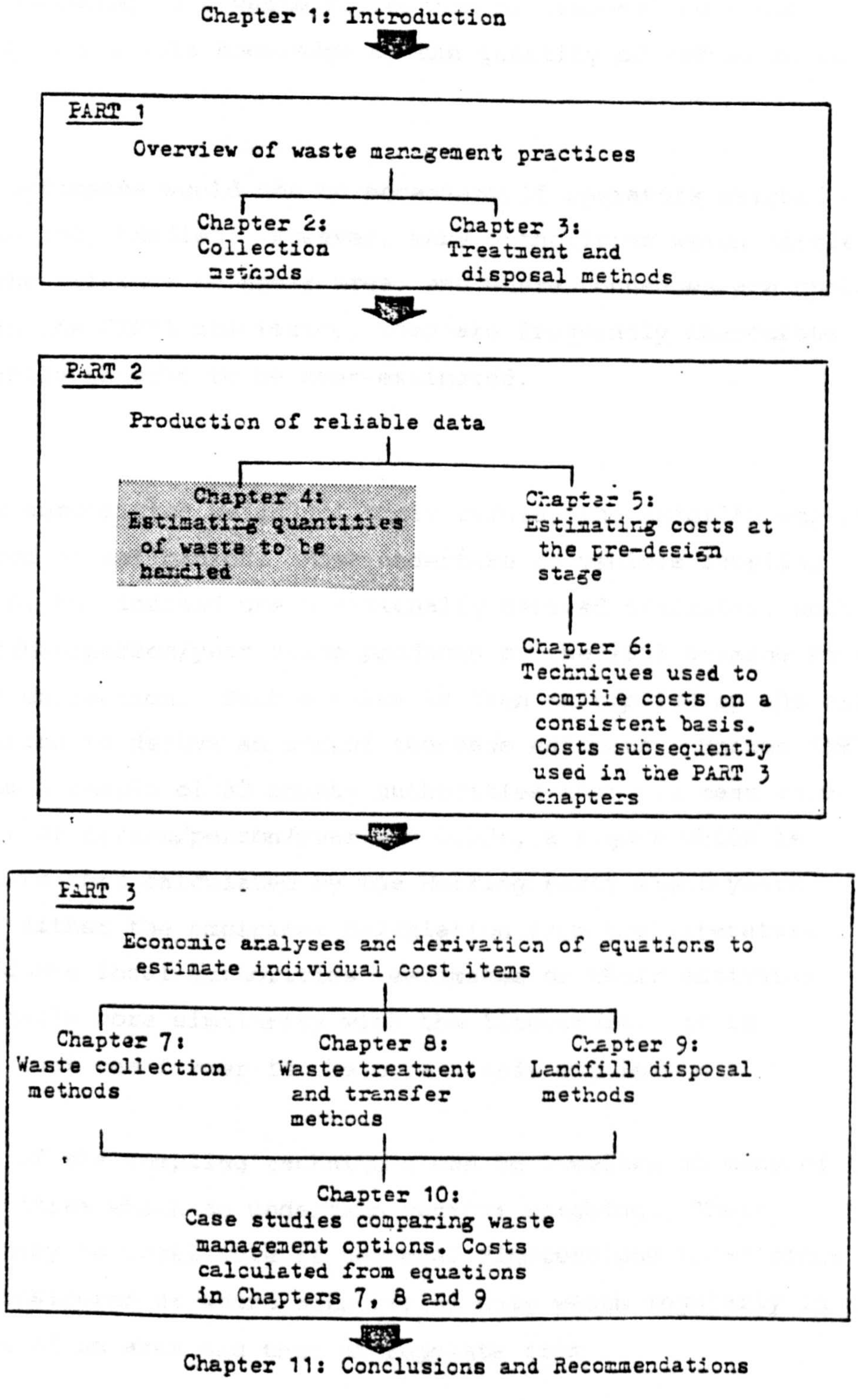
7. Wire-tied and self-sustaining baling gives densities comparable to over-the-top using compactors and onion-skinning using compactors respectively.

8. Wet pulverisation produces the highest initial density (although the value quoted includes water added during treatment), with the exception of that for horizontal layering.

The advantage of increasing a landfill's capacity by using pulverised refuse is no longer as obvious as in the early 1970s. At that time densities were quoted as between 0.75 and 0.85 tonnes/m^3 for pulverised refuse, and 0.5 to 0.7 tonnes/m^3 for untreated refuse. However, the development of steel-wheeled compactors and new emplacement techniques have increased the untreated refuse densities obtainable to approximately 0.8 tonnes/m^3. Therefore none or, at the very best, only marginal differences exist between the methods. Similar arguments can be made when comparing between the effective densities in baled landfills and direct landfills.

CHAPTER 4

TONNEAGE ESTIMATION MODEL



Chapter 4

4.1 INTRODUCTION

Accurate planning of a waste collection or disposal operation depends upon reliable knowledge of the quantity of refuse to be handled.

Tonneage estimates would not be necessary if operators weighed all of the refuse they handled. However, many authorities weigh little or none of the arisings in their area, and where tonneages are quoted, such as in the CIPFA statistics, they are frequently inaccurate and generally thought to be over-estimated.

Since few authorities weigh all their refuse, the majority employ some method of estimation. Most undertake no vehicle sampling themselves, but instead use a nationally derived statistic, such as the refuse/person/year value produced by the 1967 Working Party on Refuse Collection. Such a value is then multiplied by the size of population to derive an annual tonneage estimate. Holmes (1975) found from a sample of 32 county authorities that the mean value for weight of refuse/person/year was 0.33t, a figure which is identical to that calculated by the Working Party eight years earlier. Either the empirical calculation from the literature influenced the local authorities' estimates or their estimates coincidentally bore similarity with the literature. It is suspected that the former is the more likely explanation.

Criticism of the sampling techniques can be levelled at many of the authorities which do undertake vehicle weighing. Their estimates may be unreliable if seasonal fluctuations in arisings are not considered or where authorities only weigh regularly in a small part of an area and then extrapolate from it.

The latter practice is generally confined to those collection vehicles discharging at a particular disposal point which possesses a weighbridge. This is not a representative sampling technique since extrapolation of mean payloads or total tonneage values to the unweighed operations can hide major variations.

It is true that some authorities produce very reliable tonneage estimations but the majority certainly do not. Holmes (1975) therefore concluded:

> "It would be interesting to see these professional skills (statisticians) brought in to assess, analyse and predict the error factor ... (in properly worked out estimation techniques) ... and suggest an optimum 'modus operandi' in establishing a tolerable system (of sampling)".

In this chapter one such estimation technique, the "Tonneage Estimation Model", is described. It provides reliable estimates of tonneages from a small but representative sample size and is a significant improvement on anything previously available to local authorities.

4.2 GENERAL DESCRIPTION OF THE TONNEAGE ESTIMATION MODEL

The purpose of this model is to produce an accurate estimate for the total tonneage of refuse collected in a particular area by weighing a small, but representative, number of vehicle loads. It has been developed as an improvement to the current methods of compilation and with regard to the financial and manpower restrictions within an authority.

The model is based on determining accurately over a period of time an average vehicle payload and then multiplying this by the number of vehicle loads to derive an estimate of the total tonneage. A sampling period could span two to four weeks although weighings would probably only be necessary on four or five days within it.

The total tonneage for the sampling period is then multiplied by the appropriate factor to produce a seasonal total tonneage. The sampling procedure would then be repeated in the other seasons, and finally the seasonal totals are combined to produce an annual total (Figure 4.1).

One further refinement which can be introduced when conducting sample weighings is not to consider all vehicles as identical but to compile separate tonneage estimates for a number of pre-defined categories, each known or thought likely to produce marked variations in vehicle weights. Separate seasonal and annual total tonneages would also be calculated before combining all categories to produce a grand annual total tonneage. There could be a number of these "vehicle categories" identified by an authority, for example:

i) Vehicles of different capacities;

ii) Morning and afternoon loads;

iii) Composition of refuse carried in vehicles (e.g. household, bulky waste).

The model operates principally by combining probability distributions and as a check on the accuracy of estimates at each step the standard deviation and confidence interval are also calculated. A detailed mathematical treatment is given in Appendix 4A. In addition to the measurement of vehicle weights the model also requires the following variables to be known:

i) Number of loads in each vehicle category;

ii) Total number of loads per week;

iii) Number of disposal points.

In later sections details of other methods of tonneage estimation, together with the predictions from this model, are compared against an independent known total tonneage from an authority which weighs all of its refuse. The results have been very encouraging.

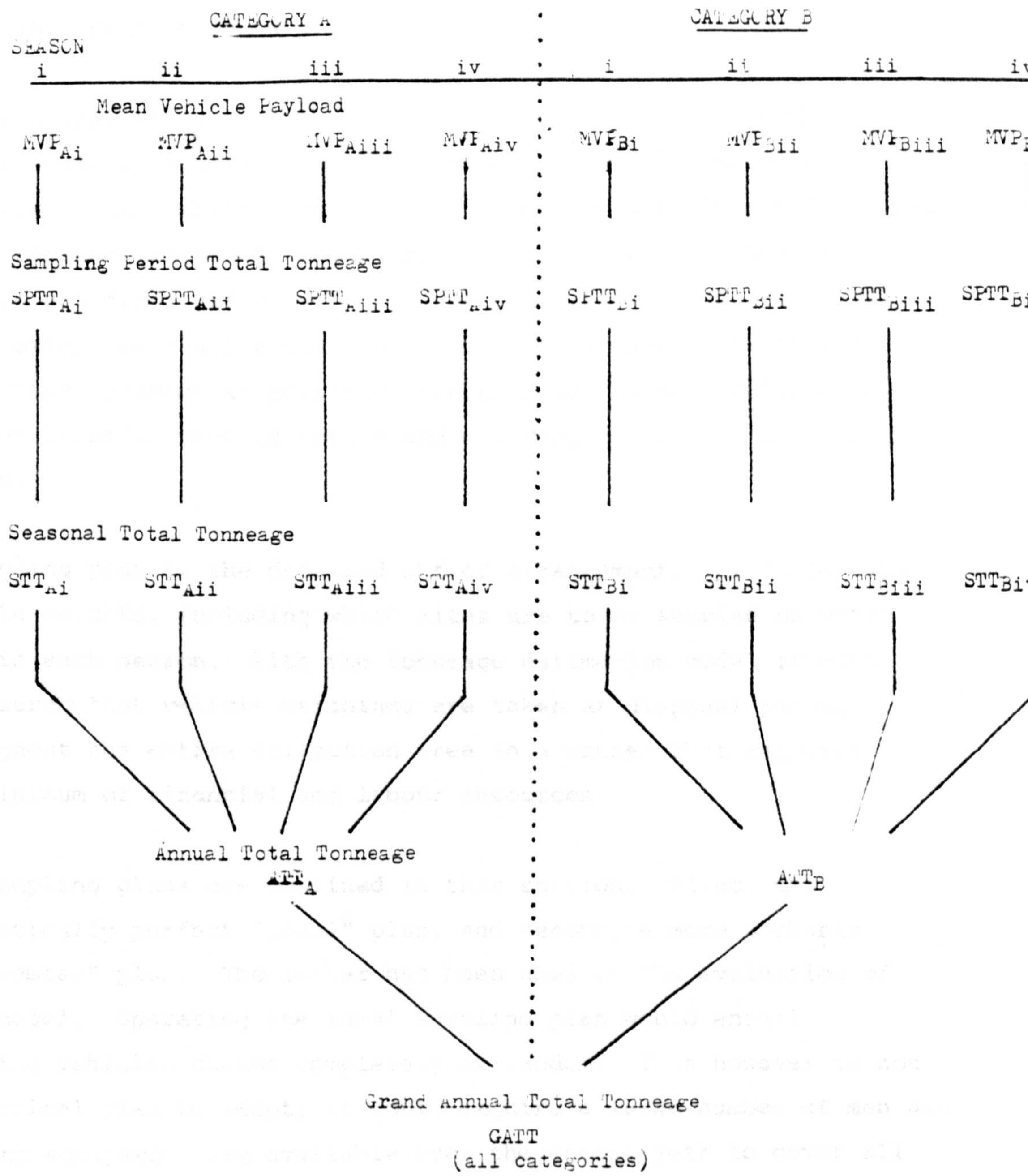


Fig 4.1 Summary of the steps in the 'Tonneage Estimation Model' for a two-category case.

4.3 A WORKABLE SAMPLING PLAN

The principal feature of the tonneage estimation model is that it achieves highly accurate estimates from very small sample sizes. To ensure that sampling variations are kept to a minimum a "sampling plan" representative of the entire collection area is necessary. This is not difficult to achieve. It is envisaged that this plan would extend over all four seasons and within each sampling would be as near "random" as possible, taking place on particular days over at least a two-week period and covering all of the disposal points.

A sampling plan is the detailed set of arrangements for collecting vehicle weights, including which sites are to be sampled on which days in each season. With the tonneage estimation model it must be ensured that vehicle weighings are taken at disposal points throughout the entire collection area in a manner that requires the minimum of financial and labour resources.

Two sampling plans are outlined in this section. First, the theoretically perfect "ideal" plan, and second, a more workable "compromise" plan. The latter has been used in the evaluation of this model. Operating the ideal sampling plan would entail weighing vehicles chosen completely at random. This however is not a practical plan to adopt; it would require a large number of men and weighing equipment to be available over the entire year to cover all of the disposal points. It also leads to an inefficient use of these resources as under completely random conditions only one or possibly two loads would be weighed at each disposal point on any particular day.

Instead, this model uses a compromise sampling plan in which weighing takes place at a random selection of sites and days within each season. This requires only one man, one set of portable weighing pads, and a small van or car. For each combination of site and day all loads arriving would be weighed, a procedure which continues until the required sample size has been obtained. Determination of the required sample size is discussed in Section 4.4.

The model was evaluated using simulated data for both sampling plans and a significant difference was only found to arise with one case in every eight.

Therefore the compromise sampling plan introduces a perceivable, though small, reduction in accuracy.

4.4 DETERMINATION OF SAMPLE SIZE

The suitability of the model's tonneage estimates for management purposes is determined by the levels of error acceptable to an authority. Simulated data, presented in Appendix 4B, was first used to evaluate the model. Four sample sizes were investigated and it was found that a sample size of less than 2% of the annual number of disposal trips produced a very accurate total tonneage; 79, 374 $\pm$ 124t with 95% confidence (Appendix 4C). A detailed review of the vehicle payload estimates from the four sample sizes identified three measures of "accuracy" (Table 4.1).

i) The size of the mean vehicle payload confidence interval - a measure of scatter about the mean payload value;

ii) The size of the mean vehicle payload standard deviation - a measure of the reliability of the mean payload error (standard deviation);

iii) The confidence level (commonly 95% in statistical calculations).

In this work the above parameters were set at:

i) Mean vehicle payload $\geqslant$ 3 x mean vehicle payload confidence interval, i.e. the range of values outside of which 1 payload mean in 100,000 would fall;

ii) Mean vehicle payload SD $\simeq$ 2 x mean vehicle payload SD confidence interval - the range of values outside of which 1 standard deviation figure in 1,000 would fall;

iii) 95% confidence interval.

Several other sample sizes were considered using the simulated data, i.e. 0.5%, 1% and 4% of the annual number of loads, to examine the improvement in the accuracy of tonneage estimates by increasing the sample size. A rise in the sample size from 0.5% and 1.0% approximately halves the CIs, while between 2.0% and 4.0% the CIs are only reduced by about one-third. This highlights an example of diminishing returns and is graphically exhibited by plotting the width of the confidence interval against sample size (Figure 4.2).

… ESTIMATES FOR SEVERAL SAMPLE SIZES USING SIMULATED FIGURES

Annual % of loads		SEASONS i		ii		iii		iv		Comments
	Vehicle Capacity (yd^3)	15	20	15	20	15	20	15	20	
Approx 0.5%	Sample Sizes:	10	10	10	5	10	8	10	9	
	Mean vehicle Payload & 95% CI	5.1 ±0.34	7.0 ±0.4	4.9 ±0.3	6.9 ±0.3	5.3 ±0.2	6.8 ±0.3	5.5 ±0.3	7.4 ±0.4	MVP>3CI
	SD and 95% CI	0.5 <1.12 >0.38	0.7 <1.46 >0.50	0.5 <1.10 >0.38	0.3 <2.19 >0.16	0.3 <0.75 >0.26	0.5 <1.37 >0.38	0.6 <1.27 >0.43	0.6 <1.53 >0.47	
	CI width Width as a proportion of SD	0.74 137%	0.96 137%	0.72 136%	2.03 534%	0.49 136%	0.99 180%	0.84 138%	1.06 156%	SD<2CI
Approx 1.0%	Sample Sizes:	19	19	20	10	20	16	19	18	
	Mean vehicle Payload & 95% CI	4.9 ±0.2	6.9 ±0.2	4.3 ±0.2	6.5 ±0.2	4.8 ±0.2	6.8 ±0.3	5.1 ±0.2	7.[illegible] ±0.2	MVP>3CI
	SD and 95% CI	0.5 <0.85 >0.42	0.6 <0.99 >0.49	0.4 <0.75 >0.38	0.4 <0.96 >0.33	0.4 <0.70 >0.36	0.6 <1.04 >0.48	0.5 <0.88 >0.43	0.5 <0.87 >0.42	
	CI width Width as a proportion of SD	0.43 78%	0.50 78%	0.37 76%	0.63 137%	0.34 74%	0.56 89%	0.43 79%	0.45 82%	SD<2CI
Approx 2.0%	Sample Sizes:	43	39	36	22	41	29	41	37	
	Mean vehicle Payload & 95% CI	4.9 ±0.1	6.9 ±0.2	4.5 ±0.1	6.6 ±0.2	5.0 ±0.1	7.0 ±0.2	5.6 ±0.1	7.4 ±0.1	MVP>3CI
	SD and 95% CI	0.4 <0.63 >0.41	0.6 <0.80 >0.30	0.5 <0.73 >0.45	0.5 <0.77 >0.41	0.4 <0.60 >0.38	0.6 <0.69 >0.48	0.5 <0.72 >0.46	0.5 <0.68 >0.42	
	CI width Width as a proportion of SD	0.22 45%	0.30 49%	0.28 51%	0.36 69%	0.22 48%	0.21 35%	0.26 47%	0.26 51%	SD≈2CI
Approx 4.0%	Sample Sizes:	82	75	68	40	78	54	78	70	
	Mean vehicle Payload & 95% CI	4.9 ±0.1	6.9 ±0.1	4.5 ±0.1	6.6 ±0.1	5.0 ±0.1	6.9 ±0.1	5.6 ±0.1	7.4 ±0.1	MVP>3CI
	SD and 95% CI	0.5 <0.60 >0.44	0.6 <0.73 >0.53	0.5 <0.65 >0.46	0.5 <0.67 >0.43	0.5 <0.60 >0.43	0.5 <0.67 >0.46	0.5 <0.71 >0.51	0.6 <0.72 >0.51	
	CI width Width as a proportion of SD	0.16 32%	0.20 33%	0.19 35%	0.24 46%	0.17 34%	0.21 39%	0.20 34%	0.21 35%	SD>2CI

MVP **Mean Vehicle Payload,** CI Confidence Interval, **SD** Standard Deviation

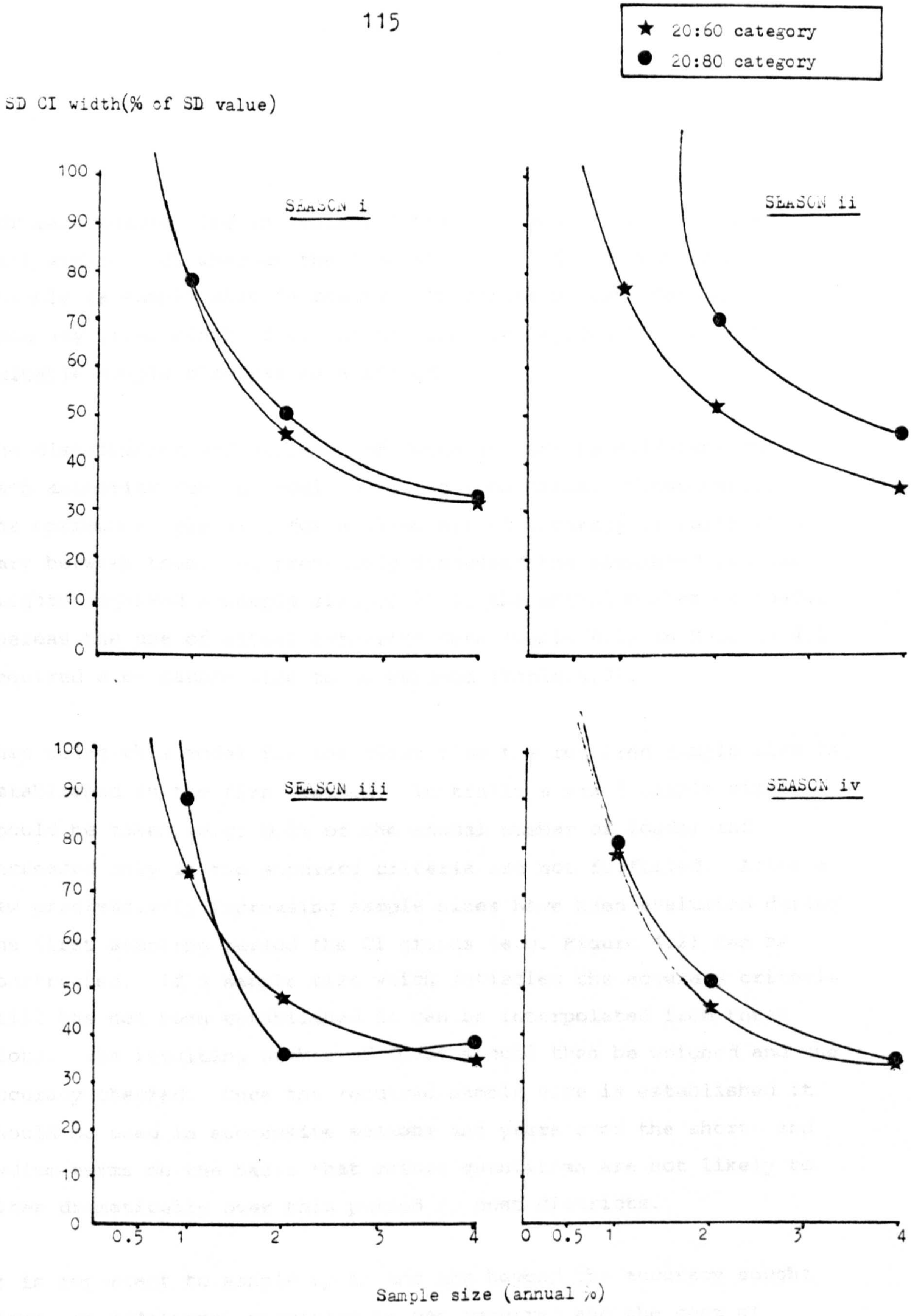


Fig 4.2 The influence of increasing sample size on standard deviation confidence interval width using simulated data.

For each sample size in Table 4.1 the mean vehicle payload lies well within 3 CI whereas the interval about the SD decreases sharply as sample size increases. Therefore by considering the accuracy (i.e. width of CI) of the vehicle payload SD the most suitable sample size was established.

The distribution and variance of tonneage data is different for each authority due to local operating conditions. Consequently the optimum sample size for a given set of accuracy criteria will vary between them. As previously discussed the simulated vehicle weights required a sample size of 2% of the annual number of loads, whereas the use of actual authority data (Table 4.2) in Section 4.5 required a 6% sample size to be weighed (Table 4.3).

When using this model for the first time the required sample size is established in the first season. Initially a small sample size should be taken (e.g. 0.5% of the annual number of loads) and increased only if the accuracy criteria are not fulfilled. After a few progressively increasing sample sizes have been evaluated during the first sampling period the CI graphs (e.g. Figure 4.2) can be constructed. If a sample size which satisfies the accuracy criteria still has not been established it can be interpolated from these plots. The resulting number of loads should then be weighed and the accuracy checked. Once the required sample size is established it should be used in successive seasons and years over the short- and medium-terms on the basis that refuse quantities are not likely to alter dramatically over this period in most districts.

It is important to sample up to and not beyond the accuracy sought since the additional precision is not required and the cost of obtaining it exceeds its value to the waste manager. If this is not the case then the accuracy criteria values should be tightened.

Table 4.2 Actual vehicle tonneages obtained from a waste collection authority

1st Quarter	Week 3 Friday	Week 1 Thursday	Week 3 Tuesday	Week 4 Monday	
(tonnes)	5.37	3.19	4.80	7.74	
	7.69	6.01	7.58	5.38	
	4.00	6.94	5.36	5.15	
	6.06	7.71	2.74	7.62	
	2.45	3.30	3.08	6.91	
	5.85	4.43	6.07	4.34	
	4.86	6.78	4.02	5.62	
		7.30	3.81	6.20	
		5.05		3.19	
		5.41		4.46	
		1.82			
		2.71			
		4.89			
No. of loads	7	13	8	10	= 38
Mean Vehicle Payload 5.16t SD 1.66t					
2nd Quarter	**Week 4 Friday**	**Week 1 Wednesday**	**Week 4 Tuesday**	**Week 2 Thursday**	
(tonnes)	5.41	6.00	2.84	7.66	
	4.93	6.58	7.23	7.22	
	6.63	7.64	4.00	3.86	
	3.23	6.95	5.11	8.23	
	3.77	7.39	5.56	6.88	
	4.73	5.96	5.54	7.51	
	2.77	5.15	3.42	7.12	
		3.04	3.85	4.05	
		2.96	1.69	4.27	
		4.31		4.32	
		5.44		3.42	
No. of loads	7	11	9	11	= 38
Mean Vehicle Payload 5.18t SD 1.72t					

Table 4.3 SUMMARY OF THE MEAN VEHICLE PAYLOAD ESTIMATES FOR SEVERAL SAMPLE SIZES USING ACTUAL FIGURES

Six-month Percentage of Loads		1st Quarter Estimates	Comments
Approx. 1.0%	Sample Size Mean vehicle payload and 95% CI SD and 95% CI CI width Width as a proportion of SD	7 5.18±1.25 1.66<4.79 >1.12 3.67 221%	 MVP >3CI SD<2CI
Approx. 3.0%	Sample Size Mean vehicle payload and 95% CI SD and 95% CI CI width Width as a proportion of SD	21 4.90±0.76 1.75<2.63 >1.36 1.27 73%	 MVP >3CI SD<2CI
Approx. 4.5%	Sample Size Mean vehicle payload and 95% CI SD and 95% CI CI width Width as a proportion of SD	28 4.97±0.64 1.70<2.38 >1.29 1.09 64%	 MVP >3CI SD<2CI
Approx. 6.0%	Sample Size Mean vehicle payload and 95% CI SD and 95% CI CI width Width as a proportion of SD	38 5.16±0.54 1.66<2.19 >1.37 0.82 49%	 MVP >3CI SD≐2CI) The chosen accuracy criteria are met with this sample size.
Approx. 8.0%	Sample size Mean vehicle payload and 95% CI SD and 95% CI CI width Width as a proportion of SD	48 5.16±0.47 1.62<2.06 >1.36 0.70 43%	 MVP >3CI SD>2CI

MVP: Mean vehicle payload

4.5 EVALUATION OF THE MODEL

Once a sample size has been determined which conforms to an authority's accuracy criteria sampling is made in accordance with the general description in Section 4.2.

An authority was identified which could supply actual vehicle weights since all arisings are weighed in the district. A sample size of 76 loads; 38 in each season (only two seasons were studied) was made using weighbridge records. This authority has about 10 loads per day, thus sampling on four days is required in each season. To reduce the likelihood of systematic error by only sampling in one week, sampling days are chosen (using random number tables) within a specified sampling period of at least two weeks duration. Appropriate values in this case for the days sampled were taken from the authority's records. The source data is given in Table 4.2.

The corresponding tonneage estimates calculated by the model are presented in Table 4.4 and compared with the authority's known values. The estimated tonneage (6,319t) is very similar to the actual figure (6,340t) and the difference between these values, and those for two similar calculations using different sets of data from their records, are within the 95% confidence interval of $\pm$ 118t. The actual difference between the six-monthly tonneages in Table 4.4 is 21 tonnes, approximately one day's arisings. In the two similar calculations this difference was no greater than four days arisings. These results suggest the model's estimates are extremely accurate.

Simulated data was evaluated in an identical manner to the actual data. As previously discussed a sample of 2% of the annual number of loads produced a very accurate total tonneage estimate, 79, 374 $\pm$ 124t with 95% confidence. The calculation of the individual steps in the model using the simulated data in Appendix B are detailed in Appendix 4C and summarised in Table 4.5.

The simulated data represents a more complex collection operation than demonstrated with the "actual" data. It involves three disposal points and two vehicle categories (15yd^3 and 20yd^3 volume sizes) with sampling taken over a twelve-month period.

Table 4.4 TONNEAGE ESTIMATES USING ACTUAL FIGURES AND A SAMPLE SIZE OF 6% OF THE ANNUAL NUMBER OF LOADS

Step		1st Quarter	2nd Quarter	Authority Actual Figures	
				1st	2nd
1(i)	Sample Sizes	38	38		
	Mean vehicle payload	5.16	5.18	5.05	5.25
	SD	1.66	1.72		
1(ii)	Mean vehicle paylod and 95% CI	5.16±0.54	5.18±0.56		
	SD CI	1.66<2.19 >1.37	1.72<2.27 >1.42		
	CI width	0.82	0.85		
	Width as a proportion of SD	49%	49%		
1(iii)	Total number of disposal trips in sampling period	188	188		
	Sampling period percentage of loads	20%	20%		
2.	Sampling period total tonneage (over 4 weeks)	970	974		
	SD	23	24		
3.	No. weeks in each quarter	13	13		
	Seasonal total tonneage	3,153	3,166	3,102	3,238
	SD	41	43		
5(i)	Six-monthly total tonneage	6,319		6,340	
	SD	59			
5(ii)	Six-monthly total tonneage and CI	6,319±118			
5(iii)	Six-monthly number of loads	1,231			
	Six-monthly percentage of loads	6.2%			

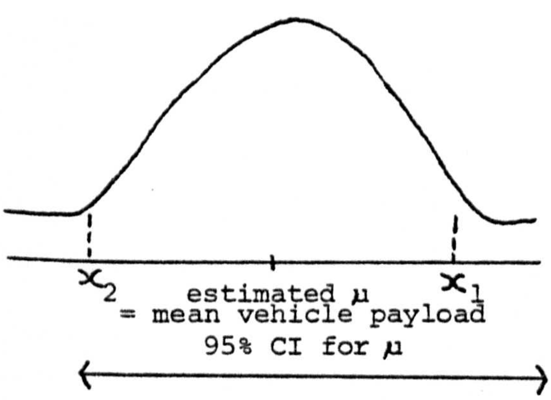
Table 4.5 TONNEAGE ESTIMATES, DETAILED IN THE APPENDIX 4C WORKED EXAMPLE USING SIMULATED FIGURES AND A SAMPLE SIZE OF 2% OF THE ANNUAL NUMBER OF LOADS

Step	SEASONS	i		ii		iii		iv	
	Vehicle capacity (yd^3)	15	20	15	20	15	20	15	20
1(i)	Sample Sizes:	43	39	36	22	41	29	41	37
	Mean vehicle payload	4.94	6.97	4.51	6.60	5.04	7.00	5.65	7.49
	SD	0.49	0.61	0.55	0.52	0.46	0.60	0.55	0.51
1(ii)	Mean vehicle payload	4.94	6.97	4.51	6.60	5.04	7.00	5.65	7.49
	Confidence Interval	±0.15	±0.20	±0.18	±0.22	±0.14	±0.22	±0.17	±0.17
	SD CI (pop. mean between limits	0.63	0.80	0.59	0.77	0.50	0.69	0.72	0.68
	95% of time)	0.41	0.50	0.47	0.41	0.38	0.48	0.46	0.42
	Interval width	0.22	0.30	0.12	0.36	0.22	0.21	0.26	0.26
	Width as a proportion of SD	45%	49%	22%	69%	48%	35%	47%	51%
1(iii)	Total No. of disposal trips made in sampling period	292	228	296	227	303	209	296	225
	Sampling period percentage (2 wks)	15.8%		11.1%		13.7%		15.0%	
2	Sampling period total tonneage (2wks)	1,442	1,589	1,335	1,498	1,527	1,463	1,672	1,685
	SD	8.4	9.2	9.5	7.8	8.0	8.7	9.5	7.7
3	No. of weeks in each season	13		13		13		13	
	Season total tonneage	9.373	10,329	8,678	9,737	9,926	9,510	10,868	10,953
	SD	21.4	23.5	24.2	19.9	20.4	22.2	24.2	19.6
4		20:60				20:80			
	Annual total tonneage:	38,845				40,529			
	SD	45.2				42.7			
5(i)	Grand annual total tonneage	79,374							
	SD	62.2							
5(ii)	Grand annual total tonneage and Confidence Interval	79,374 ± 124							
5(iii)	Annual no. of loads	13,494							
	Annual percentage of loads	2.1%							

It was observed that the calculated tonneages in each step increases as a multiple of the number of distributions combined, whereas the SD only increases as a multiple of the square root of these values. Thus, providing in the early stages of the analysis an appropriate sample size is selected the SD becomes an increasingly smaller proportion of the mean and assures the accuracy of the subsequent steps.

4.6 Variations in the Grand Annual Total Tonneage Estimates where Estimated $\mu \neq$ Real μ.

The values of $\bar{x}$ and s (quoted in the mathematical description in Appendix 4A) throughout this analysis are estimated figures with a 95% confidence and it has been assumed that these values are identical to the actual (population) μ and σ values. This need not be a valid assumption and it is therefore worthwhile re-working the analysis for a 'worst case' to determine the effect on the previously derived grand annual total tonneage and its SD. This proposed test is a sensitivity analysis on the above assumption and should it be found to be highly sensitive, the validity of the analysis would be called in question.



N.B. Sample weights do not necessarily need to be normally distributed.

In a worst case the actual mean could lie at one of the limits of the 95% CI, i.e. x_1 or x_2. The conditions and calculations of such a case are summarised in Table 4.6.

As a result of considering the worst case vehicle payload, from which successive steps in the analysis are derived, the difference between the worst case and estimated grand annual total tonneages is 2,386 tonnes, i.e. 3%. With reference to Appendix 4C the approximate weekly tonneage is 1,500 tonnes, hence a variation of 2,386t represents a difference of only 1½ weeks' arisings in a 52-week year. Furthermore, in practice a much smaller variation is likely since an actual mean vehicle payload will probably not correspond to this extreme worst case.

Table 4.6 WORST CASE VALUES AND COMPARISON WITH ESTIMATES USING SIMULATED FIGURES FROM TABLE 4.5

	SEASONS							
	i		ii		iii		iv	
Vehicle capacity (yd^3)	15	20	15	20	15	20	15	20
"Estimated" mean vehicle payload + CI	4.94 ± 0.15	6.97 ± 0.20	4.51 ± 0.18	6.60 ± 0.22	5.04 ± 0.14	7.00 ± 0.22	5.65 ± 0.17	7.49 ± 0.17
SD CI	$0.63>\sigma>0.41$	$0.80>\sigma>0.50$	$0.59>\sigma>0.47$	$0.77>\sigma>0.41$	$0.60>\sigma>0.38$	$0.69>\sigma>0.48$	$0.72>\sigma>0.46$	$0.68>\sigma>0.42$
"Real" mean vehicle payload assuming worst case	4.79	6.77	4.33	6.38	4.90	6.78	5.48	7.32
SD	0.63	0.80	0.59	0.77	0.60	0.69	0.72	0.68
Sampling period total tonneage	1,399	1,544	1,282	1,448	1,485	1,417	1,622	1,647
SD	10.8	12.1	10.2	11.6	10.4	10.0	12.4	10.2
Seasonal total tonneage	9,094	10,036	8,333	9,412	9,653	9,211	10,543	10,706
SD	27.5	30.8	26.0	29.6	26.5	25.5	31.6	26.0
Vehicle capacity (yd^3)	15				20			
Annual total tonneage	37,623				39,365			
SD	56.0				56.1			
Grand Annual total tonneage:	76,988							
SD	79.3							

"Estimated" grand annual total tonneage = 79,374 tonnes SD = 62.2 tonnes
"Worst case" grand annual total tonneage = 76,988 tonnes SD = 79.3 tonnes

Actual difference = 2,386 tonnes
Percentage difference 3%

4.7 INDEPENDENT METHODS OF ESTIMATING TOTAL TONNEAGES

There are several methods of estimating total tonneages without the need for sampling vehicle weights. Each possesses its own inherent inaccuracies and will be subsequently compared against a known total tonneage from an authority. The methods are briefly outlined:

1. Bin/Sack Counts
   Nationally or locally-derived mean weight of arisings per household bin or sack multiplied by the number of bins collected.

2. Property Counts
   Nationally or locally-derived mean weight of arisings per property multiplied by the number of properties served.

3. Population Counts
   Nationally or locally-derived mean weight of arisings per person multiplied by the total population.

4. Vehicle Counts
   Nationally or locally-derived mean weight of arisings per vehicle per disposal trip multiplied by the number of loads.

The predictions from these methods will need to be modified to take into account multi-storey buildings and other collection services. It is not clear how such modifications can be easily made, and no such modifications have been made here.

4.7.1 Comparison between the Tonneage Estimation Model and the Independent Methods

Comparison was made between the estimates produced by the tonneage estimation model, the independent methods above and the known total tonneage from a local authority. The findings are summarised in Table 4.7 and clearly indicate that the tonneage model produces a more accurate estimate than any of the independent methods. With the exception of using a nominal weight per vehicle of 5 tonnes the difference between all of the other methods and the known total is at least ± 9.5%. The difference between the tonneage model and the known total is only -0.3%.

Table 4.7 COMPARISON OF THE TONNEAGE ESTIMATION MODEL AND INDEPENDENT METHODS AGAINST THE KNOWN TOTAL TONNEAGE IN AN AUTHORITY

Estimation Method	Total Values		Unit Values	Six-month Total Tonneage	% Δ between Tonneage estimates
Bin/sack Counts	No. of sacks/week:		weight/sack:		
	26,536		SDD 0.011t x 26 wks	7,589	+19.7
Property Counts	No. of properties/week:		weight/property:		
	Domestic only:	17,941	SDD 0.015t x 26 wks	6,997	+10.4
			DOE 0.011t x 26 "	5,131	+19.1
	Domestic & Commercial:	19,981	SDD "	7,793	+22.9
			DOE "	5,715	- 9.9
	All Properties		SDD "	7,824	+23.4
			DOE "	5,738	- 9.5
Population Counts	Population of area: 48,766		Weight/capita SDD 0.38t/y ÷ 2	9,266	+46.2
Vehicle Counts	No. of loads:		Weight/vehicle:		
	1,231 ÷ 26 = 47.3	47/wk	4t x 26 wks	4,888	-22.9
			5t "	6,110	- 3.6
			6t "	7,332	+15.6
			7t "	8,554	+34.9
Tonneage Estimation Model				6,319	- 0.3
Known total from Authority				6,340	-

Sources: SDD Scottish Development Department
DOE Department of the Environment (1971)

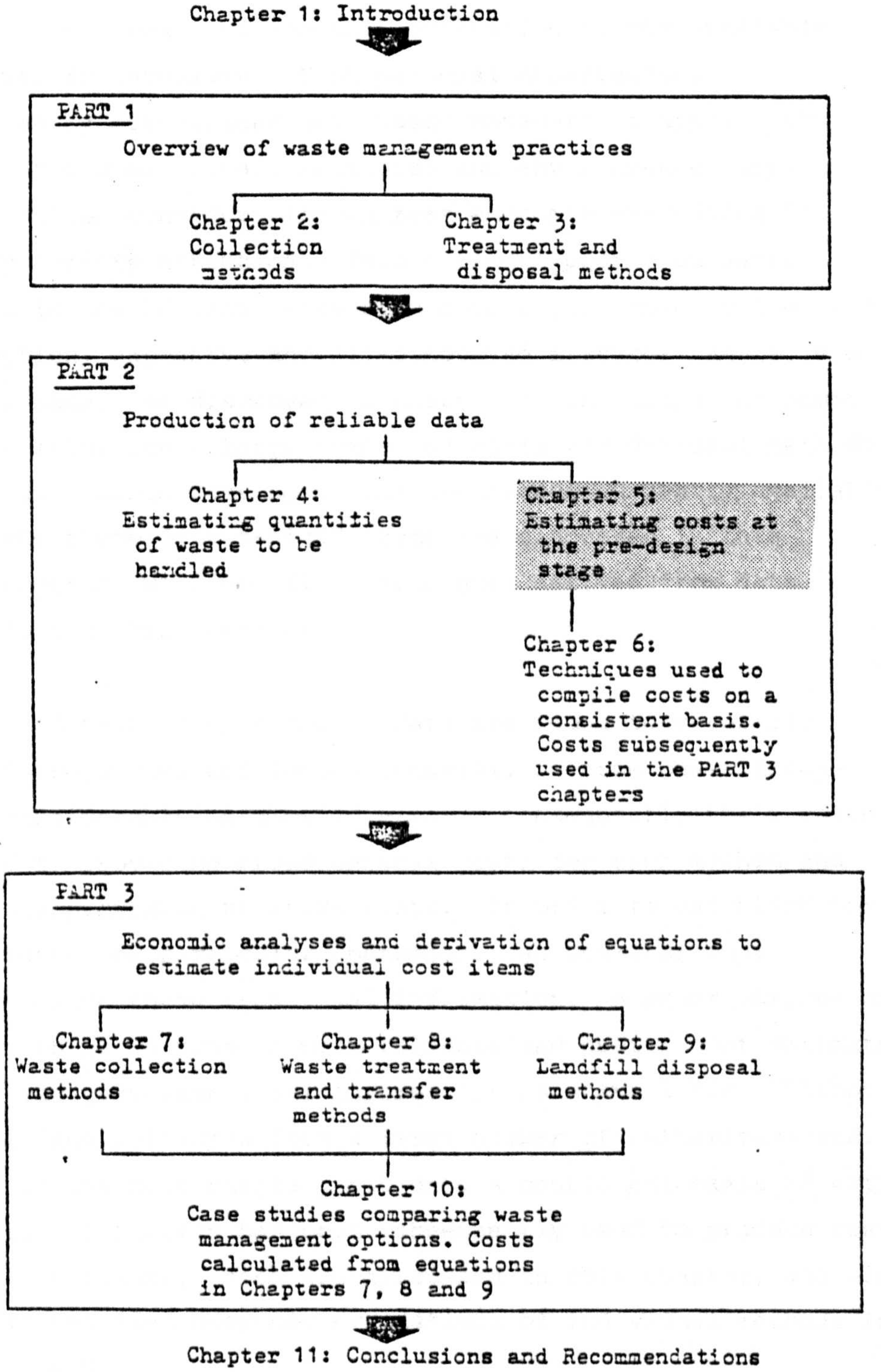
The findings of this comparison demonstrates that the tonneage model produces more accurate estimates and is therefore more useful to practical waste management than the independent methods. These latter methods should only be used when very general comparisons are to be made and even then their predictions should be treated with extreme caution.

4.8 CONCLUDING REMARKS

The tonneage estimation model is very straightforward to use, it requires the minimum of effort to collect data and is adaptable to operations of varying complexity. It produces very reliable estimates from small sample sizes providing the sampling is undertaken with due regard to the probable vehicle categories, the accuracy sought and a sampling plan devised to reduce possible systematic errors. These can all be taken into consideration with a little forethought and the resultant tonneage estimates will be an invaluable tool in the efficient management of a collection or disposal operation.

CHAPTER 5

CURRENT TECHNIQUES FOR ECONOMIC EVALUATION IN WASTE MANAGEMENT



Chapter 5

5.1 INTRODUCTION

Typically, local authorities only have experience in operating a small number of collection and disposal methods. Consequently when for example a comprehensive waste disposal plan is being developed a technical and economic evaluation of the available alternatives is necessary. From personal observations supplemented by discussions with waste managers it appears that frequently the operational, political and environmental aspects receive detailed consideration whereas economic evaluation is given only cursory attention. This reflects poorly on waste management in the UK since without proper regard towards the costs of each option, expensive and ill-conceived mistakes can be, and have been, made. As discussed in Chapter 1, an initial economic assessment involving a large number of different disposal methods would use only broad costings. The techniques currently available to calculate these "pre-design" costs are discussed in this chapter, together with modified techniques derived from data obtained during this research.

The published sources of economic data are found to regularly contain discrepancies and inconsistencies, in some cases incorporating considerable margins of error. Consequently their value is limited to providing broad general costs for each method and indicating approximate relative costs. In order to establish more accurate costs for particular operations, an operator must currently derive these from local information. A major purpose of this research is to provide more reliable and useful cost estimates for waste managers when local information is unavailable. Historic costs have been collected from a large number of authorities and, as discussed in the next chapter, put onto a consistent basis of estimation. This information has been subsequently used to produce cost estimation equations, which are discussed in this chapter, and also in the more detailed economic evaluations of individual methods in Chapters 7 to 9.

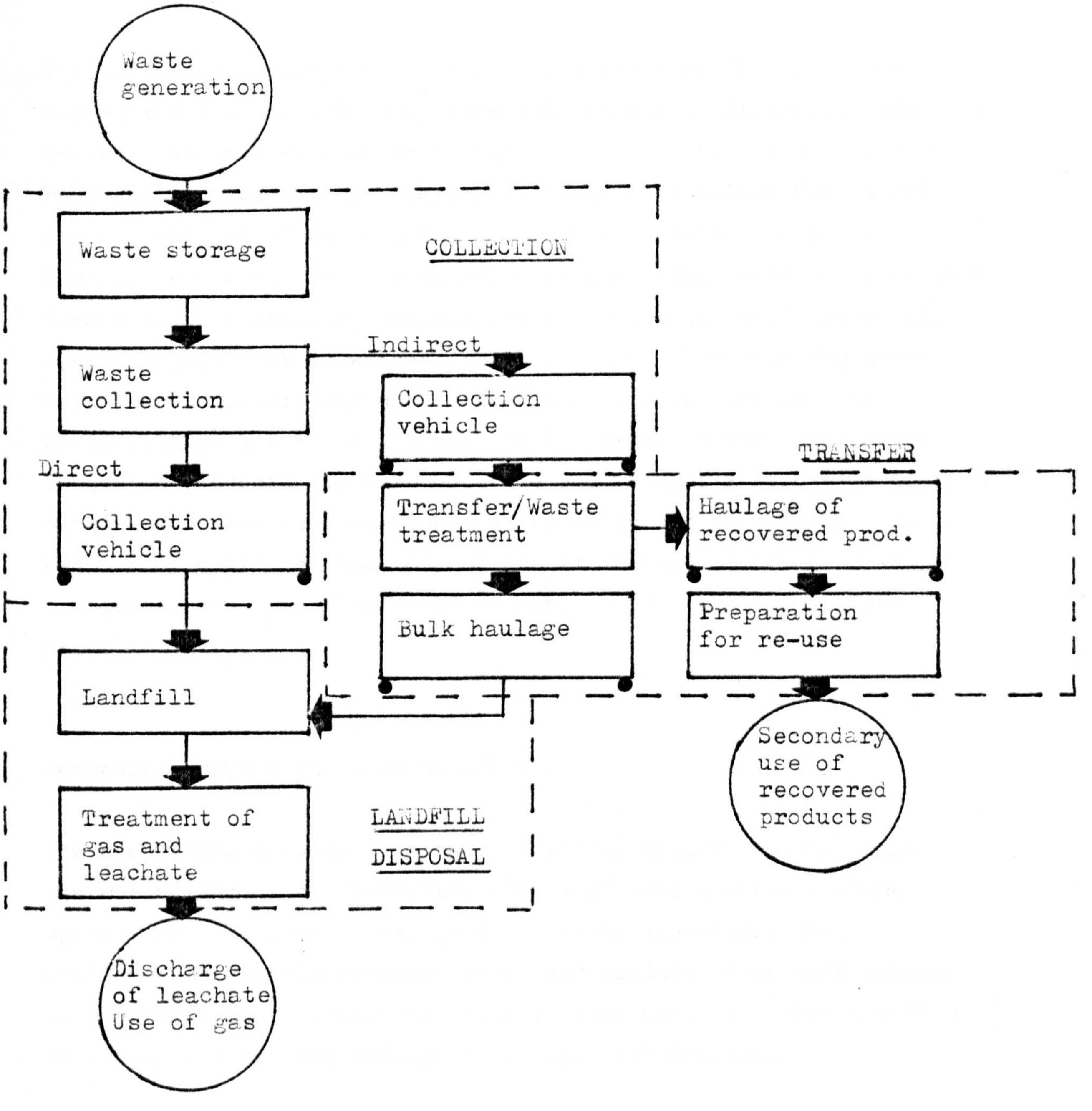
5.2 THE STRUCTURE OF WASTE MANAGEMENT

The field of waste management can be conveniently divided into three distinct processes (or sub-systems); collection of refuse from individual premises; transferal of refuse with or without treatment; and final disposal to landfill (or occasionally another means, e.g. RDF). The individual operations comprising each of these sub-systems are outlined in Figure 5.1 and the economic analyses presented in subsequent chapters for collection, transfer or land-fill disposal incorporate all of the operations in their respective sub-system.

The collection sub-system includes the storage of waste, its method of collection, and haulage to the disposal point. Haulage from the collection round to either a landfill or a transfer station is generally administered as part of the collection sub-system. However the distance to the disposal point will strongly influence this operation. Consequently, part of the haulage should be regarded as "collection" and part as "disposal" or "transfer." The Control of Pollution Act requires each English disposal authority to negotiate a payment to the collection authorities where the disposal point is "unreasonably far from the collection authority's area". Discussions with waste managers on the subject of "threshold distances" found that urban collection authorities are prepared to bear the haul cost up to approximately 12 km (return journey) from a collection round and for rural authorities up to approximately 24 km (return journey). The effect of route changes, crew sizes or number of trips per day was discussed in Section 2.8.5.

The transfer sub-system includes the transferal or treatment operation, bulk transport of residues to landfill and where applicable the haulage and preparation of recovered products for re-use. The disposal sub-system includes the various landfill operational and emplacement techniques and any required gas and leachate treatment.

Fig 5.1 Individual operations comprising municipal refuse collection and disposal in the UK.



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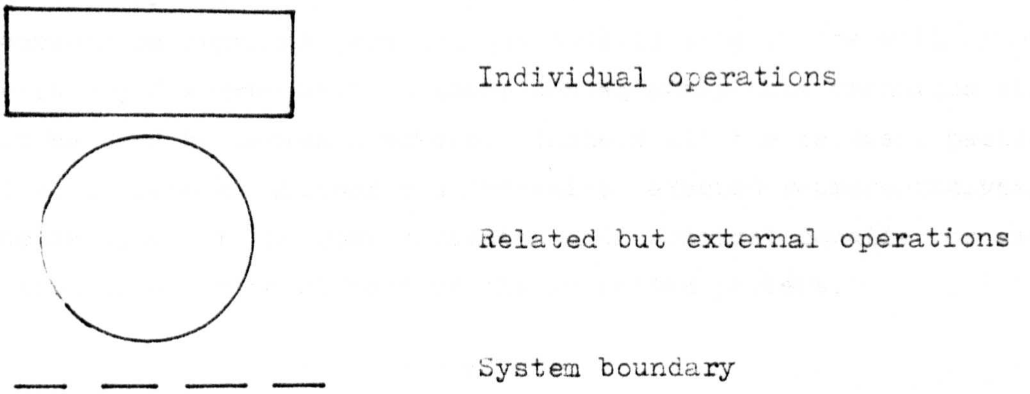


The influence of disposal on collection has been described above. Collection and transfer can conversely influence disposal. Resource recovery schemes such as waste paper collections, bottle banks, can banks and separation at transfer stations will affect the quantity and composition of waste going to landfill. Recent research, however, suggests that the quantity of materials currently recovered from municipal waste by authorities on a national basis is small, approximately 0.5% by weight (INCPEN, 1981). The quantity separated by householders and not collected by authorities is under investigation but is not thought to be large. Market prices for recovered products are very volatile and without a stable or minimum guaranteed price recovery schemes are often not undertaken. An example of waste reclamation and its financial influence on waste management has been elucidated recently by Ho (1982) for waste paper recycling.

5.3 COMPARING OPTIONS IN WASTE MANAGEMENT

The comparison between alternative options should involve first the establishment of "selection criteria" (which would include operational considerations, general design specifications, environmental considerations, cost) and against which each method is then assessed. After the criteria have been evaluated the final selection between the methods is a political decision.

A simple method of comparing options is a purely subjective discussion on the relative merits and disadvantages of each alternative without considering specific financial data and technical specifications. Such an approach is not likely to produce meaningful results. People's perceptions vary and one individual's choice will almost certainly disagree with another; consequently this technique should not be used by decision-makers. Instead all the relevant parties (i.e. operators, licensing authorities, elected representatives) should consider the cost estimates and technical details for each option as an integral part of the selection process.

The ultimate choice of a method would take into account not only this information but also the more subjective political and social aspects and their intangible effects (e.g. effect on property values, increased traffic, public resistance).

The costs of waste management operations, when used for comparative purposes, can be calculated using two approaches: annual costs, and discounted cash flow.

5.3.1 Annual Costs

To calculate the annual cost of an operation only those cash flows arising in one particular year are considered. Accounting practices, including those undertaken by local authorities, compile operating costs and incomes annually. Consequently, costs in this form are readily available and widely used to evaluate waste management operations. Capital expenditures are treated as annual payments calculated by either straight-line depreciation with separate consideration of interest payments, or by amortisation which includes both annual interest charges and debt repayments. Other forms of capital financing are possible, in particular leasing and hire-purchase. These are revenue expenditures and enable major items to be purchased when capital budgets are limited. They are however more costly in the long-term.

5.3.2 Discounted Cash Flow (DCF)

Cash flows in one time period are worth more than the same sums in a later period, since money received sooner can be re-invested in the meantime. DCF incorporates this concept by considering all operating costs, capital costs and incomes in the years they arise and discounting them back to the initial year of the project (i.e. year O). Discounting uses "discount factors" (appropriate to a particular cost of capital) to calculate the "present value" of the component costs in one time period. The most useful technique to authorities for project appraisal is "net present value" (NPV). This involves the summation of the individual present values over the whole project lifetime (Eq. 5.1):

$$NPV = \sum_{t=0}^{t=n} \frac{A_t}{(1+r)^t} - C_o \qquad \text{Eq. 5.1}$$

where: C_o = initial capital outlay

A = net cash flow (revenue - costs)

r = discount rate

t = time (years)

Since waste management is a "cost centre" the NPV is usually termed the "net present cost" (NPC). Comparison between methods over the same lifetime requires each of their NPCs to be calculated and ranked in order of least cost. Where capital budgets are restricted a method with a small NPC may become unattractive if it requires a larger initial investment than the alternatives considered.

The ranking of methods using either annual costs or NPV can be affected by uncertainty in the estimated value of a component cost or physical parameter. In order to draw attention to the effects of uncertainty the most critical costs and parameters in this work are investigated using sensitivity analysis (described in Section 6.6).

5.3.3 Comparison between Annualised Costs and NPC

If the cash flow profiles for two or more alternative methods under consideration are similar then the NPCs calculated for a range of discount factors will not change the relative ranking of each. This is true for comparisons made against the base case or some other consistent basis. Consequently the ranking of methods in terms of least cost will be identical for both the NPC and annualised cost approaches.

Each of these approaches does, however, produce a different total cost. The annualised cost gives the total cost for one year only, whereas NPC derives the total cost of the project in year 0 money for the entire life of the project (for example 5 or 10 years).

NPC is superior to annualised costs in some respects since it accounts for proportional changes in component costs over time. These however are unlikely to occur in the short-term. Leaving aside inflation which affects both techniques, NPC requires the selection of a discount rate. There is, however, much uncertainty in the determination of this. In the short term (up to 5 years) for operational planning (the period this work concentrates upon) NPC estimates may therefore have similar, or possibly larger, inaccuracies than annualised cost techniques. Consequently the latter is used here. DCF techniques are more suited to longer term, strategic comparisons where variations in the cash flow are more likely. The component costs (calculated from the cost models and presented in the later chapters) and the plant lifetimes (outlined in the base case) could be directly used for NPC calculation if so required.

5.4 COST - BENEFIT ANALYSIS

Cost - benefit analysis (CBA) is concerned with the costs and benefits of particular options for society as a whole, and not just a small section of it. In waste management the intention of CBA would be to minimise the cost of collection or disposal to the local community rather than just the direct financial expenditures of the authority. It involves not only evaluating the capital and operating costs but also the intangible effects, for example, landfilling would also include 'costs' for noise, smell, dust, loss of visual or recreational amenity, and increased traffic.

The appropriate costs for CBA are based on the concept of "opportunity costs"; the foregone benefit of the best alternative project. For most criteria this is the market price, e.g. energy costs are based on current fuel and electricity tariffs. However the opportunity cost for certain items such as land and intangibles are more difficult to evaluate.

Hwang and Rudzitis (1978) attempted to produce a single opportunity cost for all of the intangible effects related to landfilling by investigating the reduction in property values around US landfills. They suggested a total external cost to the surrounding district of 5 to 7 cents per US ton (1977 values). This is a low value but the actual cost due directly to landfilling will be smaller still, although unfortunately no exact values are available. Since landfills are generally situated out of towns, other local factors also affecting house prices include distance to shops, facilities and employment; close proximity to airport flight paths or other sources of nuisance; quality of the neighbourhood. Rudzitis (personal communication, 1980) believes that whatever is the exact intangible cost of landfilling, the "loss of amenity" component is probably the most important criterion.

CBA is not used and is unlikely to be used in the foreseeable future by waste managers in the UK, although it is recommended by the Department of the Environment (DoE, 1976). Much is evaluated from abstract and poorly approximated costs and the solutions produced are often ambiguous. Rudzitis' work is an example of this. It suggests that the intangible costs of landfilling are financially very small (Table 5.1); however this finding is contentious and in practice local residents would strongly argue to the contrary. The trade off between costs and amenity is more realistically addressed as a political decision. In this work comparisons between methods are based on financial evaluation of directly attributable costs, intangible effects are only considered by discussion. This approach produces more useful results than those obtained from contentious intangible factors.

Table 5.1 EXAMPLE CALCULATION OF INTANGIBLE COSTS OF LANDFILLS

Intangible cost of landfilling to surrounding district:

$0.05 to 0.07 / ton (1977) - Hwang and Rudzitis (1978)

Assume:

i) entire cost is due to landfilling and has doubled since 1977.

ii) exchange rate £1 = $1.75 (1981)

∴ Approx. $0.10 to 0.14/ton (US 1981 prices)

= £0.06 to 0.08/tonne (UK 1981 prices)

Example Calculation

250 t/d landfill (62500 t annually)

Annual intangible cost of landfill to the surrounding district is:

@ 0.06 £/tonne	@ 0.08 £/tonne
£3,750	£5,000

5.5 SOURCES AND ACCURACY OF FINANCIAL DATA

Comparison of the economics between methods, using either annual costs or DCF estimates of the component capital and operating costs must be made. In this and subsequent sections the sources available to estimate these costs and their accuracy are discussed.

The accurate estimation of capital and operating costs in waste management is difficult. Differences between individual operations arise through variations in plant design, operational standards, site-specific costs and the techniques of cost-estimation. The following sections discuss only the latter of these, i.e. those techniques currently used for estimating costs. However, these techniques implicitly consider the other three sources of variation. Ideally, for any one disposal method an estimation technique should produce realistic estimates by combining data from several sources and enable adjustments to be made where there exists known differences in plant design, operating standards, and costs specific to a site.

For authorities where some form of ecomomic evaluation is undertaken the sources of cost data currently available are:

- An authority's or consultant's own costings and those presented in the published literature (Section 5.6)
- Nationally published statistics (Section 5.7)
- Cost estimation procedures (Section 5.8).

5.6 EVALUATIONS USING LOCAL AUTHORITY FIGURES AND THE PUBLISHED LITERATURE

Some authorities undertake financial analysis using data from their current operations. Inevitably only one or two examples of each method are considered. Often, however, an authority's cost records lack sufficient detail to be used for satisfactory evaluations.

Authorities can be divided into three general categories regarding the detail in their costings of individual collection and disposal operations.

(i) Some authorities only keep costs at a gross collection (or disposal) level whereby any costs accruing to a particular round (or site) are directly included in the total collection (or disposal) costs for the entire authority. Large and small authorities both fall into this category.

(ii) Some authorities have limited cost accounting for individual operations, particularly those which possess their own Costing Branch or computer facility. However, it is rarely in a detailed form but usually broken down into approximately six broad headings, e.g. 'Total County Council Plant Costs', 'Total Material Costs'.

This allows for limited economic evaluation between operations but the breadth and nature of the headings are too large for individual component costs to be estimated.

(iii) Only a small number of authorities have or possess the unexploited expertise to derive very detailed cost figures. These authorities have a very high degree of professionalism in their management and are very well trained in cost accounting and its use for planning and control purposes. It is unfortunate there are so few.

Economic evaluation using this source of data is further complicated when an authority has no experience of costs for some of the methods under review. Costs are subsequently derived from those presented in the literature. This is likely to produce ambiguous comparisons since the published figures relate to other authorities and are invariably compiled on a different basis, for example, variations between authorities in accounting conventions, refuse throughput, age of plant, interest rate, accuracy of the component costs and standard of operation. What is needed is a method for unambiguous economic appraisal which also accounts for an individual authority's operational and financial criteria. The research undertaken in this study has been directed towards this end. Details of the derivation and use of the cost models calculated are presented in later chapters.

Frequently if an authority does not possess detailed costs or expertise it may employ a consultant to undertake economic evaluations. The usefulness of their reports in waste management planning vary widely and criticisms have been levelled against some evaluations. These include:

- Do not consider all available options or concentrate on their preferred options.
- Absence of any error values for their quoted figures.
- Little or no sensitivity analysis.
- Assumed values for certain costs are inaccurate. In one case the cost of bulk haulage was omitted from the evaluation of a transfer operation.
- Operational assumptions for certain methods are incorrect. For example an appraisal of options by Mason and Bidwell (1980) assumes transfer equipment to operate at 90% design capacity for a full 8-hour day over a 52-week year. This is never achieved in practice.
- Little or no justification for the choice of values given to component costs.

Evaluation of local authority or consultant-derived data do enable comparisons to be made between methods at individual sites. The results however are often far from detailed, and, without a detailed understanding of the economics their accuracy is questionable.

It is also unlikely that they can be extrapolated to operations at other locations. Authority data is usually based on only one or two examples of each method and as such some component costs may be abnormal. This contributes to further inaccuracies if the costs are used by other authorities. To overcome this criticism data from several similar operations can be collected and cost models for each method derived. A large and preferably detailed sample size is required. Operational and financial differences are reduced but are still present in the data, unless the cost criteria have been put onto a consistent basis. Two sources of data derived from large samples were identified. First, annual nationally-derived costs; and second, cost estimation procedures in which cost estimates derived from other industries are applied to waste management. These are discussed in the next two sections.

5.7 EVALUATIONS USING NATIONAL STATISTICS

Waste collection and disposal statistics for English and Welsh authorities are compiled by the Chartered Institute of Public and Finance Accountants (CIPFA). Included in these are aggregated total operating costs and tonneage figures for several collection/ disposal methods in each authority. From these, cost models can be proposed for each method. An hypothesis commonly considered in the literature (e.g. Dawson, 1970) is that total operating costs are linearly related to the tonneage handled. If this is true the total cost of a method can be estimated by multiplying the tonneage throughput with the relevant straight line cost function (Eq. 5.2). This hypothesis has been investigated by regression analysis using the CIPFA figures over a seven-year period (1974/75 to 1980/81) for English disposal authorities.

$$C = bT + a \qquad \text{Eq. 5.2}$$

where C = Annual net operating cost including capital charges

T = Annual tonneage handled

and a and b are Constants.

Net operating expenditures were used rather than gross values on the grounds that the actual cost to the ratepayer is gross expenditure less income.

5.7.1 Analytical Methods

The relationship between the costs and tonneages for each disposal method considered by CIPFA was tested statistically. The mean costs per tonne and SD were calculated and tested for randomness using the t-test. Regression analyses were then undertaken and are discussed in subsequent sections

t-test

The first test performed on the data for each method and year was the Student's t-test to determine whether the mean cost/tonne values were significantly different from zero (i.e. the theoretical mean value expected from totally random data). A second test was conducted on the slopes of the regression lines (β) to determine whether these values were significant. This, together with the coefficient of determination, indicates the goodness of fit of the regression line. A poorly fitting regression line will produce an unreliable cost model.

The t-test while indicating if a mean cost/tonne figure or slope of a regression line are significantly different from random values, does not give any indication as to the nature of this difference.

Regression Analysis

Regression analysis was subsequently performed to determine the relationship and variation between the variables; total net operating cost and refuse tonneage. Figures for each disposal method were considered in one-yearly intervals over a seven-year period, 1974/75 to 1980/81.

The amount of variability explained by the regression line is given by R^2, the "coefficient of determination". When $R^2 = 0$ none of the variation in the data is explained by the regression line (i.e. the data is totally random) and when $R^2 = 1$ all variation is explained (i.e. the line perfectly fits the data points).

5.7.2 Results

The results of the unit cost calculations, regression analyses and t-tests are detailed in Appendix 5A.

t-test

In Appendix 5A only five mean costs out of a total of 41 cases failed to show a significant result at the 5% level. When the arguments below are considered only one of the cases subsequently used failed at this level (Table 5.2). It was therefore found that most of the data does exhibit some broad correlation between cost and tonneage.

The second t-test performed on the slopes of the regression lines indicates that all of the values are significantly different from zero at the 0.1% significance level.

Straight-line Regression

The R^2 values in Appendix 5A for direct landfill changed markedly in most cases when the GLC figure was removed. This is due to the GLC figures being very much larger than other authorities and consequently dominating the regressions. Thus in the subsequent analysis for this method the "excluding GLC" results have been used. Conversely, with pulverisation and incineration the R^2 is relatively unchanged (except in one case) by the exclusion of the GLC figures and therefore the "including GLC" figures have been used. A summary of the R^2 values and the mean cost/tonne for each method used in the discussion (Section 5.7.3) is given in Table 5.2.

The selected cost functions were also plotted to exhibit the regression line and the 95% CI and are presented in Appendix 5B.

Table 5.2 SUMMARY OF THE MEAN COST PER TONNE, SLOPE and R^2 VALUES FOR EACH DISPOSAL METHOD BETWEEN 1974/75 AND 1980/81
(from the CIPFA Waste Disposal Statistics for English Authorities)

Disposal Method	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	Comments
DIRECT LANDFILL								
Mean (2) (£/t)	1.00*	1.39*	1.60*	2.01∤	2.39*	3.05*	3.14*	
SD (£/t)	0.47	0.63	0.73	0.81	1.03	1.50	1.88	
R^2 (1)	0.46	0.56	0.56	0.63	0.62	0.40	0.38	Moderate R^2 and low
Slope β	0.55≠	0.98≠	1.16≠	1.44≠	1.49≠	1.82≠	2.38≠	
PULVERISATION AND LANDFILL								
Mean (£/t)	3.27*	5.11	5.17*	5.99∤	7.82∤	12.31*	9.90*	1975/76 figure not significant at 5% SL and is considered unreliable.
SD (£/t)	1.54	3.15	2.44	2.30	2.97	6.98	4.41	
R^2 (1)	0.85	0.73	0.51	0.96	0.92	0.83	0.83	High R^2
Slope β	3.50≠	5.77≠	4.00≠	9.00≠	10.66≠	13.10≠	12.03≠	
DIRECT INCINERATION AND LANDFILL								
Mean (£/t)	7.36*	9.30∤	9.91*	11.20∤	11.83*	15.90*	11.01∤	
SD (£/t)	3.90	3.58	3.98	4.09	5.05	7.24	4.23	
R^2 (1)	0.93	0.97	0.90	0.91	0.81	0.91	0.90	High R^2
Slope β	7.58≠	10.23≠	9.58≠	10.14≠	12.13≠	15.03≠	12.10≠	

Notes:
(1). Straight line regression coefficient of determination.
(2). All mean values are significant to at least the 5% SL unless otherwise commented.
* Mean cost/tonne significantly different from zero at the 5% significance level.
∤ Mean cost/tonne significantly different from zero at the 1% significance level.
≠ Regression slope significantly different from zero at the 0.1% significance level.

5.7.3 Discussion and Criticisms of National Statistics

The plotted data in Appendix 5B takes the form of a broad band of points within which the regression line (i.e. a straight line cost function) is fitted. For the pulverisation and incineration methods the R^2 values for all years suggest that the straight line cost function explains most of the observed variation, 0.51 - 0.96 and 0.81 - 0.97 respectively. These values (as outlined in Table 5.2) agree with those calculated by Wilson (1981). For direct landfill however the amount of explained variation is considerably lower, with R^2 ranging between 0.38 and 0.63. This suggests for direct landfill the hypothesis of a linear cost model is not substantiated. The absence of high R^2 values may be due either to inaccuracies in the present methods of compiling disposal costs and tonneage figures thereby preventing meaningful comparisons between authorities; or alternatively, economies or diseconomies of scale exist in the data (Economies of scale are discussed further in Section 5.9).

Inspection of the graphs in Appendix 5B suggests that there is no apparent tendency for the points from the waste disposal authorities handling large tonneages to be aggregated above (diseconomy of scale) or below (economy of scale) the linear cost function. However, the implied concept of an economy of scale between authorities is not really meaningful since for each method only aggregated total costs are quoted in the CIPFA statistics. Furthermore, each authority will have a different combination of operations, varying both in their mode of operation and capacity. Individual economies of scale, if they exist, differ between sites and these will be masked by the aggregated CIPFA figures for an entire authority. The CIPFA figures are therefore not in a suitable form to identify economies of scale. However scale factors for individual collection, transfer and landfilling methods have been investigated in this work by other techniques (summarised in Section 5.9).

Disposal by direct landfilling in 1980/81 was estimated to account for 68% of the refuse arising (CIPFA, 1982) and the poor relationship between total cost and tonneages is due to one or more of the following:

1. Widely different accounting conventions used by individual authorities.

2. Different methods of operation and standards employed.

3. The inclusion of both direct and compaction transfer landfilling methods under the category "Landfill Untreated".

4. Unreliable determination of tonneages handled.

5. Varying haul distances to disposal sites in different authorities.

6. Aggregating costs from operations with widely different tonneage throughputs, and each authority having a unique mix of sizes of operation.

The apparent consistency of the regressions with pulverisation and incineration appears to contradict the direct landfill criticisms.

Possible reasons for the high R^2 values are:

1. Often an authority only possesses one or two plants employing these treatment methods which is small compared to the number of direct landfills. Thus the potential for financial ambiguities within an authority from non-uniform costing procedures and differing operational techniques are lower.

2. Treatment plants generally have weighbridges as an integral part of their design and as such some of the inaccuracies with direct landfill attributed to poor tonneage determinations are eliminated.

3. With pulverisation the good agreement obtained is possibly due to four authorities dominating the analysis. These authorities handle much larger tonneages than any of the others. Consequently providing their unit costs are similar the resulting R^2 values will be high, reflecting this influence. Costs from other authorities then become irrelevant.

4. Expenditure on capital repayments and energy are larger for treatment operations than for landfill disposal sites of similar size. Evidence from Chapters 8 and 9 supports this, ie

	50 t/d		500 t/d	
	Energy	Capital charges	Energy	Capital charges
	(% of total operating cost)			
Direct landfill	5	27	5	36
Dry Pulverisation and Landfill	8	45	9	45

Capital and energy charges reflect national variations rather than local influences. Conversely, landfill, which is usually less capital intensive, is more subject to local influences, such as expenditures on labour, vehicles and site preparation. Therefore, it is possible that treatment costs for comparable operations will be more closely aligned between authorities and hence explain the closer agreement in the regressions than found with direct landfill.

A compiler of the CIPFA statistics (Baker, private communication, 1980) has commented that they have no other purpose than to document figures from individual authorities and to compile approximate national values. Recently, however, CIPFA have stated to the contrary.

> "The (statistics) can also draw attention of members of the public to possible differences between their own and other authorities" (CIPFA, 1981b)

While it is envisaged that a waste manager or layman could obtain a "broad brush" indication of the relative costs of each method from them, the CIPFA figures, being aggregated total costs, do not give values for the individual component costs or distinguish between different sizes of operation. Furthermore, the figures quoted by contributing authorities are not on a consistent basis for comparison. Consequently the CIPFA waste disposal statistics should not be used for planning purposes or as a source of data for economic evaluations. However, they are presented in such a manner that it is very easy for someone not aware of their limitations to compare and contrast adjacent authorities and methods.

Some specific points where improvements need to be made are detailed below; however, their use should still be restricted to "broad brush" analyses:

1. Capital expenditures for individual operations commence in different years, therefore the annual capital charges incurred on such items reflect these historic costs. Capital charges should be evaluated at a common interest rate and from a common base date.

2. The length of time over which capital costs are written off varies widely.

3. With the more sophisticated disposal methods it is often unclear whether the costs for bulk haulages are included in the reported figures.

4. Some authorities include cover purchase in their landfill revenue expenditures, some do not. Others have sufficient available (i.e. unpurchased) on-site.

5. Often it is not known whether the costs for a disposal operation include civic amenity wastes.

6. The relative remoteness of a site will affect the disposal operating costs and bulk haulage costs.

7. Regional variations in prices can affect one or more of the component costs of an operation.

8. Departmental administration costs are treated differently between authorities and are often not apportioned over individual methods or sites.

9. No distinction is made between wet or dry pulverisation methods and baling (currently omitted in the CIPFA figures) should be included.

10. Differences in operational standards, e.g. manning levels and degrees of mechanisation, need to be resolved and put onto a consistent basis.

11. Operations handling different tonneages will have inherently different costs. Each authority's returns to CIPFA should distinguish in its costs high and low throughput operations for each method.

12. Sensitivity of the costs to different conditions is impossible to evaluate from the CIPFA figures as they are currently compiled.

5.8 EVALUATION USING COST ESTIMATION PROCEDURES

Cost estimation techniques are widely available in several engineering fields for the estimation of pre-design capital and operating costs, where a planner has no in house information. These estimates are valuable in providing first approximations from which a large number of options can be conveniently reduced (on the basis of cost) to a manageable number for more detailed appraisal.

Cost estimation procedures calculate cost estimates from "cost factors". These are correlations based on extensive historical data. One simple example would be for, say, wet pulverisation building costs are 40% (0.4) of the total capital cost. More sophisticated procedures produce factors which estimate component costs in greater detail. If the basis on which they are derived is stated the estimates can be easily adjusted to account for variations in plant design, operating standards and site-specific costs. Cost factors enable a more detailed appraisal of each method to be made than is possible from national statistics or the limited data available to individual authorities. Unfortunately there are no cost factors published in the literature specifically derived for waste management and instead authors have adopted those from various engineering fields. To remedy this situation a set of capital and operating cost factors for municipal waste landfill, transfer and treatment were derived from data obtained in this research. This data was compiled primarily to produce detailed costs for selected waste disposal methods, and are fully discussed in the following chapters.

These "waste management" cost factors produce pre-design cost estimates. They contain a sizeable error margin due to the inherent variations present in the historic costs used to derive them. When formulating waste management cost factors the aim has been to achieve an accuracy within $\stackrel{\times}{\div}$ 1.25, i.e. a similar value to that used in chemical engineering designs (Allen and Page, 1975).

5.8.1 Capital Cost Estimation

An early method of cost estimation used only one factor, the Lang factor (f_L), which was multiplied by the delivered equipment cost (DEC) to produce the total capital cost (C_T). The factors varied for different types of chemical plant.

$$C_T = f_L \cdot DEC \qquad \text{Eq. 5.3}$$

Later methods have extended the number of component factors to improve the detail and usefulness of the estimates. One approach is to divide the total capital cost (C_T) into three sub-totals: Total direct plant costs (C_{DC}); total indirect plant costs (C_{IC}); total non-plant cost (C_{NP}).

$$C_T = C_{DC} + C_{IC} + C_{NP} \qquad \text{Eq. 5.4}$$

Each sub-total is considered separately and is the function of a different set of cost factors. Most methods first determine a value for the DEC and it is argued that each direct plant cost factor (f_n) is multiplied to derive the corresponding cost. A summation of the cost factors produces an expression for the total direct plant cost. (The symbols are defined in Table 5.3):

$$C_{DC} = DEC\ \emptyset_1\emptyset_2 \qquad \text{Eq. 5.5}$$

OR

$$C_{DC} = DEC\ \emptyset_1\ (1 + f_1 + f_2 + f_3 + f_4 + f_5) \qquad \text{Eq. 5.6}$$

Next, total indirect plant costs are calculated. These include design fees, contractors overheads and contingency and they are estimated as a percentage of the total direct plant cost (C_{DC}).

$$C_{IC} = C_{DC}\ (f'_1 + f'_2 + f'_3) = \emptyset_3 \qquad \text{Eq. 5.7}$$

Finally, Non-plant costs, such as working capital and start-up costs, are calculated. These are expressed as a percentage of the annual operating cost (O_C).

5.8.2 Waste Management Capital Cost Estimation Factors

The factors in Equations 5.5 to 5.7 are based on chemical engineering and resource recovery data and are not designed for waste management. To make these factors more applicable to the latter some have been retitled and others invented. A full list of definitions is given in Table 5.3 and Equations 5.5 and 5.6 are thus rewritten:

$$C_{DC} = IEC\ (1 + (f_2 + f_4) + (f_3 + f_5) + F) \qquad \text{Eq. 5.8}$$

$$C_{IC} = C_{DC}\ ((f'_1 + f'_2) + f'_3) \qquad \text{Eq. 5.9}$$

Working capital and start-up costs (W and S) are considered as non-plant capital costs (C_{NP}) and are estimated as proportions of the annual operating cost (O_C):

$$C_{NP} = O_C\ (W + S) \qquad \text{Eq. 5.10}$$

Table 5.4 lists some of the published cost factors (from Wilson, 1981) which up until now have been the only ones even remotely applicable. Wilson (1980) comments that there is an important need to develop cost factors specifically related to waste management. The factors detailed in Table 5.5 and the corresponding Equations 5.8 to 5.10, have been derived for this purpose. They are derived from costs obtained in this research from 40 authorities which were standardised on to a common basis. (Base case details in Chapter 6; costs detailed in Chapters 8 and 9).

Care has been taken to include all relevant equipment, including mobile plant but excluding bulk transporters and subsequent landfilling for the transfer and treatment methods. Land purchase and special engineering to alleviate leachates or gas are not included in the landfill factors. Indirect plant costs, from only limited data, are taken as a fixed proportion of the annual operating costs, both irrespective of plant capacity. Direct plant cost factors for each method are produced for the following capacities (measured in number of machines):

Table 5.3 KEY TO THE SYMBOLS USED IN THE CAPITAL COST ESTIMATING EQUATIONS DISCUSSED IN THIS CHAPTER

Cost items	Symbols used in published literature (principally chemical engineering and resource recovery)*	Symbols used in the estimating equations presented in this thesis**
Absolute (monetary) values		
Delivered equipment cost	DEC	DEC
Installed equipment cost	IEC	IEC
Annual operating cost	OC	O_C
Total capital cost	C_T	C_T
Total direct plant cost	C_X	C_{DC}
Total indirect plant cost	$\emptyset_3$	C_{IC}
Total non-plant cost	C_{NPC}	C_{NP}
Factored values		
Process piping	f_1	not relevant
Instrumentation	f_2 }	ancillary equipment $(f_2 + f_4)$
Utilities	f_4 }	
Buildings	f_3 }	buildings, civil, site preparation $(f_3 + f_5)$
Services	f_5 }	
Mobile plant	not considered	F
Architectural and building fees	f'_1 }	site survey and design $(f'_1 + f'_2)$
Contractors' overheads	f'_2 }	
Contingency	f'_3	f'_3
Working capital	no symbol	W
Start-up costs	no symbol	S
$(1 + f_1 + f_2 + f_3 + f_4 + f_5)$	$\emptyset_2$	not required
Installation	$\emptyset_1$	$\emptyset_1$

* reported in Table 5.4

** reported in Table 5.5

Table 5.4 PUBLISHED CAPITAL COST ESTIMATION FACTORS (taken from a survey made by Wilson, 1981)

Component Costs	Symbol	Chemical Engineering		Waste Processing					
		Chilton, 1949 Holland et al, 1974	Haselbarth and Berk 1960	Stuckenbacker and King, 1977 RDF Plant	Stuckenbacker and King, 1977 Pyrolysis Plant	Midwest Research Inst. 1975 (corrected by Wilson, 1981)	Smith 1975	Schulz et al, 1976	Schroeder and Fabuss 1978
DIRECT PLANT COSTS									
Installation	ϕ_1	Solids 1.45		0.04	0.07				
Process Piping	f_1	Solids 0.07-0.10						0.40	
Instrumentation	f_2	Auto, some control 0.05-0.10						0.20	
Building	f_3	Indoor - outdoor units 0.20-1.00		0.53	0.23			0.43	
Utilities	f_4	New site 0.25 - 1.00						0.25	
Services	f_5	Existing plant - scattered site 0.05-0.25		0.01	0.008			0.004	
INDIRECT PLANT COST									
Architectural and Engineering Fees	f'_1	Straight forward) plant 25-35%)		5%			6.5-8.0%		7.5%
Contractor's Overheads	f'_2	Complex plant) 35-50%)	6-12%	10%		28%	Approx 25%	21%	7%
Contingency	f'_3	10-30%	7-14%	19%		-	8-15%	15%	10%
Total C_{IC}	ϕ_3	30-80%	13-26%	34%		28%	39-48%	36%	36%
NON-PLANT COST									
Working Capital				5.1%	5.6%				3%
Start-up Cost				2.6%	1.1%				20%
Total C_{NP}				7.7%	6.7%	51%	33%		23%

Table 5.5 WASTE MANAGEMENT CAPITAL COST ESTIMATION FACTORS

March 1981 figures, Greenfield Site.

See Table 5.6 Items included in each component cost.
Table 5.3 Definitions of the symbols used.

COMPONENT COSTS and SYMBOL	DIRECT LANDFILL	COMPACTION [1]			PULVERISATION [1]		BALING [1]	COMMENTS
		Without Storage	Apron	Bunker	Dry	Wet	Wire-tied	
DIRECT PLANT COSTS								
DEC Delivered Equipment Cost	O	Not considered						
$\emptyset_1$ Installation	O	-	-	-	-	-	-	
$DEC\emptyset_1 = IEC_1$ Installed Equipment Cost	O	IEC	IEC	IEC	IEC	IEC	IEC	
	PROPORTION OF TOTAL DIRECT CAPITAL COST							
f_4+f_2 Ancillary Equipment	O	0.29–0.66 (1)	0.29–0.66 (1)	0.29–0.66 (1)	0.56–0.62 (1)	0.14–0.25 (1)	0.21–1.70 (1)	↑
		0.42–0.55 (2)	0.32–0.55 (2)	0.32–0.55 (2)	0.45–0.53 (2)	0.22–0.26 (2)	1.24–1.53 (2)	
		0.29–0.34 (3)						
f_3+f_5 Building prep. costs, Access Road, Hopper-const.	48–50%	1.62–2.22 (1)	1.75–3.25 (1)	9.20–10.6 (1)	2.11–4.79 (1)	0.63–1.43 (1)	1.59–2.32 (1)	Proportion of I_{EC}
		2.82–3.21 (2)	2.55–3.55 (2)	7.76–11.20 (2)	5.37–6.01 (2)	1.63–2.40 (2)	3.77–4.63 (2)	
		3.12–3.34 (3)						
F Mobile plant, crane and conveyor feed systems	52–50%	O	0.78–1.33 (1)	0.50–1.15 (1)	0.39–0.40 (1)	0.07 (1)	0.28–0.31 (1)	
			0.53–0.73 (2)	0.55–0.95 (2)	0.44–0.60 (2)	0.07–0.13 (2)	0.20–0.23 (2)	↓
TOTAL DIRECT PLANT COST C_{DC} Given by $C_{DC} = IEC\ (1 + (f_2+f_4) + (f_3+f_5) + F)$								
INDIRECT PLANT COSTS								
$f'_1+f'_2$ Site Survey and Design	0.10	0.07	0.07	0.07	0.07	0.07	0.07	Proportion of C_{DC}
f'_3 Contingency	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
TOTAL INDIRECT PLANT COST C_{IC} Given by $C_{IC} = ((f'_1+f'_2) + f'_3)\ C_{DC}$								
NON PLANT COSTS								
W Working Capital	0.10	0.10	0.10	0.10	0.10	0.10	0.10	Proportion of Annual Operating Cost (O_C)
S Start-up Costs	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
TOTAL NON PLANT COST Given by $C_{NP} = (W+S)\ O_C$								
TOTAL CAPITAL COST C_T (£) Given by $C_T = C_{DC} + C_{IC} + C_{NP}$								

Notes

1. Transfer only, does not include landfill.

(1), (2), (3) - No. of machines used for operation.

Compaction:

Without storage	1, 2 and 3 compactors	25 - 200 tonnes/day
With storage	1 and 2 "	"
Wire-tied baling	"	75 - 300 "
Wet pulverisation	"	25 - 250 "
Dry pulverisation	" machines	25 - 600 "
Direct Landfill		10 - 500 "

If an authority's operations vary from the basis used these variations need to be noted and the estimates corrected, where necessary, onto the authority's basis before comparison. For example, 'Compaction without storage' estimates from Table 5.5 do not include the cost of site vehicles. Operations, however, at certain locations may require them. Some of the waste management capital cost factors derived here are calculated and arranged in a slightly different manner to the published factors. The principal differences are:

1. The direct plant capital costs using published factors are related to DEC. The waste management factors are related to IEC. It has proved easier to evaluate from local authority records the IEC than the costs for delivered equipment and installation separately.

2. Separate direct plant cost factors are established for operations employing 1, 2 and 3 transfer or treatment machines and a range is given for each factor to distinguish between high and low throughput.

3. The factors are based on costs for "green field" sites and are between 30 and 50% higher than "battery limit" sites. This agrees with the value of 40% quoted by Bridgwater (1974). The bases of the published factors are not always clearly defined.

4. Some of the equipment costs are different to those in the published literature. The items included within each component are defined in Table 5.4.

5. Separate factors are established for landfilling, compaction (without storage, with apron storage and with bunker storage), dry pulverisation, wet pulverisation and wire-tied baling. For the latter three methods apron storage is assumed.

5.8.3 Comparison between Capital Cost Factors

As one example, estimates calculated from published cost factors and the waste management factors presented here have been compared against the known capital costs for a compaction transfer station with apron storage (Table 5.7). The costs for this operation were not used in the compilation of any of the cost factors in Tables 5.4 and 5.5.

The total capital cost estimates produced from representative chemical engineering and resource recovery cost factors both undervalued the actual cost and were also less accurate than the waste management factors; -11% and -47% compared to +3.7%. The waste management factors have clearly produced the most accurate estimates for compaction transfer. These factors still require to be verified by independent testing but it is proposed that they are an improvement over the other techniques for estimating waste management capital costs. The accuracy of the relevant waste management factors to pulverisation, baling and landfill is also considered equally as good though comparisons of a similar type to that above are required to substantiate this.

The percentage difference between the estimates for some of the waste management component costs and the actual figures (Table 5.7) results from different interpretations as to what cost items are relevant to which cost components. The building cost for the actual figures also includes provisions for site survey, contingency, mobile and handling plant; these all being attributed to separate components in the waste management estimates. Items to be included under installed equipment or ancillary costs are another area for confusion. Authorities seldom consider working capital and start-up costs as capital expenditures. If a provision is made for them they are either included under the contingency heading, subsumed under another heading or included in the first year's operating costs. For improved comparisons of component costs the authority costs should be under the same headings as the costs used to compile the estimation factors (Table 5.6).

Table 5.6 ITEMS INCLUDED IN EACH OF THE COMPONENT COST USED TO DERIVE THE WASTE MANAGEMENT CAPITAL COST ESTIMATION FACTORS

Component Costs	Items
Delivered Equipment/ Installed Equipment	Major items of fixed plant, central to the operation with associated switchgear and motors
Ancillary Equipment	eg Dust extraction, fire protection and safety equipment, control equipment, cables and piping.
Buildings	All buildings, civil engineering, foundations and other site preparation, access roads, hopper construction
Mobile and Handling Plant	Site vehicles, crane and conveyor feed systems.
Site Survey and Design	Surveying, architect's fees and contractor's overheads, public enquiry costs.
Contingency	Covers unpredictable costs such as design modifications, replacements for failed items. It is not an allowance for error in the estimate.
Working Capital	Capital used by the management to cover short-term financial requirements related to the building phase and operation of the site. Working capital is usually held as "cash-in-hand" or as stocks, such as baling wire or machine spares.
Start-up Costs	This is a provision for new, small items (e.g. brooms, shovels, tables), teething problems and other expenses directly related to the commencement of operations.

Table 5.7 COMPARISON BETWEEN CAPITAL COST ESTIMATES PRODUCED FROM SELECTED COST FACTORS AND ACTUAL FIGURES FOR A COMPACTOR TRANSFER STATION[5]

Component	Chemical Engineering (a)	Resource Recovery (b)	Waste Management[4] (c)	Actual Figures[2] Compaction with Apron Storage	% Difference Waste Management Options with Actual Figures
IEC	215,000	215,000	215,000	215,000	-
Ancillary Equip.			141,960	100,000	+ 42%
Buildings			698,750	1,000,000	- 30%[3]
Mobile Plant/ Conveyors			285,950	11,500[1]	Not comparable
C_{DC}	690,000	491,060	1,148,100	1,326,500	- 13%
Site Survey	241,500	103,123	80,367)	Included in Building Cost	Not comparable
Contingency	207,000	73,659	114,810)		
C_{IC}	448,500	176,782	195,177)		
Working Capital	(d) 4,902		16,340	0	
Start-up Costs	32,680		16,340	0	
C_{NP}	37,582		32,680	0	
C_T	1,176,082	705,424	1,375,957	1,326,500	
% Difference from Actual Total Cost	- 11%	- 47%	+ 3.7%	-	

For notes, see next page.

Table 5.7 COMPARISON BETWEEN CAPITAL COST ESTIMATES PRODUCED FROM SELECTED COST FACTORS AND ACTUAL FIGURES FOR A COMPACTOR TRANSFER STATION[5]

(continued)

NOTES

1. Excludes cranes and conveyors. These are included in building cost.

2. 1 compactor, high throughput - 160 tonnes/day.
Apron storage cost of land and bulk transporters excluded.
Annual operating cost £163,000.
IEC = £215,000.

3. The difference will be smaller if indirect plant costs and conveyors cost are removed from the building cost.

4. The Waste Management factors and the Actual Figures are compiled on similar bases (i.e. 160 t/d ∴ 1 compactor no unusual features, no special engineering, number and type of buildings, access road and appropriate ancillary equipment included). 1 loading shovel. It is not known if the published factors have equally similar bases.

5. Mid-1981 figures.

SOURCES

(a) Chilton, 1949; Holland et al, 1974.

(b) Shulz et al, 1976

(c) This Research.

(d) Shroeder and Fabuss, 1978.

5.8.4 Operating Cost Estimation

Many authors have commented that the estimation of operating costs has received less attention than capital costs. As discussed for capital cost estimation no operating cost factors have yet been specifically designed for waste management but instead have been borrowed from the chemical engineering and resource recovery literature. The operating costs for several methods can only be usefully compared if they are all on the same basis. This should include a common daily throughput, number of shifts/day, number of working days a year, defined manning levels for each method, similar operating standards, wage rates and on-costs, level of supervision, interest rate and equipment lifetimes.

One method of estimating operating costs used by several authors is to express each component cost as a proportion against one or more of five basic variables; i.e.

- R - Raw Materials cost
- E - Energy cost
- L - Labour cost
- I - Capital (Investment) cost
- S_r - Product Sales Revenue

The cost factors for each component cost are combined to produce an estimating equation. Some published factors and their estimating equations are listed in Table 5.8. Laboratory, research, distribution costs and royalties are not normally considered relevant for municipal waste landfill or transfer methods and therefore should be treated as zero. Contingency is often also excluded from cost estimations. Wilson (1981) has introduced a new basic variable, "residual disposal cost" (D). This is particularly relevant to solid waste transfer and treatment methods.

Before operating costs can be estimated each of the basic variables must be evaluated. Investment can be readily calculated using capital cost estimation factors, however for the other variables it is more difficult. Evaluations may have to be made from empirical and technical information.

Table 5.8 PUBLISHED OPERATING COST FACTORS
(After Wilson, 1981)

COMPONENT COST	Chemical Engineering Bridgwater, 1976 Typical	Chemical Engineering Bridgwater, 1976 Range	Waste Processing: Systems Technology Corporation (1975)	Bechtel Corporation (1975)	Fairfield-Hardy (In: General Electric (1973))	Schulz et al (1976)	"Typical" factors Wilson (1981)
DIRECT COSTS							
a. Raw Materials	R		O	O	O	O	R
b. Energy	E		E	E	E	E	E
c. Labour	L		L	L	L	L	L
d. Supervision	0.2L	0.1-0.25	0.08-0.12 (c+e)	0.15	0.12	(1)	0.2
e. Payroll charge	0.25 (c+d)	0.15-0.5	(1)	0.30	0.22	0.25	0.4 (0.3 in USA)
f. Maintenance	0.06I	0.02-0.15	0.053	0.06	0.014	0.027 -0.06	0.08 (variable)
g. Operating Supplies	0.0075I	0.005-0.01	0.004	(2)	0.005	0.002 -0.014	0.008
g. Laboratory	0.12L	0.03-0.2	-	-	-	-	-
j. Royalty		0 - 0.06S_r	-	-	-	-	-
k. Contingency	0.05 (a to j)	0.01-0.10	-	-	0.15 (a to j) +0.015I	-	O
INDIRECT COSTS							
l. Rates	0.03I	0.02-0.04)	0.009	-	-	-	0.03
m. Insurance	0.01I	0.004-0.02)		0.02	0.003)	0.01	0.01
n. Overhead/ Administration	0.5L + 0.02I	0.4-0.8L + 0.01-0.04I	-	0.75L +0.015I	included) in k and r)		0.4L + 0.01I
p. Research	0.03S_r	0.015-0.055	-	-	-	-	O
q. Distribution/ Selling	0.1S_r	0.02-0.22	-	-	0.03	-	0.1
r. Contingency	0.03 (1 to n)	0.01-0.05	-	-	0.15	-	O
s. Other costs	-	-	D	-	Misc. 0.009I	D	D
Sum of factors to give an estimating equation	1.05R +1.05E +2.26L +0.132I +0.13S_r		E +1.43L +0.066I +D	E +2.25L +0.095I	1.15 E +1.57 +0.049I +0.03S_r	E 1.50L +(0.039-0.084) I +D	R+E +2.08L +0.138I +0.1S_r +D

Notes

(1) Included under L

A dash indicates that the item is not included in the operating cost estimate.

5.8.5 Waste Management Operating Cost Estimation Factors

New cost factors and additional basic variables are proposed here for estimating the operating costs of waste management methods. These have been derived in this research from local authority costs. The new factors are detailed in Table 5.9.

Revised list of basic variables for waste management purposes:

R - Raw materials cost

E - Energy cost

L - Labour, total basic wages + on-costs

I - Investment, total capital cost excluding purchase of land and non plant costs

B - Bulk transport costs to final disposal point

D - Subsequent disposal cost of transferred and treated refuse

A_r - Site rent/lease payments (Transfer methods only)

A_s - Annual airspace cost, or site rent (landfill only)

The waste management cost factors are valid over the following ranges of capacity:

Compaction:		
Without storage	1 to 3 compactors	25 - 200 tonnes/day
With storage	1 to 2 "	" "
Dry pulverisation	1 to 2 pulverisers	25 - 600 "
Wet pulverisation	1 to 2 "	25 - 250 "
Wire-tied baling	1 to 2 balers	75 - 300 "
Direct landfill		10 - 500 "

Some of the waste management operating cost factors are calculated and arranged in a slightly different manner to the published factors. The main differences are:

1. Where appropriate separete cost factors have been derived for operations employing one or two machines or above and below certain daily tonneages.

2. Some of the component costs include items different to those in the published literature. The items in each component cost are defined in Table 5.10. Payroll charges are included under labour

Table 5.9a WASTE MANAGEMENT OPERATING COST ESTIMATION FACTORS

COMPONENT COST	DIRECT LANDFILL	COMPACTION TRANSFER			PULVERISATION [2]		BALING [2]
		Without storage	Apron	Bunker	Dry	Wet	
DIRECT COSTS							
a. Raw Materials	R	O	O	O	O	O	R
b. Energy	E	E	E	E	E	E	E
c. Labour[1]	L	L	L	L	L	L	L
d. Supervision[1]	0.13L (≤300t/d) 0.2L (>300t/d)	0.19L	0.13L	0.13L	0.23L (1) 0.19L (2)	0.55L (1) 0.43L (2)	0.3L
e. Payroll Charge[1]	Included in Labour cost (c) and supervision cost (d)						
f. Maintenance	0.09I	0.015I	0.045I	0.007I	0.04I (1) 0.05I (2)	0.01I (1) 0.015I (2)	0.03I (1) 0.01I (2)
g. Operating Supplies	0.005I (<25t/d) 0.009I (>25t/d)	0.002I	0.003I	0.001I	0.002I (1) 0.003I (2)	0.003I (1) 0.005I (2)	0.008I (1) 0.010I (2)
h. Laboratory) j. Royalty) k. Contingency)	O	O	O	O	O	O	O
INDIRECT COSTS							
l_1 Rates	0.004I (≤50t/d) 0.006I (51-250t/d) 0.01I (>250t/d)	0.015I	0.01I	0.005I	0.006I (1) 0.005I (2)	0.003I (1) 0.002I (2)	0.006I (1) 0.002I (2)
l_2 Rent	A_s (<150t/d) A_s (>150t/d)	A_r	A_r	A_r	A_r	A_r	A_r
m. Insurance	Included in Administration cost (n)						
n. Administration	0.15L+0.03I (<400t/d) 0.3L+0.03I (>400t/d)	0.02L + 0.015I	0.02L + 0.02I	0.02L + 0.01I	0.035L + 0.01I (≤25t/d) [3] 0.027L + 0.02I (>25t/d)	0.03L + 0.005I	0.02L + 0.015I (1) 0.045L + 0.008I (2)
p. Research) q. Distribution/) Selling) r. Contingency)	O	O	O	O	O	O	O
s. Other costs	O	D + B	D + B	D + B	D + B	D + B	D + B

Notes

1. Payroll charges are already included in the manual and supervisory labour costs. Considered to be 70% of basic wage.

2. operated using apron storage

3. ≤25t/d factors excluded from the "1 machine estimating equation" below.

(1) one machine

(2) two machines

TABLE 5.9b WASTE MANAGEMENT OPERATING COST ESTIMATION FACTORS (continued)

Summing the factors in (a) to give estimating equations for each method.

METHOD	ESTIMATING EQUATION
Direct landfill - 50t/d	$R + E + 1.28\,L + 0.133\,I + A_s$
- 250t/d	$R + E + 1.28\,L + 0.135\,I + A_s$
- 500t/d	$R + E + 1.5\,L + 0.139\,I + A_s$
Compaction Transfer	
- without storage, up to 3 machines	$E + 1.21\,L + 0.047\,I + A_r + B + D$
- apron storage, up to 2 machines	$E + 1.15\,L + 0.078\,I + A_r + B + D$
- bunker storage, up to 2 machines	$E + 1.15\,L + 0.023\,I + A_r + B + D$
Pulverisation	
- dry, 1 machine	$E + 1.26\,L + 0.068\,I + A_r + B + D$
, 2 machines	$E + 1.22\,L + 0.078\,I + A_r + B + D$
- wet, 1 machine	$E + 1.58\,L + 0.021\,I + A_r + B + D$
, 2 machines	$E + 1.46\,L + 0.027\,I + A_r + B + D$
Wire-tied baling	
- 1 machine	$R + E + 1.32\,L + 0.059\,I + A_r + B + D$
- 2 machines	$R + E + 1.35\,L + 0.03\,I + A_r + B + D$

Table 5.10 ITEMS INCLUDED IN EACH COMPONENT COST USED TO DERIVE THE WASTE MANAGEMENT OPERATING COST ESTIMATION FACTORS

Component Cost	Items
DIRECT COSTS	
Raw Materials	Cover Material (£0 in base case), baling wire.
Energy	Site vehicle fuel, Transfer/treatment electricity, Overhead crane electricity
Labour	Manual Labour, Site vehicle driver, overhead crane operator.
Supervision	Supervisory labour
Payroll charge	70% of Basic Manual labour and supervising labour costs (included in Labour and Supervisory costs).
Maintenance	Site vehicle maintenance, overhead crane maintenance, Building maintenance, vehicle and crane spares vehicle tyres, treatment equipment maintenance.
Operating Supplies	Other materials, services
Laboratory	Not considered
Royalty	Not considered
Direct cost Contingency	Not considered
INDIRECT COSTS	
Rates	Site Rates
Insurance	Licences, vehicle, and employee insurances (considered under dept. admin)
Administration	Departmental administration apportionment.
Research	Not considered
Distribution & Selling	Not considered
Indirect cost Contingency	Not considered
Rent/Lease	Site rent
Other Costs	Bulk transport costs for final disposal point and subsequent cost of disposal.

costs and supervision costs. A new component cost "Rent" has been introduced since most sites are rented or leased rather than purchased. This would also account for debt repayments where land had been purchased.

3. Separate factors are established for landfilling, compaction (without storage, with apron storage and with hopper storage), dry pulverisation, wet pulverisation and wire-tied baling.

4. Baling and pulverisation (wet and dry) have higher supervision costs than other methods and chemical engineering and resource recovery examples, since even small operations tend to have a manager, and possibly also a deputy, on site. This may reflect their more technical nature over compaction.

An individual authority's operations may differ from the waste management basis used here. The difference should be noted and the estimates produced corrected accordingly onto the authority's basis before making comparisons.

An example of how equations can be used to make a first estimate of cost for a compaction transfer station is given in the next section.

5.8.6 Comparison between Operating Cost Factors

Operating cost estimates produced from representative chemical engineering and resource recovery cost factors (Table 5.8) and the waste management factors (Table 5.9) have been compared against the known operating costs of a compaction transfer station with apron storage. The authority's basis for estimation is given in Table 5.11 together with that for the waste management factors. Table 5.11 also lists the basic variable costs required to evaluate the cost factors.

The operating cost estimates produced by the published and waste management factors are detailed in Table 5.12 together with the authority's figures. An acceptable accuracy, as discussed earlier, is considered to be $\overset{\times}{\div}$ 1.25. The resource recovery factors gave a less accurate estimate than those proposed in this work; i.e. the resource recovery estimate differed from the actual figures by 30%, compared to 9.3% using the waste management equation. The chemical engineering factors produced a useable estimate (13%), though it still differed more widely than that presented in this work. These operating cost factors and those proposed for landfill and the other treatment methods still require further,

Table 5.11 AN EXAMPLE OF VARIATION BETWEEN WASTE MANAGEMENT AND AN AUTHORITY'S BASE CASE

a.	Compaction Transfer with apron storage, 160t/d: 4,000t/y	
	Waste Management Operating Cost Bases (developed from Chapters 6 and 8 for 160t/d compaction operations)	Authority Bases where different from the Waste Management Factors
	One, 8 hour shift/day	Two shifts/day
	5-day working week	
	250-day working year	
	4 men per shift	2 shifts x 4 men + 2 extra/shift = 12
	1 supervisor per shift	2 shifts x 2 men = 2
	On-costs 70% of base wage	Not known - assumed the same
	Capital repayments assumed at 14%pa	Not known - assumed the same
	- Building amortised over 20y - Fixed plant " " 10y - Mobile plant " " 5y Site assumed leased Revenues assumed zero.	
	Bulk transport - - Compaction into containers, 12½ tonne carrying capacity - 5 bulk transporters, 2 trailers to every one tractor unit - 70 Km return journy, 2½ trips per day approximately	
b.	Estimation of the Basic Variable Costs (£)	
	Using the Waste Management Factors	Using the Published Cost Factors
	R = 0 E = 13,000 L = 32,400 (£8,100/manual labour, £9,250/supervisory labour) I = 1,326,500 (excl. bulk transporters) D = 3.10 £/t = 124,000 £/y B = 27,700 £/vehicle = 138,500 £/y A_r = 4,500	R = 0 E = 13,000 L = 97,400 (incl. payroll charge - Authority[a]) 73,050 (excl. payroll charge[b]) 58,440 (excl. payroll charge[b]) I = 1,326,500 S_r = 0 D = 124,000 £/y B = 24,880 £/y

NOTES:

The "basic variables" above are evaluated using the authority base case except for Bulk Transport. This is evaluated according to this research (Chapter 8) since the authority figures collected are considered too imprecise.

(a) Bridgwater (1976)
(b) Wilson (1981)

Table 5.12 COMPARISON BETWEEN OPERATING COST ESTIMATES PRODUCED FROM SELECTED COST FACTORS AND ACTUAL FIGURES FOR A COMPACTION TRANSFER STATION[5]

Component Costs	Chemical Engineering: "Typical" factors suggested by Bridgwater (1976)	Resource Recovery: "Typical" factors suggested by Wilson (1981)	Waste Management (WM) This work (4): WM Basis	Waste Management (WM) This work (4): WM Values corrected onto authority basis	Actual costs (4), (6)	Comments
DIRECT COSTS						
Raw Materials	0	0	0	0	0	(3)
Energy	13,000	13,000	13,000	13,000	13,000	(3)
Labour	73,100	58,500	32,400	97,400	97,400	(3) 2 snifts
Supervision	14,600	11,700	6,400	12,700	18,500	Δ -31% (7)
Payroll charge	22,000	28,100	Included in labour and supervision costs			
Maintenance	79,600	106,100	59,700	59,700	24,100	Δ +148% (7)
Operating Supplies	9,900	10,600	4,000	4,000	2,300	Δ +74% (7)
Laboratory	11,700	0	0	0	0	
Royalty	0	0	0	0	0	
Contingency	11,500	0	0	0	0	
INDIRECT COSTS						
Rates	39,800	39,800	13,300	13,300	12,500	Δ +6.4% (7)
Rent	0	0	4,500	4,500	5,000	(3)
Insurance	13,300	13,300	Included in admin.		1,800	
Administration	75,200	52,200	9,700	9,700	7,600	Δ +28% (7)
Research	0	0	0	0	0	
Distribution/selling	0	0	0	0	0	
Contingency	3,800	0	0	0	0	
Other Costs:						
Bulk Transport	0	124,400[1]	138,500[2]	138,500[2]	124,400	Including capital
Disposal	0	124,000	124,000	124,000	124,000	charges @ 14% pa
Total Operating Cost (exc. capital charges)	367,500	581,700	405,500	476,800	430,600	
Transfer Capital Charges	72,000	72,000		72,000	72,000	@ 14% pa (3)
Total Operating Costs (inc. capital charges)	439,500	653,700		548,800	502,000	
% difference	12	30		9.3	-	

1. It is assumed Wilson's residual disposal factor also includes bulk haulage. Authority figure used.
2. Bulk transport cost calculated using waste management basis. Authority figures considered imprecise.
3. Basic variable costs are detailed in Table 5.11.
4. The basis for these values are detailed in Table 5.11.
5. Mid-1981 figures.
6. 1 compactor, 160 tonnes/day, apron storage.
7. Percentage difference - Corrected waste management options with Actual figures.

Comparison between individual component costs in Table 5.12 shows some marked differences. The largest difference between the waste management estimates and the actual cost is for maintenance, +148%. The published factors gave differences greater than this. The authority's figure is considered low and suspected to be an under-estimate. This supports the observation by Wilson (1981) of instances in planning where estimates of maintenance costs have been either unintentionally optimistic or where confused accounting conventions have costed maintenance labour to direct labour. He further suggests that the direct relationship between investment and maintenance may be misleading since one purpose of investment is to reduce maintenance. The waste management factors undervalued the supervisor cost by 31%, which suggests a higher level of supervision is sought for this operation than one normally finds. All other estimates are reasonably similar.

The published factors both produced estimates wildly dis-similar from the actual costs for the rates, insurance, administration and operating supplies component costs. The chemical engineering factors also omits both bulk transport costs and subsequent disposal costs. If these are added to the total cost estimates the revised value over-estimates the actual total by 36%, the largest over-estimate. Neither the chemical engineering or resource recovery factors in this example produce very satisfactory cost estimates for compaction transfer of municipal waste and require revision or should not be used for this purpose. It is suspected a similar criticism can be made if they are applied to the other transfer methods or landfilling.

5.8.7 Break-even Analysis

Nollet and Sherwin (1980) have proposed a cost estimation procedure designed for private companies or where a project must be self-financing. It is an extension to the estimation of total capital and operating costs. After these have been calculated for each operation a company then requires to know the revenue necessary to break-even or to achieve a particular profit margin. The Nollet and Sherwin model is designed to do this and enables the profitability of several resource recovery options to be compared. As an illustration their parameters have been recalculated from research data in Chapter 8 and applied to municipal transfer and treatment plants. An evaluation of landfilling and collection operations is also possible. This model could be useful to private companies considering whether to enter into the waste management field as an increasing number of authorities let out parts of their collection and disposal services to contractors.

To use the model (Equation 5.11) the following data is required for each method under consideration:

$$\text{Break-even cost per tonne} = \frac{A \times B}{C \times D} \qquad \text{Eq. 5.11}$$

where:

A represents the estimated capital cost expressed as total investment divided by the daily design throughput (in tonnes)

B represents the annual operating cost expressed as a percentage of the value derived for A (Table 5.13)

C represents the percentage of the design capacity the plant can be reasonably expected to achieve, eg 70%

D represents the annual number of days of operation, commonly 250 days for municipal operations in the UK.

The model produces for each level of investment the income per tonne required for the operation to break-even (Table 5.14). These break-even revenues can be increased by multiplying the desired profit margin. Using this method Nollet and Sherwin calculate the break-even revenue and 20% profit margin revenues for certain resource recovery methods in the US. They found that some commercial operations currently making losses would require absurdly high revenues just to break-even and have no hope of ever making a profit.

Table 5.13 ANNUAL REVENUE REQUIRED TO BREAK-EVEN EXPRESSED AS A PERCENTAGE OF CAPITAL INVESTMENT FOR UK MUNICIPAL WASTE TRANSFER AND TREATMENT PLANTS

Transfer Method	Dry Pulverisation			Wet Pulverisation			Wire Baling		Compaction with Apron storage	
Tonnes/day	50	300	500	50	300	500	50	300	50	200
Operating cost as a percentage of capital investment (1)	36	35	34	22	23	24	40	24	45	34
Approx. percentage over range of t/d considered	35 (2)			23			30		40	

Notes

(1) Derived from local authority figures used in this research. These are detailed in later chapters. Total operating costs (including capital charges @ 14% p.a.) have been used.

(2) Additional information from Nollet suggests this value is also valid for US dry pulverisers (Nollet, Personal communication, 1982).

Table 5.14 REVENUES PER TONNE REQUIRED TO BREAK-EVEN AT SEVERAL LEVELS OF CAPITAL INVESTMENT FOR UK WASTE TRANSFER AND TREATMENT PLANTS

Capital investment (£/daily tonneage throughput)	Revenue required to break-even (1) (£/tonne)			
	Dry Pulverisation	Wet Pulverisation	Wire Baling	Compaction with Apron storage
1,000	2.0	1.3	1.7	2.3
2,000	4.0	2.6	3.4	4.6
3,000	6.0 (2)	3.9	5.1	6.9
4,000	8.0	5.3	6.9	9.1
5,000	10	6.6	8.6	11
6,000	12	7.9	10	14
7,000	14	9.2	12	16
8,000	16	11	14	18
9,000	18	12	15	21
10,000	20	13	17	23
20,000	40	26	34	46
50,000	100	66	86	114

Notes

(1) Given by Eq 5.11, ie Break-even cost per tonne $= \frac{A \times B}{C \times D}$

Definitions for each parameter are given in the text.

(2) I Range of capital investment for each method by UK municipal authorities as found from the data in this research.

The UK values presented in Tables 5.13 and 5.14 represent municipal transfer and treatment prior to landfill and are not directly comparable with Nollet and Sherwin except for dry pulverisation. This method closely resembles their 30% figure for total operating costs as a percentage of capital costs, suggesting that some general similarity does exist between the UK and US.

The waste management values in Table 5.14 suggest that if a private company undertook these methods from authorities, maintaining similar plant design and operational standards to those considered for the cost factors (Sections 5.8.1 and 5.8.4) with no unusual site-specific costs, they would require break-even incomes of between:

Revenue/tonne (£/t) High Throughput		Revenue/tonne (£/t) Low Throughput	
5.0	-	9.0	Compaction with apron storage
6.0	-	16.0	Dry pulverisation
12.0	-	17.0	Wire-tied baling
11.0	-	26.0	Wet pulverisation

Private companies also have the additional expenditure of a plant replacement fund (depreciation), therefore their break-even revenues will be higher. Apart from compaction transfer, the absence of the private sector from the other treatment methods (with the exception of one baling operation) is not surprising. The income required (principally from disposal charges) in most circumstances far exceeds what the market, i.e. the authorities and commercial waste producers, will bear.

5.9 ECONOMY OF SCALE

The unit cost per tonne for an individual operation will change when the throughput of waste varies. Where these costs decrease as throughput rises the operation is said to exhibit an "economy of scale". Conversely, if costs increase then the operation shows a "diseconomy". "Scale factors" are a measure of this effect. The smaller the value (ie scale factor 1.0) then the more rapid the reduction in unit costs as throughput increases. The larger the value (scale factor 1.0) represents the opposite situation. Scale factors were derived from the economic data obtained in this research for waste collection, treatment and landfill methods (Table 5.15), and are applicable to operations conforming to the base case design and technical standards detailed in Section 6.3. The technique used to calculate the factors is described in Appendix 5C. The scale factors presented in Table 5.15 are strictly only valid over the range of capacities from which the cost data was collected. The relevant ranges, unless otherwise stated, are the same as those quoted for the cost models in Table 6.6.

Economies of scale for capital costs represent "once off" expenditures arising at the beginning of a project, whereas those for total operating costs, which include capital charges, can be viewed as "continous" economies likely to recur throughout the life of the project.

Few scale factors are published for municipal waste collection, treatment or landfill, and most of those in the literature only refer to total capital expenditures. One of the pioneering achievements of this work has been to produce factors for not only total capital costs but also total operating costs and individual component costs. More detailed comparisons between the literature factors and those derived here are discussed in the following chapters, together with an assessment of their implications to waste management economics.

Table 5.15 SUMMARY OF THE SCALE FACTORS IDENTIFIED IN THIS WORK FOR EACH COLLECTION, TRANSFER AND LANDFILL DISPOSAL COST
(A more detailed discussion is given in the following chapters)

Method	Capital costs	Operating costs: urban rounds	Operating costs: rural rounds
<u>COLLECTION</u>	A scale factor of 1·0 was calculated for all costs with the exception of:		
Kerbside bin - depot costs			7·77*
Backdoor bin - depot costs			7·77*
Collection vehicle haulage		1·0	

Method	Capital costs	Operating costs
<u>TRANSFER</u>	A scale factor of 1·0 was calculated for all costs with the exception of:	
Compaction methods		
-site preparation	0·13	
-total capital cost (20 - 500 t/d)	0·92	
-compactor electricity		0·44
-site rent		0·41
-site rates		0·41
Dry pulverisation		
-ancillary equipment	0·41	
-other preparatory costs	0·13	
-compactor maintenance		0·80
-departmental administration		0·61
-site rent		0·41
-site rates		0·41
-total operating cost		0·61
Wet pulverisation		
-materials cost		1·49
-site rent		0·41
-site rates		0·41
Wire-tied baling		
-site rent		0·41
-site rates		0·41
Bulk vehicle haulage		
-all 7 vehicle types		1·0

<u>LANDFILL DISPOSAL</u>	Capital costs			Operating costs		
	A scale factor of 1·0 was calculated for all costs with the exception of:					
t/d	10-200	201-500	10-1000	10-100	201-500	10-500
-site survey		0·74				
-access road	0·88	0·66				
-other preparatory costs	0·44	0·44				
-total capital cost		0·75	0·74			
-vehicle maintenance labour						0·46
-departmental administration						0·51
-total operating cost				0·74	0·75	0·51

* **These scale factors are based on limited information and may be spurious.**

5.10 COST INDICES

All costs vary over time. An indication of the magnitude of these variations is given by a cost index. It can also be used to bring forward an historic cost to a more recent time although errors up to 30% should be expected (Bridgwater, 1977). Indices are constructed from two or more "component indices" which are themselves derived from "sub-components". Since some component values are larger than others they are "weighted" to reflect this. Two types of weighting are available. Firstly base-weighing in which the weightings are set in the first year and fixed for future years.

$$\text{Base-weighted index} = \frac{\left(\frac{100P_t}{P_o} \cdot W_o\right)}{W_o} \qquad \text{Eq. 5.12}$$

Second, a current-weighted index can be calculated. This index recalculates the weightings each year (Equation 5.13):

$$\text{Current-weighted index} = \frac{\left(\frac{100P_t}{P_o} \times W_t\right)}{W_t} \qquad \text{Eq. 5.13}$$

where P_o Cost in base year, time, O
P_t Cost in time, t
W_o Weighting based on time, O
W_t Weighting based on time, t.

Both base- and current-weighted indices have disadvantages. The former is inflexible to changes in the weightings when consumption of some component items decreases and others increase. The latter tends to understate inflation, is more time-consuming to construct and more susceptible to untrustworthy or extraordinary data. In all subjects, though in this work with special regard to waste management, the factors influencing the capital and operating costs of a method and the accuracy of its weightings have been summarised by Bridgwater and Bossom (1980).

- Inflation
- Labour productivity
- Environmental legislation
- Health and safety legislation
- Contract price adjustment exploitation (capital costs only)
- Energy costs
- Learning effects
- Technological change
- Commercial forces (where significant revenues are received)

For an index to be useful it must account for these variations as quickly and as accurately as possible. Consequently it is important to periodically adjust the weightings of base-weighted indices. Current-weighted indices consider these variations automatically each year if they satisfactorily reflect in the costs of the sub-components.

Depending upon the source of the cost data a capital cost index can be classified as either an "input" or an "output" index. An input index accounts for the variation in the cost of individual constituent items, for example, the component costs in building a compaction transfer station. These costs are easy to measure and most indices are of this type. An output index measures how the gross cost of an operation changes over time. To derive this a cost estimate needs to be made for a similar plant design, at a similar location at regular periods. This approach is frequently impracticable. Similar points can also be made for operating cost indices.

5.10.1 Waste Management Indices

There are currently no capital or operating indices designed for municipal waste management. The indices used at present are non-specific and can be applied to any treatment process. One such index for capital costs is the "Process Economics International (PEI)" Index, however, no comparable index is published for operating costs. Indices have been specifically constructed here from research data for collection and landfill operating costs and landfill capital costs. Collection capital costs consist solely of the collection vehicle cost therefore an index is not necessary. Reference to past price lists is sufficient.

The waste management indices established here are all base-weighted, spanning the financial years 1977/78 to 1980/81. Further details are given in Appendix 5D and the index values derived are summarised in Table 5.16. A four-year range of figures has been calculated for each index to enable a comparison of accuracy with the PEI index. In this research a complete set of costs is only available for 1980/81 although some data has been gathered for earlier years. The costs for the other three years (1977/78 to 1979/80) have been derived by deflating back the 1980/81 costs using government cost indices (Appendix 5E). The weightings derived from the 1980/81 costs are assumed as constant over this four-year period and have therefore been applied to the initial year (1977/78) in order to produce the base-weighted waste management indices. Sample calculations discussed later suggest this assumption is reasonable.

Table 5.16 SUMMARY OF WASTE MANAGEMENT COST INDICES

Base year 1977/78

Index	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	Comments
CAPITAL COSTS								
W M Landfill Capital Cost Index				100	110.5	130.5	144.7	(1)
PEI Index				100	106,7	122.6	132.3	(2)
OPERATING COSTS								
W M Landfill Operating Cost Index				100	104.6	113.5	127.6	(3)
W M Urban Collection Op. Cost Index				100	105.9	116.0	131.5	(4)
CIPFA-based Direct Landfill Index	49.7	69.2	79.6	100	118.9	151.7	156.2	(5)
CIPFA-based Pulveris-ation and Landfill Index	54.6	85.2	86.3	100	130.6	205.5	165.6	(5)
CIPFA-based Direct Incineration and Land-fill Index	65.8	82.9	88.8	100	105.9	142.1	98.7	(5)
RPI Index	37.7	60.0	84.9	100	113.4	133.8	149.7	

(1) Based on 150t/d site - conversion factors available for sites of other sizes* (Table 5D.2)
(2) All throughputs corrected to the base year 1977/78.
(3) 150t/d site - conversion factors for other sizes of operation* (Table 5D.3)
(4) 200 Km^2 authority, kerbside sack. Conversion factors available for other areas & collection methods*(Table 5D.1)
(5) All based on the mean costs/tonne in Table 5.2, corrected to a base year of 1977/78.

* Conversion factors - see Appendix 5D.

PEI Process Economics Index RPI Retail Price Index

An alternative approach to derive total operating cost indices for direct landfill, pulverisation, and direct incineration is to use the CIPFA statistics. Bearing in mind the criticism of these figures, previously discussed in Section 5.7.3, the mean cost per tonne of each method was calculated for each year in Table 5.2. The relative differences between these unit costs are given in Table 5.17 and can be regarded as a measure of change in operating cost with time; i.e. an operating cost index. The PEI index and CIPFA-based indices are corrected for convenience on to the base year (1977/78) of the waste management indices and are also included in Table 5.16. Comparison between the operating cost indices and the Retail Price Index (RPI) suggests that the CIPFA-based values for landfill and pulverisation are rising above the current level of retail prices by up to 11%, whereas the incineration and waste management indices are below by 34 and around 13% respectively.

In Table 5.18 two illustrative comparisons are presented using a selection of the indices from Table 5.16 and actual costs obtained from local authorities, i.e.:

i) Comparison between the landfill capital cost index and the PEI index;

ii) Comparison between the waste management and CIPFA-based operating cost indices.

The landfill capital cost and PEI indices produce reasonably similar estimates, within 30% of each other, for both examples considered in Table 5.18. There appears to be a moderately closer approximation to the actual cost from the waste management index, but realistically over the years 1977/78 and 1980/81 either index could be satisfactorily used. The landfill operating cost index produced more accurate estimates than the CIPFA-based index and consequently the latter is not recommended for further use.

Further, independent, tests are needed to improve upon and confirm the validity of the municipal collection and landfill indices proposed. It is also feasible to produce similar indices for the rural collection, transfer and treatment methods. Evidence in this section suggests that they produce more accurate estimates than the indices currently available to waste managers.

Table 5.17 A CIPFA-BASED LANDFILL DISPOSAL TOTAL OPERATING COST INDEX

Disposal Method	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Direct Landfill (1)	100	139	160	201	239	305	314
Pulverisation and Landfill (1)	100	156	158	183	239	376	303
Direct Incineration and Landfill (1)	100	126	135	152	161	216	150

NOTES

Year 1974/75 taken as the base year for each method.

(1) Relative difference between cost/tonne and base year cost/tonne (see Table 5.2) multiplied by 100.

Table 5.18 COMPARISON OF PREDICTIONS FROM SEVERAL WASTE MANAGEMENT COST INDICES

Costs brought forward to 1980/81[1]

	Indices	Actual Cost	1980/81 Estimates using Indices (multiplied by conversion factor where necessary)[2]	% difference between estimates	1980/81 Actual for Similar Operation	Difference between Estimate and Actual
		£	£		£	£
	CAPITAL COSTS					
1.	1979/80 176t/d landfill	123,800				
	W M landfill capital cost index		137,000	2.7	145,000	8,000 (closest)
	PEI Index		133,600			11,500
2.	1977/78 340t/d landfill	107,500				
	W M landfill Capital cost index		155,533x1.30[2] = 202,200	30%	192,000	10,000 (closest)
	PEI Index		142,200			50,000
	OPERATING COSTS					
3.	1978/79 88t/d landfill	38,179				
	W M landfill operating cost index		46,574x0.76[2] = 35,400	42%	40,400	5,000 (closest)
	CIPFA-based operating cost index		50,200			10,000
4.	1979/80 176t/d landfill	38,338				
	W M landfill operating cost index		43,100	8.4%	43,200	100 (closest)
	CIPFA-based operating cost index		39,500			3,500

NOTES:

1. Using Present cost = Previous Cost x $\left(\frac{\text{Present Index}}{\text{Previous Index}}\right)$
2. Conversion factors - see Appendix 5D.

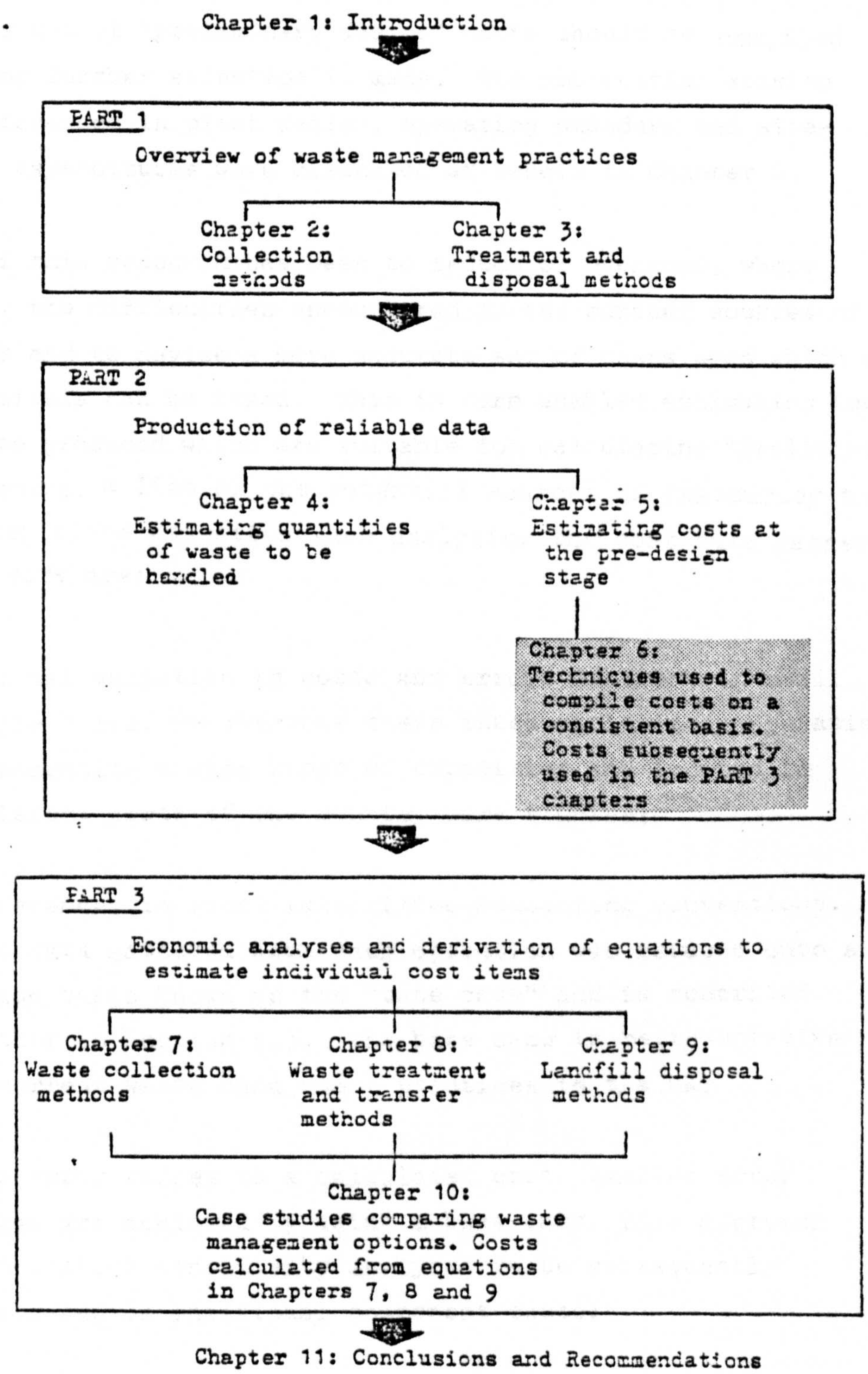
5.11 SUMMARY

The information presented in this chapter briefly summarises the current techniques for economic evaluation in waste management. The cost estimates produced from the various sources of data and any adjustments by scale factors and cost indices are used to aid the initial stages of financial appraisal between alternatives. They do not represent detailed costings for individual operations. It is stressed, after the initial selection has taken place the costs of the "preferred" operations should then be determined more rigourously for each site by the waste manager.

What is evident in waste management is that outside each authority's operations much of the economics of this field are poorly understood. In the following chapters these are studied in greater detail using local authority data which has been reduced onto a common basis for comparison. The cost values and the estimating equations presented are potentially more accurate than those used in appraisals at present.

CHAPTER 6

DERIVATION OF WASTE MANAGEMENT COST MODELS: TECHNIQUES USED



Chapter 6

6.1 INTRODUCTION

After a waste manager has used pre design costs to reduce the potential disposal options in his plan to a smaller number, a more rigourous set of "preliminary design" costs should be compiled before any further selection is made. The ambiguities arising from differences in plant design, operating standard and site-specific expenditures were discussed at length in Chapter 5.

An aim of this research has been to reduce or overcome, where possible, the difficulties encountered in the current sources of cost estimates and to devise a more accurate set of costs upon which economic appraisals can be based. This in turn enabled estimating techniques to be produced which are suitable for calculating "preliminary design" costs. A list of the potential sources of inaccuracy that were given close attention when analysing the cost data gathered in this work are:

a) regional variation in costs and errors inherent in small sample sizes. To overcome these inaccuracies many operations representing a wide range of capacities and located in different parts of the country were studied;

b) differences in local authorities accounting conventions. Cost data gathered from each operation was reduced onto a common basis known as the "base case" and is described further in Section 6.3. The base case is representative of current waste management practices in the UK;

c) wide error ranges to a calculated cost. Smaller error ranges are achieved by using a base case. This approach also enables sensitivity analyses to be subsequently undertaken on individual component costs;

d) modifications and extensions to the base case are possible for situations where it varies from a particular authority's practices. These are discussed and example calculations performed to demonstrate the flexibility of the cost functions produced by this study.

This chapter describes the methods used to collect the original financial and technical data, outlines the derivation of the base case and the conversion of the original data onto it. Subsequently cost models were calculated from this data and sensitivity analyses undertaken. Detailed discussion of the cost models and the economic comparisons between methods are considered in later chapters.

6.2 DATA COLLECTION PROCEDURES

Operational and financial data was principally obtained from local authorities. Private companies in the waste management field generally proved unhelpful. This is regrettable since private sector involvement in waste management is steadily growing and widely predicted to continue during the next decade. Inclusion of their data would have made the findings of this research more applicable to their operations. With much reluctance the economics of private sector operations were not investigated further. Information in the public sector is more freely available since local government is required to be publicly accountable for its actions and expenditures. A full list of the organisations contacted is given in Appendix 6A.

In general the small and medium size authorities were extremely helpful, whereas the larger local authorities and city councils offered noticeably less assistance. It would appear that the latter already exercise a more detailed approach to their costing by utilising the greater resources available to them. However, the larger authorities are continually inundated with requests for information from many directions and consequently are not prepared to spare the time for anything more than the most cursory of help. In order for this research to incorporate data from the widest possible range of sizes and operations sufficient information was, through persistence, eventually obtained from these authorities.

Initially, letters in a variety of formats were sent to a random selection of collection and disposal authorities requesting information on the methods employed and the costs of individual operations in their area. The response proved very disappointing both in the number and quality of the replies. It was concluded from this pilot study that indirect contact with authorities did not produce sufficiently accurate data.

The method subsequently employed was to collect data by personal interview with local authority officials. The information gathered included technical specifications of their current operations, the individual capital and operating costs they consider during the running of daily operations, and when planning new projects, their views on those externalities to be considered when planning new operations, and the usefulness of present waste disposal statistics in economic comparisons.

In order to achieve a thorough and systematic approach to data collection, details of each site, station or round were recorded on "cost sheets". Copies of these and a comprehensive list of the items included under each component cost are given in Appendix 6B. The operational and financial details included on these sheets are considered to be the most extensive it is possible to obtain from local authority records. Personal interviews did not produce enough data for detailed appraisal of the collection, pulverisation and baling methods. Therefore postal surveys were made to selected waste managers to gather specific, additional information. Appropriate authorities were chosen from the 1980 and 1981 Municipal Yearbooks as those operating the particular collection or treatment methods in question.

Scottish, Welsh and Irish district authorities undertake both collection and disposal operations, while in England responsibility for collection and disposal is split between the district and county authorities respectively. To overcome any bias attributable to one or other of these arrangements authorities throughout the country were sampled in this study. A summary of the sample sizes collected is listed below, and a more detailed breakdown is given in Table 6.1:

Collection data was obtained	for 28 authorities,
Compaction transfer data	for 13 stations,
Treatment data	for 23 stations,
Landfilling data	for 33 sites.

Table 6.1 DETAILED BREAKDOWN BY METHOD OF THE SAMPLE SIZES OBTAINED

Sample Size

Method	Capital Costs	Operating Costs	
		Urban Rounds	Rural Rounds
COLLECTION			
Kerbside Bin	-	2*	4
Kerbside Sack	-	3	1*
Backdoor Sack	-	5	2*
Backdoor Skep	-	2*	-
Backdoor Bin	-	5	3
COMPACTION TRANSFER			
Transfer without Storage	5	9	
Transfer with Apron storage	2	2	
Transfer with Bunker storage	2	2	
TREATMENT TRANSFER			
Baling	4	4	
Dry Pulverisation	5	7	
Wet Pulverisation	6	8	
LANDFILL			
Direct Landfilling	16	33	

*Analyses using these small samples are considered to be only tentative.

6.3 DERIVATION OF THE BASE CASE

Costs variations will inevitably exist between individual operations when they exhibit differences in plant design, operational standards and site-specific expenditures. Therefore, valid comparisons can only be made when the costs of each operation are expressed on a consistent basis. This is known as the 'base case' and represents a basic set of common technical and financial conditions (eg manning levels, number of shifts, interest on borrowed capital) onto which the costs from widely differing operations can be readily adjusted. The base case thus establishes for each particular method a representative cost. Additions and adjustments can be subsequently made to this value so as to perform economic appraisals for operational situations outside the base case. The use of a base case is a powerful tool in eliminating the discrepancies which can occur with direct comparisons made using data from several sources.

A family of base cases are used in this study. Each has been carefully constructed to represent the general practices currently employed by waste managers for the collection, transfer and landfill disposal of wastes. The base cases are all closely related. Table 6.2 summarizes the data required to construct each base case and the list below provides further details on the technical and financial information that was collected.

The base cases for collection, transfer and landfill are defined on a tonneage per round or per day basis, and the corresponding working practices clearly defined. No simple relationship exists between daily tonneage and the hourly design capacity of a plant since variations in working practices, eg length of working day or number of shifts, can substantially change the daily quantity handled. Consequently, for each daily tonneage considered the operation of only one size of plant has been costed. Typically, this is the size most appropiate to a one shift working at the manning levels in Table 6.5.

Table 6.2

Data required to construct the base case

Collection	Waste Treatment/Transfer	Landfill
Technical Information	Technical Information	
1. Daily tonneage handled	1. Greenfield or already developed site	1. Greenfield or already developed site
2. Area of Authority (in km^2)	2. Daily tonneage handled	2. Daily tonneage, estimated site capacity and lifetime
3. Number of compaction collection vehicles	3. Number and type of site vehicles	3. Number and type of site vehicles
4. Number of trips per week per vehicle	4. Manning levels	4. Manning levels
5. Total vehicle fleet size of collection department	5. Major items of capital plant	5. Any special engineering
	6. Method of transferal/treatment and type of storage, if any	6. Method of waste emplacement
6. Frequency of collection		7. Capital plant lifetime
	7. Capital plant lifetime	
7. Manning levels (per vehicle)		8. Effective density of waste achieved in landfill
	8. Density of waste achieved in bulk transporter	
8. Capital plant required and ancillary equipment		9. Number of shifts per day
	9. Number of shifts per day	
9. Methods of collecting and method of refuse storage		10. Length of working week and year
	10. Length of working week and year	11. Electricity consumption
10. Haul distance to disposal point of collection vehicle	11. Electricity consumption	12. On-site availability of cover used per year
11. Threshold mileage	12. -	
	13. Closure activities	13. Closure activities
12. Capital plant lifetime and type of equipment		
13. Number of shifts per day		
14. Length of working week and year		
Financial Information (other than actual costings)		
15. Sources of revenue	14. Sources of revenue	14. Sources of revenue
16. Methods of capital finance	15. Methods of capital finance	15. Methods of capital finance
17. Length, interest and conditions of any loans	16. Length, interest and conditions of any loans	16. Length, interest rate and conditions of any loans
18. Percentage employee on-costs	17. Percentage employee on-costs	17. Percentage employee on-costs
	18. Site leased or purchased	18. Site leased or purchased

The Base Case

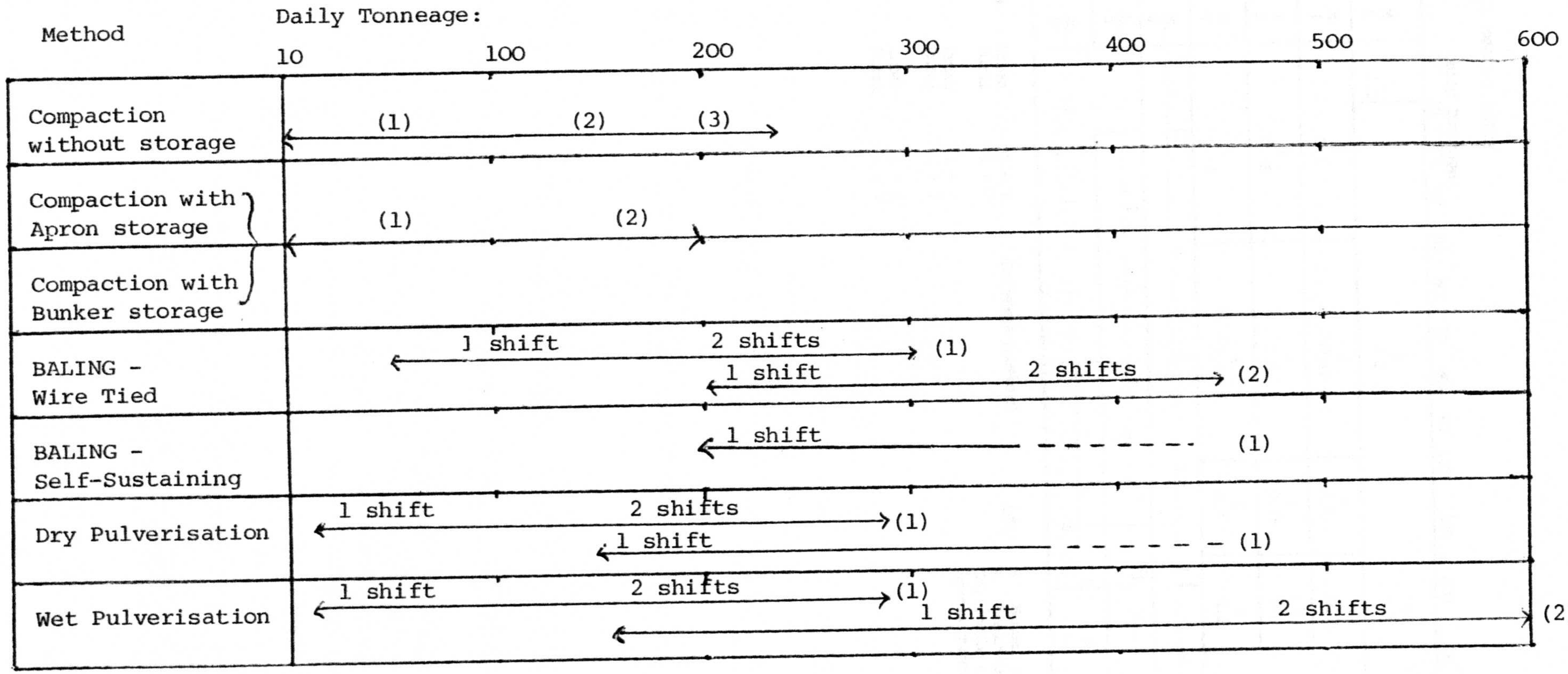
Base Date	All costs corrected to 31 March 1981 (end of the 1980/81 financial year)
Working Year	250 days
Working Times	Collection and landfill - one 8 hour shift/day Transfer - $\leq$ 400t/d one 8 hour shift/day; $\geq$ 400t/d two 8 hour shifts/day.
Collection Vehicle Haul Distance	Rural Collection Authority - 30 Km (return trip) Urban Collection Authority - 10 Km (return trip)
Mobile Plant	Collection - Rear-end loader with on-board compaction, internal volume between 11 and 15 m^3 (15 and 20 yd^3). Transfer - Bulk transport costs are considered separately. Loading shovels only used in conjunction with apron and bunker storage; 1 vehicle $\leq$ 225t/d, 2 vehicles > 225-600t/d 1 slave vehicle 300-450t/d, 2 slave vehicles 450-600t/d (All transfer methods). Landfill - See Table 6.3.
Fixed Plant	Transfer - The number and machines for each method is given in Table 6.4
Plant lifetimes	Mobile plant - Collection 7 years Transfer and Landfill 5 years Fixed plant 10 years Buildings and roads 20 years
Type of Buildings and Roads	The plant and buildings are designed to adequately cope with all reasonable eventualities and conform to all UK legal requirements. Access Roads $\leq$ 0.75 Km in length.
Plant Finance	All plant assumed purchased by loan @ 14% interest per annum Mobile plant amortised over 5 years Fixed " " " 10 years Buildings & roads " 20 years
Redundancy	No excess capacity in the fixed and mobile plant.

Nature of Operation	Collection - once a week collection of municipal waste. Vehicles required to traverse a soft surface prior to unloading at landfills. Vehicles not required to traverse a soft surface prior to unloading at transfer stations. Compaction transfer - Refuse compacted into bulk containers and does not undergo treatment during this transferral. Treatment transfer - Refuse compacted into bulk containers and undergoes changes in its physical form during transferal. Landfill - "over-the-top" emplacement approximately 2m-lift with 2 or 3 passes by emplacement machine. Landfill operates the "progressive slope" technique. All cover required available on-site. Refuse covered daily, and carrying and spreading of cover incorpprated in the mobile plant operating costs.
Extraordinary Costs	No extraordinary capital or operating costs necessary, eg major river diversion or drainage works.
Site Acquisition	Transfer and landfill - site assumed leased.
Site Lifetime	Not likely to close in the short-term. For landfill 20 year life assumed.
Revenues	None.
Manning levels	Collection - Table 6.5 and Figure 6.1 Transfer - Table 6.5 Landfill - Table 6.5
Labour On-costs	Taken as 70% of the nationally agreed basic wage. This is the median value of several authorities.

Table 6.3 BASE CASE MOBILE PLANT AT VARYING SIZES OF LANDFILL OPERATION

Site Vehicles	Daily Tonneage: 10 – 125	125 – 150	150 – 500
<u>1 Vehicle</u> Rubber-tyred shovel (Emplacement and carrying)	←→		
<u>2 Vehicles</u> 1 emplacement 1 carrying cover		Both Rubber Tyred	Emplacement by steel wheeled compactor Carrying and spreading cover by rubber tyred shovel

Table 6.4 BASE CASE NUMBER OF MACHINES AND THEIR UTILISATION



(1) 1 machine
(2) 2 machines
(3) 3 machines

Only 1 shift operations were considered in the base case for transfer stations handling 400 tonnes/day. 2 shift operations above this throughput.

Table 6.5 BASE CASE MANNING LEVELS

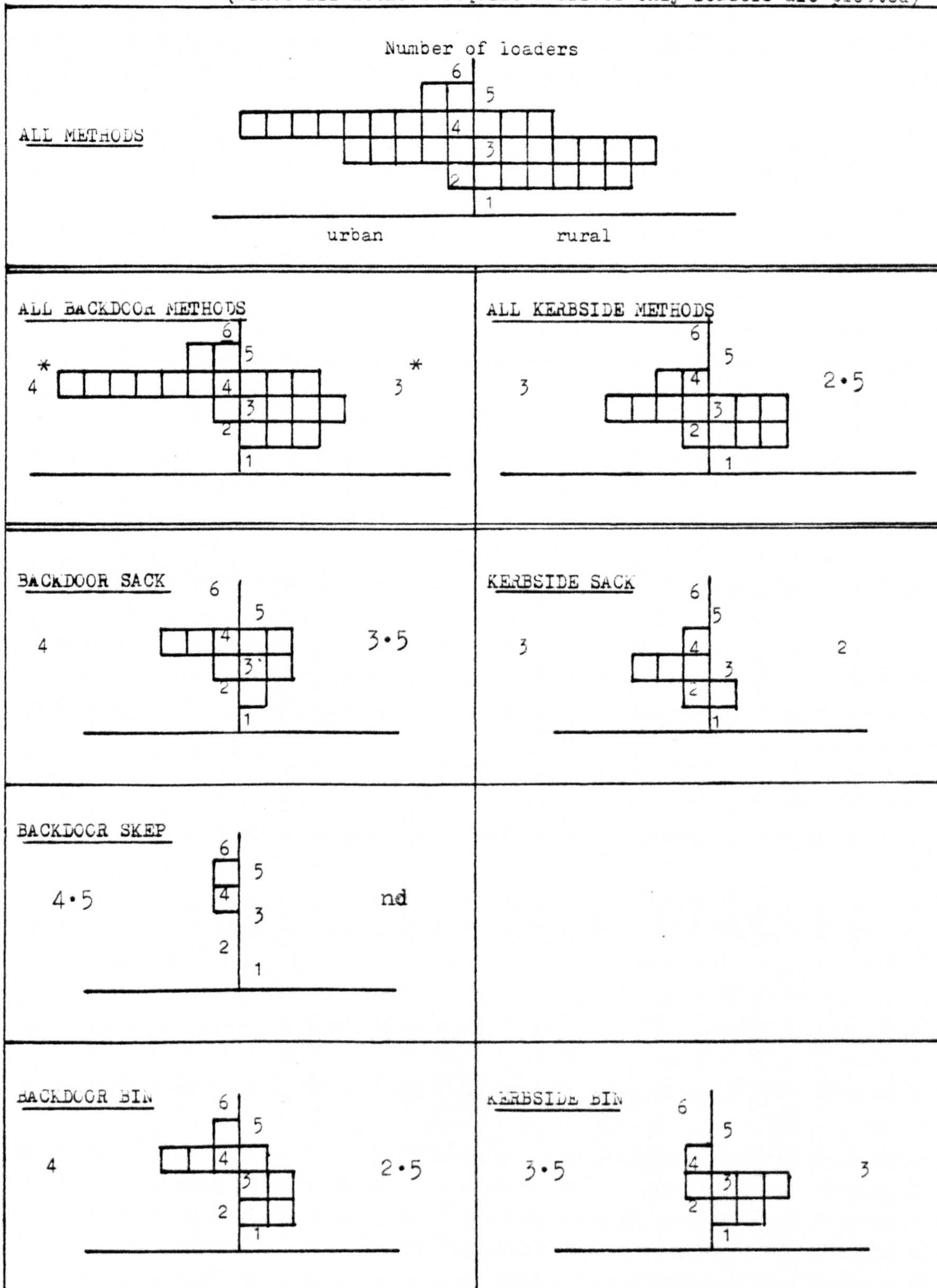
METHOD		Daily Tonneage: 10	20	30	40	50	60	70	80	90	100	150	200	250	300	350	400	450	500	600
Landfill	M	1						2					3				4			
	S	0.1						0.2					0.3				0.6			
Compaction without Storage	M			2				3				4	5							
	S			0.3				0.45				0.6	0.75							
Compaction with Apron storage	M			3				4				5	6							
	S			0.45				0.6				0.75	0.9							
Compaction with Bunker storage	M			3				4				6	8							
	S			0.45				0.6				0.9	1.2							
Dry Pulverisation	M	2				4					6		9	12		14		16		18
	S											1				2				3
Wet Pulverisation	M				2				3		4	5	6							
	S									1			2							
Wire-Tied Baling	M										4		5	6	8	10				
	S											1			2					

Kerbside Collection	Urban	1 + 3	(Driver + Loaders)
	Rural	1 + 2	
Backdoor - 1 trip Collection	Urban	1 + 4	
	Rural	1 + 3	
Backdoor - 2 trip Collection	Urban	1 + 4	
	Rural	1 + 3	

Key: M Manual labour
S Supervisory labour
Collection crew sizes are the modal values of manning levels quoted by several authorities (Figure 6.1)

Fig 6.1 Local authority crew sizes

(Since all methods require a driver only loaders are plotted)



* represents the modal number of loaders for each collection method in urban and rural authorities.

nd represents 'not determined' due to insufficient information.

Some of these conditions will be relaxed when performing the sensitivity analyses described later and others extended to economically evaluate situations outside the base case. The procedure used for adjusting the financial data onto this common base case is discussed in the next section.

6.4 TREATMENT OF DATA

The financial data received from authorities was reduced onto a common basis in two stages (original to 1st, 1st to 2nd reductions). These stages are described in the following sections.

6.4.1 Original Data and Data Ranges

The information supplied by each authority was recorded under the component headings described on the cost sheets in Appendix 6A. Costs for some components were sometimes "not available", while others, notably vehicle costs (incorporating fuel, maintenance, spares, tyres, licences and insurance and capital charges) were frequently given in an aggregated form. The only adjustment made to the original data was to bring each cost up to the base date (31 March 1981) using the cost indices in Appendix 5E and the figures collected are presented in Appendices 7A (Collection Methods), 8A (Transfer Methods) and 9A (Direct Landfilling).

The range of size of operations for which data was collected varied with each method; these ranges are detailed in Table 6.6 For direct landfill the range is wide, 10-500t/d.

Table 6.6 DATA RANGES

COLLECTION	URBAN	RURAL
Kerbside Sack	50-300Km^2 (200-300 t/y)	1,000-1,500Km^2 (150-250 t/y)
Kerbside Bin	100-300Km^2 (275-325 t/y)	500-2,000Km^2 (150-250 t/y)
Backdoor Sack	50-300Km^2 (150-325 t/y)	1,000-1,500Km^2 (150-250 t/y)
Backdoor Skep	50-150Km^2 (200-225 t/y)	-
Backdoor Bin	50-300Km^2 (175-275 t/y)	500-2,000Km^2 (200-300 t/y)
TRANSFER	**CAPITAL COSTS**	**OPERATING COSTS**
Compaction without storage	25-225t/d (5-33t/hr) extended to 500t/d (1)	25-300t/d
Compaction with Apron storage	25-200t/d (5-30t/hr)	25-200t/d
Compaction with Bunker storage	25-200t/d (5-30t/hr)	25-200t/d
Dry Pulverisation	20-340t/d (9-30t/hr) extended to 600t/d (2)	20-600t/d
Wet Pulverisation	20-600t/d (5-375t/hr)	20-180t/d extended to 600t/d(3)
Wire-tied Baling	75-300t/d (23-70t/hr)	75-320t/d
DIRECT LANDFILL	10-500t/d	10-500t/d
Landfill sub-divisions:		
Small operation	10-200t/d	10-100t/d
Intermediate operation		101-200t/d
Large operation	201-500t/d	201-500t/d

Key Overleaf

Table 6.6 DATA RANGES
(continued)

Key

t/d	Daily throughput	- tonnes per day
t/hr	Rated capacity	- tonnes per hour
t/ry	Annual throughput	- tonnes per round per year
Km^2	Area of authority	- square kilometres

(1) Total capital cost model supplemented with literature values and subsequently extended up to 500 t/d.

(2) Total capital cost model extrapolated up to 600 t/d to compare with operating costs.

(3) Total operating cost model extrapolated up to 600 t/d to compare with capital costs.

To determine whether any relationships could be identified which would otherwise have been masked by considering only one broad range, the data was divided into three smaller ranges. These subjectively distinguish between small, intermediate and large-scale operations.

6.4.2 First Reduction

The original data contained many variations between authorities reflecting accounting and operational differences. The costs received had not been compiled on a consistent basis. All were therefore reduced onto the base case unless already compiled on a similar basis to it. Typical adjustments to the capital costs included standardisation of the fixed and mobile plant required for each size of operation; exclusion of extraordinary costs such as access roads longer than 0.75 Km, landfill leachate treatment, large drainage schemes and gas alleviation or collection measures; adjustment to costs for buildings where designed for less than a 20 year lifetime; sites where purchased outright were costed as if leased. Further details on the reduction of each component cost onto the base case are given in Appendices 7B (Collection Methods), and 9B (Landfill Disposal).

An example of the reduction of a set of capital costs from the original data, onto the base case is given in Table 6.7 for a 20t/d landfill site. Site acquisition was originally by direct purchase of land costing £28,000. In the base case all sites are assumed to be leased, therefore this value was reduced to zero in the first review of the figures. Site survey was not considered by the authority supplying the original data. A regression analysis in the second review (i.e. second reduction) estimated survey costs as £4,032. The building costs provided only considered the purchase of a portable building. This cost was adjusted in the first reduction to the expenditure required for brick-built facilities as well as a sum for initial site earthworks. The length and quality of the access road conformed to the base case and the original cost of £4,000 was unchanged. Drainage and gas measures are assumed to be zero in the base case and consequently the cost of clay lining was excluded. Mobile plant costs were slightly reduced on the second reduction so as to match the manufacturer's quoted prices for one rubber tyred loader. Preparation costs were considered to be underestimated when compared to operations elsewhere. They were therefore increased over three fold in the final set of values to match other sites.

Table 6.7 EXAMPLE OF THE REDUCTION OF A SET OF CAPITAL COSTS ONTO THE BASE CASE

	Original Data (App. 9A)	1st Reduction (App. 9C)	2nd Reduction (App. 9D)
Site Acquisition	28,000	0[1]	0
Site Survey	0	0	4,032[2]
Buildings and Civils	1,500[3]	15,000[4]	15,000
Access Road	4,000	4,000	4,000
Drainage/Leachate Measures	2,500[5]	0[6]	0
Gas Alleviation Measures	0	0	0
Mobile Plant	18,500	18,500	15,000[2]
Other Preparation Costs	2,000	2,000	6,320[2]

1. Assumed leased.
2. Derived by regression analysis or empirically - details in Appendix 9B.
3. Portable building.
4. Cost adjusted to account for brick built facilities - Appendix 9B.
5. Clay lining.
6. Drainage measures assumed as zero cost in the base case.

Operating costs were reduced in a similar manner. Manning levels, wage rates and percentage on-costs were standardised; adjustments made to the number of site and slave vehicles so as to confirm with the base case; exclusion of bulk transporter costs from the transfer methods; exclusion of revenues and landfill cover costs; exclusion of capital charges.

Aggregated vehicle running costs were split into estimated component values by considering the percentage proportion of each component cost calculated from authorities supplying non-aggregated running costs. The percentage proportions varied for each method possibly reflecting differences in operational requirements. Specific costs were attributed to some of those "not available" in the original data. For example, electricity costs where quantity used was known; services, supplies, materials or building maintenance costs where figures were available for operations of similar size.

An example similar to that above for capital costs is given in Table 6.8 for the reduction of a set of operating costs from a 130t/d dry pulverisation transfer station onto the base case.

Transfer equipment maintenance and electricity were costed by the local authority as £24,000 and £20,000 respectively. These values were considered to represent the likely costs for a two pulveriser operation and were therefore used in the final figures (i.e. the second reduction values). Costs were not available for each individual vehicle running expenditure, consequently values were estimated using cost models derived from data supplied by other authorities (further information is given in Appendix 8B regarding their derivation). Only aggregated labour costs were available in the operator's records. These were dis-aggregated in the first review of the data (i.e. the first reduction) onto the basis of eight manual workers (@ £8,000/y) and one supervisor (@ £9,000/y). Costs for materials, services and building maintenance were not available so values were adopted from operations of similar sizes. Departmental administration, site rates and rent did not conform to the base case used in this work. Cost models, discussed in Appendix 8B, were therefore used to calculate the estimated values presented in the final, second reduction costs.

Table 6.8 EXAMPLE OF THE REDUCTION OF A SET OF OPERATING COSTS ONTO THE BASE CASE (1981£)

Figures are presented for a 130t/d dry pulverisation transfer station operating two pulverisers.

	Original Data (App. 8A)	1st Reduction (App. 8C)	2nd Reduction (App. 8D)
Transfer Equipment Maintenance	24,000	24,000	24,000
Site Vehicles -			
Fuel	N/A	N/A[1]	2,104[2]
Maintenance Labour	"	"	3,275[2]
Spares	"	"	1,314[2]
Tyres	"	"	2,034[2]
Licences and Insurance	"	"	150[2]
Electricity	20,000	20,000	20,000
Manual Labour	77,650	48,000[3]	48,000
Supervisory Labour		9,000[3]	9,000
Materials	N/A	N/A[1]	650[3]
Services	N/A	N/A[1]	975[3]
Building Maintenance	N/A	N/A[1]	700[3]
Dept. Admin.	26,000	26,000	12,248[3]
Site Rent	0	0[1]	6,232[3]
Site Rates	41,000[4]	41,000	4,046[2]
N/A = Not available.			

1. Insufficient number of cases to carry out a regression analysis on the first reduction costs.
2. Available 1st reduction costs from other sites first disaggregated and then regressed enabling second reduction values for the remaining sites to be interpolated. (Sections 8B.3.11, 9B.2.1)
3. Derived (or modified) by regression or empirical analyses. (see Sections 8B.2, 3, 4, 5, 6, 7, 8, 10)
4. Includes site rent and other, site-specific costs.

It should be appreciated that the adjustments made in the first and subsequent reductions are subjective and may not reflect a waste managers particular point of view. Considerable care was taken to be consistent and to only make realistic changes.

After making the adjustments discussed the first reduction capital and operating costs for each method were regressed against the physical size of operation. The physical variables used are as detailed in Table 6.6. This was to determine if any relationship existed from which cost models may be established, so as to calculate the cost of intermediate sizes of operation. Both XY and logXlogY regressions were made to test for linear and curvilinear relationships respectively. A regression line was considered to usefully represent the data if the R^2 value (coefficient of determination) was > 0.70. Where both the XY and logXlogY regressions gave $R^2 > 0.70$ the largest value was taken and the relationship used subsequently. Where both R^2 values are the same, the XY (linear) relationship was used.

For those collection methods with only small sample sizes the acceptable R^2 values (i.e. within the 5% SL) were increased above 0.70 in accordance with published tables. Collection operations are calculated in terms of the annual cost of a round. (A "round" is defined in Chapter 7) and transfer and landfill operations are calculated in terms of annual cost for each operation. First reduction costs and corresponding R^2 values are given in Appendices 7C (collection method, 8C (transfer methods) and 9C (direct landfill).

6.4.3 Second Reduction

Those first reduction costs which gave regressions with $R^2 > 0.70$ were carried forward unaltered to the second reduction, and their cost functions (given by the equation of the regression line) were also unchanged. As necessary at those sites where these components were previously "not available" interpolated values have been calculated.

The remaining first reduction costs gave low R^2 values. These were therefore reviewed in greater detail. As appropriate corresponding second reduction costs were produced by (i) relating them to different variables; (ii) removing outlier points; (iii) deriving an empirical relationship; or (iv) using constant values.

The regression analyses as described for the first reduction were repeated for these second reduction values and cost models derived. These models are included in the following collection, transfer and landfill chapters.

Complete sets of the second reduction costs and their corresponding R^2 values are given in Appendices 7D (collection methods); 8D (transfer methods); 9D (direct landfill).

As a check on the accuracy of derivation the second reduction component costs were summated to produce total operating and capital costs. For each method these totals were regressed and cost functions derived. A total cost function is an approximation of the summated component costs and their inherent variations. The total cost function and its 95% confidence interval (CI) for each method was plotted together with the summated individual component costs. If the derivation of the second reduction costs has been accurate the summated totals should lie well within the 95% CI of the total cost function. This was found to be so for all methods and examples are given in Figure 6.2a and b. Both methods of deriving the total cost of an operation have consequently been used as appropriate.

The upper and lower limits of the 95% CI for a particular size of operation are a measure of the error about the total cost value. The 95% CI corresponds to 2 x standard deviation. The larger the CI the greater the variation about the total. An error can therefore be calculated for all sizes of operation using the 95% CI.

6.4.4 Selected Values

The second reduction cost functions represent the costs for a base case operation at March 1981 values. These functions are thus a source of reliable, unambiguous costs and of enormous practical use for evaluating and comparing individual waste disposal methods. Using these functions costs were calculated for selected sizes of operation (e.g. 50, 100, 150 tonnes/day), and are discussed further in the following chapters. The annual capital charges are not considered in the total operating cost functions and are instead added to this stage. Excluding the site survey (or route planning) cost which is not considered to be financed by loan capital, the capital costs were amortised using the base case interest rate of 14%.

Fig 6.2a Base case total capital cost for selected daily tonneages with a 95% confidence interval.

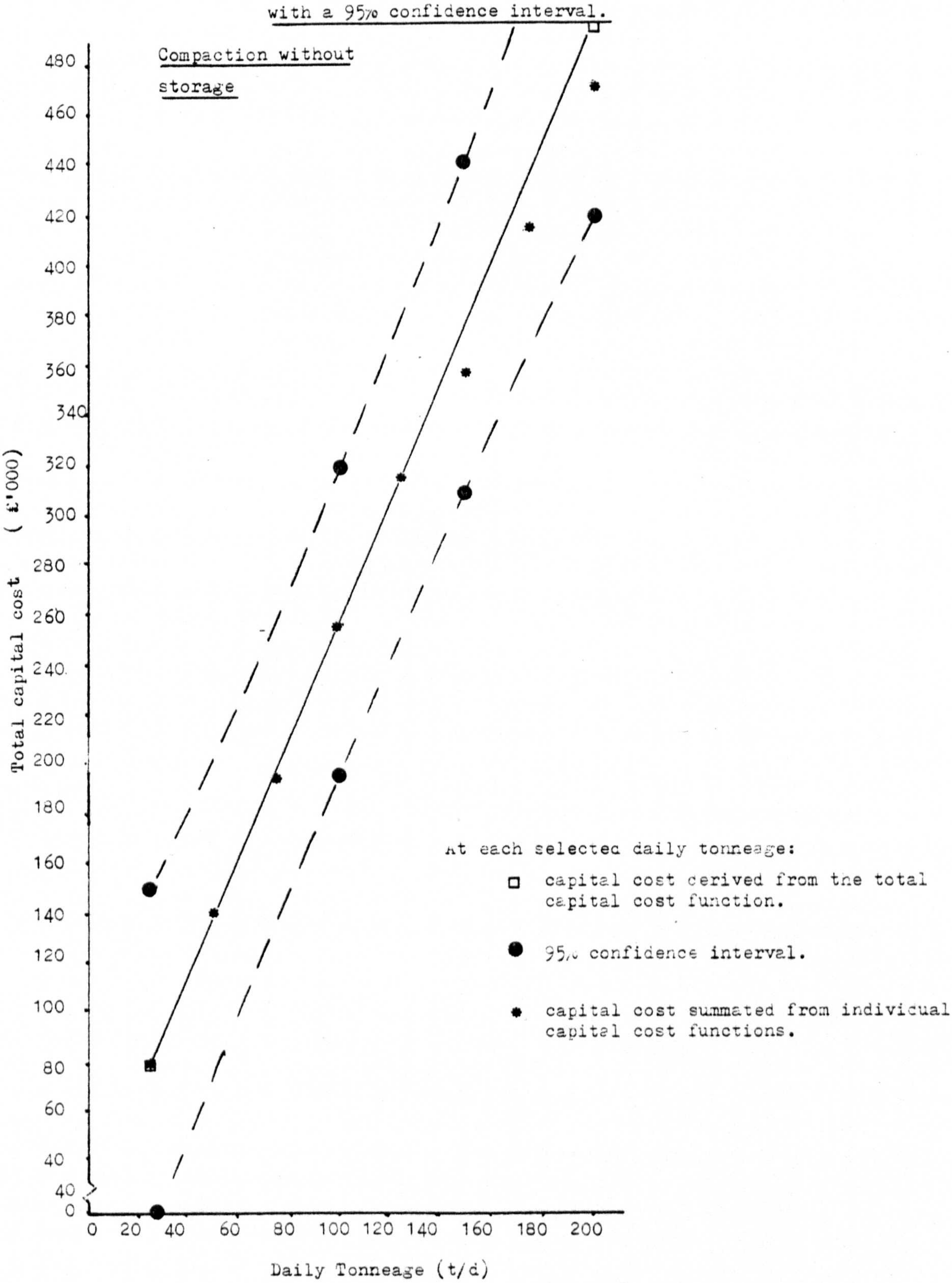
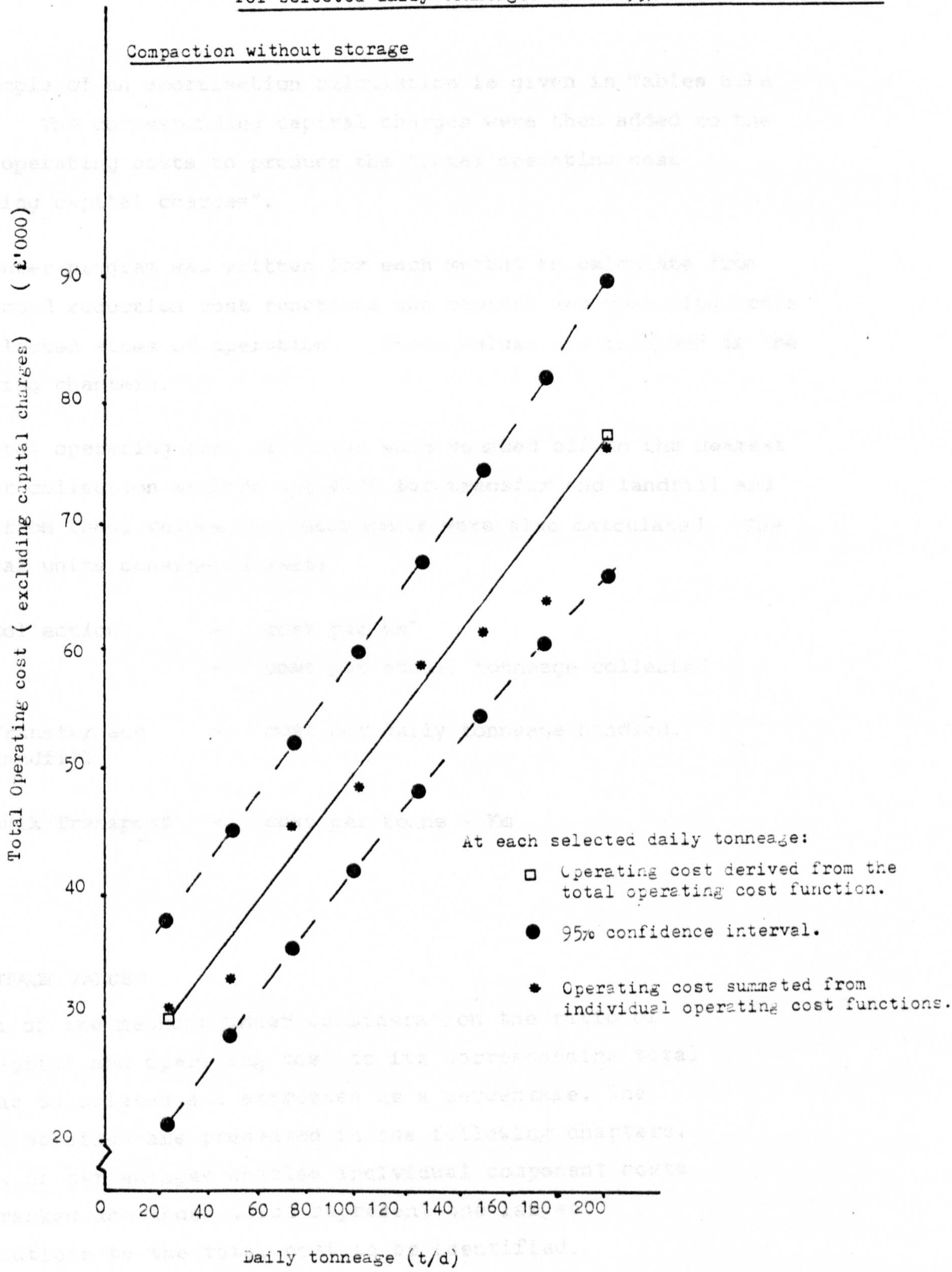


Fig 6.2b Base case total operating cost (excluding capital charges) for selected daily tonneages with a 95% confidence interval.



An example of an amortisation calculation is given in Tables 6.9 a and b. The corresponding capital charges were then added to the total operating costs to produce the "total operating cost including capital charges".

A computer program was written for each method to calculate from the second reduction cost functions the capital and operating costs for selected sizes of operation. These values are included in the following chapters.

The total operating cost estimates were rounded off to the nearest £10 for collection methods and £100 for transfer and landfill and it is from these values that unit costs were also calculated. The physical units considered were:

Collection	-	cost per Km^2
	-	cost per annual tonneage collected
Transfer and Landfill	-	cost per daily tonneage handled.
Bulk Transport	-	cost per tonne - Km

6.5 PERCENTAGE VALUES

For all of the methods under consideration the ratio of each capital and operating cost to its corresponding total cost was calculated and expressed as a percentage. The results obtained are presented in the following chapters. The use of percentages enables individual component costs to be ranked and those which represent the largest contributions to the total cost to be identified.

Table 6.9 (a) EXAMPLE AMORTISATION CALCULATION

A detailed explanation and calculation of the base case annual capital charges for a 20t/d landfill site.

Capital Financing

Building and Civils, other preparation and Access Road loan repaid over 20 years @ 14% interest p.a.

Mobile plant paid by loan or leased over 5 years @ 14% interest p.a.

Site survey costs are not considered to be financed by loan capital and no capital charges are calculated.

Explanation of Amortisation

Loans are repaid in equal instalments over the period for which they run. The annual repayments, a, are calculated by Equation 6.1.

$$a = \frac{PV_{at}}{PVIF_a} \qquad \text{Eq. 6.1}$$

where: PV_{at} = Present value of annuity (the sum borrowed)

$PVIF_a$ = Present value of annuity, derived from financial tables with reference to the appropriate interest rate and length of loan.

Capital Costs (2nd reduction costs) (From Appendix 9D)

Buildings and Civils (£15,000) Access Road (£4,000) Prep. (£6,320)	Mobile Plant
Repay over 20y; 14% interest p.a. £15,000 + 4,000 + 6,320 = £25,320 Using Equation 6.1: $\frac{£25,320}{6.623} = £3,823$	Repay over 5y; 14% interest p.a. $\frac{£15,000}{3.433} = £4,369$

∴ Total annual capital charge =

£3,823 + 4,369 = £8,192 = £1.64/tonne

The annual capital charge above incorporates two components, interest and payment of the principal, in differing proportions, each year.

These can be described in an amortisation schedule; example schedule for this 20t/d site's Mobile Plant Costs is given in Table 6.9b.

Table 6.9 (b) AMORTISATION SCHEDULE FOR A 20t/d LANDFILL SITE MOBILE PLANT CAPITAL COSTS

Year	Capital Charges	Interest (14%) (1)	Principal Repayment (2)	Remaining Balance (£)
0	-	-	-	15,000
1	4,369	2,100	2,269	12,731
2	4,369	1,782	2,567	10,144
3	4,369	1,420	2,949	7,195
4	4,369	1,007	3,362	3,833
5	4,369	536	3,833	

(1) Interest = Balance x 0.14

(2) Principal Repayment = Total Instalment - Interest

The capital charges for collection, transfer and landfill methods are detailed in Appendices 7E, 8E and 9E respectively.

6.6 SENSITIVITY ANALYSIS

Uncertainty exists in all economic evaluations. Technical and financial data when initially gathered are unlikely to be estimated with complete accuracy. Uncertainty is also inherent when planning for the future using historic costs and inaccuracies in certain component expenditures are likely to have a greater influence on the total than others. Sensitivity analysis is a means of measuring this uncertainty and is used in this study as appropriate on several base case costs. Its use is also recommended by the DOE for all waste management financial appraisals (DOE, 1976).

The relative sensitivity of a base case total cost to its individual component costs has been determined by varying each in turn. This served to identify those components which require accurate estimation and those which need less detailed attention. Consequently, for each disposal method the relative sensitivity of each component cost was calculated by computer using Equation 6.2.

$$R_S \simeq \frac{\Delta F_o}{\Delta F_i} \cdot \frac{F_i}{F_o} \qquad \text{Eq. 6.2}$$

where:
- R_S - Relative sensitivity
- ΔF_o - Difference in total cost
- ΔF_i - Difference in component cost
- F_o - Base Case Total Cost
- F_i - Base Case Component Cost

Sensitivity analysis only measures the effect of variation in one parameter at a time. Each parameter studied was attributed a likely range of variation above and below the base case value (Table 6.10) and it is within this range that the sensitivities were calculated. The ranges are determined from differences identified between the original data and that used in the base case. Where a component cost is derived from a linear cost function the relative sensitivity is constant over the entire range of variation considered. Where the component is derived from a curvilinear cost function this is not so. Instead relative sensitivities were calculated for selected values within the appropriate range in Table 6.10, e.g. where the overall range was taken to be $\overset{\times}{\div}$ 1.25, relative sensitivities were also calculated at $\overset{\times}{\div}$1.10 and $\overset{\times}{\div}$1.15.

Table 6.10 SENSITIVITY RANGE DERIVED FOR EACH COMPONENT COST[1]

Sensitivity Range Considered	Component Costs
	CAPITAL COSTS
x ÷ 2.00	Site survey, Route Planning
x ÷ 1.50	Buildings, Compactor/baler, Pulveriser, Ancillary Equipment, Site Preparations, Access Road, Bunker Construction.
x ÷ 1.25	All Mobile Plant, Grab crane/Conveyor System.
	OPERATING COSTS
x ÷ 2.00	Compactor/Baler/Pulveriser Maintenance, Building Maintenance, Site Rent, Vehicle Fuel and Lubricants, Baling Wire, Slave Vehicles.
x ÷ 1.50	Drivers, Crane Operators, Manual and Supervisory Labour, Dept. Admin. Site Rates, Capital Charges, Vehicle Maintenance, Services, Crane/conveyor Maintenance, Depot Costs, Operating Supplies
x ÷ 1.25	Electricity, Materials (excluding cover), Vehicle Spares, Tyres, Licenses and Insurances

1. Includes collection, transfer and landfill methods.

The largest costs (identified by percentage) were usually found to be also the most sensitive. Excluding collection, building construction was the most sensitive capital cost for the transfer methods, $0.10 < R_s < 0.68$, and mobile plant for direct landfill, $R_s \simeq 0.45$. Furthermore, fixed plant was found to be very sensitive in wet pulverisation ($0.24 < R_s < 0.48$) but in the other methods this and the other capital components were all relatively insensitive.

Capital charges were generally the most sensitive operating cost component, $0.11 < R_S < 0.70$, followed by manual labour, $0.07 < R_S < 0.46$. The total operating costs were fairly insensitive to the other components, i.e. $R_S < 0.10$, except for manual labour costs (most methods), Dept. Admin. (all collection methods), and operating supplies (sack collection methods only).

It is suggested from the percentage and sensitivity analyses of transfer and landfill methods that the building, mobile plant and fixed plant capital costs require the closest attention, together with the corresponding capital charges and all labour related operating costs. For collection the most sensitive component costs are capital charges, driver and loaders, departmental administration (which includes collection supervisors) and operating supplies.

To ensure the most accurate total cost estimations possible are produced the total cost functions derived in this work (and presented in Chapters 7 to 9) would initially be used. The component cost functions are then subsequently used to evaluate the major components identified above when a more detailed appraisal is sought.

Where necessary additional effort could be made to gather further information if a disposal option does not conform to the base case. The remaining, minor component costs can be estimated using the cost functions in Chapters 7 to 9, or alternatively, the cost factors in Chapter 5.

The effect of changes in physical parameters such as quantity of waste handled or plant lifetimes were also appraised. These changes are treated as extensions to the base case and are discussed further in the following chapters. The extensions specifically considered are detailed in Table 6.11.

6.7 CONCLUDING NOTE

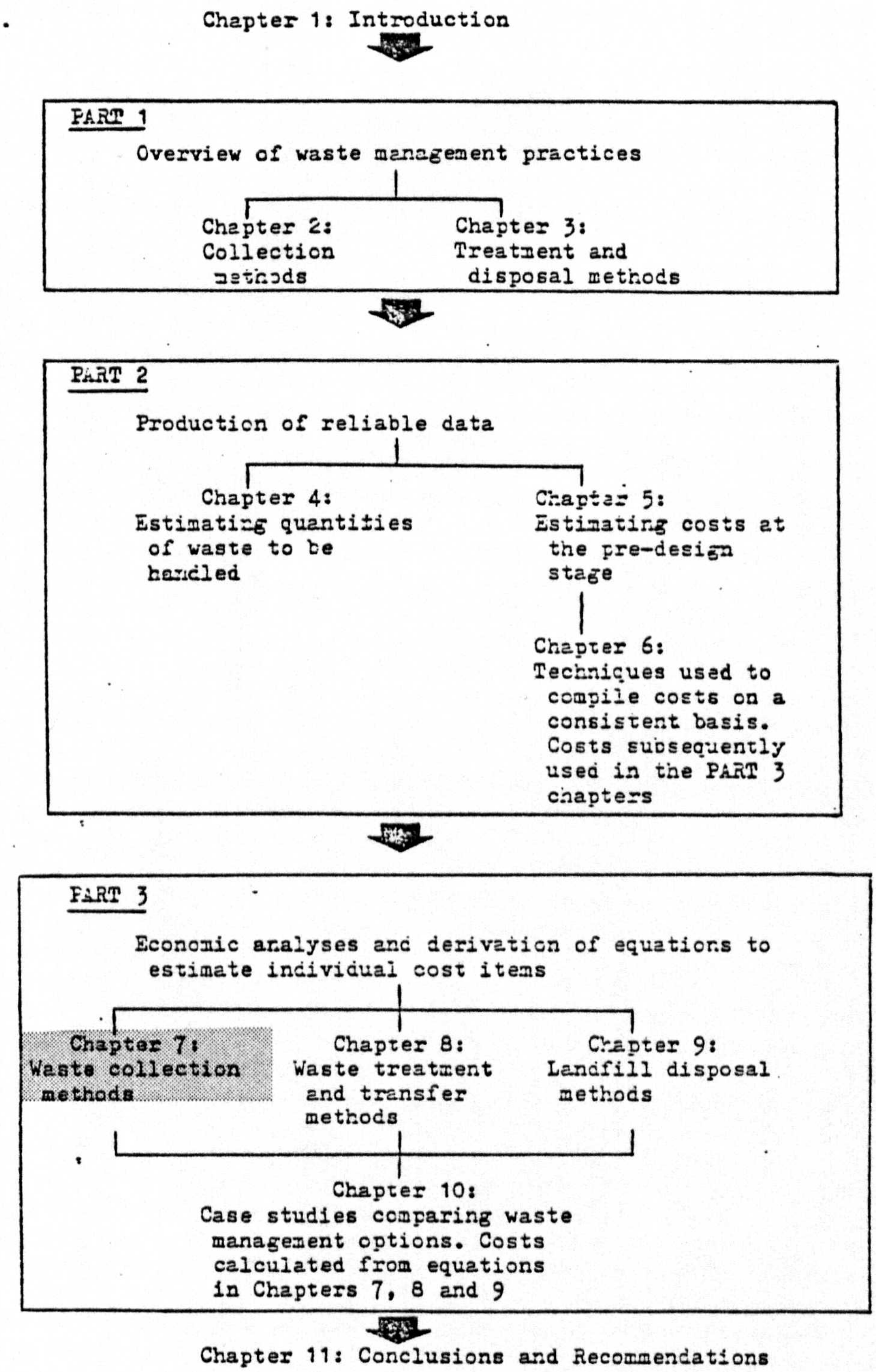
In Chapters 7, 8 and 9 respectively, the techniques discussed in this chapter were used to derive "preliminary design" costs for waste collection, transfer and landfill methods. These costs conform to the base case specified in Section 6.3. Sufficient detail was also obtained to enable this work to produce when necessary "specific cost estimates" for individual capital and operating items of expenditure.

Table 6.11 EXTENSIONS TO THE BASE CASE CONSIDERED IN THE RESEARCH

COLLECTION	Number of collectors Distance of haulage to disposal point Interest rates Number of trips per day by a collection vehicle
TRANSFER	Interest rates
BULK TRANSPORT	Number of return trips per day, turnaround time and average speed Interest rates
LANDFILL DISPOSAL	Purchased intermediate cover: Soil cover options Foam cover options No cover used on site Cell construction Drainage and Leachate measures: Drainage options Leachate options Gas alleviation and collection measures Interest rates Landfill revenues Site lifetime

CHAPTER 7

ECONOMICS OF WASTE COLLECTION



Chapter 7

7.1 INTRODUCTION

The techniques discussed in Chapter 6 to produce "preliminary design" costs were used in this chapter to produce cost estimating models for the five most widely used waste collection methods, i.e:

- Backdoor - Bin
- Backdoor - Sack
- Backdoor - Skep
- Kerbside - Bin
- Kerbside - Sack

Sufficient detail was obtained to derive useful values for several component costs. These in turn have been used to comprehensively review the economics of each method.

Whereas the technical aspects of collection were considered in Chapter 2, they can be summarised as five separate activities (Wilson, 1981):

(i) Journey to and from depot;
(ii) Actual collection operation;
(iii) Haul to and from disposal point;
(iv) Discharge of load at disposal point;
(v) Crew break-time.

The collection costs calculated here implicitly incorporate activities (i), (ii), (iv) and (v), and part of (iii). The remainder of this latter expense is borne by the disposal authority in England or the disposal budget in Scotland, Wales and Northern Ireland. The haulage distance beyond which the disposal authority bears the cost is known as the "threshold distance" and is negotiated locally between the respective collection and disposal departments. In the base case threshold distances were estimated from the Original Data (Appendix 7A) to be 10 Km return journey and 30 Km return journey in urban and rural authorities respectively. Haulage up to a threshold distance is borne by the collection authority.

In this chapter collection cost functions have been derived for both individual components (such as fuel, sacks, labour) and total costs. These functions produce estimates for a range of sizes of authority and are different for each collection method. Costs are quoted as "costs per round" a definition of which is given in Section 7.1.1. Other variables have also been found to influence some of the component cost functions and are listed in Section 7.3. These are known as "physical variables" and to derive the base case costs they were attributed a fixed set of values. This, however, is subsequently relaxed in the sensitivity analysis. Costs produced by the cost functions described in this chapter are also compared with corresponding literature values detailed earlier in Table 2.5.

7.1.1 Definition of a Collection Round

The nomenclature for collection operations is confused. Round, route and beat are used by different officials to describe either an individual trip by a collection vehicle involving uplifting of refuse, haul to and from disposal point and discharge, or, the weekly set of trips undertaken by a collection vehicle. Here the term "round" has been used to describe the former, the collection of an individual load by a collection vehicle.

7.2 URBAN AND RURAL ROUNDS

A distinction has been made between urban and rural authorities. In urban areas the travelling distances between bins, to and from disposal points and between rounds are generally much shorter than for rural authorities. The number of bins serviced by a vehicle and crew is also likely to be higher in urban areas than rural, while conversely, travelling speeds are likely to be greater in the countryside than in towns.

Marked cost differences (described in Appendix 7B) were found between urban and rural operations principally affecting crew sizes (and hence labour costs), fuel consumption and maintenance costs. These findings are supported by Loram (1978) who undertook a detailed study into transfer stations and the delivery of refuse to them, and also by various Local Government Operational Research Unit reports.

Consequently, two analyses for each collection method were undertaken: One for urban authorities; and one for rural authorities.

An urban authority is defined as having a populated area between 50 and 300 Km^2 and a rural authority as between 500 and 2,000 Km^2. No information has been obtained from authorities with areas between 300 and 500 Km^2 since those approached proved unhelpful; consequently the economics of their operations could not be considered. No extrapolations were made to cover this range since some costs differ markedly between urban and rural operations and it is uncertain which, if either, would prevail in these intermediate-sized authorities. Alternatively, there may be some overlap in this region where large urban and small rural authorities with the same area have different component costs.

No rural authority was identified as operating backdoor skep collection and consequently no costs were obtained for this method.

7.3 EVALUATION OF THE COLLECTION COST MODELS

The total cost of a collection operation includes the following expenditures:

- Vehicle fuel
- Vehicle maintenance labour
- Vehicle spares
- Vehicle tyres
- Vehicle licenses and insurance
- Depot costs
- Operating supplies
- Driver
- Loaders
- Departmental Administration.

(A full definition of items included in each of these components is given in Appendix 6A).

The cost functions for each individual expenditure are listed in Tables 7.1 (urban methods) and 7.2 (rural methods) together with those for the total costs. They were derived from data collected with the aid of local authorities and analysed using the methods previously discussed in Chapter 6. A full description of their derivation is presented in Appendix 7B and they represent plausible models from which meaningful cost estimates can be calculated.

Six "physical variables" were found, each influencing one or more of the component cost functions. Individual costs are calculated from these functions using an appropriate value for each variable (Tables 7.1 and 7.2). Those selected to evaluate the base case were:

	Physical Variable	Urban	Rural
x_{km}	Area of Authority (Km^2)	50-300	500-2,000 Various values selected
x_{try}	Annual tonneage per round (t)	250	250
x_{rwv}	Rounds per week per vehicle	10	10
x_{nrw}	Total number of residential rounds per week in the authority	100	100
x_{ncv}	Total number of collection vehicles in the authority	20	15
x_m	Number of loaders -		
	Kerbside methods	3	2
	Backdoor methods	4	3

The cost functions were produced by regression analysis on the "Second Reduction" costs (i.e. the Original data reduced onto the base case), using figures gathered from authorities. Full details of the derivation of these functions and the base case are described in Chapter 6.

Attention is drawn to the Chapter 7 Appendices; these provide further details on the original costs and the analyses performed on them to produce the base case values. For additional information on a particular point in the text reference can be made to the relevant appendix, i.e.

Table 7.1 OPERATING COST FUNCTIONS FOR EACH COLLECTION METHOD IN URBAN AUTHORITIES

URBAN

	Kerbside Sack	Kerbside Bin*	Backdoor Sack	Backdoor Skep*	Backdoor Bin
Fuel	$y=1.21X_{Km}$	$y=1.19X_{Km}$	$y=1.68X_{Km}$	$y=1.68X_{Km}$	$y=1.31X_{Km}$
Maintenance Labour	$y=1.37X_{Km}$	$y=2.52X_{Km}$	$y=2.64X_{Km}$	$y=2.64X_{Km}$	$y=1.19X_{Km}$
Spares	$y=1.02X_{Km}$	$y=0.06X_{Km}$			$y=0.51X_{Km}$
Tyres	$y=0.28X_{Km}$	$y=0.35X_{Km}$	$y=0.35X_{Km}$	$y=0.35X_{Km}$	$y=0.35X_{Km}$
Supplies	$y=2.5X_{try}+1.26$	y=100	$y=2.67X_{try}+1.02$	y=100	y=100
Driver	$y=\frac{7500}{X_{rwv}}$	$y=\frac{7500}{X_{rwv}}$	$y=\frac{7500}{X_{rwv}}$	$y=\frac{7500}{X_{rwv}}$	$y=\frac{7500}{X_{rwv}}$
Loaders	$y=\frac{6900.X_m}{X_{rwv}}$	$y=\frac{6900.X_m}{X_{rwv}}$	$y=\frac{6900.X_M}{X_{rwv}}$	$y=\frac{6900.X_m}{X_{rwv}}$	$y=\frac{6900.X_m}{X_{rwv}}$
Vehicle Licenses and Insurance	y=120	y=120	y=120	y2120	y=120
Depot Costs	y=300	$y=\frac{1591X_{ncv}-672}{X_{nrw}}$	$y=\frac{350X_{ncv}+24700}{X_{nrw}}$	$y=\frac{1591X_{ncv}-672}{X_{nrw}}$	$y=\frac{1591X_{ncv}-672}{X_{nrw}}$
Dept. Admin.	$y=0.68X_{Km}+612$	15% of total op. cost excl. capital charges	$y=1.03X_{Km}+653$	15% of total op. cost excl. capital charges	$y=0.65X_{Km}+591$
Calculated Total Op. Cost (excl. Capital Charges) 1.+	$y=5.25X_{Km}+4717$	Insufficient values to derive equation	$y=7.92X_{Km}+4907$	Insufficient values to derive equation	$y=4.99X_{Km}+4520$

PHYSICAL VARIABLES' RANGES OVER WHICH TIME COST FUNCTIONS ARE VALID:

						Symbol used
Area of Authority (Km^2)	50 - 300	100 - 300*	50 - 300	50 - 150*	50 - 300	X_{Km}
Tonne/round/year	200 - 300	275 - 300	150 - 300	200 - 225	175 - 275	X_{try}
Rounds/week/vehicle	5 - 12	5 - 12	5 - 12	5 - 12	5 - 12	X_{rwv}
Total number of rounds/week	50 - 150	75 - 225	60 - 160	175 - 200	50 - 350	X_{nrw}
Total number of collection vehicles	10 - 25	15 - 35	10 - 45	25 - 45	15 - 70	X_{ncv}
No. of collectors	2 - 4	2 - 4	3 - 5	3 - 5	3 - 5	X_m

* Findings considered tentative.
1. Total cost equations graphically represented in Figure 7.1

Several physical variables were investigated for each cost. The cost models presented adopted those that gave the best fit. Further details are given in Appendix 7B.

The coefficient of determination (R^2 value) for each cost function is given in Appendix 7D.

"y" represents cost in 1981£

\+ Annual capital charges per round are estimated as £874

Fig 7.1 Base case total operating costs per round (excluding capital charges) for different sizes of URBAN authorities.

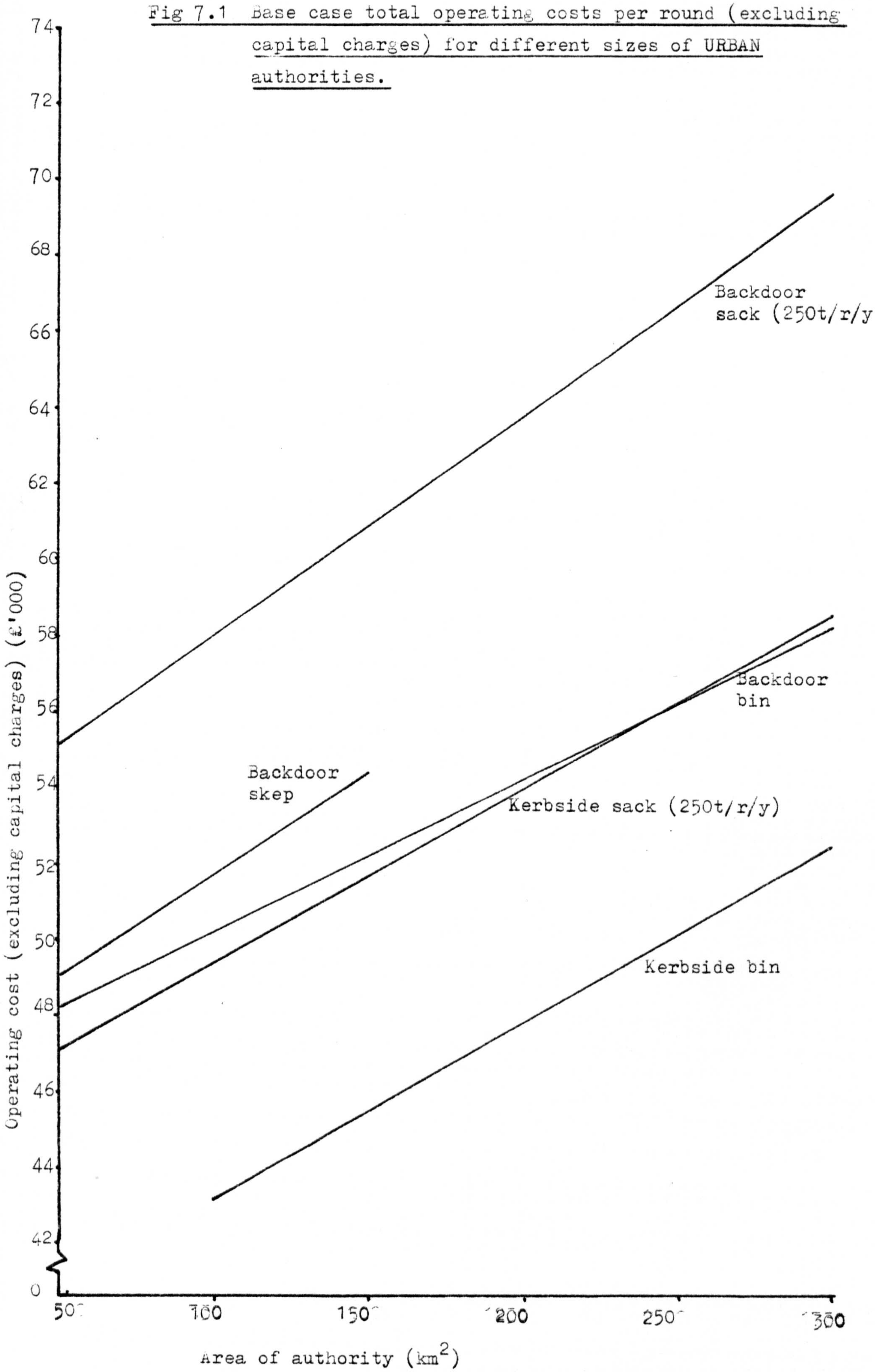


Table 7.2 OPERATING COST FUNCTIONS FOR EACH COLLECTION METHOD IN RURAL AUTHORITIES

RURAL

	Kerbside Sack*	Kerbside Bin	Backdoor Sack*	Backdoor - Skep	Backdoor Bin
Fuel	$y=0.24X_{Km}$	$y=0.14X_{Km}$	$y=0.25X_{Km}$	NO INFORMATION AVAILABLE	$y=0.33X_{Km}$
Maintenance Labour	$y=0.28X_{km}$	$y=0.20X_{km}$	$y=0.20X_{Km}$		$y=0.30X_{Km}$
Spares			$y=0.16X_{Km}$		$y=0.16X_{Km}$
Tyres	$y=0.04X_{Km}$		$y=0.11X_{Km}$		$y=0.09X_{Km}$
Supplies	$y=1000$	$y=140$	$y=1100$		$y=150$
Driver	$y=\frac{7500}{X_{rwv}}$	$y=\frac{7500}{X_{rwv}}$	$y=\frac{7500}{X_{rwv}}$		$y=\frac{7500}{X_{rwv}}$
Loaders	$y=\frac{6900.X_m}{X_{rwv}}$	$y=\frac{6900.X_m}{X_{rwv}}$	$y=\frac{6900.X_m}{X_{rwv}}$		$y=\frac{6900.X_m}{X_{rwv}}$
Vehicle Licences and Insurance	$y=120$	$y=120$	$y=120$		$y=120$
Depot Costs	$y=150$	$y=\frac{8\times10^{-6}X_{ncv}^{7.77}}{X_{nrw}}$	$y=150$		$y=\frac{8\times10^{-6}X_{ncv}^{7.77}}{X_{nrw}}$
Dept. Admin.	15% of total op. cost excl. capital charges	$y=0.03X_{Km}+401$	15% of total op. cost excl. capital charges		$y=0.12X_{Km}+497$
Calculated Total Op. Cost (excl. Capital Charges)[1] +	Insufficient values to derive equation	$y=0.24X_{Km}+3095$	Insufficient values to derive equation		$y=0.93X_{Km}+3803$

PHYSICAL VARIABLES' RANGES OVER WHICH THE COST FUNCTIONS ARE VALID:

						Symbol used
Area of Authority (Km^2)	1000 - 1500*	500 - 2000	1000 - 1500*	No information available	500 - 2000	X_{Km}
tonne/round/year	150 - 250	150 - 250	150 - 250		200 - 300	X_{try}
rounds/week/vehicle	5 - 10	5 - 12	5 - 12		5 - 12	X_{rwv}
total number of rounds/week	40	70 - 105	20 - 75		65 - 115	X_{nrw}
total number of collection vehicles	8	12 - 18	5 - 7		14 - 16	X_{ncv}
No. of collectors	1 - 3	1 - 3	2 - 4		2 - 4	X_m

* Findings considered tentative.

1. Total cost equations graphically represented in Figure 7.2.

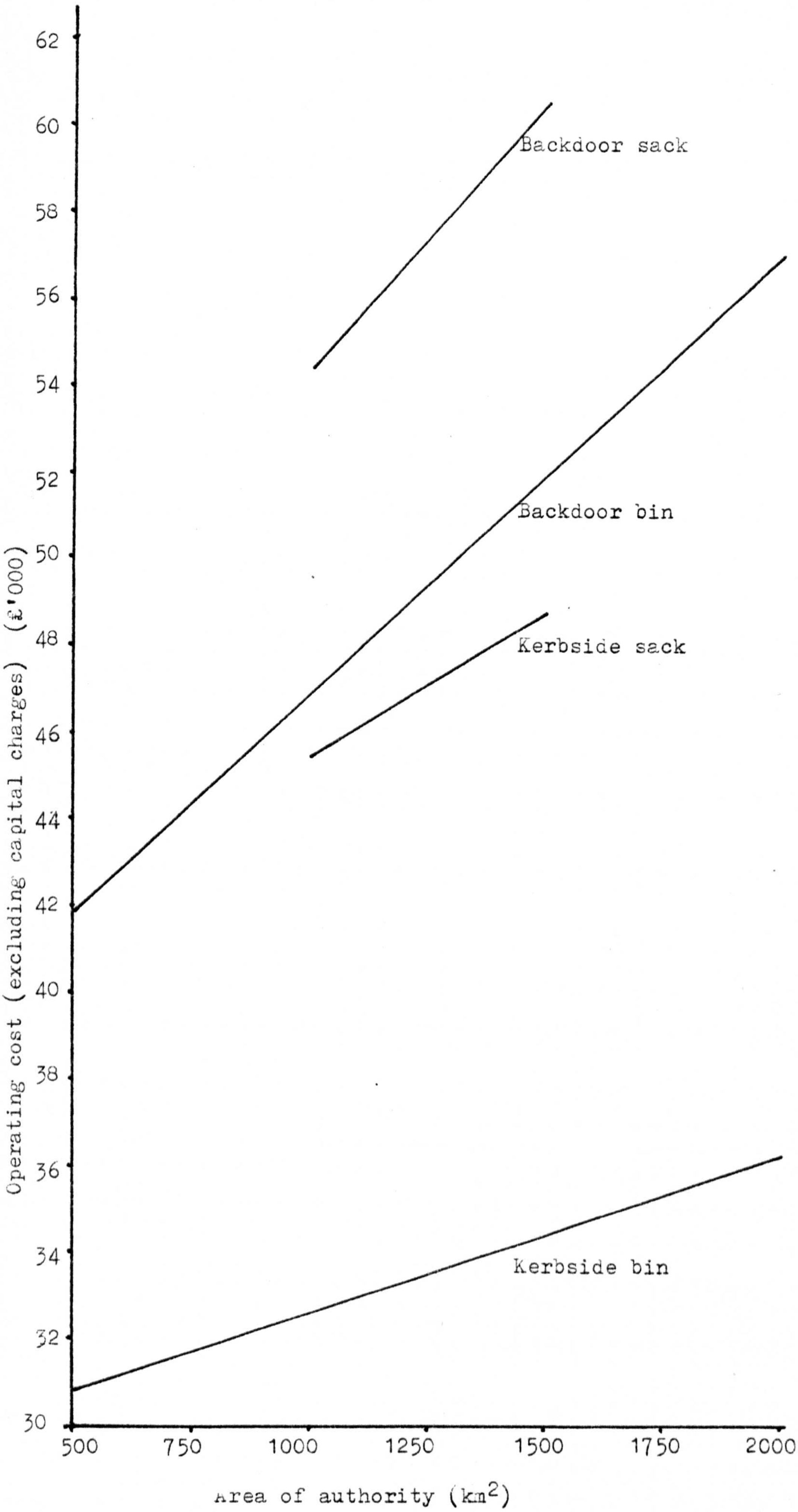
Several physical variables were investigated for each cost. The cost models presented adopted those that gave the best fit. Further details are given in Appendix 7B.

The coefficient of determination (R^2 value) for each cost function is given in Appendix 7D.

"y" represents cost in 1981£

\+ Annual capital charges per round are estimated as £874

Fig 7.2 Base case total operating costs per round (excluding capital charges) for different sizes of RURAL authority.



Appendix 7A	Original Data
Appendix 7B	Descriptive Derivation of each First and Second Reduction Component Cost and the Amortisation Calculation
Appendix 7C	First Reduction Costs and Corresponding R^2 Values
Appendix 7D	Second Reduction Costs and Corresponding R^2 Values
Appendix 7E	Base Case Operating Costs (all methods) and Percentage Values
Appendix 7F	Relative Sensitivities for Base Case Operating Costs

7.4 CAPITAL COSTS AND AMORTISATION DISCUSSION

The base case capital costs and relative sensitivities for each size of authority are identical for all collection methods (Table 7.3). The total capital cost is dominated by collection vehicle purchase (approximately 97%) with the other component, route planning, comprising only 3%. The total cost is accordingly very sensitive to changes in collection vehicle cost (R_S = 0.882), for example, an 8.3% increase, £30,000 to £32,500, produces an 8.1% increase in total cost.

Conversely, a large increase in planning costs has only a minor effect on the total cost. For example, a 100% increase, £1,000 to £2,000, produces just a 3% increase in the total.

Amortisation charge for each vehicle (@ 14% interest over five years) is approximately £8,700/year. The base case 10 rounds per vehicle produces a capital charge per round of approximately £870. This accounts for between 11 and 22% of the total operating cost (urban backdoor sack and rural kerbside bin respectively - further details in Appendix 7E) and is the second or third largest operating expenditure (depending upon collection method and size of authority). Sensitivity analysis also indicates that total operating costs are moderately sensitive to variations in their capital charges.

<u>For example: Urban, kerbside bin 250 Km^2 (R_S = 0.146)</u>

A 25% increase in capital charges produces a 3.7% increase in total operating cost

Table 7.3a Base case collection capital costs
- Urban and rural collection methods.

BASE CASE COSTS FOR SELECTED COLLECTION METHODS (1981£)

CAPITAL COSTS

AREA(KM2)	50.	75.	100.	125.	150.	175.	200.	225.	250.	275.	300.	0.	0.
ROUTE PLANNING	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	0.0	0.0
REAR-END LOADING COMPACTION COLLECTION VEHICLE	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	0.0	0.0
SUM.TOTAL	31000.0	31000.0	31000.0	31000.0	31000.0	31000.0	31000.0	31000.0	31000.0	31000.0	31000.0	0.0	0.0

CAPITAL COSTS AMORTISED OVER 5Y AT 14%PA - MOBILE PLANT

Table 7.3b Relative sensitivities for the collection base case capital costs - Urban and rural methods.

SENSITIVITY RANGES CONSIDERED
X OR / 2.00 : ROUTE PLANNING
X OR / 1.25 : MOBILE PLANT

RS VALUES

LINEAR FUNCTIONS PRODUCE A CONSTANT RS VALUE FOR THE ENTIRE SENSITIVITY RANGE
CURVILINEAR FUNCTIONS DO NOT, INSTEAD SELECTED RS VALUES ARE GIVEN

AREA(KM2)	500.	750.	1000.	1250.	1500.	1750.	2000.	0.	0.	0.	0.	0.	0.
ROUTE PLANNING	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.000	0.000	0.000	0.000	0.000	0.000
REAR-END LOADING COMPACTION COLLECTION VEHICLE	0.882	0.882	0.882	0.882	0.882	0.882	0.882	0.000	0.000	0.000	0.000	0.000	0.000

7.4.1 Sensitivity of Collection Capital Costs to Interest Rates

Interest rates are notoriously volatile. The base case rate of 14% was that prevailing at the base date, 31 March 1981, and is by no means a constant value. The cost of capital will vary substantially over time under the influence of domestic and foreign affairs.

The annual capital charges were therefore recalculated for different interest rates: 5%, 10%, 12% and 20%. In Table 7.4 these variations in interest rate, even the small ones, exhibit a large effect on the capital charges. For example, a 2% difference in interest rate (14% to 12%) produces a 5% change in the capital charges, and as the variation from the base case becomes larger the corresponding effect on the capital charges increases.

However, while the annual capital charge is clearly demonstrated in Table 7.4 to be highly sensitive to variations in interest rate the effect of these variations on the total cost is surprisingly small (Table 7.5).

7.5 OPERATING COSTS DISCUSSION

The operating costs for each method of collection over a range of sizes of authority are given in Appendix 7E, and as an example one set of costs is reproduced in Table 7.6. The corresponding relative sensitivities are detailed in Appendix 7F and an example for one method is given in Table 7.7.

Table 7.4 SENSITIVITY OF CAPITAL CHARGES TO VARIATIONS IN THE INTEREST RATE

Interest Rate	Capital Charges (£/round/y)	% to base case capital charges
5% p.a.	693[1]	- 21
10%	791	- 9.5
12%	832	- 4.8
20%	1,003	+ 15

1. Base case: 14% p.a. - 874 £/round/y.

Table 7.5 SENSITIVITY OF TOTAL OPERATING COSTS TO CHANGES IN THE INTEREST RATE

Interest Rate	% increase in total operating cost from a 25% increase in interest rate*
14% base case	3.7%
5%	3%
10%	3.4%
12%	3.5%
20%	4.2%

* See Table 7.4

Example calculations of the percentage size of increase in the total cost produced by a 25% increase in the capital charges with each interest rate. Costs for urban, kerbside bin, 250Km^2 have been used.

Table 7.6 Example of the Base Case Operating Costs for one Collection Method (1981£/r/y)

URBAN - Backdoor Bin													
AREA(KM2)	50.	75.	100.	125.	150.	175.	200.	225.	250.	275.	300.	0.	0.
VEH.FUEL	65.5	96.2	131.0	163.8	196.5	229.2	262.0	294.8	327.5	380.2	393.0	0.0	0.0
V.MT.LAB	59.5	89.3	119.0	148.6	178.5	208.3	238.0	267.8	297.5	327.3	357.9	0.0	0.0
V.SPARES	25.5	38.3	51.0	63.8	76.5	89.3	102.0	114.6	127.5	140.3	153.0	0.0	0.0
V.TYRES	17.5	26.3	35.0	43.8	52.5	61.3	70.0	78.6	87.5	96.3	105.0	0.0	0.0
LICENCES	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	0.0	0.0
DRIVER	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	0.0	0.0
LOADERS	2760.0	2760.0	2760.0	2760.0	2760.0	2760.0	2760.0	2760.0	2760.0	2760.0	2760.0	0.0	0.0
SUPPLIES	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0
DEPOT	311.5	311.5	311.5	311.5	311.5	311.5	311.5	311.5	311.5	311.5	311.5	0.0	0.0
ADMIN	623.5	639.8	656.0	672.3	688.5	704.8	721.0	737.3	753.5	769.8	786.0	0.0	0.0
SUM.TOTAL (EXCLUDING CAPITAL CHARGES)	4833.0	4933.2	5033.5	5133.7	5234.0	5334.2	5434.5	5534.7	5635.0	5735.2	5835.5	0.0	0.0
CP.CHARGE	873.9	873.9	873.9	873.9	873.9	873.9	873.9	873.9	873.9	873.9	873.9	0.0	0.0
SUM.TOTAL (INCLUDING CAPITAL CHARGES)	5706.8	5807.1	5907.3	6007.6	6107.8	6208.1	6308.3	6408.6	6508.8	6609.1	6709.3	0.0	0.0

(Information on the other collection methods is presented in Appendix 7E)

Table 7.7 *Example of the Base Case Relative Sensitivities for one Collection Method*

URBAN - Backdoor Bin

SENSITIVITY RANGES CONSIDERED
X OR / 2.00 : FUEL
X OR / 1.50 : VEHICLE MAINT LABOUR, DRIVER, LOADERS, ADMIN, DEPOT COSTS, CAPTIAL CHARGES
X OR / 1.25 : VEHICLE SPARES, TYRES, VEH. INSURANCE & LICENCES, SUPPLIES

RS VALUES

SEE COMMENT IN CAPITAL COST SECTION

AREA(KM2)	50.	75.	100.	125.	150.	175.	200.	225.	250.	275.	300.	0.	0.
VEH.FUEL	0.011	0.017	0.022	0.027	0.032	0.037	0.041	0.046	0.050	0.054	0.058	0.000	0.000
V.MT.LAB	0.010	0.015	0.020	0.025	0.029	0.033	0.038	0.042	0.045	0.049	0.053	0.000	0.000
V.SPARES	0.004	0.007	0.009	0.011	0.013	0.014	0.016	0.018	0.020	0.021	0.023	0.000	0.000
V.TYRES	0.003	0.005	0.006	0.007	0.009	0.010	0.011	0.012	0.013	0.015	0.016	0.000	0.000
LICENCES	0.021	0.021	0.020	0.020	0.020	0.019	0.019	0.019	0.018	0.018	0.018	0.000	0.000
DRIVER	0.130	0.128	0.125	0.123	0.121	0.119	0.117	0.116	0.114	0.112	0.111	0.000	0.000
LOADERS	0.461	0.454	0.446	0.439	0.432	0.426	0.419	0.413	0.407	0.401	0.395	0.000	0.000
SUPPLIES	0.017	0.017	0.017	0.017	0.016	0.016	0.016	0.016	0.015	0.015	0.015	0.000	0.000
DEPOT	0.054	0.053	0.052	0.052	0.051	0.050	0.049	0.048	0.048	0.047	0.046	0.000	0.000
ADMIN	0.108	0.109	0.110	0.111	0.111	0.112	0.113	0.114	0.114	0.115	0.116	0.000	0.000
CP.CHARGE	0.151	0.146	0.146	0.143	0.141	0.139	0.137	0.135	0.132	0.130	0.129	0.000	0.000

(Information on the other collection methods is presented in Appendix 7F)

7.5.1 Principal Findings

1. Labour (loaders and driver) is the largest operating expenditure.

2. The second largest expense is capital charge, except for some sack collection methods where the operating supplies cost is dominant.

3. Four components: labour costs, capital charges, operating supplies, and departmental administration; together account for between 70% and 90% of the total operating cost.

4. Vehicle running cost is only a major expense in authorities with large ground areas.

5. The remaining component costs identified are only minor expenditures.

6. The total costs are most sensitive to:
   - Labour costs - all methods
   - Capital charges - all methods
   - Operating supplies- sack methods in rural authorities
   - Vehicle running costs - all methods in large authorities

7.5.2 Labour Costs

The largest component cost with all methods is loader cost, which, when combined with the driver cost, comprises between 41% and 68% of the total operating expenditure. This range is comparable with the Scottish Development Department (SDD) (1977) estimate of 53%. Total costs consequently are highly sensitive to variations in labour costs.

<u>For example:</u> <u>Rural, backdoor bin, 1,000 Km^2</u> (R_S = 0.358)

A 25% increase in loader cost produces a 9.3% increase in total cost.

A 25% increase in loader and driver costs produces a 12.6% increase in total cost.

A comparison between the costs of alternative methods derived here (Table 7.8) and those implied in the literature (Table 2.7) is influenced by the base case manning levels (i.e. urban backdoor methods - driver and four loaders, urban kerbside methods - driver and three loaders). At these levels the kerbside sack and bin labour costs compare favourably with the published literature. The literature however underestimates costs for both backdoor sack and skep methods. If the manning levels of these two methods are reduced to driver and three loaders there is a corresponding reduction in labour costs. They are then similar to the published values. Therefore it is possible that the literature values for backdoor sack and skep were derived from authorities with manning levels or staff costs below those used in the base case.

7.5.3 Operating Supplies Costs

The operating supplies costs for sack collection methods are large, comprising approximately 10% (urban authorities) and 17% (rural authorities) of the total cost, as opposed to generally less than 3% for the bin and skep methods. These findings apply to the collection of 250 tonnes/year. At 300 t/r/y ($\simeq$ 5.8 tonnes/round/week), the approximate upper tonneage per round, the sack method supplies costs are higher, accounting for 12% (urban) and 19% (rural). These percentages suggest the operating supplies costs for sack methods implied in the literature (Table 2.7) as over 20% are only valid when very high tonneages are collected or where an authority has purchased more expensive sacks than considered here. The total costs of the rural sack method are reasonably sensitive to this component. However the converse is true for urban sack, skep and bin, and rural bin operations.

For example a 25% increase in operating supplies for:

URBAN 100 Km^2	Backdoor Bin	250t/r/y	$R_S = 0.017$	produces a 0.4% increase in total cost
" "	Backdoor Sack	250 "	$R_S = 0.099$	produces a 2.5% increase in total cost
" "	Backdoor Sack	300 "	$R_S = 0.116$	produces a 2.9% increase in total cost
RURAL 500 Km^2	Backdoor Sack	300 "	$R_S = 0.177$	produces a 4.5% increase in total cost

Table 7.8 COMPARISON BETWEEN PUBLISHED TRANSPORT AND LABOUR COSTS AND THOSE DERIVED IN THIS RESEARCH

All costs are given as relative to the backdoor bin method

Collection Method	Transport Costs[2]		Labour Costs[2]		Comments
	Chapter 2	This Research[1]	Chapter 2	This Research[1]	
Backdoor Bin	-	-	-	-	
Backdoor Skep	Up to 20% less	39% above	Up to 20% less	0	Transport (T): Literature under estimate Labour (L): Literature under estimate
Backdoor Sack	Up to 20% less	15% above	Up to 20% less	0	T: Literature under estimate L: Literature under estimate
Kerbside Bin	20-50% less	23% above	Up to 20% less	21% less	T: Literature under estimate L: Literature and this work similar
Kerbside Sack	20-50% less	39% above	Up to 20% less	21% less	T: Literature under estimate L: Literature and this work similar

1. Urban authorities only. 250 tonnes/round/year
2. % differences with respect to backdoor bin method.

7.5.4 Departmental Administration Costs

Administration costs are broadly similar for all methods. At between 10% and 12% of the total cost they are below those for the operating supplies component. Correspondingly, the total costs are also relatively insensitive.

For example Rural backdoor sack, 1,750 Km^2 (R_S = 0.113)

A 25% increase in administration cost produces a 2.9% increase in total cost.

7.5.5 Vehicle Running Costs

It is interesting to note that although the physical collection of refuse includes a large element of transport the vehicle running costs (combining fuel, maintenance, spares and tyres) comprise only a small proportion of the total operating costs. In the small urban and rural authorities this component accounts for about 4% and 6% respectively. This is probably due to more waste producers being within a small area and hence only short travelling distances between collection points are required. In the larger, more extensive authorities, the travelling distances are likely to be higher and bin densities lower. This would be correspondingly reflected in the vehicle running costs; i.e. 16% (urban) and 20% (rural) of the total costs. For comparison, the Scottish Development Department (1977), estimate a general value in Scotland of 25%.

The vehicle running costs in the larger authorities are also small when compared with loader, capital charges, administration or operating supplies expenditures. Thus, even though physically vehicles are a major part of a collection operation, surprisingly the individual running costs (such as fuel or maintenance) have a relatively small influence on the total cost.

For example Rural kerbside sack, 2,000 Km^2

A 25% increase in the individual expenditures:

Fuel Costs	(R_S 0.078) produces a 2% increase in total cost
Maintenance and Spares	(R_S 0.091) produces a 2.3% increase in total cost
Tyre costs	(R_S 0.013) produces a 0.3% increase in total cost

It is only where the running costs all increase together (e.g. as is the case with contract vehicles) in authorities with large areas do they exert a noteable effect on the total cost. Using the same examples as above:

COMBINED VEHICLE RUNNING COST produces a 4.5% increase in total cost.

In spite of the vehicle running costs representing only minor expenditures the results of this work when compared with literature sources (as cited in Table 2.7) implies that the published figures seriously under-estimate the vehicle running costs (Table 7.8). The reasons for the disparity are not known.

Notable variations between rural and urban operations, and bin and sack methods, have been identified and are summarised below:

<u>Fuel Costs</u> - Bins Rural operations about 80% higher than urban
Sacks Rural operations about 70% higher than urban

This reflects the larger travelling distances, higher local fuel costs and higher threshold haul distances encountered in rural authorities.

<u>Maintenance Labour Costs</u>

Overall maintenance costs are up to 30% greater than fuel costs.

Rural operations are 20-40% larger than in urban districts.

This variation is probably due to the same factors as those discussed under "fuel costs". In addition, repairs and maintenance are frequently undertaken by private garages as country authorities often do not possess full technical facilities. Any external work is likely to be more costly than that undertaken in-house.

<u>Spares and Tyres Costs</u>

Both expenditures are much smaller than those for fuel and maintenance labour.

Rural operations are around 25% larger than in urban districts.

7.5.6 Licences and Depot Costs

Licences and depot costs are minor expenditures, less than 2% and 5% of the total costs respectively. The total costs correspondingly have very low sensitivities to these components, i.e. licenses $R_S < 0.02$ and depot costs $R_S < 0.05$. All urban methods have depot costs per round in the region of £300 whereas rural methods are approximately half this figure. The higher urban values are probably due to a larger number of bigger and better equipped depots in the town authorities than are constructed in the country districts. This would influence the depot capital charges. No details were available from authorities on depot capital costs and as explained in Appendix 7B depots are treated solely as an operating cost. Rates are also likely to be higher in towns.

7.6 TOTAL OPERATING COSTS AND SENSITIVITY TO CREW SIZE

The total operating costs vary widely for different methods. To investigate their magnitude and the relative order between them, two example comparisons are made: One for urban authorities, and the other for rural. Each comparison is for one particular size of authority and set of physical variables. The collection methods are summarised and ranked in terms of least cost in Tables 7.9(a) and 7.9(b).

In the urban comparison, Table 7.9(a) (authority area 100 Km^2 collecting 250t/round/y), kerbside bin, is the cheapest method, followed by kerbside sack, backdoor bin and backdoor skep, both of which have similar values, and finally backdoor sack which is clearly the most expensive.

In the rural comparison, Table 7.9(b) (authority area 1,000 Km^2 collecting 250t/round/y), kerbside bin is again the cheapest method, followed by kerbside sack and backdoor bin, both with similar costs, and lastly backdoor sack which again is the most expensive.

Table 7.9 COMPARISON BETWEEN COLLECTION METHOD COSTS DERIVED FROM A COMMON SET OF VALUES FOR THE PHYSICAL VARIABLES

(a) Urban Comparison

COLLECTION METHOD	URBAN			RANKINGS	
	Total Op. Cost (£) (incl. Capital Charges)	£ /Km^2 (1) ($\pm$ 95% CI)	£ /tonne (1) ($\pm$ 95% CI)	Based on this Analysis	Based on Collection Literature Survey
Kerbside Bin	5,200	52.00 (*)	20.80 (*)	1	1
Kerbside Sack	5,820	58.20 ($\pm$10.78)	23.28 ($\pm$4.31)	2	4
Backdoor Bin	5,910	59.10 ($\pm$2.94)	23.64 ($\pm$1.18)	3	3
Backdoor Skep	6,060	60.60 (*)	24.24 (*)	4	2
Backdoor Sack	6,710	67.10 ($\pm$2.38)	26.84 ($\pm$0.95)	5	5

Physical Variables:

X_{Km}	Area of Authority	100 Km^2
X_{try}	Annual Tonneage/round	250t
X_{rwv}	Rounds/week/vehicle	10
X_{nrw}	Total number of rounds/ week in Authority	100
X_{ncv}	Total number of collection vehicles in authority	20
X_m	No. of loaders - kerbside	3
	- backdoor	4

*These estimates are based on very small sample sizes and hence subject to a wide, though undefined, margin of error.

1. 95% Confidence Interval based on the total operating cost function for each collection method. (Appendix 7E)

Table 7.9 COMPARISON BETWEEN COLLECTION METHOD COSTS DERIVED FROM A COMMON SET OF VALUES FOR THE PHYSICAL VARIABLES (continued)

(b) Rural Comparison

COLLECTION METHOD	RURAL			RANKINGS	
	Total Op. Cost (£) (incl. Capital Charges)	£/Km^2 (1) ($\pm$ 95% CI)	£/tonne (1) ($\pm$ 95% CI)	Based on This Analysis	Based on Collection Literature Survey
Kerbside Bin	4,050	4.05 ($\pm$0.25)	16.20 ($\pm$0.98)	1	1
Kerbside Sack	5,430	5.43 ($\bar{*}$)	21.72 ($\bar{*}$)	2	3
Backdoor Bin	5,570	5.57 ($\pm$0.21)	22.28 ($\pm$0.84)	3	2
Backdoor Sack	6,520	6.52 ($\bar{*}$)	26.08 ($\bar{*}$)	4	4
(No analysis for backdoor skep)				-	-

Physical Variables

X_{Km}	Area of Authority	1,000 Km^2
X_{try}	Annual Tonneage/round	250t
X_{rwv}	Rounds/week/vehicle	10
X_{nrw}	Rounds/week in Authority	100
X_{ncv}	Total Number of collection vehicles in Authority	15
X_m	No. of loaders - kerbside	2
	- backdoor	3

Differences exist between the ranking of collection methods in this study and that compiled from published information in Chapter 2. In both the rural and urban operations the rankings for kerbside sack and backdoor bin are reversed (see Table 7.9). However, due to their wide 95% confidence intervals (CI) no significant difference exists between them and the ranking given to these methods is therefore only nominal. Furthermore, the costs comprising the literature-derived rankings are not on a consistent basis and are likely to contain many more generalisations and inaccuracies than the costs estimated in this work. The research-derived rankings in Table 7.9 will not apply to all possible combinations of values the physical variables could take, nor for comparisons using component costs outside the base case. Some extensions to the base case are discussed in this chapter and also Chapter 10.

In the base case it has been assumed that all kerbside or backdoor methods require the same manning level irrespective of the use of bins or sacks. Since sack methods also incur an additional operating supplies cost (i.e. purchase of sacks) they will thus always be more expensive than bin methods. Evidence suggests this is not the case in all authorities. Waste managers point out that when sack collection replace bins savings in collection time per house are achieved, providing there are no restrictive union practices. Therefore, either the number of loaders on a vehicle can be decreased, or the tonneage collected per vehicle increased (both lead to a decrease in the overall number of men and vehicles required by the authority).

The effect on the cost ranking of collection methods from changes in the base case manning levels has therefore been considered. Two illustrative analyses are presented using the same physical variables as in Table 7.9.

(i) One loader was added to the kerbside methods so as to match the backdoor manning levels; and

(ii) One loader subtracted from the backdoor methods so as to match the kerbside manning levels.

The results are summarised in Table 7.10.

Table 7.10 SENSITIVITY OF COLLECTION COST TO ONE LOADER ABOVE AND ONE BELOW THE BASE CASE

COLLECTION METHOD (2)	Base Case Ranking	1 additional loader to KERBSIDE Methods[1]		1 loader less to BACKDOOR Methods[1]	
		Ranking	Total Cost per round (£/y)	Ranking	Total Cost per round (£/y)
URBAN					
Kerbside Bin	1	1	6,000	1	5,200
Kerbside Sack	2	4	6,510	4	5,820
Backdoor Bin	3	2	5,910	2	5,220
Backdoor Skep	4	3	6,060	3	5,370
Backdoor Sack	5	5	6,710	5	6,020
RURAL					
Kerbside Bin	1	1	4,740	1	4,050
Kerbside Sack	2	3	6,120	3	5,430
Backdoor Bin	3	2	5,570	2	4,880
Backdoor Sack	4	4	6,520	4	5,830

(1) Using the same physical variables as Table 7.9.

1 loader = £6,900/y @ 10 rounds/week loader cost = £690/round.

(2) "One additional loader" (urban authorities) graphically represented in Figure 7.3
"One additional loader" (rural authorities) graphically represented in Figure 7.4
"One less loader" (urban authorities) graphically represented in Figure 7.5
"One less loader" (rural authorities) graphically represented in Figure 7.6

Fig 7.3 Base case total operating costs per round (excluding capital charges) for different sizes of URBAN authority - Sensitivity to one additional loader with each kerbside method.

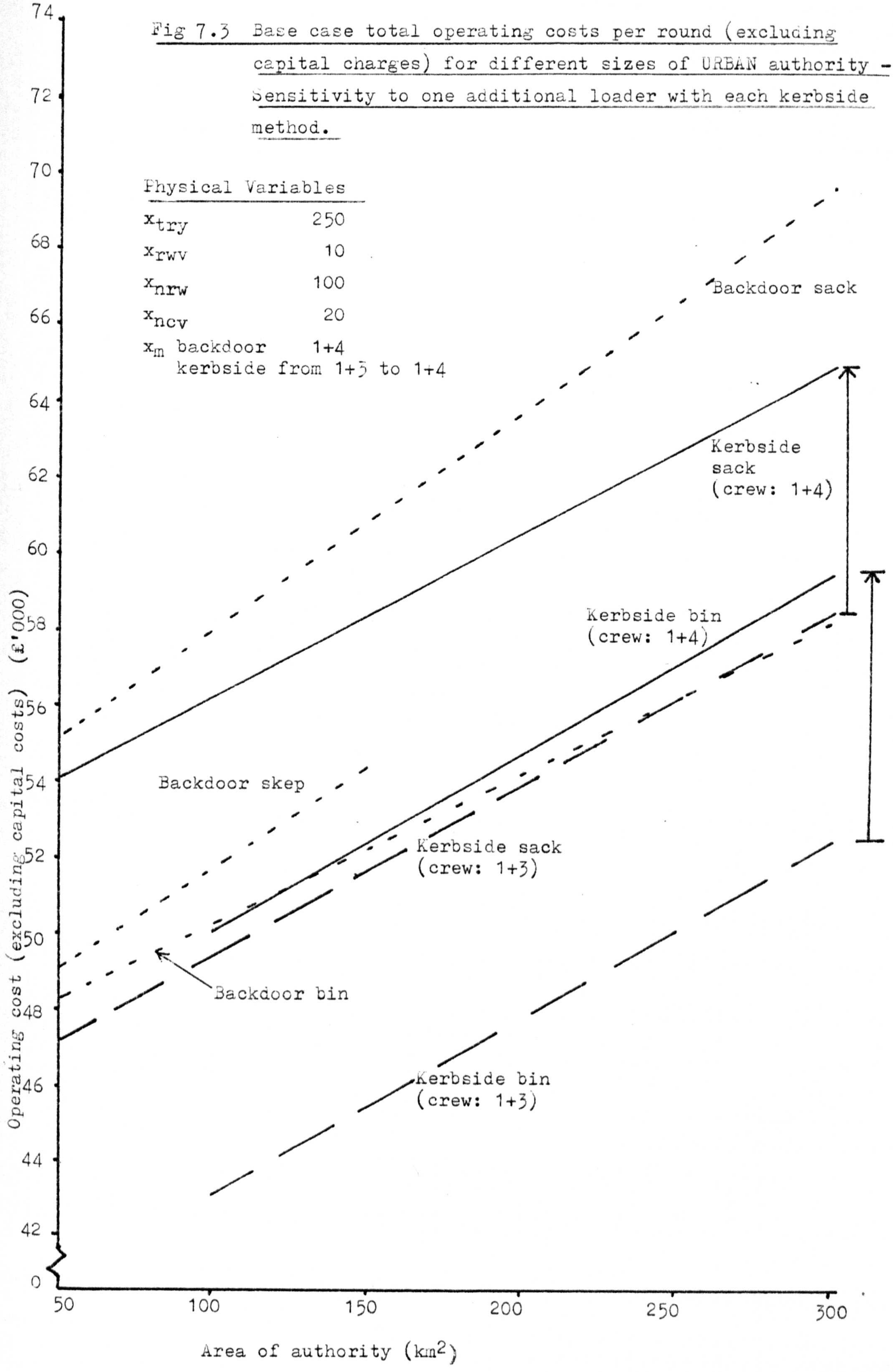


Fig 7.4 Base case total operating costs per round (excluding capital charges) for different sizes of RURAL authority - Sensitivity to one additional loader with each kerbside method.

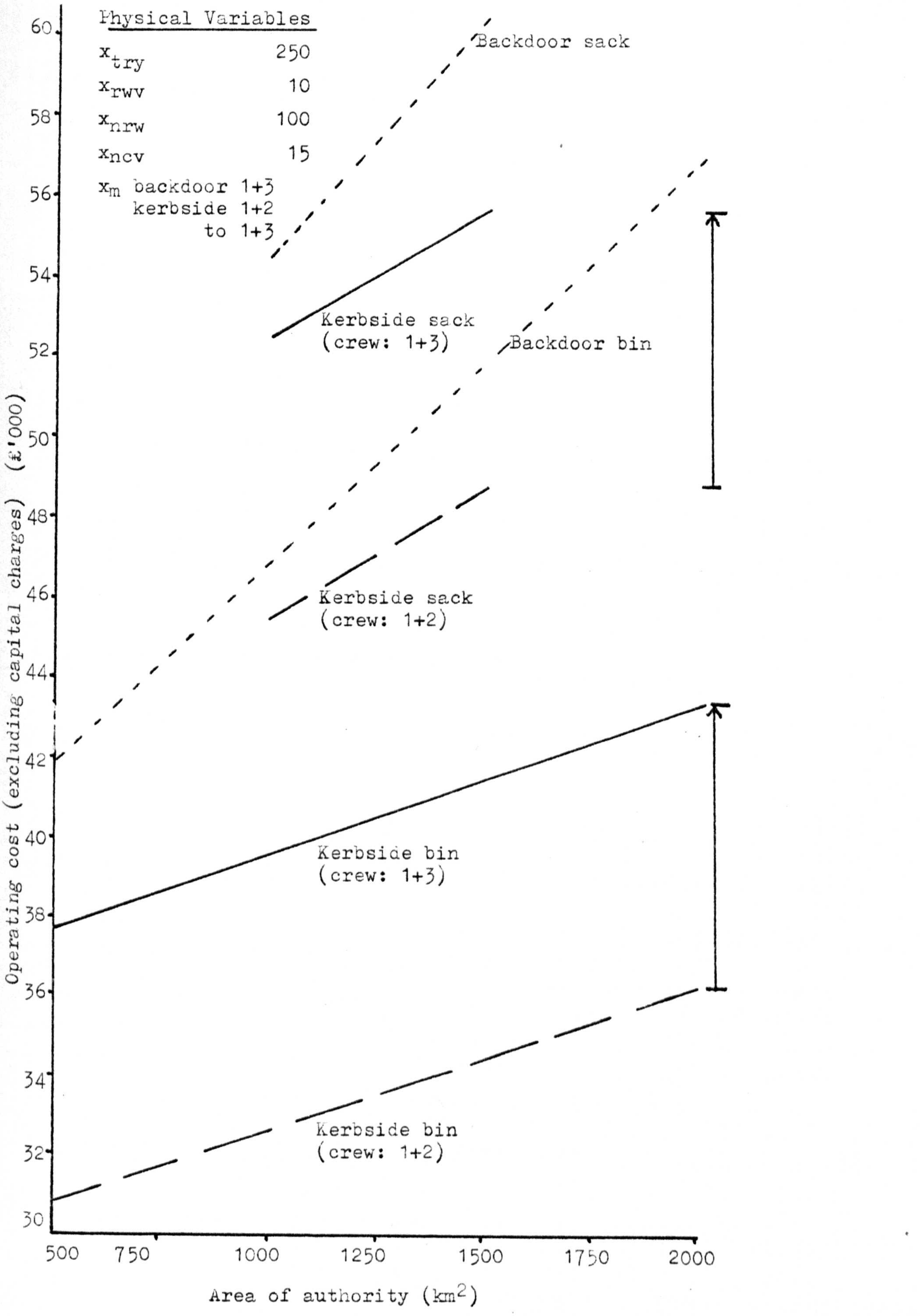


Fig 7.5 Base case total operating costs per round (excluding capital charges) for different sizes of URBAN authority - Sensitivity to one loader less with each backdoor method.

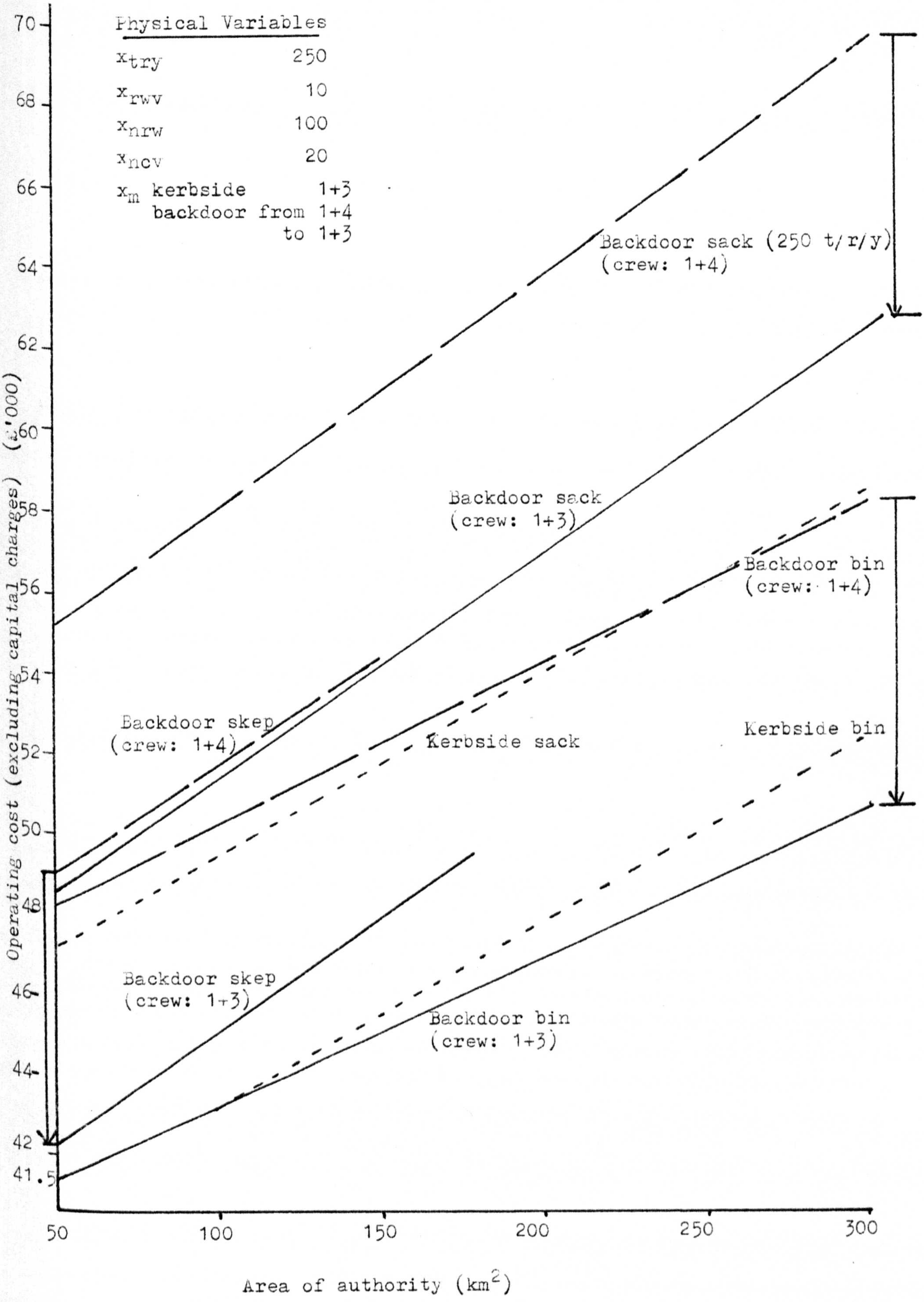
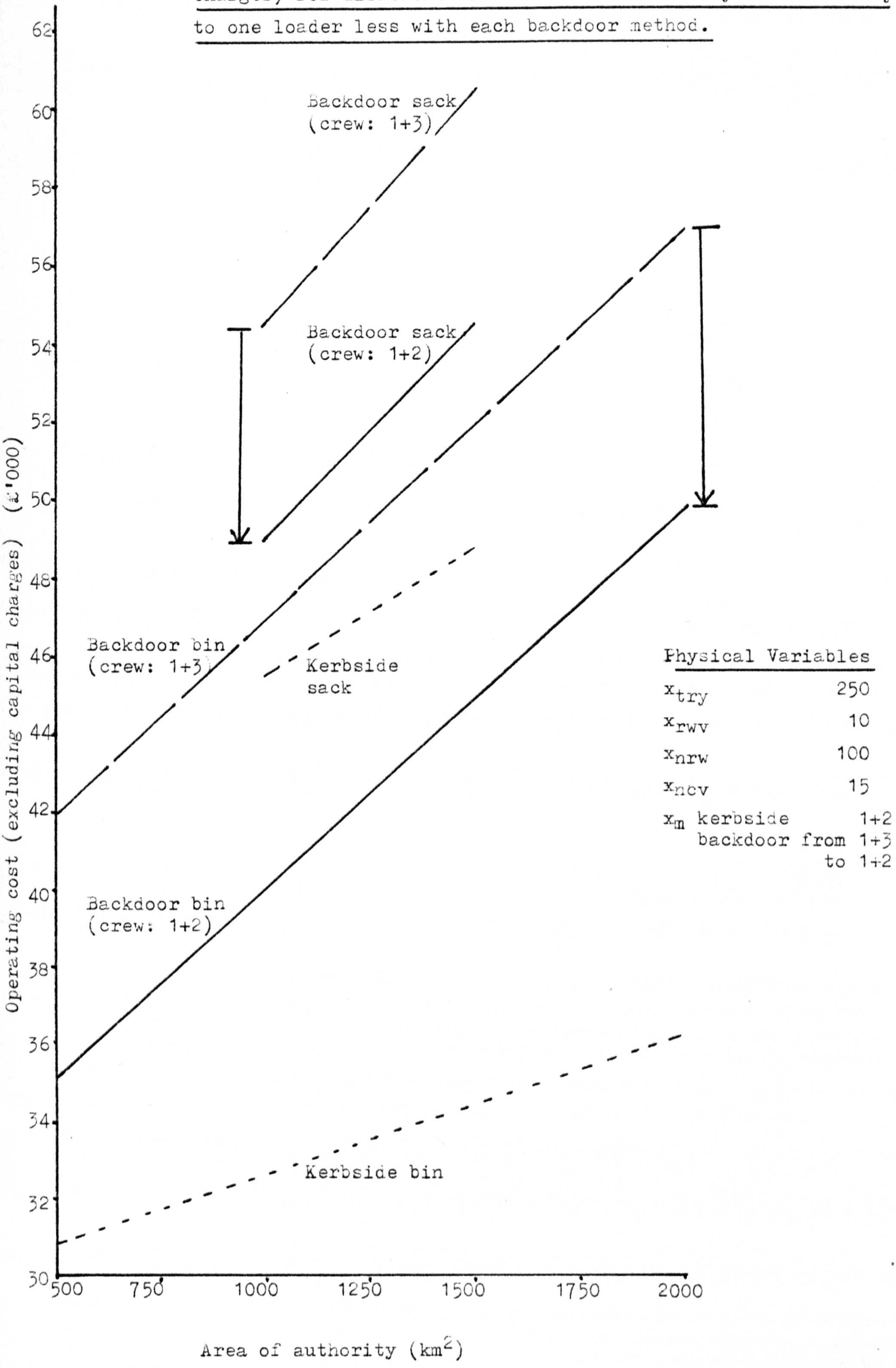


Fig 7.6 Base case total operating costs per round (excluding capital charges) for different sizes of RURAL authority - Sensitivity to one loader less with each backdoor method.



The "one additional" and "one less" rankings are identical. The cost differences are not surprising since in the first kerbside methods are increased up to the backdoor manning levels, and in the second, the backdoor methods are reduced down to the kerbside levels. The rankings however do differ from the base case order (Table 7.10).

In the above analyses kerbside bin still remains the cheapest option and backdoor sack the most expensive, but the reduction of one loader results in backdoor bin displacing kerbside sack for second position. This is an important "displacement" since the two methods are both very widely employed. Therefore on economic grounds any change by an authority from backdoor bin to kerbside sack depends critically upon achieving a reduction in manning level. Financial savings are also possible, though less likely, for backdoor bin collection. A reduction in the number of loaders will increase the tonneage handled and working day of the remaining men. Additional wages will invariably be paid to these men, reducing the savings and possibly even overturning the ranking in favour of another method (i.e. kerbside sack (rural authorities) or backdoor skep (urban authorities).

7.6.1 Sensitivity to Weekly Number of Rounds per Vehicle

Evaluation of the base case costs was based upon 10 rounds per week per vehicle (Tables 7.3 and 7.6). However, the number of rounds serviced by each vehicle will vary within an authority. A vehicle operating on rounds requiring very little travelling between each pick-up and haul to disposal point may achieve $>$ 10 rounds/week. In most authorities the maximum usually obtained, if at all, is 15 and then only by one or two vehicles.

Conversely, some vehicles achieve <10 rounds/week particularly where excessive travelling is necessary before they are filled. Five rounds/week is a practical minimum in which only one round is serviced each day.

The effect on the base case from variations in the number of rounds has consequently been considered for five and 15 rounds/week/vehicle. Combinations of one, two or three rounds/day resulting in a weekly number of rounds between 5 and 15 are also possible and while not explicitly considered here their effect on the base case cost will lie somewhere between that for 5 and 15 rounds/week/vehicle.

The component costs affected are driver, loaders, capital charges and administration, which together comprise between 61% and 88% of the total cost. Also, as identified in previous sections, the total operating costs are sensitive to the first three of these. Consequently, the potential savings or increases in total costs from varying the number of rounds per week are large (Table 7.11).

The total cost of a collection operation is therefore highly sensitive to both reductions and increases in the number of rounds serviced by a vehicle. It is noticeable in Table 7.11 that the "5 rounds" variants of each method have larger percentage increases than the "15 rounds" counterparts. This is due to the component costs in the latter being spread over a larger number of rounds and hence reducing the difference in the cost/round between it and the base case.

7.6.2 Extension of the Base Case to Account for Variations in Haul Distance to Disposal Point

The original data collected was not in a suitable form to enable the derivation of a model to explain the cost of haulage to a disposal point. Local authorities do not make a distinction in their cost accounting between collecting from properties and haulage to and discharge at the disposal point. However, implicit in a base case collection cost is a haulage cost component, the size of which would be related to the haul distance. The usual distances travelled in the urban authorities were found to be statistically similar, as were those for the rural authorities; i.e.

Table 7.11 SENSITIVITY OF TOTAL OPERATING COSTS TO VARIATIONS IN THE NUMBER OF ROUNDS/WEEK/VEHICLE

Collection Method	% over base case total operating costs[1]			
	5 rounds/week/vehicle		15 rounds/week/vehicle	
	Urban	Rural	Urban	Rural
Kerbside Bin	+ 83	+ 76	- 25	- 23
Kerbside Sack	+ 78	+ 65	- 20	- 19
Backdoor Sack	+ 68	+ 67	- 21	- 20
Backdoor Skep	+ 85	-	- 26	-
Backdoor Bin	+ 77	+ 73	- 24	- 20

1. Base case: 10 rounds/week/vehicle

Base case haul distances:

Urban authorities: mean 10.7 Km SD 7.6 Km (12 cases)

Significant from zero at 10% level
10 Km subsequently used

Rural authorities: mean 29.5 Km SD 11.0 (4 cases)

Significant from zero at 5% level
30 Km subsequently used

Many collection operations will involve haulage distances different to those implied in the base case. Suitable figures were not available from the original data in this research so instead a cost model had to be developed from independent published data. This enabled the estimation of haulage costs over a range of distances. Several models for this purpose are described in the literature, each predicting reasonably dissimilar costs per load (Figure 7.7). Consequently, their predicted values were first corrected to the base date (31 March 1981) (Table 7.12) using government statistics relating to road haulage costs, and then amalgamated and regressed to produce a "combined collection vehicle cost model". i.e.

$$y = 0.34\, x_K + 4.39$$

where y = cost/load (ie cost/return trip)

x_K = return haulage distance in Km.

The combined cost function is represented in Figure 7.8. Using this model (Table 7.13) the haulage cost per load for the urban base case distance of 10 Km is estimated as £7.79 (= 400 £/round/y). Correspondingly, the rural distance of 30 Km is £14.59 (= 760 £/round/y). These values apply to all of the collection methods considered. The combined model was also used to produce estimates for other return haul dustances (ie 0 Km to 50 Km) and are treated as increments added to or subtracted from a total operating cost.

It is pointed out that hauls over 30 Km usually apply to collection vehicles undertaking one return journey per day, unless overtime working has been specifically included in the total operating cost thereby enabling two trips to be made.

Fig 7.7 Published collection vehicle haul cost models.

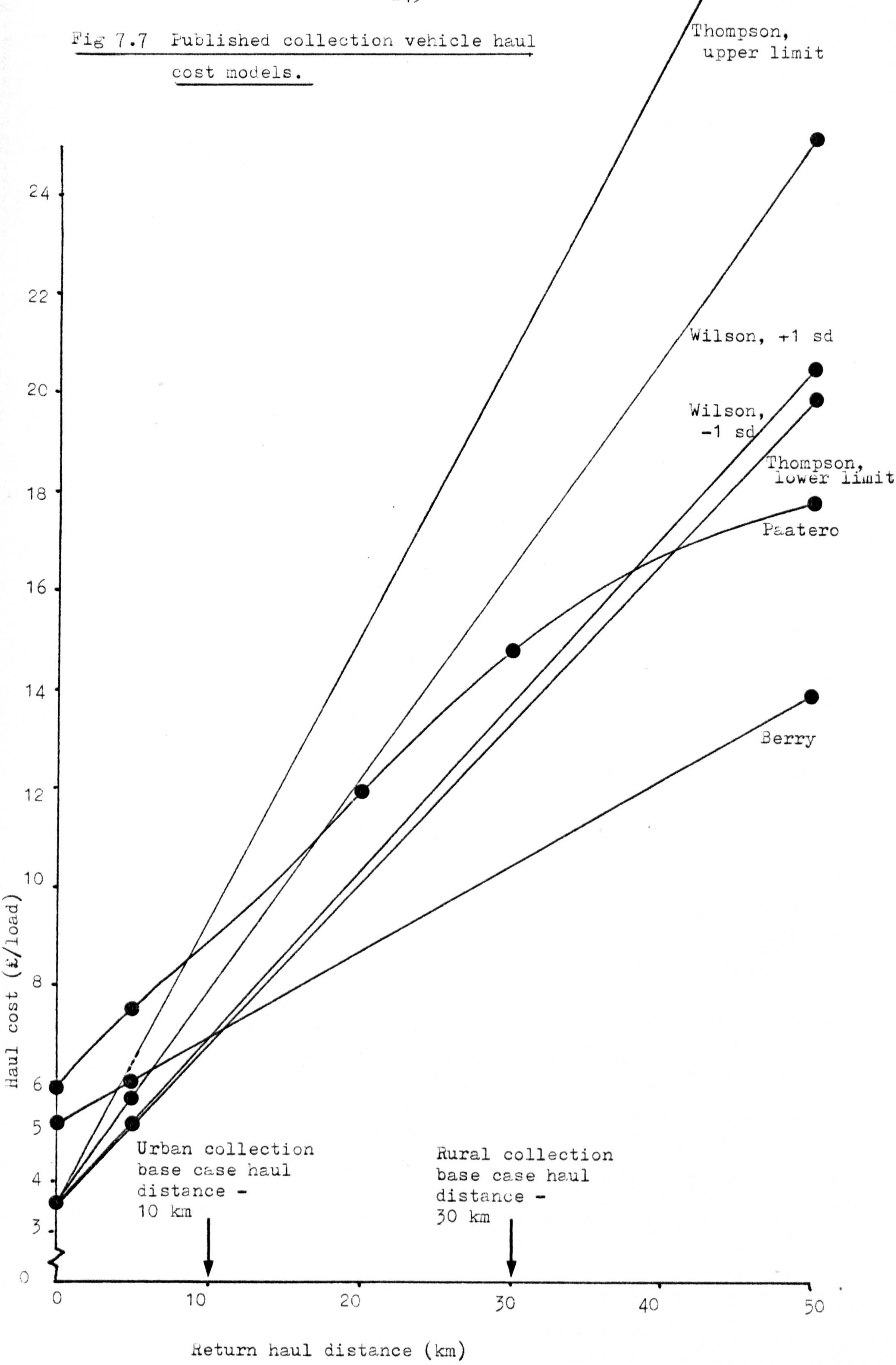


Table 7.12 HAUL COST PREDICTIONS FROM PUBLISHED MODELS

Collection Vehicle Haulage Cost Model (Updated to 1981)		Haul Cost with Distance (in Km) (£/load)						
		0	2	5	10	20	30	50
Paatero (1981) Backdoor Sack*		5.93	6.57	7.64	8.93	11.86	14.86	17.79
Berry (1976) £5.15 + £0.175/Km		5.15	5.50	6.02	6.90	8.65	10.40	13.90
Wilson (1981) 1977 values (	+1SD	3.57	4.39	5.62	7.67	11.77	15.87	24.07
£3.57 + (£0.374±0.036) Km (	-1SD	3.57	4.25	5.26	6.95	10.33	13.71	20.47
Thomson (1978) £3.57 + £0.328 Km	MAX	3.57[1]	4.73	6.47	9.36	15.15	20.94	32.52
to £3.57 + £0.579 Km	MIN	3.57[1]	4.23	5.21	6.85	10.13	13.41	19.97

1. Assumed from Wilson (1981)

* Converted from Finnish Marks: £1 = 8 Finnish marks.

Fig 7.8 A combined collection vehicle haul cost model.

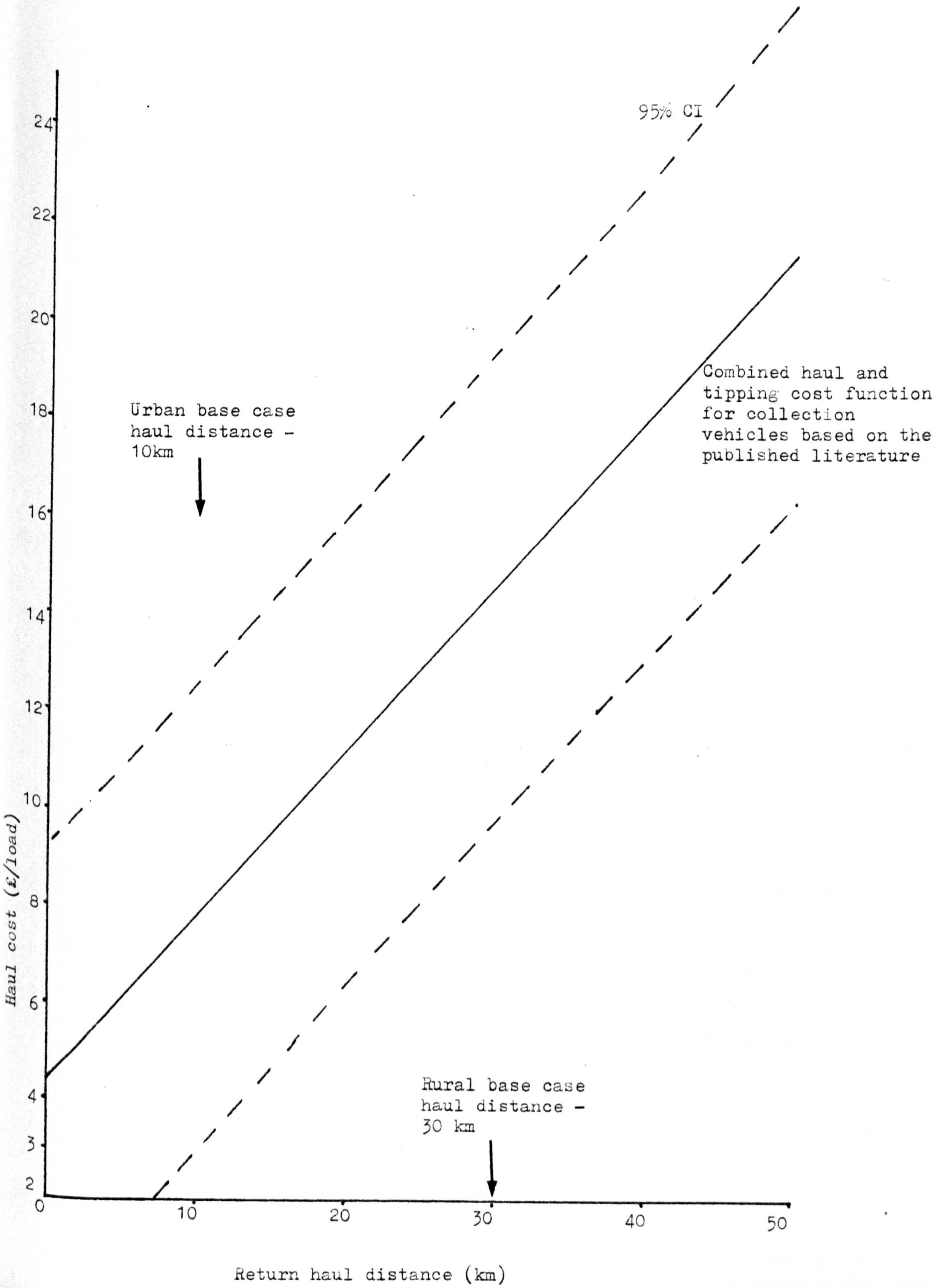


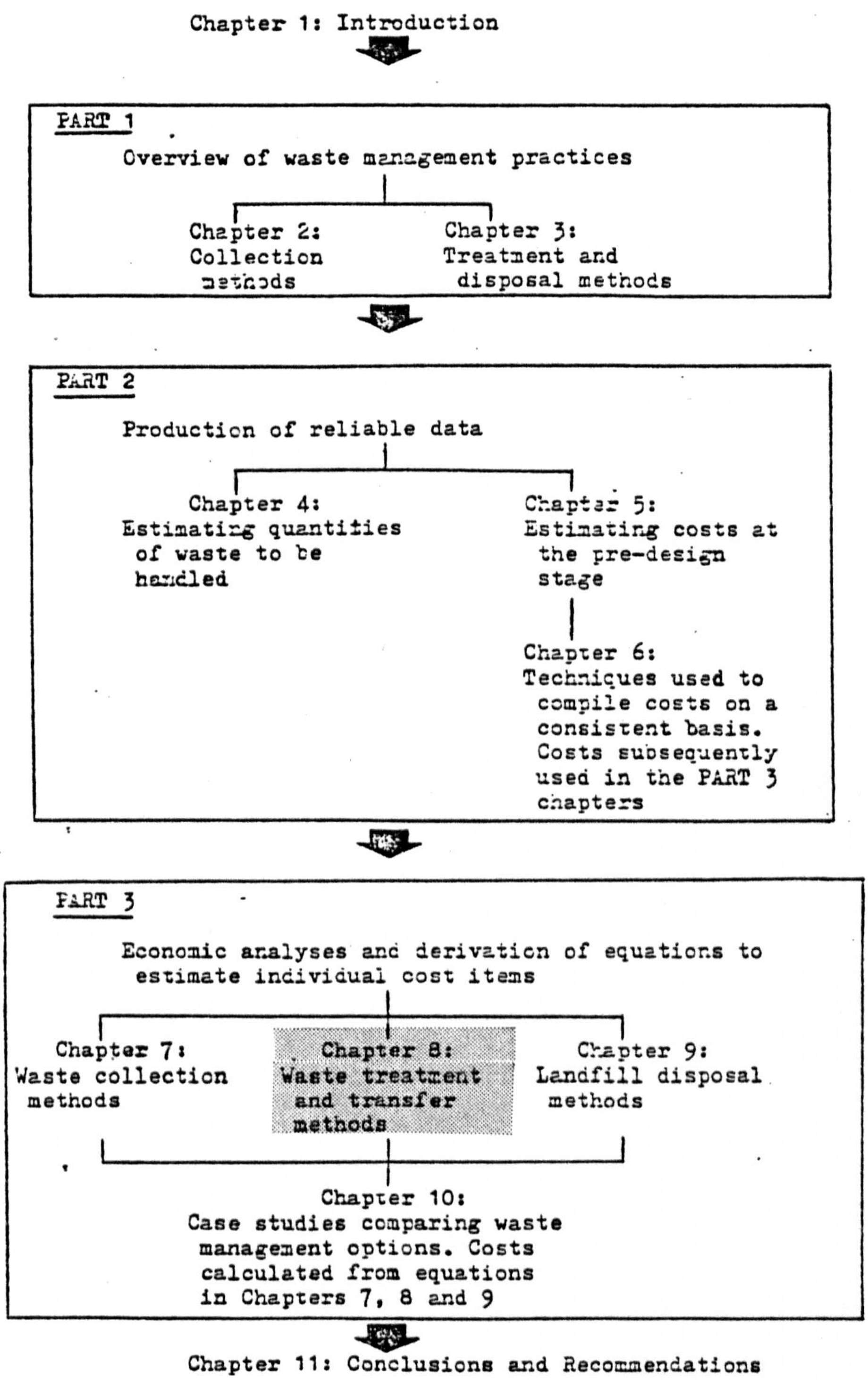
Table 7.13 HAUL COST PREDICTION FROM THE COMBINED HAUL COST MODEL

Round trip Haul Distance (Km)	0	2	5	10	20	30	50
URBAN							
Base case £/load				7.79[1]			
Base case £/round/y				(400)			
Adjustments to the Base Case £/load	-3.40	-2.72	-1.70[2]	-	+3.40	+6.80	+13.80
Adjustments to the Base Case £/round/y	(-180)	(-140)	(-90)	-	(+180)	(+350)	(+710)
RURAL							
Base case £/load						14.59[1]	
Base case £/round/y						(760)	
Adjustments to the Base Case £/load	-10.20	-9.52	-8.50	-6.80	-3.40	-	+6.80
Adjustments to the Base Case £/round/y	(-530)	(-500)	(-440)	(-350)	(-180)	-	(+350)

1. Base case haul distances.
2. Sample calculation: URBAN 0.34 x 5Km + 4.39 = 6.09 - 7.79 = cost saving of £ 1.70/load (ie, - £1.70 x 52 ≃ -90 £/round/y)

CHAPTER 8

ECONOMICS OF WASTE TRANSFER, TREATMENT and BULK TRANSPORT



Chapter 8

8.1 INTRODUCTION

In many places suitable landfills are only available at considerable distances from the principal areas of waste generation. Haulage of refuse to these in collection vehicles is expensive due primarily to their small payloads and the excessive time lost away from collecting refuse while the crew travels to and from the landfill. In these situations transfer stations are a practical solution. They enable the refuse to be transferred from the collection vehicles to higher payload, more economic, bulk transporters. A transfer station also enables the collection operation to deliver refuse to a central, permanent location thereby eliminating the need to reorganise collection rounds each time a new landfill site is opened.

A detailed discussion on the technical aspects of alternative methods of refuse transfer formed part of Chapter 3, though broadly to recap, there are two categories of transfer operation: "compaction transfer" where refuse is loaded into bulk containers by stationary compactors; and "treatment transfer" where refuse is physically altered by either shredding or baling prior to loading onto bulk transporters.

In this chapter an estimation of preliminary design costs and a review of the economics of six transfer methods has been undertaken:

Compaction transfer
- compaction without storage
- compaction with apron storage
- compaction with bunker storage

Treatment transfer
- dry pulverisation (apron storage assumed)
- wet pulverisation (apron storage assumed)
- wire-tied baling (apron storage assumed)

A transfer operation is considered here to incorporate all the activities involved after refuse is discharged from the collection vehicle until it is loaded into the bulk transporter.

A set of cost functions has been established for the individual capital and operating costs of each method of transfer. This chapter firstly contrasts and compares these preliminary design costs, and then secondly, reviews the effects on them from variations to the base case assumptions (defined in Chapter 6). Later sections describe bulk transport cost models developed from the published literature for seven types of road vehicle; i.e.

Rigid chassis vehicles	10t carrying capacity
	16t carrying capacity
Articulated vehicles	12t carrying capacity - covered trailers
	14t carrying capacity - covered trailers
	16t carrying capacity - covered trailers
	16t carrying capacity - flatbed trailers
	22t carrying capacity - covered trailers

Bulk transport by rail or barge is not examined in this work due to the very small number of operations in the UK and an absence of suitable data.

8.2 EVALUATION OF THE TRANSFER COST MODELS

The economics of transfer are presented for several sizes of operation and expressed in terms of the daily tonneage handled. Several appendices accompany this Chapter providing further details on the original costs collected from local authorities and stages in the economic analyses performed upon them to produce consistent, base case costs.
For additional information on a particular part of the economic discussion (when not specifically cited in the text) reference can be made to the relevant Appendix:

Appendix 8.A	Original Data
Appendix 8.B	Descriptive Derivation of each First and Second Reduction Component Cost
Appendix 8.C	First Reduction Costs and Corresponding R^2 values
Appendix 8.D	Second Reduction Costs and Corresponding R^2 values
Appendix 8.E	Base Case Capital and Operating Cost Functions (all methods)
Appendix 8.F	Base Case Capital and Operating Costs (all methods)
Appendix 8.G	Base Case Percentage Values (all methods)
Appendix 8.H	Base Case Relative Sensitivities (all methods)

The total cost functions derived for each transfer method are summarised for capital costs in Table 8.1, and for operating costs in Table 8.2. The derivation of these as well as those for each individual component cost are detailed in Appendix 8.E. It is interesting to note from the graphical plots of the total cost functions (Figures 8.1 and 8.2) that even when bulk transport and subsequent landfill costs are excluded all transfer methods remain more expensive than direct landfill where short haul distances are incurred. Furthermore, these higher costs are not offset by cheaper landfilling operations (Section 9.5) despite the claims of manufacturers.

As mentioned above several component expenditures were studied for each method and were collectively used to derive the total capital and operating costs. These components are:

Capital cost components:

Site Survey
Transfer Equipment
Ancillary Equipment
Buildings and Civil Engineering, Bunker construction
Site Vehicles, Crane or conveyor handling equipment
Slave Vehicles
Other preparation costs

Table 8.1 CAPITAL COST FUNCTIONS FOR EACH TRANSFER METHOD AND THEIR RANGES OF VALIDITY

Transfer Method	Total Capital Cost Function[3]	Extended cost function	Ranges over which cost functions valid (t/d)	R^2 value (from App. 8D)
Compaction without Storage	$y = 2393\ X_D + 20000$)		20-200 Extension in brackets using some published data[1] (20-500)	0.98)
Compaction with Apron storage	$y = 2406\ X_D + 54000$)	($y = 3889\ X_D^{0.9}$)		0.98) 0.7
Compaction with Bunker storage	$y = 4177\ X_D + 179000$)			0.98)
Baling	$y = 11698\ X_D - 604000$		75-300	0.94
Dry Pulverisation	$y = 3418\ X_D + 256000$		20-340 (20-600)[2]	0.94
Wet Pulverisation	$y = 7146\ X_D + 672000$		20-600	0.99

X_D - Daily Tonneage handled.

y - Cost in 1981£.

1. Additional capital costs updated to base date taken from Wilson (1981). The extended equation is for general guidance only and will be only very broadly representative of all compaction variants.

2. Arbitarily extrapolated up to 600t/d to match operating cost range.

3. Graphically represented in Figure 8.1.

Table 8.2 OPERATING COST FUNCTIONS FOR EACH TRANSFER METHOD AND THEIR RANGES OF VALIDITY

Transfer Method	Total Operating Cost Function[2]		Ranges over which cost functions valid (t/d)	R^2 value (from App. 8D)
Compaction without Storage	$y = 272\ X_D + 23000$		20 - 200	0.90
Compaction with Apron storage	$y = 295\ X_D + 36000$		20 - 200	0.90
Compaction with Bunker storage	$y = 361\ X_D + 31000$		20 - 200	0.90
Baling	$y = 786\ X_D + 26000$		75 - 320	0.97
Dry Pulverisation	$y = 7340\ X_D^{0.62}$		20 - 600	0.98
Wet Pulverisation	$y = 600\ X_D + 28000$		20 - 250 (20 - 600)[1]	0.98

1. Arbitarily extrapolated up to 600t/d to match capital cost range.
2. Graphically represented in Figure 8.2.

X_D - **Daily tonneage handled**

y - **Cost in 1981£**

Fig 8.1 Base case total capital cost functions - Direct landfill and transfer methods (excluding bulk transport and subsequent landfill capital costs).

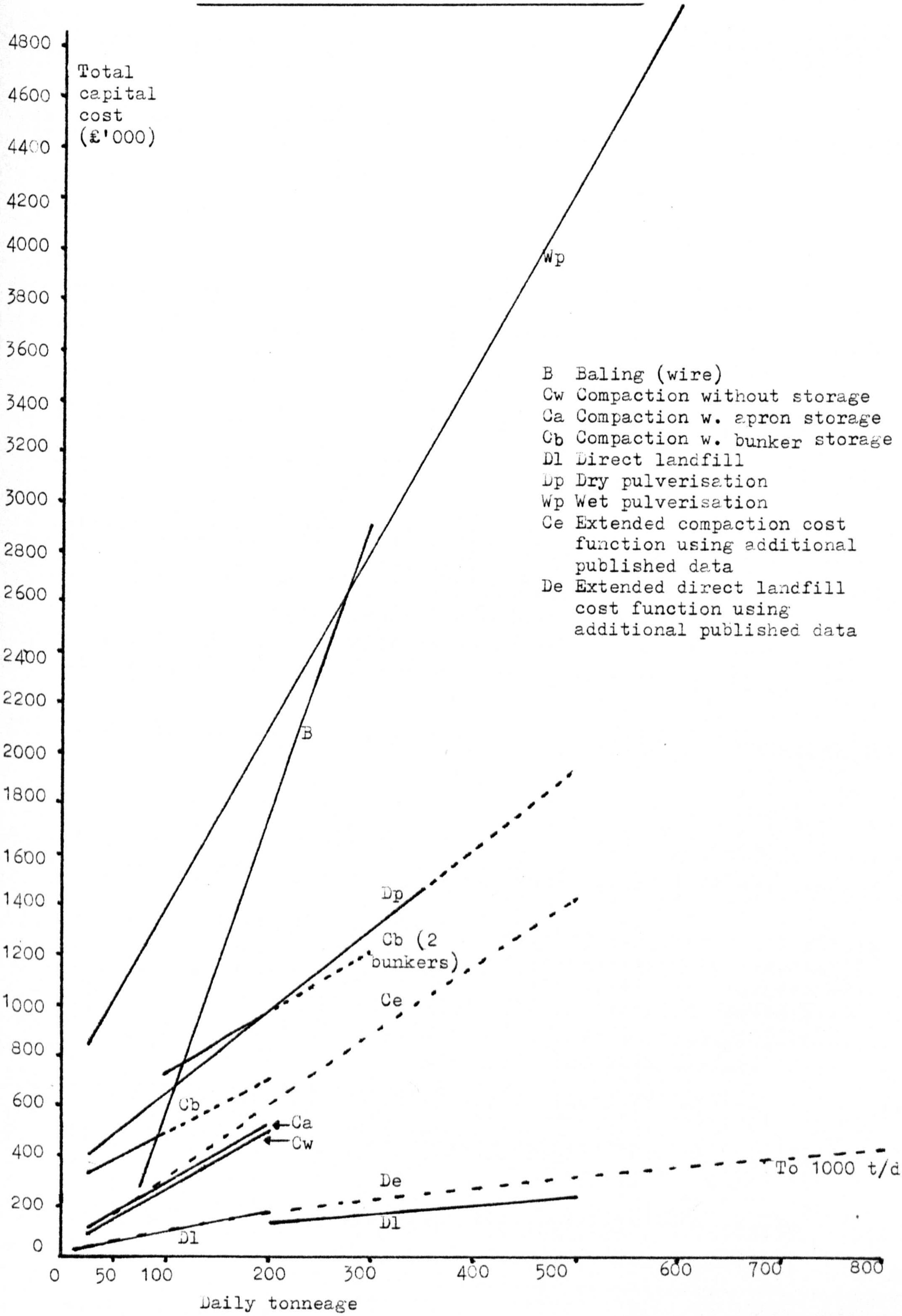
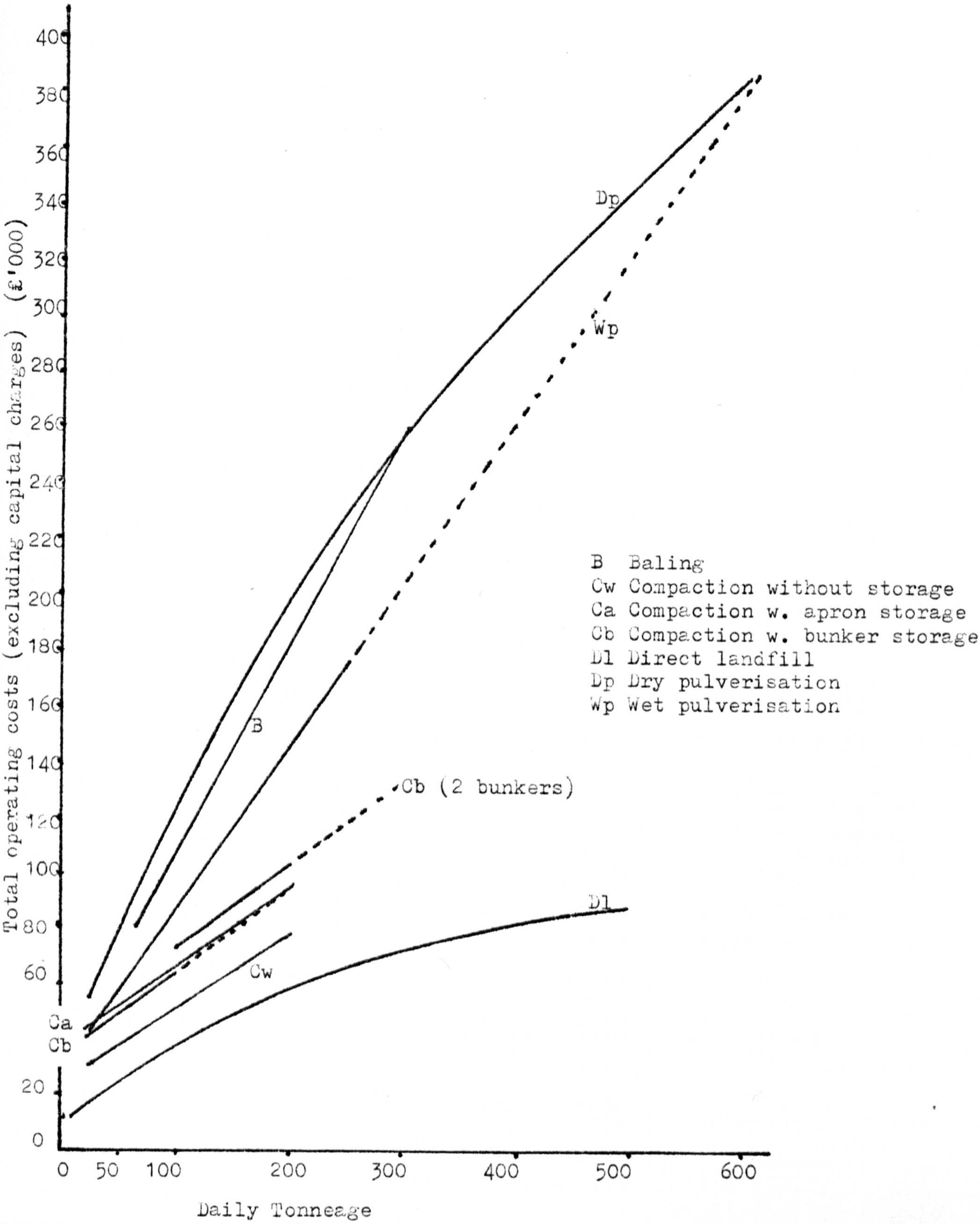


Fig 8.2 Base case total operating cost functions (excluding capital charges) - Direct landfill and transfer methods (excluding bulk transport and subsequent landfill operating costs).



Operating cost components:

Transfer Equipment Maintenance
Site Vehicle - Fuel, Maintenance Labour, Spares, Tyres, Licences and Insurance
Slave Vehicle Running Costs
Electricity
Manual Labour
Supervisory Labour
Materials, Baling Wire
Services
Building Maintenance
Site Rent
Site Rates
Departmental Administration

(A full definition of the items included under each of these component costs is given in Appendix 6.A).

8.3 CAPITAL COSTS AND AMORTISATION DISCUSSION

For selected sizes of transfer station the component and total costs were calculated from their base case cost functions. The costs for all transfer methods are presented in Appendix 8.F and as an example the set of costs for one method are reproduced in Table 8.3. The percentage values and relative sensitivities for all component costs are detailed in Appendices 8.G and 8.H respectively.

8.3.1 Principal Findings

1. Treatment transfer methods are more expensive than compaction transfer. At, for example, a 100t/d transfer station the total capital cost ranking is (Table 8.4):

   Compaction without storage
   Compaction with apron storage
   Compaction with bunker storage
   Dry pulverisation
   Wire-tied baling
   Wet pulverisation

   (Cost increasing in descending order).

Table 8.3 *Example of the Base Case Capital Costs for one Transfer Method* (1981£)

BASE CASE COSTS AT SELECTED DAILY TONNEAGES FOR LANDFILL-RELATED DISPOSAL METHODS

COMPACTION TRANSFER WITH APRON STORAGE

CAPITAL COSTS (RANGE 25 TO 200 TONNES PER DAY)

T/D	25.	30.	40.	50.	60.	70.	80.	90.	100.	125.	150.	175.	200.
RATED CAP	5.	5.	11.	11.	11.	11.	11.	15.	15.	16.	22.	22.	30.
SURVEY	7283.0	8093.0	9713.0	11333.0	12953.0	14573.0	16193.0	17813.0	19433.0	23463.0	27533.0	31583.0	35633.0
BUILDINGS	32131.0	40586.0	57496.0	74406.0	91316.0	108226.0	125136.0	142046.0	158956.0	201231.0	243506.0	285781.0	328056.0
PREPARE	7411.1	7588.9	7678.1	8110.0	8304.5	8472.6	8620.9	8754.0	8674.7	9135.9	9355.0	9544.4	9711.5
COMPACTOR	22610.0	22610.0	39992.0	39992.0	39992.0	39992.0	39992.0	51580.0	51580.0	54477.0	71859.0	71859.0	95035.0
ANCILLARY	15000.0	15000.0	15000.0	15000.0	15000.0	15000.0	15000.0	15000.0	15000.0	30000.0	30000.0	30000.0	30000.0
MOBILE PT	30000.0	30000.0	30000.0	30000.0	30000.0	30000.0	40000.0	40000.0	40000.0	40000.0	40000.0	50000.0	50000.0
SUM.TOTAL	114435.1	123877.9	160079.1	178841.0	197565.5	216263.6	248941.9	275193.0	293683.7	358326.9	422253.0	478767.4	548435.5

CAPITAL COSTS AMORTISED OVER 10Y AT 14%PA - COMPACTION AND ANCILLARY EQUIPMENT
" " " " 20Y AT 14%PA - BUILDINGS AND SITE PREPARATIONS
" " " " 5Y AT 14%PA - MOBILE PLANT

(Information on the other transfer methods is presented in Appendix 8F)

Table 8.4 TOTAL BASE CASE CAPITAL COST AND ERROR MARGIN FOR EACH TRANSFER METHOD AT A 100t/d TRANSFER STATION

Transfer Method	Total Capital Cost for a 100t/d Operation (£)	95% CI[1] (± £)	Source (App 8F) page nos.
Compaction without storage	255,000	± 60,000	231
Compaction with Apron storage	294,000	± 60,000[2]	233
Compaction with Bunker storage	500,000	± 60,000[2]	235
Dry Pulverisation	592,000	± 280,000	237
Wire-tied Baling	712,000	± 450,000	241
Wet Pulverisation	1,410,000	± 200,000	239

1. Derived from the confidence interval of each transfer method's total capital cost function. Individual capital cost functions with their confidence intervals are plotted in Appendix 8.E.

2. These total cost functions are heavily dependent upon the compaction without storage component costs. No separate confidence interval is calculated therefore the "without storage" value is used for general indication only.

2. The two largest capital expenditures are building costs and transfer equipment costs, which together account for between 48% and 85% of the total costs.

3. Compaction with bunker storage is the one exception to (2) above where buildings and bunker construction are the two larger costs.

4. Other large cost components at small transfer stations are mobile plant (in compaction with apron storage operations) and ancillary equipment (in compaction without storage plants).

5. The total costs are most sensitive to the largest two components i.e. buildings and transfer equipment, and also bunker construction in bunker storage operations.

6. All other component costs are comparatively minor and correspondingly the total costs are relatively insensitive to them.

8.3.2 Building and Transfer Equipment Costs

These, as described above, are the largest two expenditures in all but one of the transfer methods (Table 8.5). Consequently, it is not surprising that the total costs are also highly sensitive to them.

For example Compaction without Storage 100t/d (R_s = 0.537)

Building and Civils

A 25% increase in building cost produces
a 14% increase in total capital cost

Wet Pulverisation 200t/d (R_s = 0.310)

Transfer Equipment

A 25% increase in transfer equipment produces
an 8.0% increase in total capital cost.

Table 8.5 COMBINED PERCENTAGES FOR BUILDING AND TRANSFER EQUIPMENT CAPITAL COSTS

Transfer Method	Building Cost (%)	Transfer Equipment (%)	Combined (% of total cost)
Compaction without storage	37 - 63[1]	28 - 22[1]	65 - 85[1]
Compaction with apron storage	28 - 60	20 - 17	48 - 77
Compaction with bunker storage	10 - 33	62 - 41[2]	72 - 74
Wire-tied Baling	52 - 60	28 - 13	80 - 73
Dry Pulverisation	45 - 72	23 - 9	68 - 81
Wet Pulverisation .	31 - 60	51 - 25	82 - 85

1. % values for a range of sizes and operation (smallest operation - largest operation). Ranges given in Table 8.1.

2. Building costs and bunker construction costs are the two largest capital expenditures with this method.

8.3.3 Mobile Plant Costs in Smaller Transfer Stations

Mobile plant accounts for 26% of the total cost at smaller apron storage compactor stations, declining to 9% as the tonneage handled increases. At these small stations (i.e. $<$ 100t/d) the total cost is reasonably sensitive to this expenditure, a particularly useful observation since there are many stations about this size in operation.

For example Compaction with Apron Storage

(R_s = 0.236) At 30t/d a 25% increase in mobile plant cost produces a 6% increase in total capital cost (total cost is reasonably sensitive)

(R_s = 0.094) At 150t/d a 25% increase in mobile plant cost produces a 2.4% increase in total capital cost (total cost is insensitive)

8.3.4 Ancillary Equipment Costs in Smaller Transfer Stations

Ancillary equipment costs at smaller compaction without storage stations represents 18% of the total costs, half the expenditure for the compactor itself. In the larger stations however this is reduced to about 6%, less than one-third that of the compaction machinery. Consequently at smaller stations ($<$ 100t/d) the "without storage"total cost is reasonably sensitive to this expenditure and it is therefore important to consider it carefully in these situations.

For example Compaction without storage

(R_s = 0.185) At 25t/d a 25% increase in ancillary equipment cost produces a 4.7% increase in total capital cost. (Total cost is reasonably sensitive)

(R_s = 0.083) At 150t/d a 25% increase in ancillary equipment cost produces a 2.1% increase in total capital cost (Total cost is insensitive)

8.3.5 Compaction Transfer Discussion: Capital Costs

Compaction transfer without storage is demonstrated to be the cheapest transfer option in Figure 8.1 and Appendix 8.F. The philosophy behind no storage before transferal requires an over-capacity of compacting equipment to cope with peak delivery rates and down-time. If a collection vehicle must wait for a long time before it discharges, this can undermine the economic argument for transfer rather than direct haul. The capital costs of a "without storage" site are lower than that required for the additional building space and handling equipment of a "with storage" operation. The GLC at its Hendon transfer station use compaction without storage, an operation requiring ten compactors working over two shifts to deal with the daily peaks and a total load of around 800 t/d. If front-end storage had been employed the number of machines necessary could be reduced by two or three. Technically, "without storage" employs rear-end storage, i.e. in the bulk containers. The costs of the extra containers required is not reflected in the transfer cost presented here, they should however be included in the bulk transport capital costs which are discussed later in Section 8.6.3.

Apron storage is the most popular storage method, the provision of a large open reception hall and a loading shovel to handle the discharged refuse is easier to maintain and easier to substitute should the vehicle breakdown than bunker storage. Bunkers at transfer stations are primarily a legacy of incineration and sites operating this form of storage are frequently converted incinerator plants, e.g. Whetstone in Leicestershire. Refuse handled by grab crane is slow compared with apron storage and in-bunker conveyor systems are prone to jamming. Furthermore, the cost of bunker construction is the principal component contributing to bunker storage being more expensive than apron storage; e.g.

<u>200t/d operation</u>

Bunker storage	- Bunker construction cost ≃ £400K		
	- Total capital cost	≃	£980K
Apron storage	- Total capital cost	≃	£550K
		Δ	£430K

Bunker storage is the most expensive compaction option at all sizes of operation and around 30t/d and 100-150t/d the capital cost is similar to that for wire-tied baling and dry pulverisation respectively.

Detailed capital costs have only been obtained for compaction transfer stations handling up to 200t/d. Additional information from the literature, updated to the base date, has enabled capital costs to be determined for plants up to 500t/d. The estimates between 200 and 500t/d however are not considered as reliable as those below 200t/d, since they represent both with and without storage methods and some of the published data may not conform with the base case. The general conclusions from this extended function is that compaction costs become markedly lower than treatment transfer as the tonneage handled rises; e.g.

<u>500t/d operation</u>	
Compaction Transfer	≃ £1,425K
Dry Pulverisation	≃ £1,930K
Wet Pulverisation	≃ £2,880K

(Outside the cost range for wire-tied baling)

No published information is available on the economies of scale for component capital costs, however this work has established that up to 200t/d all of the component costs are reasonably linear except for site preparation which from an empirical derivation (described in Appendix 8.B) gave a scale factor of 0.13. No economy of scale was identified for the total capital costs of the three compaction alternatives up to 200t/d and it is suspected that the range of plant sizes may be too small to show up any economies. The extended combined total cost function (up to 500t/d) did produce a small economy of scale (0.92). This compares favourably with the Midwest Research Institute (1973) factor of 0.93 based on US data, and that of Wilson (1981), 0.85 based on empirical data.

8.3.6 Treatment Transfer Discussion: Capital Costs

The use of sophisticated transfer machinery and ancillary equipment, and the more extensive site planning and buildings required together result in treatment transfer being more expensive than compaction (Figure 8.1). Authorities adopting a treatment method invariably claim the improved "refuse product" is worth the extra expense and enables closer landfills to be used than would be possible with untreated refuse. The financial implications of these arguments are explored in Chapter 10.

Wet pulverisation is the most costly of the treatment alternatives, due primarily to the high cost of the drum pulveriser.
At larger stations (e.g. 300t/d) the wet pulveriser equipment is around seven times more expensive than a dry pulveriser (hammermill), a finding supported by Marsden (1973). These results also clarify the work by Wilson (1981). He took the mean of the capital costs for several UK pulveriser plants and found any differences in cost between wet and dry pulverisation are swamped by other variations. To obtain his mean values the costs for each plant were mathematically inflated to a base year (1977) in some cases by as much as ten years and corrected to a particular size of plant (300t/d). In addition to the systematic errors inherent in these adjustments he combined together plants of different designs and operational standards so further compounding the inaccuracies.

This work, by studying the individual component costs in detail over a relatively short time base (no costs were considered over five years before the base date - 1981) and reducing them on to a base case, has sought to minimise systematic errors from this source. Consequently more reliable capital cost estimates are produced.

In defence of their high capital cost wet pulveriser manufacturers claim that the operating costs of this equipment are considerably lower than dry pulverisers. Their claim is not supported by this work (see Section 8.4.4); i.e.

200t/d operation

	Dry Pulverisation (Hammermills)	Wet Pulverisation (Rotary drum)
Total capital cost (£)	902K	2,119K
Total operating cost (£/y)	318K	488K

Small wire-tied baling operations (eg 50t/d) are marginally less expensive than compaction with bunker storage, whereas at around 100t/d baling is above dry pulverisation and finally superceding wet pulverisation at approximately 300t/d as requiring the largest investment (Figure 8.1); i.e.

	50t/d	100t/d	300t/d
Wire-tied baling (£)	≃ 350K	≃ 710K	≃ 2,910K
Compaction with bunker storage (£)	≃ 390K		
Dry pulverisation (£)		≃ 590K	
Wet pulverisation (£)			≃ 2,880K

Above 300t/d self-sustaining balers are usually employed, and as only a small number of these are in use in the U.K. it proved impossible to obtain sufficient economic data on them for financial analysis.

A similar situation exists for treatment transfer as discovered for the compaction methods, no information exists on the economy of scale for component costs. This work therefore probably provides the first scale factors to be derived (Table 8.6).

No economies of scale were identified for the total capital costs of any of the treatment methods. Conversely, published figures indicate small to moderate economies of scale. In this work data has only been obtained for authorities operating plants up to 300t/d for baling and dry pulverisation, it is possible the literature values in Table 8.6 are applicable over a wider range. The absence of economies of scale in the total costs is argued to be realistic, since they are strongly influenced by the two largest component costs, buildings and treatment equipment. Neither of which exhibit an economy of scale. Furthermore, the bases of estimation of the published values are not relevant to waste management. The pulverisation factors from Bridgwater (1977), and Parkinson and Mular (1972) are only strictly applicable to rock crushing equipment. That from Wilson (1981) is based on empirical data and likely to contain inherent inaccuracies. The only other factor, produced by Guthrie (1969) is 0.85. This is the largest of those published and the

Table 8.6 TREATMENT TRANSFER CAPITAL COST SCALE FACTORS

Component Cost	This Work	Wilson (1981)	Bridgwater (1977)	Parkinson and Mular (1972)	Guthrie (1969)
PULVERISATION					
Ancillary Equipment (Dry)	0.41[3]				
Ancillary Equipment (Wet)					
Other Prep. Costs (Dry)) (Wet))	0.13[4]				
TOTAL CAPITAL COSTS (Dry)) (Wet))	1.00[4]	0.80	0.67[1)] 0.80	0.67[2]	0.85
WIRE-TIED BALING					
Other Prep. Costs	0.13[4]				
TOTAL CAPITAL COSTS	1.00[4]	0.90			

1. Taken from Parkinson and Mular (1972). See Note (2).
2. Scale factor refers to rock crushing hammermills and not derived directly from mills handling domestic refuse.
3. Scale factor for rated capacity (t/hr).
4, Scale factor for daily tonneage (t/d).

The only published baling scale factor is that from Wilson. He assumed a factor of 0.90 from limited empirical data, again this approach is likely to contain many inaccuracies but in spite of this it agrees reasonably well with the factor of 1.00 obtained in this research.

8.3.7 Amortisation Charges

Since each option involves the use of different equipment the capital charges inevitably vary, with the more capital intensive, treatment methods incurring the larger charges. These charges represent the largest operating cost at between 30% and 58% of the total operating cost for compaction methods and between 43% and 76% for the treatment options (Table 8.7). Not surprisingly the total operating costs are highly sensitive to this component.

For example Compaction without storage, 100t/d (R_s = 0.427)

A 25% increase in capital charges represents an 11% increase in total capital cost.

Wet pulverisation 300t/d (R_s = 0.647)

A 25% increase in capital charges represents a 17% increase in total capital cost.

8.4 OPERATING COSTS DISCUSSION

The component and total costs for each transfer method were calculated using the base case cost functions as detailed in Appendix 8.E. An example set of costs for one method are reproduced in Table 8.8 and full information on all methods is given in Appengix 8.F. The percentage values and relative sensitivities discussed throughout this section are fully documented in Appendices 8.G and 8.H respectively.

Table 8.7 COMBINED PERCENTAGES FOR CAPITAL CHARGES AND LABOUR OPERATING COSTS

Transfer Method	Capital Charges (%)	All Labour (%)	Combined (% of total cost)
Compaction without storage	30 - 48[1]	33 - 23[1]	63 - 71[1]
Compaction with apron storage	34 - 48	21 - 18	55 - 66
Compaction with bunker storage	54 - 58	15 - 14	69 - 72
Wire-tied Baling	43 - 65	20 - 9	63 - 74
Dry Pulverisation	51 - 47	13 - 16	64 - 63
Wet Pulverisation	76 - 68	7 - 7	83 - 75

1. % values for a range of sizes of operation (smallest operation - largest operation).
   Ranges given in Table 8.2

Table 8.8 Example of the Base Case Operating Costs for one Transfer Method (1981£)

Compaction with Apron Storage

T/O	25.	30.	40.	50.	60.	70.	80.	90.	100.	125.	150.	175.	200.
COMPCT MT	1283.9	1416.0	1682.0	1948.0	2214.0	2480.0	2746.0	3012.0	3278.0	3943.0	4608.0	5273.0	5938.0
ELECTRIC	3062.5	3318.3	3766.1	4154.7	4601.7	4817.6	5109.1	5384.9	5636.2	6217.7	6737.0	7209.8	7645.1
DRIVER	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0
VEH.FUEL	1113.8	1160.9	1255.2	1349.5	1443.8	1538.1	1632.4	1726.7	1821.0	2056.6	2292.5	2528.3	2764.0
V.MT.LAB	1805.0	1875.0	2015.0	2155.0	2295.0	2435.0	2575.0	2715.0	2855.0	3205.0	3555.0	3905.0	4255.0
V.SPARES	482.0	521.6	600.8	680.0	759.2	838.4	917.6	996.8	1076.0	1274.0	1472.0	1670.0	1868.0
V.TYRES	1219.8	1258.5	1336.0	1413.5	1491.0	1568.5	1646.0	1723.5	1801.0	1994.8	2188.5	2382.3	2576.0
VEH.LIC	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
LABOUR	13800.0	13800.0	13800.0	13800.0	20700.0	20700.0	20700.0	20700.0	20700.0	26500.0	26500.0	34500.0	34500.0
SUPER.LAB	2683.0	2683.0	2683.0	2683.0	4025.0	4025.0	4025.0	4025.0	4025.0	5366.0	5366.0	6708.0	6708.0
MATERIALS	125.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0	625.0	750.0	875.0	1000.0
SERVICES	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	300.0	300.0	300.0	300.0
BUILD.MT	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	700.0	700.0	700.0	700.0
ADMIN	3973.0	4107.0	4375.0	4643.0	4911.0	5179.0	5447.0	5715.0	5983.0	6653.0	7323.0	7993.0	8663.0
RENT	3169.9	3415.9	3843.5	4211.7	4538.6	4834.7	5106.8	5359.5	5596.1	6132.2	6608.2	7039.3	7435.4
RATES	2056.3	2218.1	2495.8	2734.9	2947.2	3139.4	3316.1	3480.2	3633.8	3961.9	4291.0	4571.0	4826.2
SUM.TOTAL (EXCLUDING CAPITAL CHARGES)	42995.2	44144.3	46272.4	48243.3	58346.5	60125.8	61841.1	63504.6	65125.1	76599.4	80341.2	93304.6	96831.8
CP.CHARGE	21919.2	23222.6	29151.8	31740.0	34322.6	36901.1	42389.5	47184.3	49755.7	59609.2	69357.6	78681.9	89533.3
SUM.TOTAL (INCLUDING CAPITAL CHARGES)	64914.4	67366.9	75424.2	79983.3	92669.0	97026.9	104230.6	110688.9	114880.8	136208.5	149698.8	171986.5	186365.0

(Information on the other transfer methods is presented in Appendix 8F)

8.4.1 Principal Findings

1. Treatment transfer methods are more expensive to operate than the compaction methods. At say, a 100t/d station the operating costs are listed in Table 8.9 and their ranking is given below:

   Compaction without storage
   Compaction with apron storage
   Compaction with bunker storage
   Dry pulverisation
   Wire-tied baling
   Wet pulverisation

   (Cost increasing in descending order)

2. Capital charges is the largest single component cost for all transfer methods, with labour cost second. Combined they account for between 55% and 83% of the total operating costs.

3. Other notably high cost components at all sizes of operation are: electricity (compaction without storage and dry pulverisation), mobile plant operating costs (compaction with apron storage), grab crane operating costs (compaction with bunker storage), and pulveriser maintenance (dry pulverisation).

4. The total costs are most sensitive to the largest components; capital charges and manual labour.

5. The total costs are relatively insensitive to the remaining component costs.

8.4.2 Capital Charges and Labour Costs

These were identified as the two largest expenditures and an indication of their magnitude is given in Table 8.7. The capital charges fall into three groups: first, the compaction without storage and with apron storage methods account for around 45% of the total cost. Second, dry pulverisation, wire-tied baling and compaction with bunker storage are about 55%; and third, wet pulverisation >75%.

Table 8.9 TOTAL BASE CASE OPERATING COSTS AND ERROR MARGIN FOR EACH TRANSFER METHOD AT A 100t/d TRANSFER STATION

Transfer Method	Total Operating Cost (£)	Total Operating Cost ± 95% CI (£)[1]	Unit Operating Cost (£)	Unit Operating Cost ± 95% CI (£)	Literature Values: Wilson (1981)	Literature Values: Humberside CC (1981)
Compaction without Storage	88,000	± 8,000	3.53	± 0.32		)
Compaction with Apron storage	115,000	± 8,000	4.60	± 0.32 [2]		) 4.20 - 5.64
Compaction with Bunker storage	136,000	± 8,000	5.44	± 0.32 [2]		)
Dry Pulverisation	212,000	± 10,000	8.48	± 0.40	6.70	7.20
Wire-tied Baling	219,000	± 55,000	8.76	± 2.20 [3]		5.64 - 8.52
Wet Pulverisation	309,000	± 10,000	12.37	± 0.40		≃9.96

1. Derived from the confidence interval of the total operating cost for each transfer method.

2. These total cost functions are heavily dependent on compaction without storage component costs. No separate CI calculations were possible therefore the "without storage" value is used for general indication only.

3. High variability due to small sample size.

CI Confidence Interval

This directly reflects the difference in the capital investment required by each of the transfer methods and is demonstrated by plotting labour costs against capital costs (Figure 8.3). For treatment transfer operations below 200t/d there is a direct trade-off between the two expenditures where operators switch to the more mechanised transfer methods requiring a larger investment and labour requirement (and hence cost) proportionately decreases. Above 200t/d this relationship breaks down principally due to very low manning levels required for wire-tied baling.

The compaction methods do not apparently follow this relationship.

Due to the large magnitude of the capital charges and labour costs the total costs are highly sensitive to both of them.

For example   Dry pulverisation   250t/d   (R_s = 0.413)

Capital charges

A 25% increase in capital charges produces an 11% increase in total operating cost.

Compaction with bunker storage   100t/d   (R_s = 0.205)

Labour

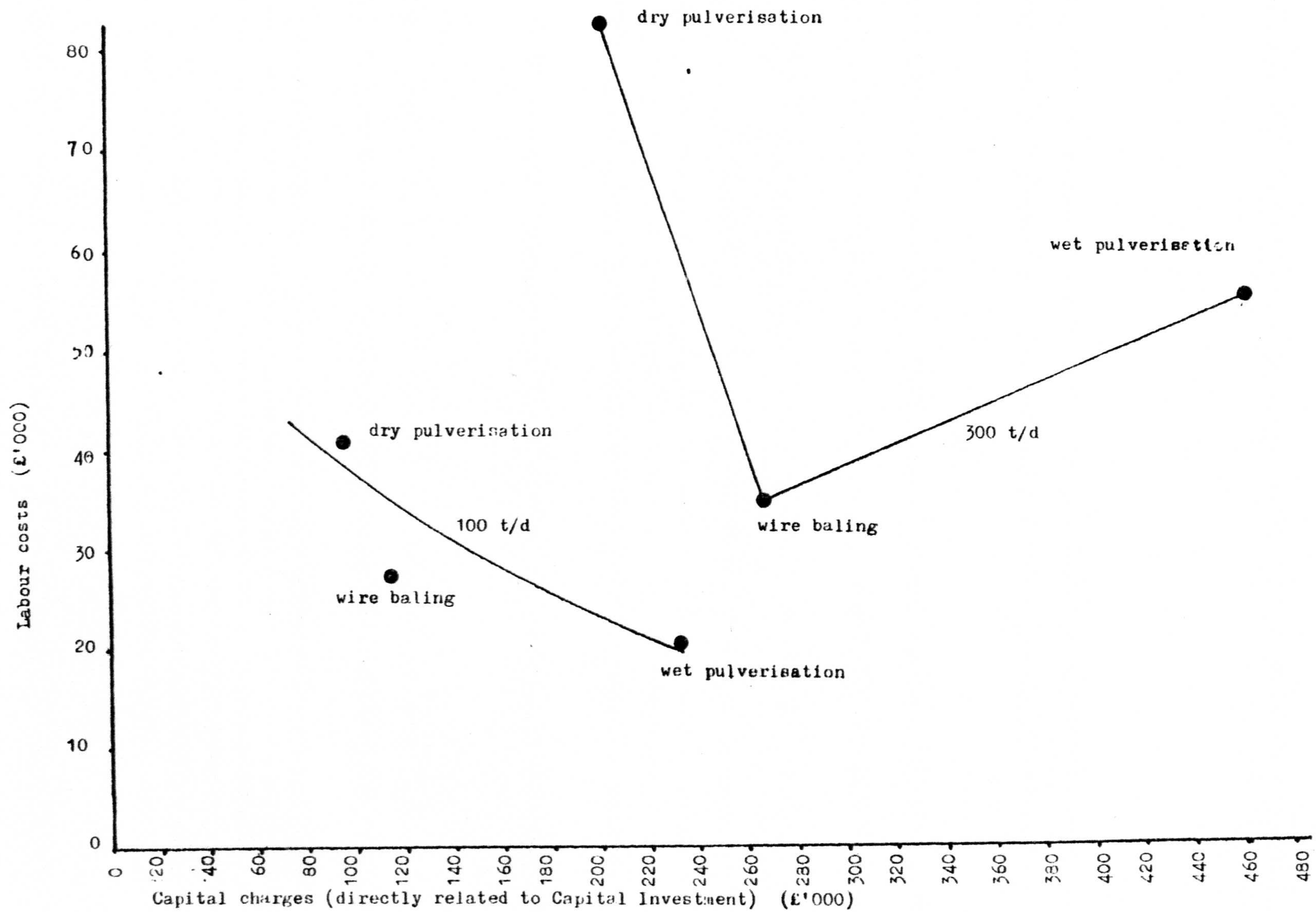
A 25% increase in labour cost produces a 6.6% increase in total operating cost.

8.4.3 Other Notable Operating Costs

Other component costs have been identified in Section 8.4.1 which produce a notable, though less marked, effect than capital charges or labour on the total costs.

Refuse handling costs are large expenditures for both of the compaction methods requiring storage; 10 - 19% apron storage; 10 - 12% bunker storage. The important influence of handling costs on the compaction methods employing storage should be borne in mind when considering the economics of a particular operation. Examples of their effect on the total cost are given below.

Fig.8.3 Comparison between labour costs and capital investment.



For example 150t/d operation

Mobile plant operating costs (apron storage)

A 25%increase produces a 2.9% increase in total operating cost.

Crane/conveyor operating costs (bunker storage)

A 25% increase produces a 2.7% increase in total operating cost.

Electricity expenditures are a higher proportion of the total cost at compaction without storage plants due mainly to the fewer component costs over which the total is spread. Electricity costs are also high for dry pulverisation. This method uses high speed motors to spin the hammers responsible for shredding the refuse and in overcoming the resistance to rotation exerted by the waste a large power demand is created. Consequently, dry pulverisation inevitably uses large quantities of power and is therefore vulnerable to fluctuations in electricity cost.

For example Dry pulverisation 200t/d (R_s = 0.085)

A 25% increase in electricity cost produces

a 2.1% increase in total operating cost.

Dry pulverisation is also susceptible to high maintenance costs. This is due to the nature of the operation which involves continuous high velocity impacts between the refuse and the hammers. The maintenance expenditure is primarily on frequent hammer refacing, with as much as 10Kg of metal replaced on each hammer every four weeks and regular preventative maintenance on the shaft, bearings and conveyor feed system.

For example Dry pulverisation 200t/d (R_s at 25% = 0.106)

A 25% increase in pulveriser maintenance cost produces

a 2.7% increase in total operating cost.

8.4.4 Total Operating Costs and Economies of Scale

In general the compaction transfer total costs are approximately half the lowest treatment transfer method as illustrated in Table 8.9 for a 100t/d operation. The cost ranking between methods bears similarity to that of the capital costs and further supports the finding that capital charges dominate the operating costs. Capital charges are of course directly related to the capital investment. Unit costs for compaction range between 3.53 - 5.44 £/t (100t/d site) ± 0.32 £/t and those for treatment between 8.48 ± 0.40 £/t (dry pulverisation 100t/d) and 12.37 ± 0.40 £/t (wet pulverisation 100t/d).

The unit costs at other daily tonneages can be calculated from the total cost equations in Table 8.2 and their 95% CI from Appendix 8E.

No economy of scale was found for the compaction total operating costs over the range 20 - 200t/d. A principal influence being that the larger component costs (notably labour and overheads) also exhibited no economies at these capacities. Unfortunately the absence of sufficient published data prevented an "extended" function up to 500t/d being calculated as was done for the capital costs. However, economies of scale were derived for three of the component costs; i.e.

	Scale Factor (SF)
Compactor electricity	0.44
Site rent	0.41
Site rates	0.41

No scale factors were found in the literature and consequently no comparison with an independent source could be made.

An economy of scale was identified for the dry pulverisation total operating cost (SF = 0.61) over the range 20 - 600t/d (Table 8.10). Expenditures on pulveriser maintenance, administrative overheads, rents and rates also exhibited notable economies of scale. The economy for pulveriser maintenance is probably due to the ability of large plants to handle higher quantities of waste between periods of downtime for preventative maintenance. This expenditure, mainly involving hammer re-facing, is reasonably similar for most sizes of operation. Maintenance charges for wet pulverisation and baling appear to rise more uniformly with increasing throughput and the repairs undertaken may therefore be of a more capacity-dependant nature. The total costs for wire-tied baling and wet pulverisation did not exhibit any such economies but rent and rates from each of the methods do. These are also listed in Table 8.10. One minor component, wet pulverisation materials cost, was found to have a diseconomy of scale (SF = 1.49).

As was the case with compaction transfer, no literature values were found against which the treatment transfer scale factors could be compared. It is suspected the values produced here are the first to be derived for operating costs at municipal waste transfer stations and will prove

Table 8.10 TREATMENT TRANSFER OPERATING COST SCALE FACTORS

Criteria and Range		This work
PULVERISATION (Dry: 20 - 600t/d) (Wet: 20 - 600t/d)		
Transfer and Treatment Eq.	(Dry)	0.80
Maintenance	(Wet)	
Materials	(Dry)	
	(wet)	1.49
Dept. Admin	(Dry)	0.61
	(Wet)	
Site Rent	(Dry)	0.41
	(Wet)	0.41
Site Rates	(Dry)	0.41
	(Wet)	0.41
Total Operating Costs (excl. Capital Charges)	(Dry)	0.61
	(Wet)	1.00
BALING (75 - 320t/d)		
Site Rent		0.41
Site Rates		0.41
Total Operating Cost (excl. Capital Charges)		1.00

<u>NB</u> (Wet) - Wet Pulverisation

(Dry) - Dry Pulverisation

8.4.5 Sensitivity of Transfer Operating Costs to Interest Rate

Variation of the interest rate above and below that used in the base case calculations (i.e. 14%) are considered in Table 8.11. Capital charges increase as the interest rate rises by the magnitude indicated in Table 8.11 and comparable work on Bulk Transport values (Section 8.8.2) has established that they become a larger proportion of the total cost as the rates increase. The total cost also becomes marginally more sensitive to capital charges.

8.5 ECONOMICS OF BULK TRANSPORT

After the waste has been treated at a transfer station the refuse product is then packed into bulk transport vehicles. These can carry up to five times the payload of a collection vehicle, at higher speeds and require only one man to operate them.

Only road transport is considered in this research although identical arguments to those presented (but with different costs) can be applied to rail and river transport. Many types of road vehicle are used in bulk transport operations, each suited to a particular size of transfer station or method of waste treatment. Seven common vehicle types, listed in Table 8.12, are reviewed to represent the range of vehicles available.

The 10-tonne rigid chassis tipper or hooklift is popular at small transfer stations. It is a reliable and proven class of vehicle requiring a smaller capital investment than articulated vehicles and the equipment can be used if necessary for other duties including civic amenity site collection or construction wastes. The larger 16t rigid is known to be in use at one larger compactor and a dry pulverisation plant. Articulated vehicles are generally favoured over rigids at large transfer stations. They provide a more flexible system capable of handling large throughputs of refuse and enable breakdowns to be more easily covered. The trailers are equipped with on-board ejection rams so eliminating the need for sophisticated tipping equipment on the tractor unit, and as a consequence tractors are freely interchangeable.

Table 8.11 TRANSFER CAPITAL CHARGES AT SELECTED INTEREST RATES AND THEIR INCREMENTAL EFFECT ON TOTAL OPERATING COSTS[1] (1981£)

	Transfer Method					
Interest Rate	Compaction Without Storage	Compaction with Apron storage	Compaction with Bunker storage	Dry Pulverisation	Wire-tied Baling	Wet Pulverisation
5%	21,544	31,329	41,505	58,176	72,553	144,153
10%	31,761	41,101	58,272	77,942	96,375	190,491
(base case) 14%	39,349	49,755	73,286	95,512	117,502	231,514
20%	51,641	63,721	97,618	123,916	151,662	297,868
% additions (or reductions) to the base case total operating costs[2]						
5%	(45)	(38)	(43)	(39)	(38)	(38)
10%	(19)	(18)	(20)	(18)	(18)	(18)
(base case) 14%	-	-	-	-	-	-
20%	31	28	33	30	29	29

1. Annual capital charges for a 100t/d operation.
2. The % differences of a method are likely to be very similar for all sizes of operation.

Table 8.12 DETAILS ON SEVEN COMMON BULK TRANSPORT ROAD VEHICLES

Chassis Type	Carrying Capacity (t)	Gross Vehicle Weight (£)	Refuse Unloading Equipment
RIGID	10	15	Tipper/hooklift
	16	22.5	Tipper/hooklift
ARTICULATED	12	16.5	Covered trailer and ram ejection
	14	19	Covered trailer and ram ejection
	16	22.5	Covered trailer and ram ejection
	16	22.5	Flatbed trailer for bales, unloaded by forklift
	22	32	Covered trailer and ram ejection

Unfortunately in this work it was not possible to obtain detailed costs for each vehicle type since many waste disposal departments do not directly administer the transport fleet, but instead "hire" them internally from a transport department. These disposal departments apparently accept and pay a unit hire cost without any knowledge of how it is derived. Enquiries to transport departments produced some, though incomplete, financial data commonly limited in detail by inadequacies in the authority's accounting system. The development of cost models for each vehicle type therefore relied heavily upon capital and operating costs presented in the publication "Commercial Motor" (CM). Alternative transport costs published by the National Association of Waste Disposal Contractors were not used. The vehicle types considered by this Association are different to the bulk transporters known to be operating from transfer stations.

CM Tables are compiled annually using data collected from many sources and are more accurate than anything which could be derived from this research. The CM costs were modified to represent waste management operations and to account for local authority accounting practices, i.e. tyre costs were increased above the CM's values to account for the increased likelihood of punctures when running over a landfill surface, and the capital charges altered onto the local authority rate of interest.

The CM costs are based on an eight-hour working day and include legally-required driver breaks and turnaround times. The latter component, turnaround time, is likely to be a larger proportion of the working day in waste-carrying operations than commercial road haulage. However, the base case uses the CM turnaround time and variations to this are studied by sensitivity analysis in Section 8.8.1.

8.6 CAPITAL AND OPERATING COST MODELS

The capital and operating costs used to derive the vehicle cost models are detailed in Tables 8.13 and 8.14, and are referenced throughout this section.

Table 8.13 BULK TRANSPORT CAPITAL COSTS AND CAPITAL CHARGES FOR EACH VEHICLE TYPE (1981£)

Chassis Type:	RIGID		ARTICULATED				
Carrying Capacity:	10t	16t	12t	14t	16t (covered)	16t (flatbed)	22t
Tractor and Trailer Capital Cost (excl. Cost of Tyres) (1)	17,500	27,000	21,350	23,500	27,000	24,000	37,500
Capital Charges (2)	5,097	7,865	6,219	6,845	7,865	6,991	10,923

(1) Based directly on the cost tables in Commercial Motor (1981).

(2) Capital cost amortised over five years at 14% interest p.a.

Table 8.14 BULK TRANSPORT OPERATING COSTS FOR EACH VEHICLE TYPE

N.B. Total Annual Operating Cost =

Total Standing Charges + (Total Running Cost x Annual Distance Travelled)

(a) Standing Charges (1981£/year)

Chassis Type:	RIGID		ARTICS				
Carrying Capacity:	10t	16t	12t	14t	16t (covered)	16t (flatbed)	22t
Licences[1]	494	728	600	632	1,000	900	1,753
Driver[2]	7,500	7,500	7,500	7,500	7,500	7,500	8,500
Depot Costs[1]	510	528	578	608	633	633	682
Insurance[1]	1,190	1,632	1,561	1,630	1,630	1,630	3,082
Capital Charges[3]	5,097	7,865	6,219	6,845	7,865	6,991	10,923
Total Standing Costs[4]	14,790	18,250	16,460	17,220	18,630	17,650	24,940

(b) Running Costs /

Table 8.14 BULK TRANSPORT OPERATING COSTS FOR EACH VEHICLE TYPE (continued)

(b) Running Costs (1981£/year)

Chassis Type:	RIGID		ARTICS				
Carrying Capacity:	10t	16t	12t	14t	16t (covered)	16t (flatbed)	22t
Fuel[1]	12.50	15.00	12.50	15.00	16.67	16.67	21.43
Lubricants[1]	0.48	0.51	0.48	0.48	0.49	0.49	0.49
Tyres (incl. replacements)[6]	7.45	8.00	8.22	7.41	7.41	5.11	8.63
Maintenance[1]	18.09	21.06	11.10	13.17	14.08	14.08	21.27
Total Running Cost p./mile[5]	38.52	44.57	32.30	36.06	38.65	36.35	51.82
Total Running Cost p./Km[5]	23.90	27.70	20.10	22.40	24.00	22.60	32.20

(in 1981 £/y)

NOTES

1. Based directly on the cost tables in Commercial Motor (1981).
2. Driver wages adjusted to include 70% on-costs.
3. From Table 8.13
4. Rounded off to the nearest £10
5. The CM tables are based on Imperial Units, however, the "Total Running Cost" value was subsequently converted to the metric equivalent.
6. 45% is added to the CM tyre cost. This adjustment accounts for additional tyre wear on tractor and trailer units from soft surface tipping. The 45% value is based on a comparison of loading shovels (detailed in Appendix 8.B), operating on both firm and soft surfaces.

8.6.1 Operating Costs

The standing charges are fixed irrespective of annual distance travelled by a bulk transporter. The largest expenditure is driver wages and together with capital charges represents about 80% of the total standing charges for all vehicle types.

Running costs are directly related to annual distance travelled with the largest expenditures being maintenance and fuel. For rigid chassis vehicles maintenance cost is approximately 33% larger than the fuel expenditure while for articulated vehicles the ranking is reversed; fuel costs are around 12.5% greater than maintenance. Apparently CM have found through experience that maintenance on rigid chassis lorries is far larger than on equivalent articulated vehicles, this is possibly due to the tipping and hoisting mechanisms on the former also requiring routine attention.

Tyre cost is another notable expenditure for vehicles running over landfills. It ranges from 30% lower than maintenance cost (12t artic) to 60% lower (10t rigid and 22t artic). Other standing and running costs are comparatively minor.

As an example in Table 8.15 individual operating costs for each bulk transporter were calculated over one annual distance (25,000 Km/y) using the standing and running costs previously described.

8.6.2 Derivation of Total Cost Models

For each vehicle type a total operating cost model was derived from the costs outlined in Table 8.14; i.e.

Rigid 10t $y = 0.239\ X_K + 14,790$

16t $y = 0.277\ X_K + 18,250$

Table 8.15 BULK TRANSPORT OPERATING COSTS AND PERCENTAGES FOR VEHICLES TRAVELLING 25,000 KILOMETRES PER YEAR. (1981£)

Operating costs:

CARRY.CAP	10.	16.	12.	14.	16.	16.	22.
	Rigid		Artics				
VEH.FUEL	3125.0	3750.0	3125.0	3750.0	4167.5	4167.5	5357.5
V.MT.LAB	4522.5	5265.0	2775.0	3292.5	3520.0	3520.0	3317.5
LUBRICNT	120.0	127.5	120.0	120.0	122.5	122.5	122.5
V.TYRES	1862.5	2000.0	2035.0	1832.5	1852.5	1277.5	2137.5
LICENCES	494.0	728.0	600.0	632.0	1000.0	900.0	1753.0
DRIVER	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0	8500.0
DEPOT	510.0	528.0	578.0	608.0	633.0	633.0	682.0
INSURANCE	1190.0	1632.0	1561.0	1630.0	1630.0	1630.0	3082.0
SUM.TOTAL (EXCLUDING CAPITAL CHARGES)	19324.0	21530.5	18314.0	19385.0	20425.5	19750.5	26972.0
CP.CHARGE	5097.5	7864.7	6218.9	6845.2	7864.7	6990.8	10923.1
SUM.TOTAL (INCLUDING CAPITAL CHARGES)	24421.5	29395.2	24532.9	26230.2	28290.2	26741.3	37895.1

PERCENTAGE VALUES - OPERATING COSTS (INCLUDING CAPITAL CHARGES)

CARRY.CAP	10.	16.	12.	14.	16.	16.	22.
	Rigid		Artics				
VEH.FUEL	12.8	12.8	12.7	14.3	14.7	15.6	14.1
V.MT.LAB	18.5	17.9	11.3	12.6	12.4	13.2	14.0
LUBRICNT	0.5	0.4	0.5	0.5	0.4	0.5	0.3
V.TYRES	7.6	6.8	8.4	7.1	6.5	4.8	5.7
LICENCES	2.0	2.5	2.4	2.4	3.5	3.4	4.6
DRIVER	30.7	25.5	30.6	28.6	26.5	28.0	22.4
DEPOT	2.1	1.8	2.4	2.3	2.2	2.4	1.8
INSURANCE	4.9	5.6	6.4	6.2	5.8	6.1	8.1
CP.CHARGE	20.9	26.8	25.3	26.1	27.8	26.1	28.8
SUM.TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Artic 12t		$y = 0.201\ X_K + 16,460$
14t		$y = 0.224\ X_K + 17,220$
16t	(covered)	$y = 0.240\ X_K + 18,630$
16t	(flatbed)	$y = 0.226\ X_K + 17,650$
22t		$y = 0.322\ X_K + 24,940$

where y = annual cost (£)

X_K = Annual distance in kilometres

The cost models are inclusive of capital charges.

A graphical representation of each model is given in Figure 8.4.

The bulk transport cost models are taken as linear due principally to the CM cost models from which they are derived also being linear. The cost models estimate the annual operating cost for one bulk transporter (tractor and trailer) when the appropriate annual distance travelled is known. Correspondingly, the annual cost of two or more bulk transporters covering similar distances is regarded as a simple multiple of the annual cost for one.

8.6.3 Cost of Additional Trailers

The total cost models discussed in the previous section produces estimates for an individual tractor and trailer combination. However, a transfer operation has more trailers than tractors, common ratios being 2:1 or 3:1. To account for this additional equipment they are treated as an increment to the total costs. The capital cost of a covered trailer or hooklift body is estimated at £2,500 and for a flatbed at £2,000. Correspondingly, when amortised at 14% p.a. over five years (i.e. in accordance with the base case) the annual capital charges are:

£728 - covered trailer and hooklift body

£583 - flatbed

These values were used as the incremental cost for additional trailers serviced by a tractor unit.

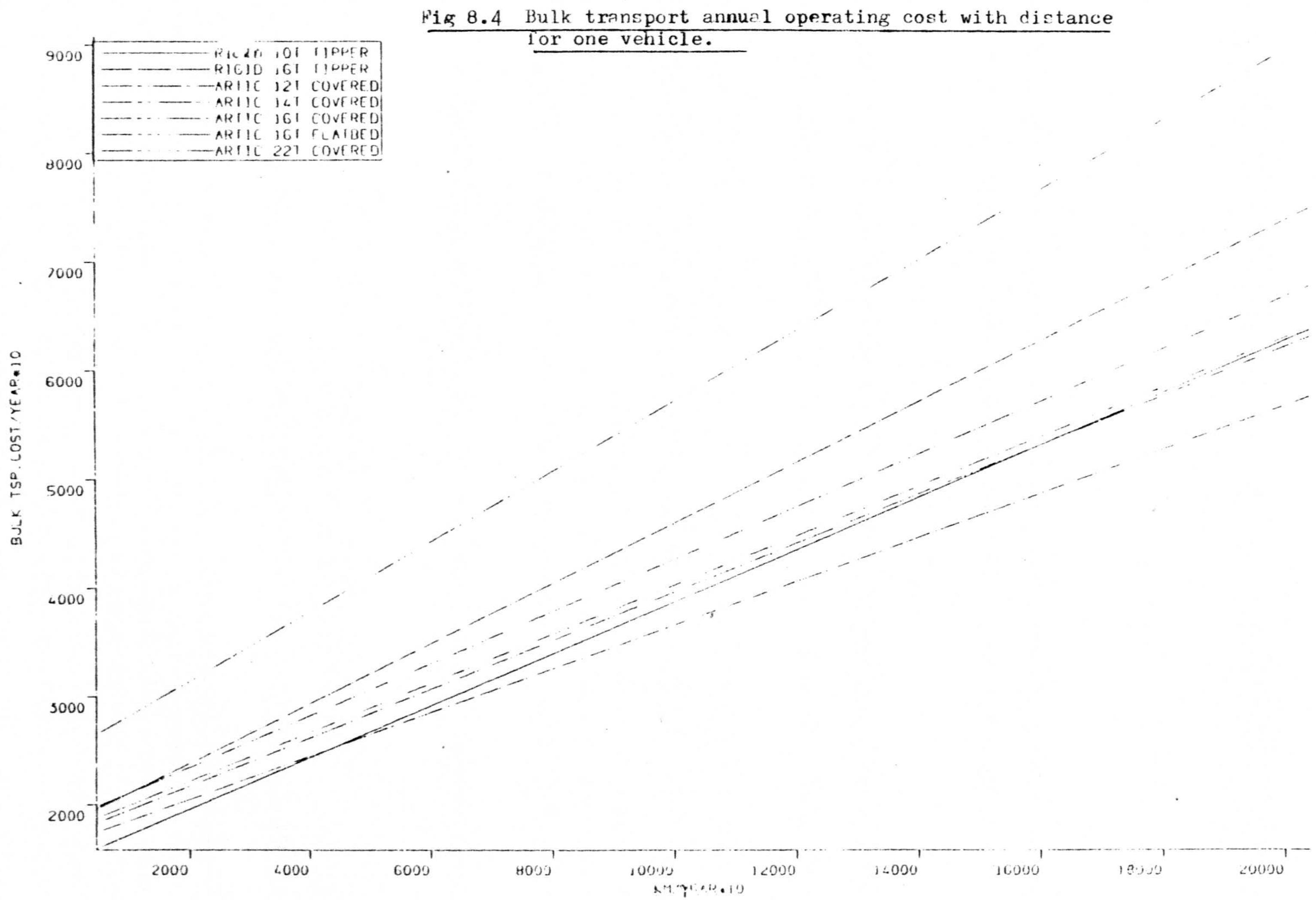


Fig 8.4 Bulk transport annual operating cost with distance for one vehicle.

8.7 COMPARISON BETWEEN COST MODEL PREDICTIONS AND LOCAL AUTHORITY FIGURES

Close agreement was found between local authority total costs and the models' values for single tractor and multiple trailer combinations (Table 8.16). Only two cases out of twelve studied had a percentage difference greater than ± 10%; the overall range being -13.5% to +13.7% (with respect to the models' values).

It was not possible to compare the individual component costs since no authority was identified that compiles its bulk transport expenditure in sufficient detail.

8.8 COMPARISON BETWEEN BULK TRANSPORTER COSTS

Transport cost varies with both total distance travelled and tonneage carried. For a fixed set of these parameters the costs of each vehicle type can be compared and assuming, quite unrealistically, that all of the vehicles cope with the same tonneage within the same working day, the cost ranking produced in Table 8.17 suggests the smallest rigid and artic vehicles are cheapest followed by the progressively larger vehicles. In practice, however, the larger vehicles handle far higher daily tonneages and this substantially alters the Table 8.17 ranking (Table 8.18).

8.8.1 Influence of the Number of Return Trips per Day, Turnaround Time and Average Speed on Fleet Size and Bulk Transport Costs

The number of return journeys a bulk transporter can achieve in a day is influenced by:

(i) The length of the working day

(ii) The turnaround time in each return journey.

(iii) The distance to disposal point.

(iv) The average speed.

(v) The payload achieved.

Table 8.16 COMPARISON BETWEEN LOCAL AUTHORITY ANNUAL OPERATING COSTS AND COST MODEL ESTIMATES FOR ONE TRACTOR UNIT AND ONE OR MORE TRAILERS

Vehicle Type

Km/y	RIGID 10t			RIGID 16t			ARTIC 12t			ARTIC 16t (covered)		
	Model	L.A.	% Δ	Model	L.A.	% Δ	Model	L.A.	% Δ	Model	L.A.	% Δ
13,000	19,353	20,321	- 5.0	21,851	20,658	+ 5.5						
16,000				22,682	22,385	+ 1.3						
18,000										23,678	26,866	-13.5
20,000				23,790	23,000	+ 3.3						
29,000				27,011	24,570	+ 9.0	22,289	21,000	+ 5.8			
32,000				27,842	29,958	- 7.6						
34,000	22,916	19,780	+13.7									
35,000				28,673	27,738	+ 3.3						
39,000				30,500	31,776	- 4.2						
40,000				30,786	29,751	+ 3.4						

N.B. Model - Model total annual cost estimate for one tractor and trailer combination (£)[1]

L.A. - Local Authority total annual cost figures (£)

% Δ - Percentage difference with respect to the model estimate.

1. These figures are modified where additional trailers are serviced by one tractor unit (Section 8.6.3).

Table 8.17 COMPARISON OF BULK TRANSPORT ANNUAL OPERATING COSTS BETWEEN ALL VEHICLE TYPES

Vehicle Type	Total Cost	Cost/ Tonne	Ranking
	£	£/t	
Rigid 10t	24,400	0.98	1
Rigid 16t	29,400	1.18	6
Artic 12t	24,500	0.98	1
Artic 14t	26,200	1.05	3
Artic 16t (covered)	28,300	1.13	5
Artic 16t (flatbed)	26,700	1.07	4
Artic 22t	37,900	1.52	7

All vehicles run 25,000 Km/y and handle 25,000t/y within the same working year.

Table 8.18 COMPARISON OF BULK TRANSPORT ANNUAL OPERATING COSTS BETWEEN ALL VEHICLE TYPES WHERE THE ANNUAL TONNEAGE HAULED REQUIRES A VARYING NUMBER OF VEHICLES DEPENDING ON CARRYING CAPACITY

Vehicle Type	No. of trips required/day	Minimum number of Vehicles Required[1]	Annual Total Cost	Cost/Tonne	Ranking
			£	£/t	
Rigid 10t	10	2	48,800	1.95	5
Rigid 16t	6	1	29,400	1.18	3
Artic 12t	8	2	49,000	1.96	6
Artic 14t	7	2	52,400	2.10	7
Artic 16t (covered)	6	1	28,300	1.13	2
Artic 16t (flatbed)	6	1	26,700	1.07	1
Artic 22t	5	1	37,900	1.52	4

1. Output 100t/d all to be hauled within the working day (1 shift). Maximum number of trips per day by a vehicle is 6.

The maximum time available for haulage varies with length of working day and turnaround times at the landfill and transfer station. Three examples of these are given in Table 8.19. The maximum distance per day is a multiple of the maximum time available and the average haul speed. The maximum distance for one of the three examples considered in Table 8.19 is evaluated for two average speeds in Table 8.20.

The information in Tables 8.19 and 8.20 can be plotted against annual cost per trip for any of the vehicle types to determine the variations in cost with distance. To illustrate this the cost functions for two vehicle types, 16t rigid and 16t artic (covered), were arbitarily chosen and presented in Figs.8.5 and 8.6. The haulage cost is dominated by the standing (fixed) costs and it was found the greater the number of trips per vehicle achieved over a given distance, then the lower the overall cost of the transport operation. This relationship was first elucidated by Wilson (1981). The savings are thus achieved by carrying more refuse in fewer vehicles. Furthermore, from Wilson (1981) and Figures 8.5 and 8.6, for a given number of trips per day the most critical factors are (i) ensuring that vehicles carry full payloads on each trip; and (ii) the fixed costs of the haulage operation.

The total cost of one bulk transporter per year is given in Figure 8.4, and the cost for one vehicle must be multiplied by the fleet size to derive the overall cost for the entire operation. However, the size of the vehicle fleet will be strongly influenced by the number of loads any one vehicle can make per day or year, and this in turn is dictated by the factors discussed above.

8.8.2 Sensitivity of Bulk Transport Operating Costs to Interest Rate

An interest rate of 14% has been considered in all of the preceeding bulk transport cost calculations. This however is not likely to remain constant over time. Consequently the effect on the operating costs were investigated for three other rates; 5%, 10% and 20%. In Tables 8.21 and 8.22 general trends were established for a situation where interest rates are rising:

Table 8.19 MAXIMUM TIME AVAILABLE PER RETURN TRIP FOR HAULAGE IN A WORKING DAY

Length of Working Day (hr):		8	8	9
Turn-round Time per Return Trip (hr):		1	½	1
No. of Return Trips per Day:	5	0.6	1.1	0.8
	4	1.0	1.5	1.3
	3	1.7[1]	2.2	2.0
	2	3.0	3.5	3.5
	1	7.0	7.5	8.0

1. Sample Calculation: 8 hr - (3 x 1 hr) = 5 hr
   5 hr ÷ 3 trips/day = 1.7 hr/trip

Table 8.20 MAXIMUM DAILY AND ANNUAL HAUL DISTANCE FOR ONE RETURN TRIP AND ALL RETURN TRIPS AT TWO AVERAGE SPEEDS

(using first case above, i.e. 8 hr Working Day, 1 hr Turn-round time/return trip)

No. of Return Trips Per day	DAILY DISTANCE: For 1 return trip (for all return trips) Km/d		ANNUAL DISTANCE:[1] For 1 return trip (for all return trips) Km/y	
	20 Km/hr	30 Km/hr	20 Km/hr	30 Km/hr
5	12 (60)	18 (90)	3,000 (15,000)	4,500 (22,500)
4	20 (80)	30 (120)	5,000 (20,000)	7,500 (30,000)
3	34 (102)[2]	51 (153)	8,500 (25,500)	12,750 (38,250)
2	60 (120)	90 (180)	15,000 (30,000)	22,500 (45,000)
1	140 (140)	210 (210)	35,000 (35,000)	52,500 (52,500)

1. Assuming a 250-day working year.
2. 1.7 hr/trip (from Table 8.19) x 20 Km/hr = 34 Km for one trip
   34 Km x 3 return trips/day = 102 Km

Fig 8.5 Rigid 16t bulk transporter cost for one vehicle as a function of distance with regard to number of trips per day and average speed

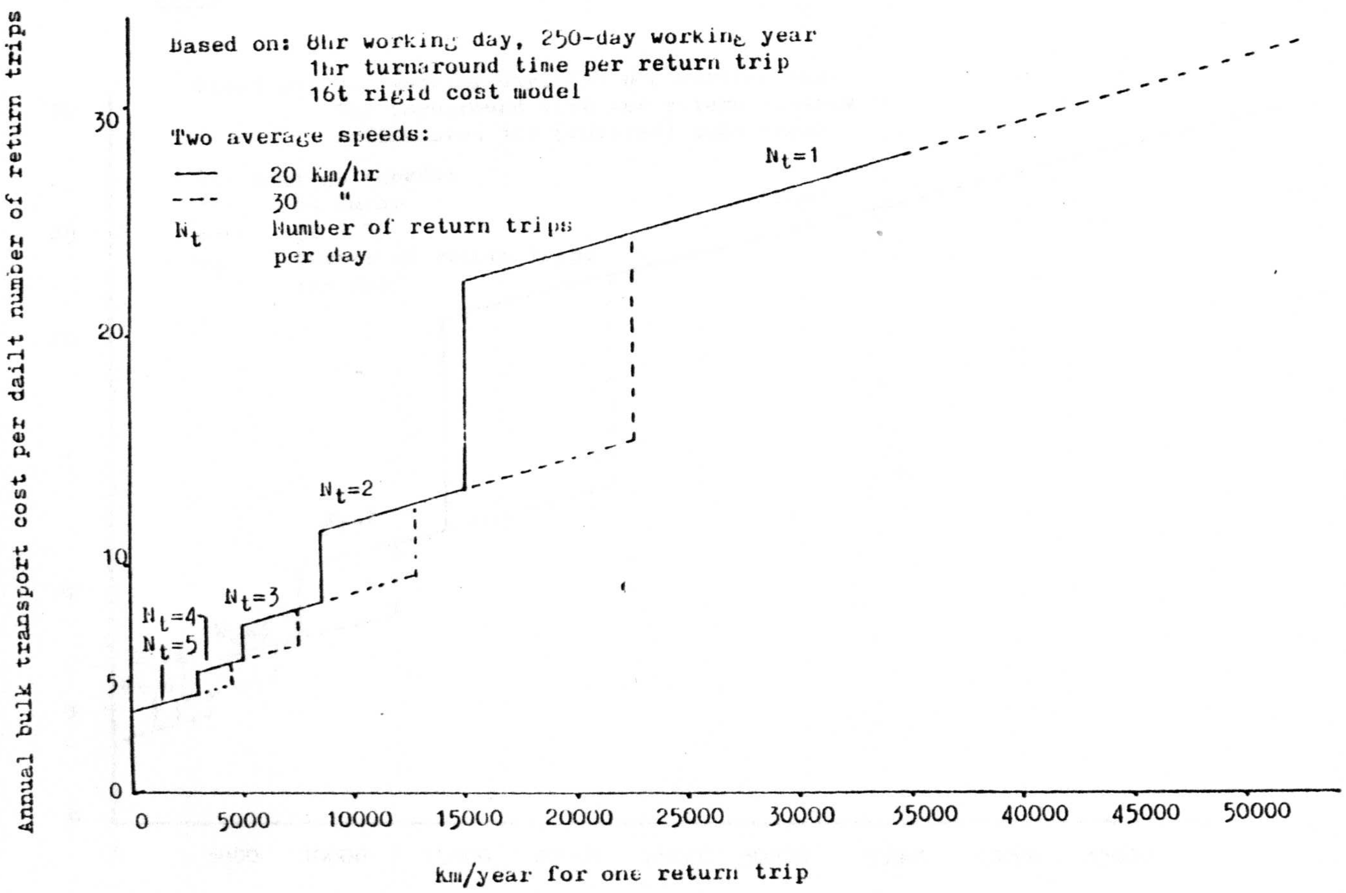
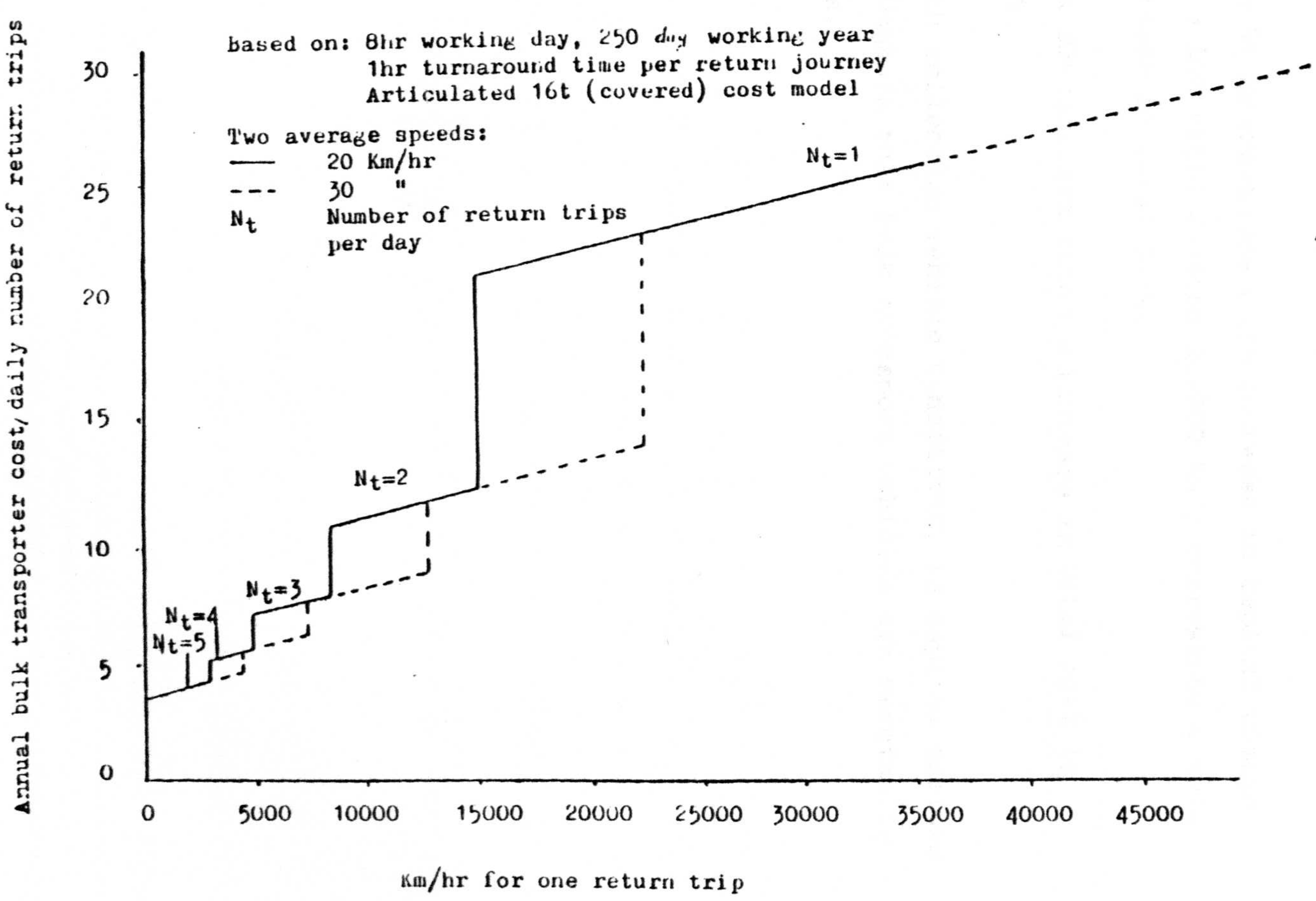


Fig 8.6 Articulated 16t (covered) bulk transporter cost for one vehicle as a function of distance with regard to number of trips per day and average speed



- Capital charges become a larger proportion of the total operating cost (Table 8.21).

- The total operating cost becomes more sensitive to capital charges (Table 8.22); i.e.

  At a 5% interest rate a 25% increase in capital charge for a 10t rigid running 25,000 Km/y represents a 4.3% increase in total cost.

  At a 20% interest rate the increase in total cost is 5.8%.

Comparison with collection vehicle sensitivity to capital charges (Table 7.5) suggests that bulk transport vehicles are marginally more sensitive.

Table 8.21 BULK TRANSPORT CAPITAL CHARGES AT SELECTED INTEREST RATES AND THEIR INCREMENTAL EFFECT ON TOTAL OPERATING COSTS[1]

Chassis Type	RIGID		ARTICULATED				
Carrying Capacity	10t	16t	12t	14t	16t (covered)	16t (flatbed)	22t
Base Case Tractor and Trailer Capital Cost	17,500	27,000	21,350	23,500	27,000	24,000	37,500
Interest Rates:	Capital costs amortised over 5 years @:						
5% [2]	4,042 17%	6,236 22%	4,931 21%	5,428 22%	6,236 23%	5,543 22%	8,662 24%
10%	4,616 19%	7,123 25%	5,632 24%	6,199 24%	7,123 26%	6,331 24%	9,892 27%
(base case) 14%	5,097 21%	7,865 27%	6,219 25%	6,845 26%	7,865 28%	6,991 26%	10,923 29%
20%	5,852 23%	9,028 32%	7,139 28%	7,858 29%	9,028 31%	8,025 29%	12,539 32%
Base Case total operating cost (incl. Capital Charge at 14%)	24,420	29,400	24,530	26,230	28,290	26,740	37,900
Interest Rate @:	% Additions (or reductions) to the base case total operating costs:						
5%	(1,055)	(1,629)	(1,288)	(1,417)	(1,629)	(1,448)	(2,261)
10%	(481)	(742)	(587)	(646)	(742)	(660)	(1,031)
(base case) 14%	-	-	-	-	-	-	-
20%	755	1,163	920	1,013	1,163	1,034	1,616

1. Annual capital charge (1981 £)
2. Capital charge expressed as a percentage of the total operating cost.
3. Operating costs at 25,000 Km/y.

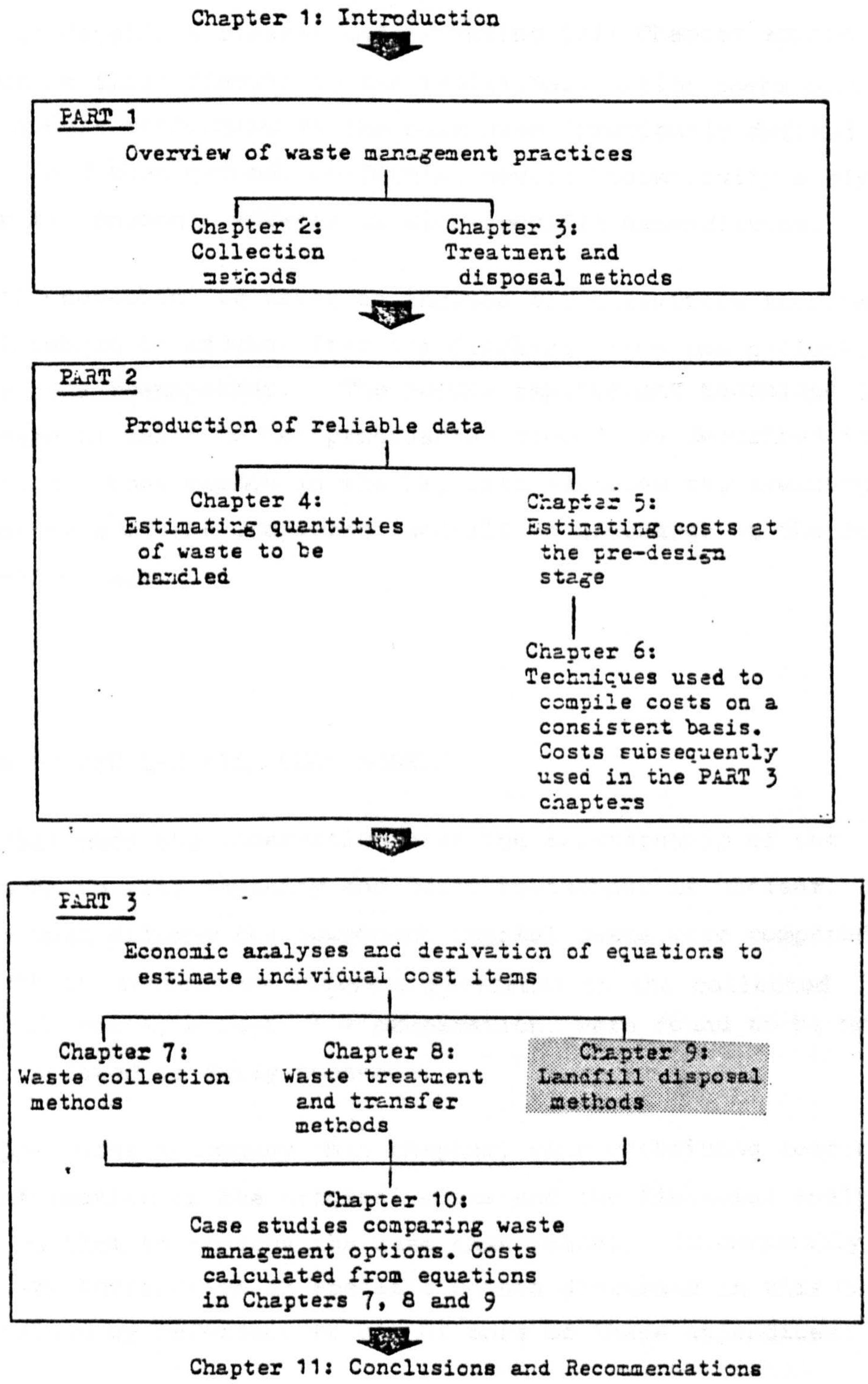
Table 8.22 RELATIVE SENSITIVITY VALUES FOR CAPITAL CHARGES AT SELECTED INTEREST RATES

Carrying Capacity		RIGID 10t [1]	ARTIC 12t	ARTIC 16t (flatbed)	ARTIC 22t
Interest Rate:					
	5%	0.170	0.208	0.214	0.237
	10%	0.189	0.230	0.237	0.261
(base case)	14%	0.204	0.247	0.255	0.280
	20%	0.227	0.273	0.281	0.308

1. Relative sensitivity for each vehicle type rises with increasing interest rate.

CHAPTER 9

ECONOMICS OF LANDFILL DISPOSAL



Chapter 9

9.1 INTRODUCTION

The economics of landfilling are complex and highly site-specific. Therefore to develop a clearer understanding this Chapter approaches the subject by first discussing the preliminary design costs calculated from cost models conforming to the base case (previously defined in Chapter 6), and then second, performing several sensitivity analyses to explore the economic effects on site-specific expenditures.

A "landfill operation" is taken to include all activities involved in the final emplacement of refuse after its discharge from the collection vehicle or bulk transporter. The refuse emplacement technique in the base case is taken to be "progressive slope" (as described in Chapter 3), the most common in the UK, with vehicles transversing over the surface of the completed landfill to discharge at the top of the working face.

9.2 EVALUATION OF THE LANDFILL COST MODELS

Wilson (1981) made the observation that the relationship of the capital costs to site capacity and daily throughput is unclear. To resolve this dilemma the component capital costs were compared against both in regression analyses performed on the collected data. All costs, except site preparation, were found to be more accurately related to daily tonneage.

Several appendices accompany this chapter, each containing comprehensive information on the original costs and the financial analyses performed on them to produce the base case values. Consequently, supplementary information on specific points discussed in this Chapter can be obtained by reference to one or more of these appendices:

Appendix 9.A	Original Data
Appendix 9.B	Descriptive Derivation of each First and Second Reduction Component Cost
Appendix 9.C	First Reduction Costs and Corresponding R^2 values
Appendix 9.D	Second Reduction Costs and Corresponding R^2 values
Appendix 9.E	Modifications to Base Case Operating Costs to account for Landfilling Baled, Wet and Dry Pulverised Waste

Several individual capital and operating costs were studied for direct landfill and cost functions calculated to explain their variation with site size. The items of expenditure are listed below and their corresponding functions in Table 9.1.

Capital Cost Components

- Site survey and design
- Buildings and civil engineering
- Access roads
- Mobile plant
- Other site preparation

Operating Cost Components

- Cover purchase
- Site vehicle - Fuel, Maintenance Labour, Spares, Tyres, Licences and Insurance
- Manual labour
- Supervisory Labour
- Materials
- Services
- Building Maintenance
- Site Rent
- Site Rates
- Departmental Administration

(A full definition of the items included under each of the component costs is given in Appendix 6.A).

Table 9.1a *INDIVIDUAL CAPITAL COST FUNCTIONS FOR LANDFILL DISPOSAL OVER THE RANGE 10-500t/d*[1]

(A discussion of the physical bases and the ranges of applicability for each cost function are discussed in Appendix 9.B)

Daily Tonneage: 10, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500

<table>
<tr><th>Criteria</th><th colspan="7">10 – 200</th><th colspan="3">200 – 500</th></tr>
<tr><td>Site Survey</td><td colspan="7">$y = 72.2X_D + 1,564$</td><td colspan="3">$y = 206X_D^{0.74}$</td></tr>
<tr><td>Buildings & Civils</td><td colspan="7">$y = 128X_D + 6,056$</td><td colspan="3">$y = 77.8X_D + 4,297$</td></tr>
<tr><td>Access Roads</td><td colspan="7">$y = 263X_D^{0.88}$</td><td colspan="3">$y = 676X_D^{0.66}$</td></tr>
<tr><td>Other Prep. Costs</td><td colspan="10">$y = 40.4X_C^{0.44}$</td></tr>
<tr><td>Mobile Plant (y=)</td><td>15,000</td><td>20,000</td><td>30,000</td><td>50,000</td><td>65,000</td><td>80,000</td><td>85,000</td><td>90,000</td><td>95,000</td><td>110,000</td></tr>
<tr><td>TOTAL CAPITAL COSTS[1]</td><td colspan="7">$y = 794X_D + 17,206$</td><td colspan="3">$y = 2,269X_D^{0.75}$</td></tr>
</table>

y = 0: Site Acquisition, Drainage and Gas Alleviation; X_D = Daily Tonneage; X_C = Total Site Capacity.

1. Extended function to 1,000t/d using additional, published costs: $y = 3,104X_D^{0.74}$

The coefficient of determination (R^2 value) for each cost function is given in Appendix 9D.

"y" represents cost in 1981£.

Table 9.1b *INDIVIDUAL OPERATING COST FUNCTIONS FOR LANDFILL DISPOSAL OVER THE RANGE 10-500t/d*

(A discussion of the physical bases and the ranges of applicability for each cost function are discussed in Appendix 9.B)

Daily Tonneage: 10 50 100 150 200 250 300 350 400 450 500

Criteria					
Fuel	$y = 11.1X_D + 1,032$				
Maintenance Labour	$y = 346X_D^{0.46}$				
Spares	$y = 7.2X_D + 258$				
Tyres	$y = 14.1X_D + 1,865$				
Manual Labour (y=)	6900	13800	20700	26500	
Supervisory Labour (y=)	890	1790	2680	5300	
Materials	$y = 5X_D$				
Services	$y = 3.5X_D + 0.184$	$y = 1.25X_D + 0.305$			
Building & Other Maint. (y=)	200	500	800	1100	1400
Dept. Admin.	$y = 337X_D^{0.51}$				
Site Rent	$y = 35.5X_D$	$y = 31.3X_D$			
Site Rates	$y = 6.5X_D$	$y = 5.3X_D$			
Vehicle Lic. & Insurance	$y = 0.7X_D + 186$				
TOTAL OPERATING COST (incl. Capital Charges)	$y = 3586X_D^{0.51}$				

The coefficient of determination (R^2 value) for each cost function is given in Appendix 9D.
"y" represents cost in 1981£.

9.3 CAPITAL COSTS AND AMORTISATION DISCUSSION

For selected sizes of landfill the component and total costs were calculated by computer from the base case cost functions in Table 9.1a. The derived values are given in Table 9.2 and the associated percentage values and relative sensitivites are given in Tables 9.3 and 9.4 respectively. Detailed information was only obtained for sites handling up to 500t/d and is representative of the majority of sites in Britain.

A few sites do landfill over 500t/d but most of these are operated by private companies and it consequently proved impossible to gather financial data from these organisations. However, by supplementing these costs with those from the literature a total capital cost function was derived for operations up to 1,000t/d, thereby complimenting the detailed appraisal for sites up to 500t/d.

The "extended cost function" is:

$$y = 3{,}104\ X_D^{0.74}$$

where X_D = t/d

y = total capital cost.

9.3.1 Principal Findings

1. The largest capital expenditure at all sizes of site, representing about 40% of the total cost, is mobile plant, reflecting the highly mechanised nature of a properly organised landfill operation.

2. The second largest expenditure is principally the building and civil engineering cost which includes all site earthworks. However, operations over 200t/d require a more substantial access road and as a consequence this cost progressively increases in magnitude until it matches the building expenditure. For example:

Table 9.2 Landfill Disposal Base Case Capital Costs

****

BASE CASE COSTS AT SELECTED DAILY TONNEAGES FOR LANDFILL-RELATED DISPOSAL METHODS (1981£)

****

DIRECT LANDFILL
****

CAPITAL COSTS (RANGE 10 TO 500 TONNES PER DAY)

T/D	10.	25.	50.	75.	100.	150.	200.	250.	300.	350.	400.	450.	500.
TOT.CAP.	50000.	125000.	250000.	375000.	500000.	750000.	1000000.	1250000.	1500000.	1750000.	2000000.	2250000.	2500000.
SURVEY	2286.0	3369.0	5174.0	6979.0	8784.0	12394.0	16004.0	12255.8	14026.1	15720.9	17353.7	18934.1	20469.4
BUILDINGS	7330.0	9256.0	12456.0	15656.0	18856.0	25256.0	31656.0	23747.0	27637.0	31527.0	35417.0	39307.0	43197.0
ACCESS RD	1995.1	4468.3	8223.4	11749.2	15134.1	21623.0	27652.4	25857.5	29164.0	32287.3	35261.9	38112.5	40857.1
PREPARE	4719.9	7063.5	9582.4	11453.9	12999.5	15538.5	17635.2	19454.6	21079.6	22558.9	23924.0	25196.6	26392.2
MOBILE PT	15000.0	15000.0	20000.0	30000.0	50000.0	65000.0	85000.0	90000.0	90000.0	95000.0	95000.0	110000.0	110000.0
SUM.TOTAL	31336.9	39156.8	55435.8	75838.2	105773.6	139811.5	178147.6	171315.0	181906.6	197094.1	206956.7	231550.2	240915.6

CAPITAL COSTS AMORTISED OVER 5Y AT 14%PA - MOBILE PLANT
" " " " 20Y AT 14%PA - BUILDINGS, SITE PREPARATIONS AND ACCESS ROADS

Table 9.3 Landfill Disposal Base Case Capital Cost Percentage Values

T/D	10.	25.	50.	75.	100.	150.	200.	250.	300.	350.	400.	450.	500.
TOT.CAP.	50000.	125000.	250000.	375000.	500000.	750000.	1000000.	1250000.	1500000.	1750000.	2000000.	2250000.	2500000.
SURVEY	7.3	8.6	9.3	9.2	8.3	8.9	9.0	7.2	7.7	8.0	8.4	8.2	8.5
BUILDINGS	25.4	23.6	22.5	20.6	17.8	18.1	17.8	13.9	15.2	16.0	17.1	17.0	17.9
ACCESS RD	6.4	11.4	14.8	15.5	14.3	15.5	15.6	15.1	16.0	16.4	17.0	16.5	17.0
PREPARE	15.1	18.0	17.3	15.1	12.3	11.1	9.9	11.4	11.6	11.4	11.6	10.9	11.0
MOBILE PT	47.9	38.3	36.1	39.6	47.3	46.5	47.7	52.5	49.5	48.2	45.9	47.5	45.7
SUM.TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 9.4 Landfill Disposal Base Case Capital Cost Relative Sensitivities

SENSITIVITY RANGES CONSIDERED
X OR / 2.00 : SURVEY
X OR / 1.50 : BUILDINGS, ACCESS ROADS, SITE PREPARATIONS
X OR / 1.25 : MOBILE PLANT

RS VALUES
LINEAR FUNCTIONS PRODUCE A CONSTANT RS VALUE FOR THE ENTIRE SENSITIVITY RANGE
CURVILINEAR FUNCTIONS DO NOT, INSTEAD SELECTED RS VALUES ARE GIVEN

T/D	10.	25.	50.	75.	100.	150.	200.	250.	300.	350.	400.	450.	500.
TOT.CAP.	50000.	125000.	250000.	375000.	500000.	750000.	1000000.	1250000.	1500000.	1750000.	2000000.	2250000.	2500000.
SURVEY													
1.10	0.072	0.085	0.092	0.091	0.082	0.088	0.089	0.071	0.077	0.079	0.083	0.081	0.084
1.25	0.072	0.085	0.092	0.091	0.082	0.088	0.089	0.069	0.074	0.077	0.080	0.079	0.082
1.50	0.072	0.085	0.092	0.091	0.082	0.088	0.089	0.067	0.072	0.074	0.077	0.076	0.078
BUILDINGS	0.229	0.231	0.220	0.202	0.175	0.177	0.175	0.137	0.150	0.157	0.166	0.167	0.176
ACCESS ROAD													
1.10	0.063	0.113	0.146	0.153	0.141	0.152	0.154	0.149	0.158	0.161	0.168	0.162	0.167
1.25	0.063	0.111	0.143	0.149	0.138	0.149	0.150	0.145	0.154	0.157	0.163	0.158	0.163
1.50	0.062	0.108	0.138	0.144	0.134	0.144	0.145	0.140	0.148	0.151	0.157	0.152	0.156
PREPARE													
1.10	0.146	0.177	0.170	0.149	0.121	0.110	0.098	0.112	0.115	0.113	0.114	0.108	0.108
1.25	0.145	0.173	0.166	0.146	0.119	0.108	0.097	0.110	0.113	0.111	0.112	0.106	0.107
1.50	0.140	0.165	0.159	0.140	0.116	0.105	0.094	0.107	0.110	0.108	0.109	0.103	0.104
MOBILE PT	0.457	0.369	0.348	0.381	0.451	0.444	0.455	0.499	0.471	0.460	0.439	0.454	0.437

10t/d operation:

Building	23% of total cost
Access Road	6% of total cost

500t/d operation:

Building	18% of total cost
Access road	17% of total cost

3. The "site preparation" cost (primarily earthworks and fencing) is also a notable expenditure, ranging between 15% and 11% of the total cost. In contrast, site survey is a relatively minor cost.

9.3.2 Sensitivity of the Total Cost to Component Expenditures

The sensitivity of the total cost varies for each component cost and the ranking below demonstrates this variation. The only difference between large and small sites is a reversal of the order for site preparation and access road. (A full listing is given in Table 9.4). i.e.

Small operations ($\leqslant$150t/d) sensitivity ranking:

$M >> B > P > A > S$

Larger operations (>150t/d up to 500t/d) sensitivity ranking:

$M >> B \simeq A > P > S$

where: M - Mobile plant
B - Buildings and civils
A - Access road
P - Site preparations
S - Site survey

Most of these component costs have a major effect on the total cost and an example of their influence is given for a site receiving 300t/d, i.e.

a 25% increase in:

Mobile Plant	represents a 12% increase in total cost
Buildings and civils	represents a 3.8% increase in total cost
Access road	represents a 4.0% increase in total cost
Site preparation	represents a 2.9% increase in total cost
Site survey	represents a 1.9% increase in total cost.

9.3.3. Total Capital Costs and Economies of Scale

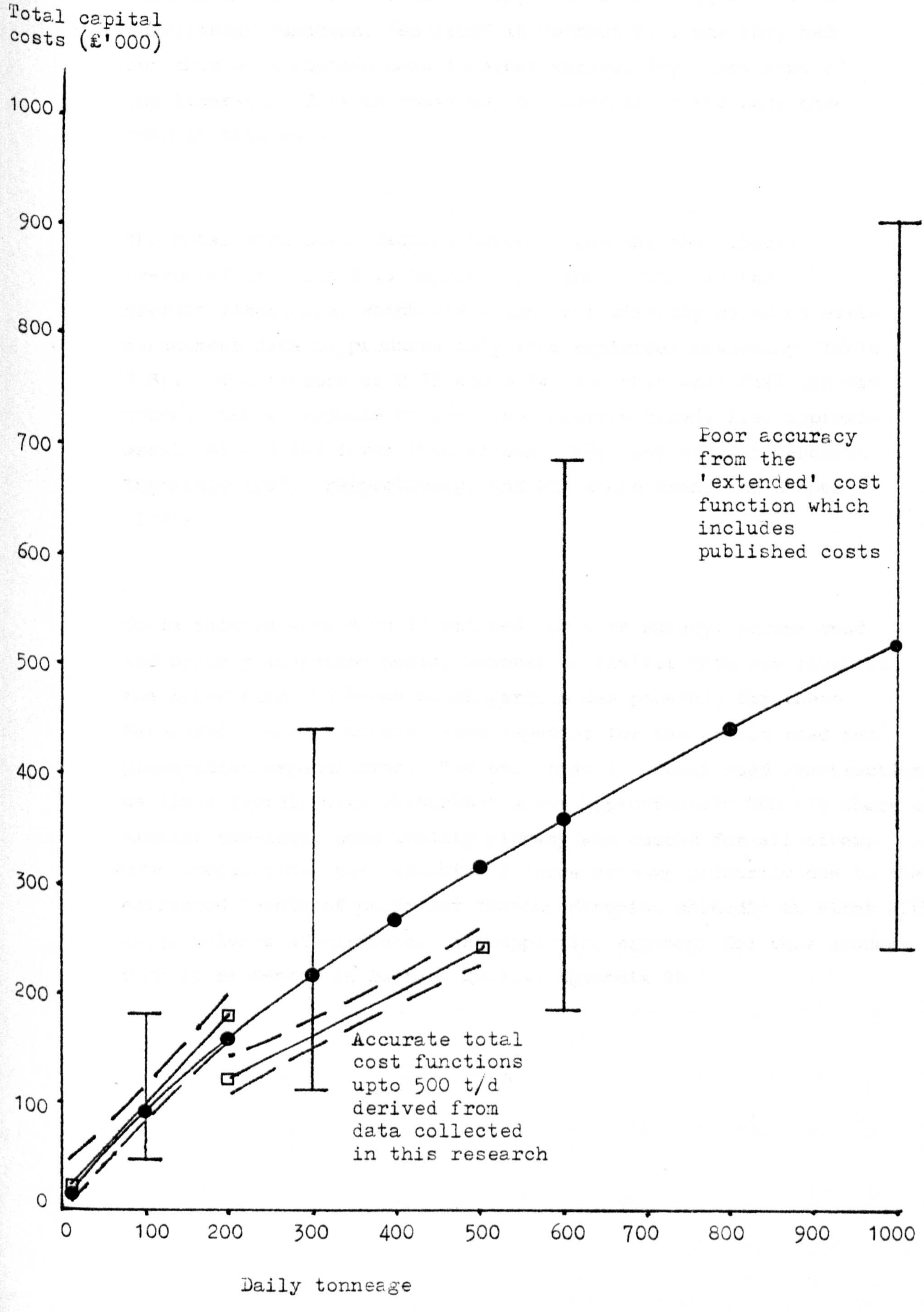
As already discussed it was only possible to obtain detailed costs for sites over the range 10 to 500t/d. Within this range a single total cost function does not accurately represent the base case data points. Instead two were derived, a linear function between 10 and 200t/d and a curvilinear one above this up to 500t/d. Both functions and their associated 95% confidence intervals are drawn in Figure 9.1.

At smaller sites the two largest items of expenditure, mobile plant and civil engineering, both rise at a constant rate. This is reflected in the total capital cost function. The purchase price of site vehicles rises steeply from the relatively cheap multipurpose machines at very small sites to those suitable for larger operations. More extensive (and costly) earthworks are also required before larger sites are ready to receive wastes.

At sites above 200t/d site vehicle prices rise only marginally, as do other component expenditures. Consequently, a curvilinear total cost function was found to most satisfactorily represent these costs.

Sites larger than 500t/d are becoming more commonplace in the UK and there are even operations known to be handling in excess of 1,000t/d. It was considered important for the practical application of this research to reflect this general increase in the size of new sites. Accordingly the base case values were supplemented with updated published figures from Wilson (1981) to determine an

Fig 9.1 Landfill disposal base case total capital cost function and the 95% confidence interval.



"extended" total cost function applicable up to 1,000t/d. A curvilinear function, described in Section 9.3, was obtained but this will contain more inherent variability since some of the literature-derived costs may not conform to the base case used in this work.

The total cost scale factors derived from the cost models presented in Table 9.1a improve upon those found in the present literature, which are either not directly based on waste management data or produced only from empirical reasoning (Table 9.5). The factors of 0.75 and 0.74 from this work fall mid-way between those produced by the other sources cited, i.e. approximately 6% and 19% lower than Wilson (1981) and Midwest Research Institute (1973) respectively, and 25% above Grant and Cooper (1981).

Scale factors were also identified for site survey, access road and other preparation costs, however no similar data was found in the literature and hence no comparison was possible for these. Reasonably large economies were expected for the access road and preparation expenditures. The unit cost of access road construction declines rapidly with throughput above approximately 200 t/d where a similar two-lane, good quality highway was costed for all sites. Site preparation also exhibits a large economy primarily due to the estimated length of perimeter fencing dropping markedly at sites with large volumes of airspace. (A supporting argument for this assumption is presented in Section 9B.1.4, Appendix 9B.)

Table 9.5 LANDFILL DISPOSAL CAPITAL COST SCALE FACTORS

Source and Range / Component	This Work (t/d)			Midwest Research Institute (1973)	Wilson (1981)	Grant and Cooper (1981)
	10-200	201-500	10-1000			
Site Survey		0.74				
Access Road	0.88	0.66				
Other Preparations	0.44	0.44				
Total Capital Cost		0.75	0.74	0.93[1]	0.80	0.60[2]

[1] Based on highly variable Canadian data.

[2] Based on U.S. data.

9.3.4 Amortisation Charges

All capital costs except site survey are amortised over the lifetimes laid down in the base case, i.e. mobile plant 5 years; buildings and access roads 20 years. Detailed calculations of the capital charges for selected sizes of site are listed in Table 9.6. Capital charges are jointly the largest operating cost along with maintenance labour at between 31 and 35% of the total. As found for collection, bulk transport and transfer operations the landfill total operating cost is highly sensitive to variations in this expenditure; for example:

100t/d landfill (R_s = 0.373)
A 25% increase in capital charges represents a 9.7% increase in total operating cost.

500t/d landfill (R_s = 0.343)
A 25% increase in capital charges represents an 8.9% increase in total operating cost.

9.4 OPERATING COST DISCUSSION

The component and total costs for the same sizes of site considered in the capital cost discussion were calculated from their base case cost functions as listed in Table 9.1b (Table 9.7). The corresponding percentage values and relative sensitivities are given in Tables 9.8 and 9.9 respectively. Information was only received from local authorities for sites handling up to 500t/d this, combined with an absence of published data for larger landfills, prevented the derivation of an extended cost function up to 1,000t/d in a similar manner to that produced for capital costs. If necessary however, in the absence of better data, one could conceivably extrapolate the "up to 500t/d" total cost function to calculate an approximate value for larger operations.

Table 9.6 ANNUAL CAPITAL CHARGES FOR SELECTED SIZES OF LANDFILL SITE (1981£/year)

Daily Tonnage	10	25	50	75	100	125	150	175	200	250	300	350	400	450	500
Buildings and Other Prep. Access Road	14051	20788	30261	38859	46990	54815	62417	69849	77143	69060	77881	86373	94603	102616	110446
Mobile Plant	15000	15000	20000	30000	50000	50000	65000	80000	85000	90000	90000	95000	95000	110000	110000
Annual Charges (1): Buildings, Prep. Access Road (over 20y)	2122	3139	4569	5867	7095	8276	9424	10546	11648	10427	11759	13041	14284	15494	16676
Annual Charges (1): Mobile Plant (over 5y)	4369	4369	5826	8739	14565	14565	18934	23303	24760	26216	26216	27673	27673	32042	32042
Annual Charges (1): TOTAL	6491	7508	10395	14606	21660	22841	28358	33849	36408	36643	37975	40714	41957	47536	48718

(1) At 14% p.a.

Table 9.7 Landfill Disposal Base Case Operating Costs (1981£/year)

(RANGE 10 TO 500 TONNES PER DAY)

T/D	10.	25.	50.	75.	100.	150.	200.	250.	300.	350.	400.	450.	500.
VEH.FUEL	1143.0	1309.5	1587.0	1864.5	2142.0	2697.0	3252.0	3807.0	4362.0	4917.0	5472.0	6027.0	6582.0
V.MT.LAB	997.9	1521.0	2092.2	2521.2	2877.9	3468.0	3958.7	4386.6	4770.4	5120.9	5445.3	5748.5	6034.0
V.SPARES	330.0	438.0	618.0	798.0	978.0	1338.0	1698.0	2058.0	2418.0	2778.0	3138.0	3498.0	3658.0
V.TYRES	2006.0	2217.5	2570.0	2922.5	3275.0	3980.0	4685.0	5390.0	6095.0	6800.0	7505.0	8210.0	8915.0
VEH.LIC	193.0	203.5	221.0	238.5	256.0	291.0	326.0	361.0	396.0	431.0	466.0	501.0	536.0
LABOUR	6900.0	13800.0	13800.0	13800.0	13800.0	20700.0	20700.0	20700.0	26500.0	26500.0	26500.0	26500.0	26500.0
SUPER.LAB	890.0	1790.0	1790.0	1790.0	1790.0	2680.0	2680.0	2680.0	5300.0	5300.0	5300.0	5300.0	5300.0
MATERIALS	50.0	125.0	250.0	375.0	500.0	750.0	1000.0	1250.0	1500.0	1750.0	2000.0	2250.0	2500.0
SERVICES	35.2	87.7	175.2	262.7	350.2	187.8	250.3	312.8	375.3	437.8	500.3	562.8	625.3
BUILD.MT	200.0	200.0	200.0	200.0	500.0	500.0	800.0	800.0	1100.0	1100.0	1400.0	1400.0	1400.0
ADMIN	1090.5	1740.1	2478.0	3047.3	3528.8	4339.5	5025.2	5630.9	6179.6	6685.0	7156.2	7599.2	8018.7
RENT	355.0	887.5	1775.0	2662.5	3550.0	5325.0	6260.0	7825.0	9390.0	10955.0	12520.0	14085.0	15650.0
RATES	65.0	162.5	325.0	487.5	650.0	975.0	1060.0	1325.0	1590.0	1855.0	2120.0	2385.0	2650.0
SUM.TOTAL (EXCLUDING CAPITAL CHARGES)	14255.6	24482.3	27681.4	30969.6	34197.9	47231.3	51695.2	56526.3	69976.3	74629.8	79522.6	84066.5	88569.0
CP.CHARGE	6490.7	7507.9	10394.8	14605.7	21659.0	28357.6	36406.7	36642.5	37974.4	40713.1	41955.7	47534.8	48717.0
SUM.TOTAL (INCLUDING CAPITAL CHARGES)	20746.3	31990.2	38276.2	45575.3	55856.9	75588.9	88101.9	93168.8	107950.7	115342.9	121478.5	131601.3	137286.0

Table 9.8 Landfill Disposal Base Case Operating Cost Percentage Values

(INCLUDING CAPITAL CHARGES)

T/D	10.	25.	50.	75.	100.	150.	200.	250.	300.	350.	400.	450.	500.
VEH.FUEL	5.5	4.1	4.1	4.1	3.8	3.8	3.7	4.1	4.0	4.3	4.5	4.6	4.8
V.MT.LAB	4.9	4.8	5.5	5.5	5.2	4.6	4.5	4.7	4.4	4.4	4.5	4.4	4.4
V.SPARES	1.6	1.4	1.6	1.8	1.6	1.8	1.9	2.2	2.2	2.4	2.6	2.7	2.8
V.TYRES	9.7	6.9	6.7	6.4	5.9	5.3	5.3	5.8	5.0	5.9	6.2	6.2	6.5
VEH.LIC	0.9	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
LABOUR	33.3	43.1	36.1	30.3	24.7	27.4	23.5	22.2	24.5	23.0	21.8	20.1	19.3
SUPER.LAB	4.3	5.6	4.7	3.9	3.2	3.5	3.0	2.9	4.9	4.6	4.4	4.0	3.9
MATERIALS	0.2	0.4	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8
SERVICES	0.2	0.3	0.5	0.6	0.6	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5
BUILD.MT	1.0	0.6	0.5	0.4	0.9	0.7	0.9	0.9	1.0	1.0	1.2	1.1	1.0
ADMIN	5.3	5.4	6.5	6.7	6.3	5.7	5.7	6.0	5.7	5.8	5.9	5.8	5.8
RENT	1.7	2.8	4.6	5.8	6.4	7.0	7.1	8.4	8.7	9.5	10.3	10.7	11.4
RATES	0.3	0.5	0.8	1.1	1.2	1.3	1.2	1.4	1.5	1.6	1.7	1.8	1.9
CP.CHARGE	31.3	23.5	27.2	32.0	38.8	37.5	41.3	39.3	35.2	35.3	34.5	36.1	35.5
SUM.TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 9.9 Landfill Disposal Base Case Capital Cost Relative Sensitivities

SENSITIVITY RANGES CONSIDERED
X OR / 2.00 : FUEL, BUILDING MAINT, SITE RENT
X OR / 1.50 : VEHICLE MAINT LABOUR, MANUAL & SUPERVISORY LABOUR, DEPT. ADMIN., SITE RATES, SERVICES, CAPITAL CHARGES
X OR / 1.25VEH.SPARES & TYPES, VEH.INSURANCE & LICENCES, MATERIALS (EXCLUDING COVER)

RS VALUES

SEE COMMENT IN CAPITAL COST SECTION

T/D	10.	25.	50.	75.	100.	150.	200.	250.	300.	350.	400.	450.	500.
VEH.FUEL	0.055	0.041	0.041	0.041	0.038	0.036	0.037	0.041	0.040	0.042	0.045	0.046	0.048
V.MT.LAB													
1.10	0.048	0.047	0.054	0.055	0.051	0.046	0.045	0.047	0.044	0.044	0.045	0.043	0.044
1.25	0.048	0.047	0.054	0.055	0.051	0.045	0.044	0.047	0.044	0.044	0.044	0.043	0.043
1.50	0.047	0.046	0.053	0.054	0.050	0.045	0.044	0.046	0.043	0.043	0.044	0.043	0.043
V.SPARES	0.016	0.014	0.016	0.017	0.017	0.018	0.019	0.022	0.022	0.024	0.026	0.027	0.028
V.TYRES	0.096	0.069	0.067	0.064	0.058	0.052	0.053	0.058	0.056	0.059	0.061	0.062	0.065
VEH.LIC	0.009	0.006	0.006	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
LABOUR	0.322	0.414	0.348	0.294	0.241	0.267	0.230	0.217	0.240	0.225	0.213	0.197	0.189
SUPER.LAB	0.043	0.056	0.047	0.039	0.032	0.035	0.030	0.029	0.049	0.046	0.043	0.040	0.038
MATERIALS	0.002	0.004	0.007	0.008	0.009	0.010	0.011	0.013	0.014	0.015	0.016	0.017	0.018
SERVICES	0.002	0.003	0.005	0.006	0.006	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.005
BUILD.MT	0.010	0.006	0.005	0.004	0.009	0.007	0.009	0.009	0.010	0.010	0.012	0.011	0.010
ADMIN													
1.10	0.052	0.054	0.064	0.066	0.063	0.057	0.057	0.060	0.057	0.058	0.059	0.057	0.058
1.25	0.052	0.054	0.064	0.066	0.062	0.057	0.056	0.060	0.056	0.057	0.058	0.057	0.056
1.50	0.051	0.053	0.063	0.065	0.061	0.056	0.055	0.059	0.056	0.056	0.057	0.056	0.057
RENT	0.017	0.028	0.046	0.056	0.063	0.070	0.071	0.083	0.086	0.094	0.102	0.106	0.113
RATES	0.003	0.005	0.008	0.011	0.012	0.013	0.012	0.014	0.015	0.016	0.017	0.018	0.019
CP.CHARGE	0.303	0.229	0.264	0.311	0.373	0.362	0.397	0.378	0.340	0.341	0.334	0.349	0.343

9.4.1 Principal Findings

1. Manual labour is the largest expenditure at small sites (≤ 50t/d) fluctuating between 30 and 40% of the total cost. At larger sites this component is superceded by capital charges reflecting the increased investment required to establish and operate a controlled landfill with high refuse inputs.

2. Together manual labour and capital charges account for between 54 and 64% of the total operating cost.

3. When the individual vehicle running costs are combined they represent a reasonably large expenditure, ranging from 19 to 22%. Site rent at operations > 350t/d is also a significant expenditure accounting for about 10% of the total cost.

4. All other expenditures are relatively minor.

5. The base case total operating costs are most sensitive to capital charges and manual labour together with site rent at larger sites. For example:

25t/d Landfill

(R_s = 0.414)	Labour	A 25% increase represents an 11% increase in total cost
(R_s = 0.219)	Capital Charges	A 25% increase represents a 5.9% increase in total cost
(R_s = 0.028)	Site Rent	A 25% increase represents a 0.7% increase in total cost

400t/d Landfill

(R_s = 0.213)	Manual Labour	A 25% increase represents a 5.5% increase in total cost
(R_s = 0.334)	Capital Charges	A 25% increase represents an 8.6% increase in total cost
(R_s = 0.102)	Site Rent	A 25% increase represents a 2.6% increase in total cost

6. The total cost is also moderately sensitive to the combined vehicle running cost, though not to the individual components; for example:

200t/d Landfill

(R_s = 0.037)	Fuel	A 25% increase represents a 0.9% increase in total cost
(R_s at $\overset{\times}{\div}$ 1.50 = 0.044)	Maintenance Labour	A 25% increase represents a 1.1% increase in total cost
(R_s = 0.019)	Spares	A 25% increase represents a 0.5% increase in total cost
(R_s = 0.053)	Tyres and Wheels	A 25% increase represents a 1.3% increase in total cost
Combined Vehicle Running Cost		A 25% increase represents a 3.9% increase in total cost

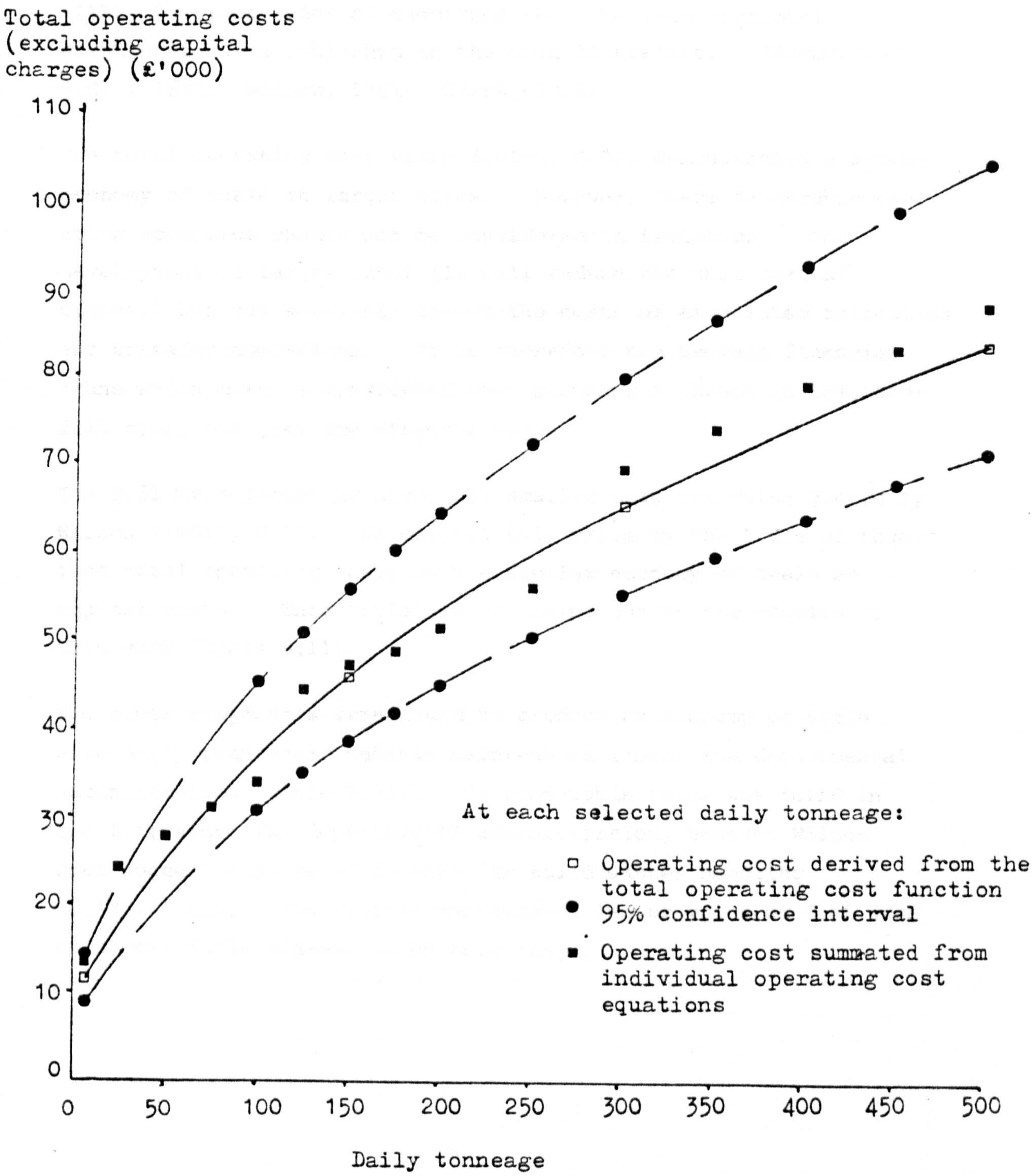
It is questionable if all running cost components would vary in unison and it is therefore doubtful if the sensitivity to the combined cost would ever be fully realised. Fluctuations involving just one or two of these components has an insignificant effect on the total cost including, perhaps surprisingly, fuel costs given the widespread publicity of the effect of fuel prices recently.

Some of the other component costs are highly site-specific, being influenced by local circumstances such as drainage, leachate quality, cover material and available lifetime. It is therefore difficult to interpret the sensitivity of these. However, the effects of their variation from the base case are explored in later sections.

9.4.2 Total Operating Costs and Economies of Scale

The total costs are explained most satisfactorily by a curvilinear relationship with daily tonneage (R^2 = 0.96) rather than total capacity as one would intuitively expect. This cost function is graphically reproduced in Figure 9.2 together with its 95% confidence interval. Thus, it is evident the operating costs are most strongly influenced by the daily tonneage handled and not the physical size or capacity of the site itself. This finding is significant given the trend towards bigger landfills where from an economic viewpoint this development in itself will not reduce the unit cost markedly. Financial savings will only occur if the new landfill handles a larger quantity of refuse each day.

Fig 9.2 Landfill disposal base case total operating cost (excluding capital charges) and the 95% confidence interval



In Table 9.10 the base case costs per tonne are given for selected sizes of site, together with their 95% C.I. These values are within the same order of magnitude than the less rigorously compiled figures published in the open literature. (Humberside C.C. , 1981; Wilson, 1981; CIPFA, 1982).

The total operating cost scale factor, 0.51, demonstrates a strong economy of scale at larger sites. However, these favourable operating economics should not be considered in isolation. The development of larger landfills will reduce the unit cost of disposal but may adversely affect the costs of associated collection and transfer operations. It is therefore the overall financial scene which must be considered when planning a change in the landfill size, not just the disposal costs.

The 0.51 scale factor is about 40% smaller than the value quoted by Wilson (1981), 0.71. He derived this value by the "rule of thumb" that total operating costs have a similar economy of scale as capital costs. This "rule" is not borne out by the results of this work (Table 9.11).

Two other components were found to produce an economy of scale with daily tonneage; vehicle maintenance labour and departmental administration. (Table 9.11). No comparable value was found in the literature for departmental administration, however Wilson does suggest a range of factors for solid wastes handling (0.13 - 1.00). The vehicle maintenance labour value of 0.46 from this work falls mid-way along this range.

Table 9.10 COMPARISON BETWEEN THE BASE CASE UNIT OPERATING COSTS AND PUBLISHED VALUES

	10	25	50	75	100	150	200	250	300	350	400	450	500
Base Case Operating Cost (£/t)[1]	8.28	5.12	3.06	2.43	2.24	2.02	1.76	1.49	1.44	1.32	1.22	1.17	1.10
± 95% CI (£/t)	1.00	0.50	0.40	0.30	0.24	0.20	0.17	0.16	0.13	0.12	0.12	0.11	0.10
Wilson (1981)									2.20[2]				
Humberside CC (1981)	←			≃ £6.00		to		≃ £3.00		→			
	Non-Metropolitan Counties (England)						Mean cost all sizes of operation					£2.46	
CIPFA	Metropolitan Counties (England)						"					£2.45	
(1982)	GLC						"					£9.28	
	Urban Districts (Wales)						"					£2.76	
	Rural Districts (Wales)						"					£1.44	
	Cardiff											£0.56	
	All Authorities, all sizes of site											£2.47	

1. Excluding capital charges.
2. Excluding cover material.

Table 9.11 LANDFILL DISPOSAL OPERATING COST SCALE FACTORS

Component \ Range	This Work (10-500 t/d)	Wilson (1981)
Vehicle Maintenance Labour	0.46	0.13-1.00
Departmental Administration	0.51	
Total operating Costs (2)	0.51 (1)	0.71

(1) For comparison: Total Capital Cost scale factors at other ranges of daily tonnage:

10-200 t/d, 1.00; 200-500 t/d, 0.75; 10-100 t/d, 0.74.

(2) Excluding capital charges.

9.5 EXTENSIONS TO THE LANDFILL BASE CASE

Several highly site-specific aspects of landfilling were not considered in the base case. However, for a realistic appraisal of a landfill operation these aspects should be included. This is achieved by first calculating the base case unit cost and then adding to or subtracting from it the cost of each extension. The extensions considered in this study are:

- Purchased intermediate cover
- No cover
- Cell construction
- Drainage and leachate treatment
- Gas alleviation and collection
- Interest rates
- Landfill revenues
- Site lifetime.

Four base cases have been calculated. The first, for untreated refuse, is based on the operating costs in Table 9.7. These values however do not directly apply to landfilling baled, wet pulverised, or dry pulverised refuse. This is overcome by modifying the unit cost for untreated refuse. These modifications are only minor, principally concerning site vehicles and airspace costs, and their calculations are fully documented in Appendix 9.E.

The extensions considered are typical of those encountered when appraising and comparing landfill operations. Their derivations are discussed in detail in the following sections and summarised for selected daily tonneages in Table 9.12. The largest effect on the base case is produced where major leachate treatment facilities have to be installed on site. Between £3 to £5 is added to the landfill cost/tonne on "containment" sites and about £1 on "dispersal" sites.

Further significant increases in cost arise where large-scale drainage and gas collection measures are required. The effect of changes in interest rates, site lifetime or "no cover" operations were found to be less significant by comparison. Cell construction and soil cover purchase are both similar in cost at approximately one-third of the major drainage or gas engineering expenditures. Soil cover at £1.30 per tonne is more expensive than using foam cover and disposal revenues received by a site able 9.12 SUMMARY OF THE LANDFILL BASE CASE EXTENSIONS EXPRESSED AS UNIT COSTS (£/t)

(t/y)	(2500)	(6250)	(12500)	(18750)	(25000)	(37500)	(50000)	(62500)	(75000)	(87500)	(100000)	(112500)	(125000)	comments
t/d	10	25	50	75	100	150	200	250	300	350	400	450	500	
ounded off Unit Op. Costs (Cover on Site):														
Base Case - Unweighted	8.28	5.12	3.06	2.43	2.24	2.02	1.76	1.49	1.44	1.32	1.22	1.17	1.10	)
Baled	-	-	2.97	2.20	1.81	1.72	1.47	1.32	1.30	1.18	1.09	1.08	0.02	) Inc. capital charges
Dry Pulverised	-	5.06	3.01	2.38	2.19	1.98	1.75	1.48	1.43	1.31	1.20	1.16	1.09	) @ 14% p.a.
Wet Pulverised	-	5.02	2.98	2.35	2.16	1.98	1.73	1.52	1.41	1.28	1.18	1.19	1.07	)
DD OR SUBTRACT FROM BASE CASE UNIT COSTS ABOVE														
OIL COVER -														
Options 2a, 2b	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	
2c	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	
3a, 3b	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	
3c, 4, 5	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	
OAM COVER -														
Options 2a	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.o7	0.17	0.17	0.17	0.17	0.17	
2b	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	
2c	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	
3a	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	
3b	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	
3c	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	
4/5	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	
ELL CONSTRUCTION														
Low	-	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	
Medium	-	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	
High	-	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	
RAINAGE MEASURES														
Low	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Medium	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	
High	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	
EACHATE MEASURES														
Low	1.07	0.61	0.49	0.40	0.35	0.29	0.25	0.23	0.21	0.19	0.18	0.17	0.16	
Medium	3.65	2.33	1.66	1.36	1.18	0.97	0.84	0.75	0.69	0.64	0.60	0.56	0.54	
High	9.71	6.61	4.94	4.16	3.69	3.11	2.76	2.51	2.33	2.18	2.06	1.96	1.88	
O COVER OPERATION (aled and pulverised efuse only)														
Baled	-	-	0	0	0	(0.24)	(0.20)	(0.19)	(0.17)	(0.13)	(0.12)	(0.13)	(0.12)	) Reduction in respective
Dry Pulverised	-	0	0	0	0	(0.12)	(0.12)	(0.10)	(0.08)	(0.07)	(0.05)	(0.07)	(0.06)	) unit op. costs for which
Wet Pulverised	-	0	0	0	0	(0.11)	(0.12)	(0.09)	(0.08)	(0.06)	(0.06)	(0.07)	(0.06)	) 'on-site' cover assumed.
AS MEASURES (Alleviation and Collection)														
Low	1.55	0.62	0.32	0.21	0.16	0.11	0.08	0.07	0.11	0.09	0.08	0.07	0.07	) Revenues not considered
Medium	3.10	1.24	0.64	0.42	0.32	0.22	0.16	0.14	0.22	0.18	0.16	0.14	0.14	) in this extension.
High	-	-	-	-	-	-	1.20	1.09	1.02	0.97	0.93	0.90	0.88	)
EVENUES														
Low	(0.83)	(0.51)	(0.31)	(0.24)	(0.22)	(0.20)	(0.18)	(0.15)	(0.14)	(0.13)	(0.12)	(0.12)	(0.11)	
Medium	(2.07)	(1.28)	(0.27)	(0.61)	(0.58)	(0.50)	(0.44)	(0.37)	(0.36)	(0.33)	(0.30)	(0.23)	(0.27)	
High	(6.21)	(3.84)	(2.31)	(1.83)	(0.68)	(1.50)	(1.32)	(1.11)	(1.08)	(0.99)	(0.90)	(0.87)	(0.82)	
NTEREST RATES (ntreated Refuse nly - Base Case 14%)														
5%	(0.76)	(0.58)	(0.27)	(0.24)	(0.26)	(0.23)	(0.21)	(0.16)	(0.15)	(0.14)	(0.13)	(0.12)	(0.12)	) Resultant unit costs for
10%	(0.32)	(0.18)	(0.12)	(0.12)	(0.12)	(0.11)	(0.10)	(0.08)	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	) wet & dry pulverised and
20%	0.60	0.29	0.20	0.18	0.18	0.16	0.16	0.12	0.11	0.09	0.09	0.09	0.08	) baled landfills will be marginally lower.
TE LIFETIME (ntreated refuse nly - Base Case 20y)														
5 years	(0.16)	(0.14)	(0.12)	(0.12)	(0.12)	(0.11)	(0.10)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	) Resultant unit costs for
10 years	(0.12)	(0.11)	(0.10)	(0.10)	(0.10)	(0.10)	(0.09)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	) wet & dry pulverised and
15 years	0.32	0.46	(0.01)	(0.04)	(0.05)	(0.06)	(0.06)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)	) baled landfills will be marginally lower.

are by no means uniform. The pricing policies in authorities for the disposal of commercial waste are highly variable. Some authorities only charge the marginal cost incurred to dispose of each delivered load. The fixed costs being borne by the site's budget where in effect commercial disposal is subsidised by the council. Elsewhere the pricing policy is designed to maximise income by charging the full disposal cost and possibly also a profit margin. A "high charge" policy is also pursued where an operator is seeking to preserve landfill lifetime by choking-off demand. The high revenue category in Table 9.12 also includes income from landfill gas sales.

9.5.1 Purchased Intermediate Cover

	Soil Cover Options	Weight Ratio - Soil: Refuse[1]
1.	All cover on site BASE CASE	-
2.	Half cover required is purchased, half on-site	
	a. - Rubber tyred vehicle	0.17
	b. - Tracked vehicle	0.17
	c. - Steel-wheeled vehicle	0.15
3.	All cover purchased, 'Over-the-top' emplacement	
	a. - Rubber-tyred vehicle	0.34
	b. - Tracked vehicle	0.34
	c. - Steel-wheeled vehicle	0.30
4.	All cover purchased, Onion Skinning	0.30
5.	All cover purchased, Horizontal layering	0.30[2]

1. After Campbell and Parker, 1980)
2. After Parker (Private communication, 1982).

The quantity of cover purchased depends on how much inert waste is received and how much suitable material is won on-site.

For any daily tonneage of refuse the weight of purchased cover can be calculated by multiplying the "weight ratio" with the unit cost of cover. The latter having been taken as £1.30/t (Mean of 13 cases, SD £0.81/t) including both the material itself and haulage to landfill.

The cost of purchased soil cover for each option is detailed in Table 9.13a with the actual and percentage increases over the base case given in Table 9.13b. Where all cover must be purchased this expenditure can increase the operating cost by up to 40%, with larger sites being most affected.

The total operating costs were subsequently divided by the annual tonneages to give a corresponding cost per tonne (Table 9.12).

	Foam Cover options	Refuse Density Achieved by Emplacement Vehicle, t/m^3 *
1.	All cover on-site BASE CASE	-
2.	Half cover is required to be purchased, half on-site	
	a. - Rubber tyred vehicle	0.50
	b. - Tracked vehicle	0.55
	c. - Steel-wheeled vehicle	0.65
3.	All cover purchased, 'Over-the-top' Emplacement	
	a. - Rubber tyred vehicle	0.50
	b. - Tracked vehicle	0.55
	c. - Steel-wheeled vehicle	0.65
4. and 5.	All cover purchased, Thin layering methods	0.90

* Based on Campbell and Parker, 1980.

Foam cover is measured in area. Therefore, area to be covered is given by:

$$\frac{t/d}{\text{refuse density}} = m^3/d \div 3m \text{ lift (assumed)} = m^2/d$$

$$m^2/d \times 250d = m^2/\text{year}.$$

Foam costs of approximately £0.50/m^2 for materials and equipment are quoted by two manufacturers. No labour cost is included since foam application is assumed to be incorporated into the duties of the staff currently on-site. The cost of purchased foam cover for each option is detailed in Table 9.14a, and the actual and percentage increase over the base case each option represents is given in Table 9.14b.

Table 9.13a COST OF PURCHASED INTERMEDIATE SOIL COVER @ £1.30/t INCLUDING TRANSPORT (1981£/t)

Cover Options	Selected Tonnages t/d (t/y)												
	10 (2500)	25 (6250)	50 (12500)	75 (18750)	100 (25000)	150 (37500)	200 (50000)	250 (62500)	300 (75000)	350 (87500)	400 (100000)	450 (112500)	500 (125000)
1 (Base case)	0	0	0	0	0	0	0	0	0	0	0	0	0
2 a, b	553	1381	2763	4144	5525	8288	11050	13813	16575	19338	22100	24863	27625
c	488	1219	2438	3656	4875	7313	9750	12188	14625	17063	19500	21938	24375
3 a, b	1105	2763	5525	8288	11050	16575	22100	27625	33150	38675	44200	49725	55250
c, 4, 5	975	2438	4875	7313	9750	14625	19500	24375	29250	34125	39000	43875	48750

Table 9.13b SOIL COVER - INCREASE IN TOTAL OPERATING COST AND % INCREASE ON BASE CASE

Cover Options Revised total cost (% increase over base case		Selected Tonnages t/d (t/y) 10 (2500)	25 (6250)	50 (12500)	75 (18750)	100 (25000)	150 (37500)	200 (50000)	250 (62500)	300 (75000)	350 (87500)	400 (100000)	450 (112500)	500 (125000)
1*	£	20747	31993	38276	45578	55858	75589	88003	93170	107951	115344	121479	131602	137287
	%	0	0	0	0	0	0	0	0	0	0	0	0	0
2 a } b }	£	21300	33374	41039	49722	61383	83877	99053	106983	124526	134682	143579	156465	164912
	%	2.7	4.3	7.2	9.1	9.9	11.0	12.6	14.8	15.4	16.8	18.2	18.9	20.1
c	£	21235	33212	40714	49234	60733	82902	97753	105358	122576	132407	140979	153540	161662
	%	2.4	3.8	6.4	8.0	8.7	9.7	11.1	13.1	13.5	14.8	16.1	16.7	17.8
3 a } b }	£	21852	34756	43801	53866	66908	92164	110103	120795	141101	154019	165679	181327	192537
	%	5.3	8.6	14.4	18.2	19.8	21.9	25.1	29.7	30.7	33.5	36.4	37.8	40.2
c } 4 } 5 }	£	21722	34431	43151	52891	65608	90214	107503	117545	137201	149469	160479	175477	186037
	%	4.7	7.6	12.7	16.0	17.5	19.3	22.2	26.2	27.1	29.6	32.1	33.3	35.5

* Estimated total (Base case)

For subsequent purposes these revised total operating costs are rounded off to the nearest £100.

Table 9.14a COST OF PURCHASED INTERMEDIATE FOAM COVER @ £0.50/m² INCLUDING MATERIALS AND EQUIPMENT (1981£)

Cover Options	Selected Tonnages t/d (t/y)												
	10 (2500)	25 (6250)	50 (12500)	75 (18750)	100 (25000)	150 (32500)	200 (50000)	250 (62500)	300 (75000)	350 (87500)	400 (100000)	450 (112500)	500 (125000)
1 (base case)	0	0	0	0	0	0	0	0	0	0	0	0	0
2a	417	1041	2083	3125	4167	6250	8333	10417	12500	14583	16667	18750	20833
b	379	947	1894	2841	3788	5682	7576	9470	11364	13258	15152	17045	18939
c	321	801	1603	2404	3205	4808	6410	8013	9615	11218	12821	14423	16026
3a	833	2083	4167	6250	8333	12500	16667	20833	25000	29167	33333	37500	41667
b	758	1894	3788	5682	7575	11364	15152	18939	22727	26515	30303	34091	37879
c	641	1603	3205	4808	6410	9615	12821	16026	19231	22436	25641	28846	32051
4 and 5	463	1157	2315	3472	4630	6944	9259	11574	13889	16204	18519	20833	23148

Assuming a reduction of 5% of the airspace required per year where all cover purchased and 2½% where only half purchased there will be approximately a 5% or 2½% reduction in appropriate site rent.

Less 5% site rent (18) (44) (88) (133) (178) (266) (313) (391) (470) (548) (626) (704) (783)

Less 2½% site rent (9) (22) (44) (67) (84) (133) (157) (196) (235) (274) (313) (352) (392)

These reductions in rent have been included in Table 9.14b.

Table 9.14b FOAM COVER - INCREASE IN TOTAL OPERATING COST AND PERCENTAGE INCREASE OVER BASE CASE

Cover Options		Selected Tonnages t/d (t/y)												
		10 (2500)	25 (6250)	50 (12500)	75 (18750)	100 (25000)	150 (32500)	200 (50000)	250 (62500)	300 (75000)	350 (87500)	400 (100000)	450 (112500)	500 (125000)
1 (base case)	£	20747	31993	38276	45578	55858	75589	88003	93170	107951	115344	121479	131602	137287
	%	0	0	0	0	0	0	0	0	0	0	0	0	0
2a	£	21155	33012	40315	48636	59941	81706	96179	103391	120216	129653	137833	150000	157728
	%	2.0	3.2	5.3	6.7	7.3	8.1	9.3	11.0	11.4	12.4	13.5	14.0	14.9
b	£	21117	32918	40126	48352	59562	81138	95422	102444	119080	128328	136318	148295	155834
	%	1.8	2.9	4.8	6.1	6.6	7.3	8.4	10.0	10.3	11.3	12.2	12.7	13.5
c	£	21059	32772	39835	47915	58979	80264	94256	100987	117331	126288	133987	145673	152921
	%	1.5	2.4	4.1	5.1	5.6	6.2	7.1	8.4	8.7	9.5	10.3	10.7	11.4
3a	£	21562	34032	42355	51695	64013	87823	104357	113612	132481	143963	154186	168398	178171
	%	3.9	6.4	10.7	13.4	14.6	16.2	18.6	21.9	22.7	24.8	26.9	28.0	29.8
b	£	21487	33843	41976	51127	63255	86687	102842	111718	130208	141311	151156	164989	174383
	%	3.6	5.8	9.7	12.2	13.2	14.7	16.7	19.9	20.6	22.5	24.4	25.4	27.0
c	£	21370	33552	41393	50253	62090	84938	100511	108805	126712	137232	146494	159744	168555
	%	3.0	4.9	8.1	10.3	11.2	12.4	14.2	16.8	17.4	19.0	20.6	21.4	22.8
4 and 5	£	21192	33106	40503	48917	60310	82267	96949	104353	121370	131000	139372	151731	159652
	%	2.1	3.5	5.8	7.3	8.0	8.8	10.2	12.0	12.4	13.6	14.7	15.3	16.3

For subsequent purposes these revised total operating costs are rounded to the nearest £100.

Assuming the cost of foam cover at £0.50/m^2 is not over-optimistic, it is a far cheaper form of intermediate cover than the purchasing of soil at the current rate of £1.30/t. The use of soil cover is only economic if it is won cheaply on-site or can be bought in for less than about £1.00/t.

During this research observations were made in Britain and Hong Kong on foam covering, together with comments from manufacturers and local authorities with experience of using synthetic cover materials. A brief list of advantages and disadvantages is outlined:

ADVANTAGES of synthetic cover over soil cover:

1. Requires less volume in the landfill than soil and will compress down to 1-2cm when the next lift is emplaced.
2. At landfills where purchased soil cover is greater than £0.98/ delivered tonne then synthetic cover is more favourable on economic grounds, providing no additional staff are required.
3. Synthetic cover is simple to apply to the refuse.

DISADVANTAGES

Operational Grounds

1. The foam takes approximately five minutes to harden. In windy weather the newly applied material easily becomes airborne and blown around the site "like soap suds".
2. Site workmen are reluctant to use "sophisticated" equipment and chemicals without additional remuneration.
3. Synthetic cover cannot be used in heavy rain since this weather inhibits the hardening process.
4. This material does not produce a firm running surface over the emplaced refuse.

Environmental Grounds

5. There is a reluctance by local authorities, probably strengthened by the efforts of environmentalists, to add further chemicals to the environment.

6. The brilliant white colour is visible from long distances and draws attention to landfill operations rather than away from them. One would have expected a colour which blends more easily into the background countryside, e.g. earth brown or dark green.

7. Medical queries over a major constituent of the foam, urea formaldehyde, have been raised recently. It is claimed this compound can adversely affect people with respiratory disorders such as asthma.

9.5.2 No Cover used on Site

This extension to the base case is only considered for baled or pulverised waste landfills which some operators claim do not require cover. It is derived by excluding the cost of the support vehicle for sites handling over 125t/d. Details on the calculations are given in Appendix 9.E and the resultant unit cost reductions are included in Table 9.12.

9.5.3 Cell Construction

Most sites emplace refuse using the progressive slope (base case) method. However, at an increasing number of operations large earth bunds are constructed to compartmentalise the site into "cells" with each holding between three and six months' waste. Emplacement in cells confer the advantages of minimising the risk of fire spreading across the site and enable a site to be completed and capped in sections so reducing rainfall ingress and leachate production.

The cost of cell construction is variable between sites for a number of reasons:

1. The sizes of cell constructed vary widely.
2. The materials of construction are different.
3. In some places material can be won on site, elsewhere it must be purchased.
4. The cost of hiring construction plant and men varies between different parts of the country.

The cost of construction was obtained for five sites. Regression analysis failed to show a satisfactory relationship between cost and daily tonneage or site capacity.

The mean of the five costs per tonne was found to be significant at the 5% level:

Mean = £0.29/t   SD = $\pm$ £0.12/t.

The first edition of the "National Schedule of Rates", February 1982, suggests a figure for grading and excavation of £0.36/t. This is consistent to that derived above.

In order to overcome some of the variability between sites three costs for cell construction have been used. Mean (intermediate cost) £0.29/t;
High cost = Mean + 1 SD = £0.41/t
Low cost = Mean - 1 SD = £0.17/t

In any evaluation which includes cell construction costs it is necessary for one to use discretion and judgement when determining which of the unit costs to apply. An evaluation of each of the cell construction costs is given in Table 9.15 and the sensitivity of the base case total operating cost to each option is indicated below:

Cell construction:	Low option	3 to 15% of base case
	High option	8 to 37% of base case (Small to large sites)

9.5.4 Drainage and Leachate Measures

The base case assumes neither of these measures are necessary. As was found with cell construction the drainage and leachate treatment measures are very site-specific. Therefore in order to adequately consider them three unit costs were calculated i.e. high, intermediate and low, representing the broad range of methods available. The cost category into which each method should be placed are discussed below.

Table 9.15 CELL CONSTRUCTION COSTS AT SELECTED DAILY TONNAGES

	Cell construction cost	Daily Tonnage											
		25	50	75	100	150	200	250	300	350	400	450	500
(1)	0.17 (-1SD)	1063	2125	3188	4250	6375	8500	10625	12750	14875	17000	19125	21250
(2)		33056	40401	48766	60108	81964	96503	103795	120701	130219	138479	150727	158537
(3)		5.29	3.23	2.60	2.40	2.19	1.93	1.66	1.61	1.49	1.38	1.34	1.27
(1)	0.29 (Mean)	1813	3625	5438	7250	10875	14500	18125	21750	25375	29000	32625	36250
(2)		33806	41901	51016	63108	86464	102503	111295	129701	140719	150479	164227	173537
(3)		5.41	3.35	2.72	2.52	2.31	2.05	1.78	1.73	1.61	1.50	1.46	1.39
(1)	0.41 (+1SD)	2563	5125	7688	10250	15375	20500	25625	30750	35875	41000	46125	51250
(2)		34556	43401	53266	66108	90964	108503	118795	138701	151219	162479	177727	188537
(3)		5.53	3.47	2.84	2.64	2.43	2.17	1.90	1.85	1.73	1.62	1.58	1.51
(2)	Base case for comparison	32000	38300	45600	55900	75600	88000	93200	108000	115300	121500	131600	137300
(3)		5.12	3.06	2.43	2.24	2.02	1.76	1.49	1.44	1.32	1.22	1.17	1.10

(1) Annual cell construction cost (1981£/y)
(2) Total operating cost (1981£/y)
(3) Cost/tonnes (1981£/t)

Drainage Options

Capital cost (and hence capital charges):

Cost		Methods (used individually or in combination)
LOW) INTERMEDIATE) HIGH)	Cost dependant at each landfill upon scale of each drainage measure and site geology.	Culverting, surface run-off catch-waters and groundwater interception ditches, stream diversion, retaining walls, lining and grouting, sewerage and piping, valves and pumps.

Probable Highest cost: Long length of culverting or diverted streams, extensive surface run-off and groundwater interception with the intercepted freshwater pumped to sewer or stream.

Probable Lowest Cost: Site well above water table and relatively permeable, only shallow surface run-off, intercepted and passed directly to drain or stream on the down-slope side.

The costs for a small number of cases were obtained and the unit costs in Table 9.12 are based on this limited sampling: Intermediate, 0.30 £/t; High, £1.50/t; Low, £0.06/t. This range is based on the observed range approximately corresponding to the intermediate cost $\overset{\times}{\div}$ 5.0.

Independent studies by Grant et al (1982) for flood-plain landfills lie well within the range used here (Figure 9.3).

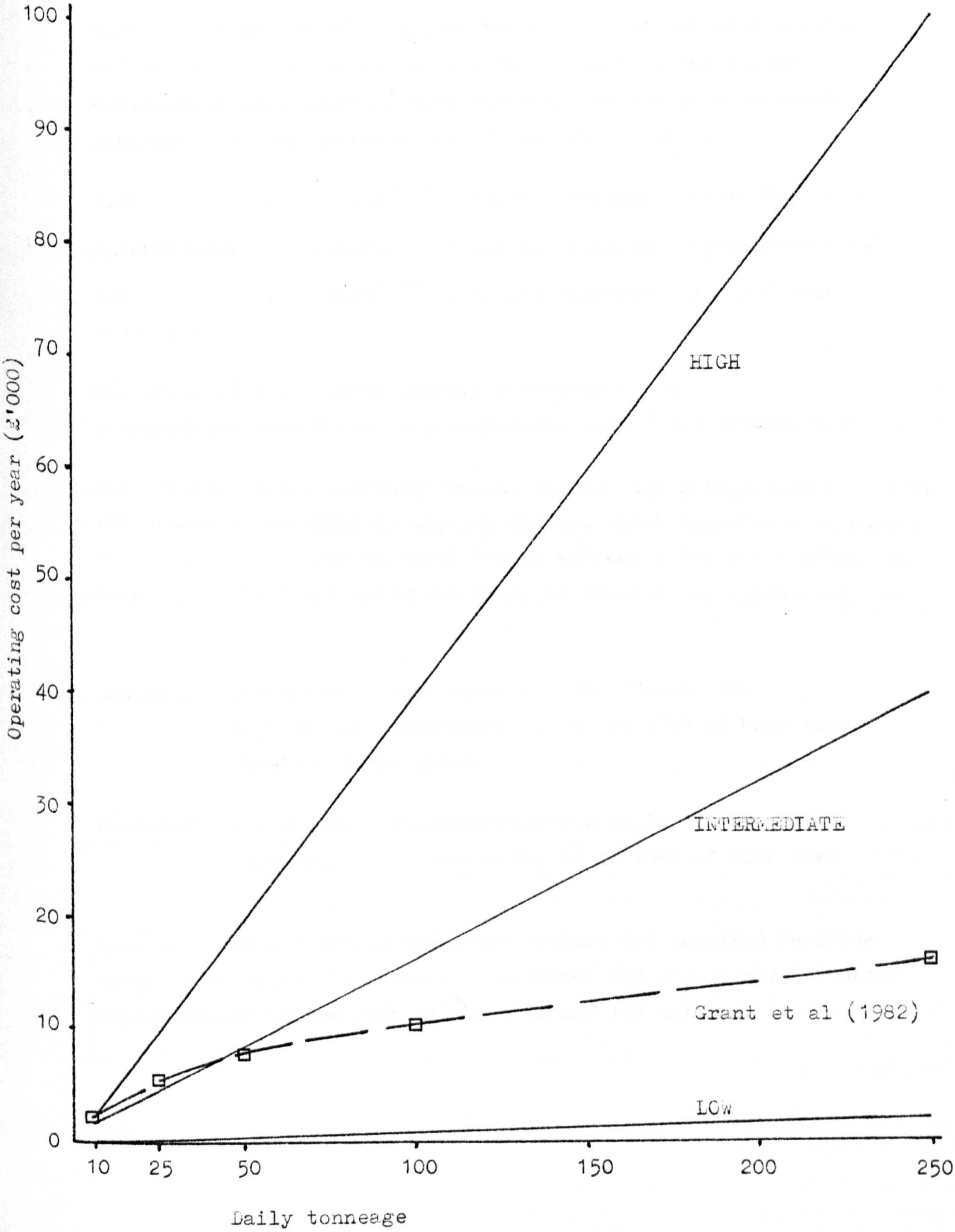
Leachate Options

Capital cost (and hence capital charges):

Cost	Containment Sites	Dispersal Sites
LOW)	Pass to sewer for dispersal at sewer works. Recirculate leachate through landfill. Spray irrigation onto adjacent land. Lagooning.	Monitoring boreholes.
INTERMEDIATE) HIGH)	On-site treatment. (Cost of each is site-specific and heavily influenced by the extent of lining necessary and the equipment required by each method)	Small sites / Large Sites: Monitoring boreholes, Site grading and other preparation, possible semi-permeable lining.

These methods can be used individually or in combination.

Fig 9.3 Cost range of drainage options



Probable highest cost: Containment site, 100% lined with full on-site treatment.

Probable lowest cost: Containment site, no lining with lagooning/discharge to sewer;

Dispersal site, no lining with monitoring boreholes.

Limited information on leachate treatment cost has been obtained and the unit costs in Table 9.12 are based on these values. Curvilinear relationships were derived from the data gathered supplemented with American data (Grant et al, 1982).

High	$y = 6{,}383x^{0.58}$	$\div$ Annual tonnage	Scale Factor 0.58
Intermediate	$y = 2{,}818x^{0.51}$	$\div$ Annual tonnage	Scale Factor 0.51
Low	$y = 803x^{0.52}$	$\div$ Annual tonnage	Scale Factor 0.52

where x = t/d.

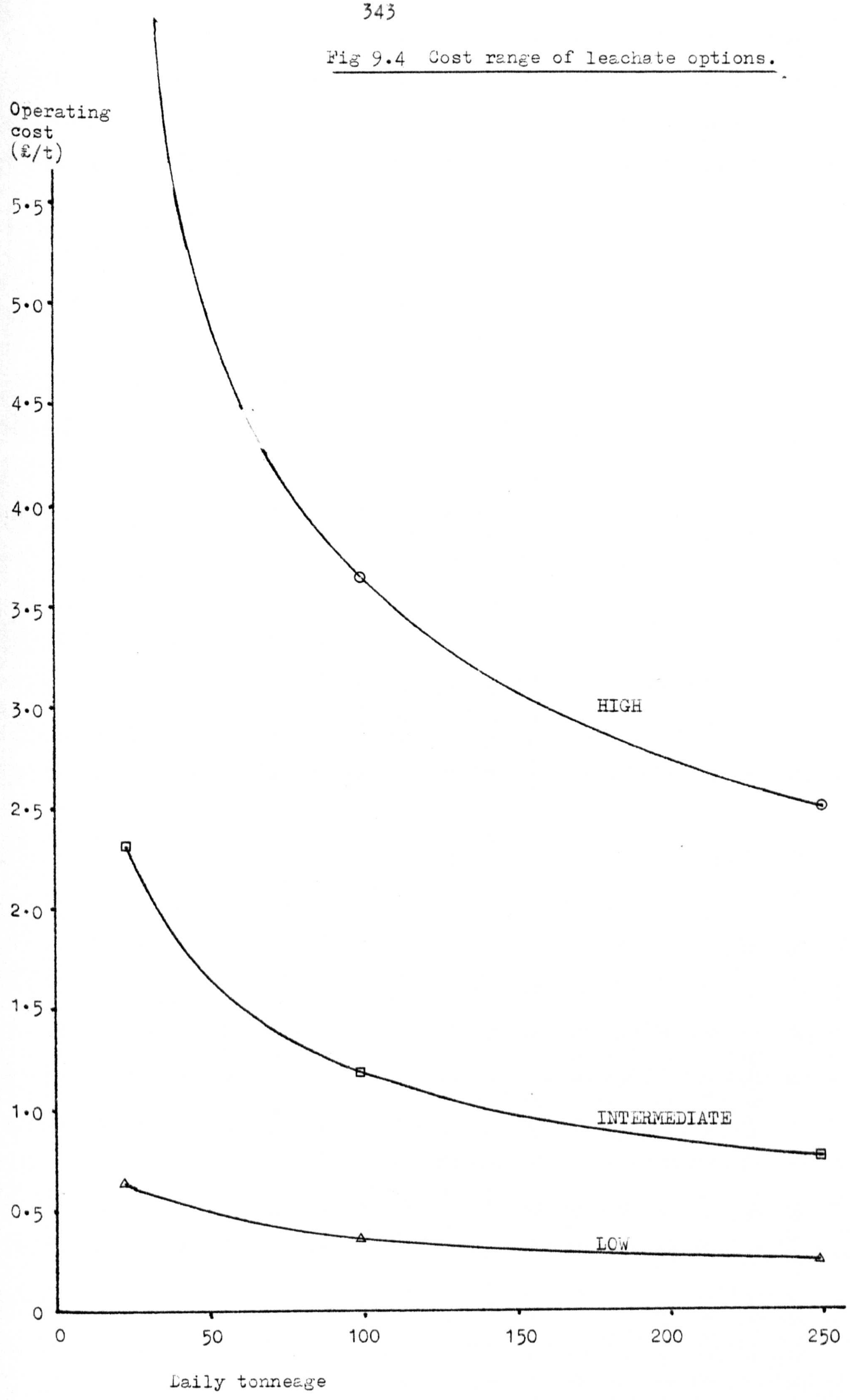
The observed range approximately corresponds to:
intermediate cost $\overset{\times}{\div}$ 2.5 to intermediate cost $\overset{\times}{\div}$ 3.5 (Figure 9.4).

The largest single component annual expenditure with leachate control (or drainage) measures is capital charge, which together with power, materials and monitoring costs has an extremely important effect on both the capital and operating costs of landfilling operations i.e.

Leachate	Low option	approximately 14% of base case
	High option	approximately 117 to 170% of base case
	(small - large sites)	
Drainage	Low option	approximately 0.1 to 5% of base case
	High option	approximately 18 to 136% of base case

More research and allied financial studies are required in these areas to evaluate the individual measures and enable more accurate determination of the cost of the high and low options.

Fig 9.4 Cost range of leachate options.



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9.5.5 Gas Alleviation and Collection Measures

In landfills the bulk of the refuse decomposes anaerobically producing two major projects; methane and carbon dioxide. Whereas the latter is inert, methane is flammable and toxic and may require alleviation when it accumulates in significant quantities. The effect of methane gas and its need for alleviation are very site specific, however many techniques have been developed. Alleviation can be simply a mechanism to passively vent the gas safely, or more sophisticated methods to collect and use the gas as a fuel source.

No revenues are considered at this stage, but are discussed in detail in Case Study E, Chapter 10.

Gas Alleviation:

1. Passive Alleviation. Diffusion of gas via peripheral ditches and venting on-site.
2. Active Alleviation. Pumping and collecting gas via wells and connecting pipework with subsequent burning off in flare stacks.

Gas Collection:

3. Pump, dewater and fire boiler, kiln, furnace etc.
4. Pump, dewater and power converted engine to produce electricity
5. Pump, dewater and remove impurities to produce pipeline quality gas. Enter local or national grid.
6. Pump, dewater and use as a feedstock for conversion to other chemical products.

As for drainage and leachate measures financial information for only a small number of cases were obtained with Options 1 and 2 being considered the lowest cost alternatives. The "low cost" values are based on a manufacturer's estimates for turnkey gas flaring equipment; one machine to every 250t/d of refuse handled. Number of wells assumed as four wells for the first 50t/d and an additional two for every subsequent 50t/d or part thereof.

1 machine @ £9,000 Amortised at 14% p.a. over 10 years
each well @ £200

Operating cost @ £2,000 / machine / year
Table 9.16 outlines the resultant values for the "low cost option".

Table 9.16 SUMMARY OF THE "LOW COST" GAS ALLEVIATION OPTION

Daily Tonnage	10	25	50	75	100	150	200	250	300	350	400	450	500
Operating Cost	2000	2000	2000	2000	2000	2000	2000	2000	4000	4000	4000	4000	4000
Capital Charge	1880	1880	1995	1995	2030	2030	2110	2260	4060	4140	4220	4300	4370
Total	3880	3880	4000	4000	4030	4030	4110	4260	8060	8140	8220	8300	8370

Unit costs are given in Table 9.12

Table 9.17 THE EFFECT OF A 50% REDUCTION IN CAPITAL CHARGES

t/d	25	100	250	500
Direct Landfill	12%	19%	20%	18%

% changes in base case total operating costs

Three interest rates were studies, 5, 10 and 20% p.a. Their effect on the base case unit costs are detailed in Table 9.12.

The "high cost option" (Options 4, 5 and 6) was deduced from data published in the literature or obtained in the course of this work. They represent large sites, i.e. 1 million tonnes emplaced refuse. Sites smaller than this are not currently considered to produce commercially viable quantities of gas.

Regression analysis of the "high cost" options produce a linear relationship with daily tonneage.

$$y = 167x + 26,680$$

Unit costs are detailed in Table 9.12.

"Intermediate cost options" (Options 2 and 3) are assumed as twice the low cost option. This is based on a very small sample size of general costs. Figure 9.5 details the high, intermediate and low cost gas collection options.

The financial effects of gas measures on the base case operating costs are calculated below:

Landfill gas:	Low Option	19 to 6% of base case
	High Option	68 to 80% of base case
	(small - large sites)	

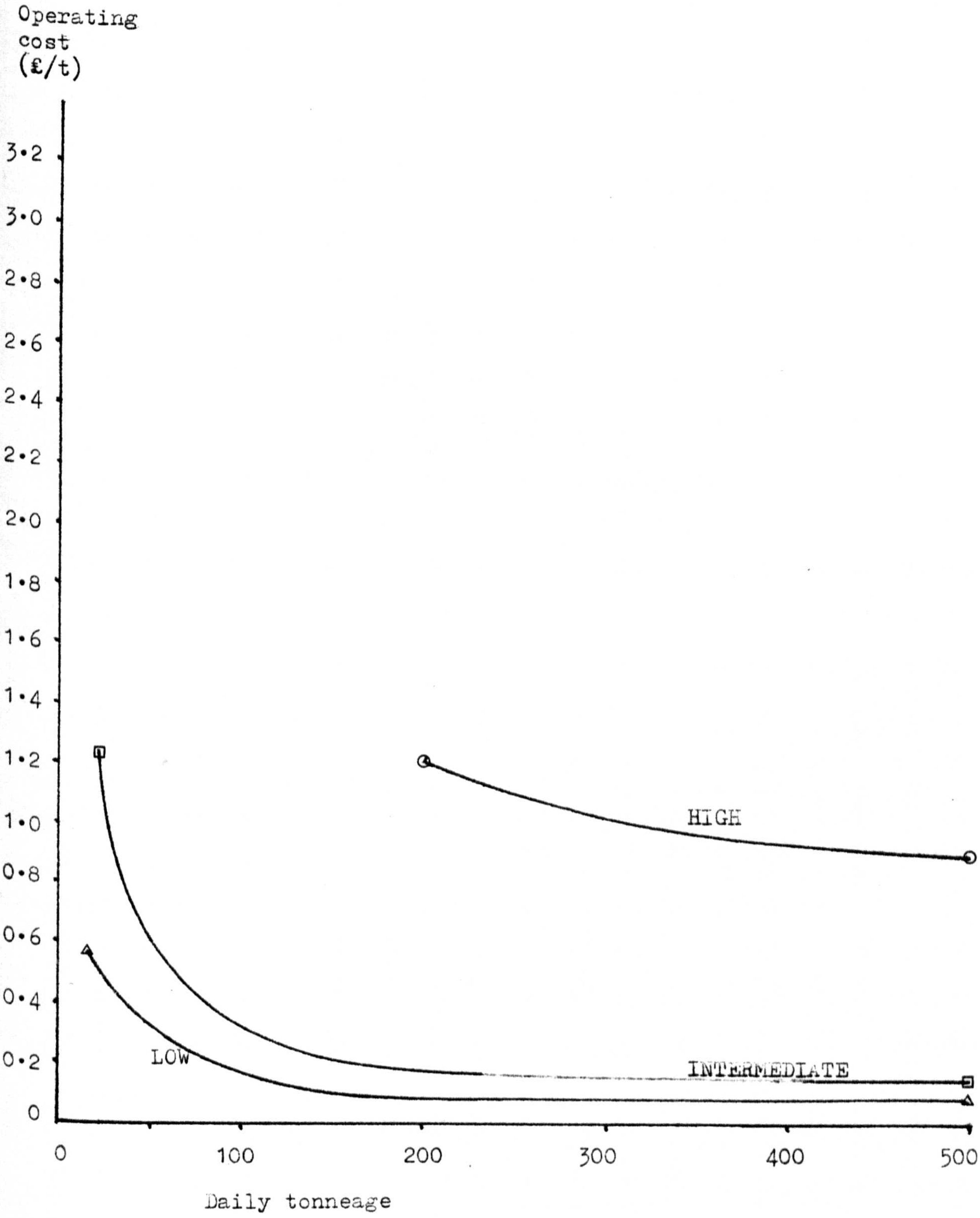
Further research on the economics of gas alleviation and collection is clearly required.

9.5.6 Interest Rates

The effects on the base case from changes in interest rates are identical to the arguments discussed for transfer, collection and bulk transporting, i.e. as interest rates increase then the total operating cost becomes more sensitive to the increase in capital charges.

A reduction of 50% in the capital charges brings about the reduction in total operating cost depicted in Table 9.17.

Fig 9.5 Cost range of landfill gas options.



9.5.7 Landfill Revenues

Sources of revenues:

- Trade waste disposal charges
- Disposal charges to other local authorities or public bodies
- Sale of equipment - often reflected in the price of replacement equipment.
- Sale of restored land - not fully accredited to the disposal authority due to the accounting conventions within local authorities.
- Sale of recovered materials - not commonly undertaken at landfill sites
- Sale of gas.

No revenues are assumed in the base case and those known to be received vary widely from site to site. Several factors have been observed which influence the income derived:

Trade and other Authorities Disposal Charges:

- Charging policy of disposal authority
- Operating policy of whether or not to accept trade waste
- Proximity of site to waste producing areas
- Types of industrial wastes a site is licenced to accept.

Landfill Gas Revenue:

- Price negotiated with end user

Sale of Equipment/Restored Land:

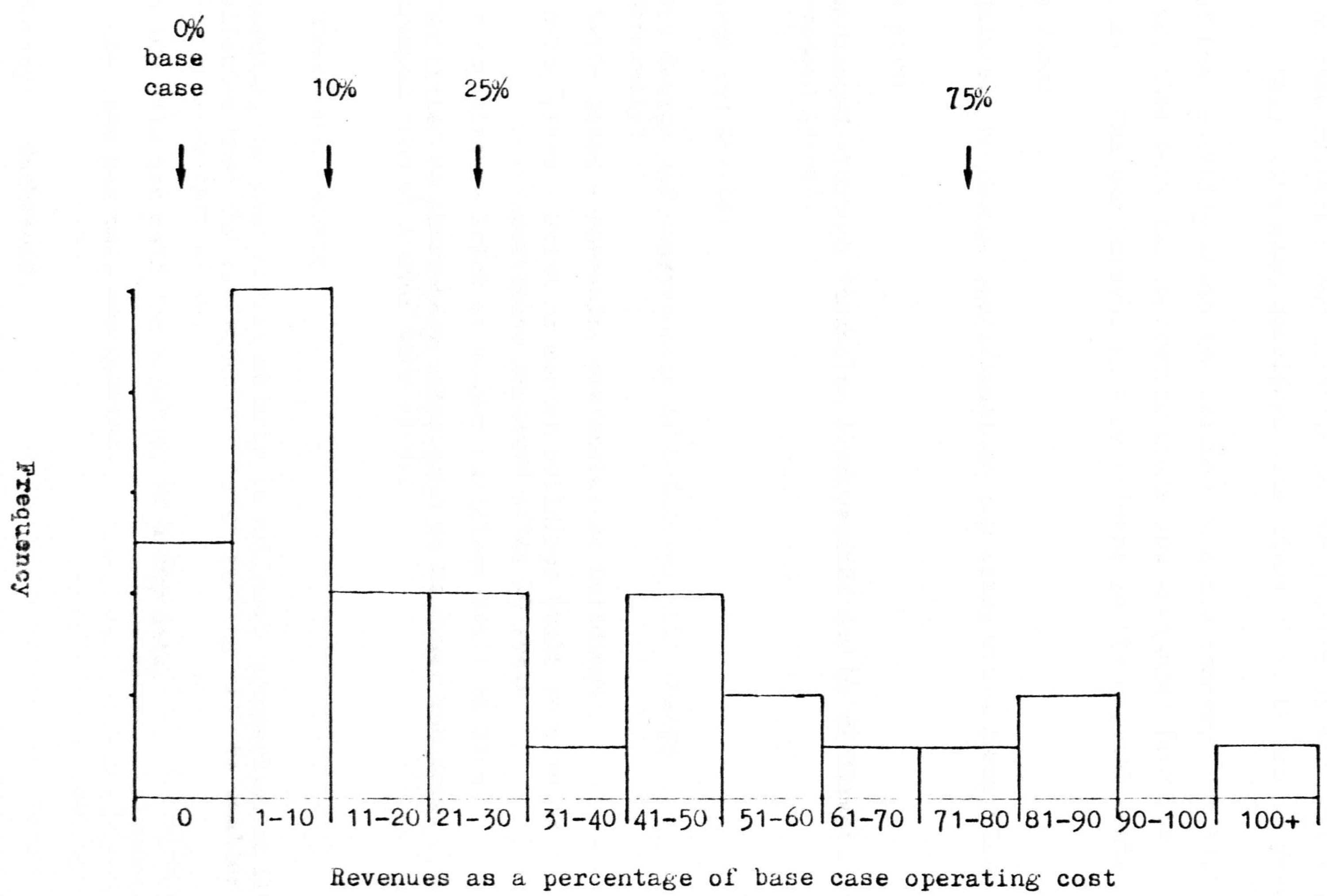
Not considered as regular incomes, however, they ought to be fully accredited to the disposal authority.

Three income regimes are taken into consideration derived as a percentage of the base case. These percentages are based on 35 sites sampled where revenues are received (Figure 9.6).

Low income regime:	10% of base case
Intermediate income regime:	25% of base case
High income regime:	75% of base case (This regime would include gas sales)

The observed range is approximately intermediate cost $\overset{\times}{\div}$ 3.0. Unit costs are given in Table 9.12.

Fig 9.6 Revenues from landfill sites expressed as a percentage of the base case operating cost



9.5.8 Site Lifetime

The base case assumes a 20y lifetime but many sites do not last this long. This extension considers site lives of 5, 10 and 15 years.

Most of the operating costs are related to daily tonneage not site capacity, therefore all operating costs are unchanged from the base case. Changes however will be evident in the capital costs.

Access road:

Unlikely to change specifications for sites with different lives.

Mobile plant:

Unchanged although financing arrangements may be different. Assumed leased.

Buildings and Civils:

The design and construction of buildings will change. Generally:

5-10y sites - Portable, prefabricated buildings

10-20y sites - Brick or wooden buildings built on site or portables replaced after 10 years

> 20y sites - Brick or wooden buildings built on site.

Facilities on short-term sites tend to be fewer and more cramped than at longer term sites.

Other Preparation Costs

Assuming the same refuse density is achieved irrespective of site lifetime then the perimeter and hence fencing will be smaller for shorter-term sites.

A 10y site has half the capacity of a 20y site,

5y site has only one-quarter.

Site Survey: Unchanged.

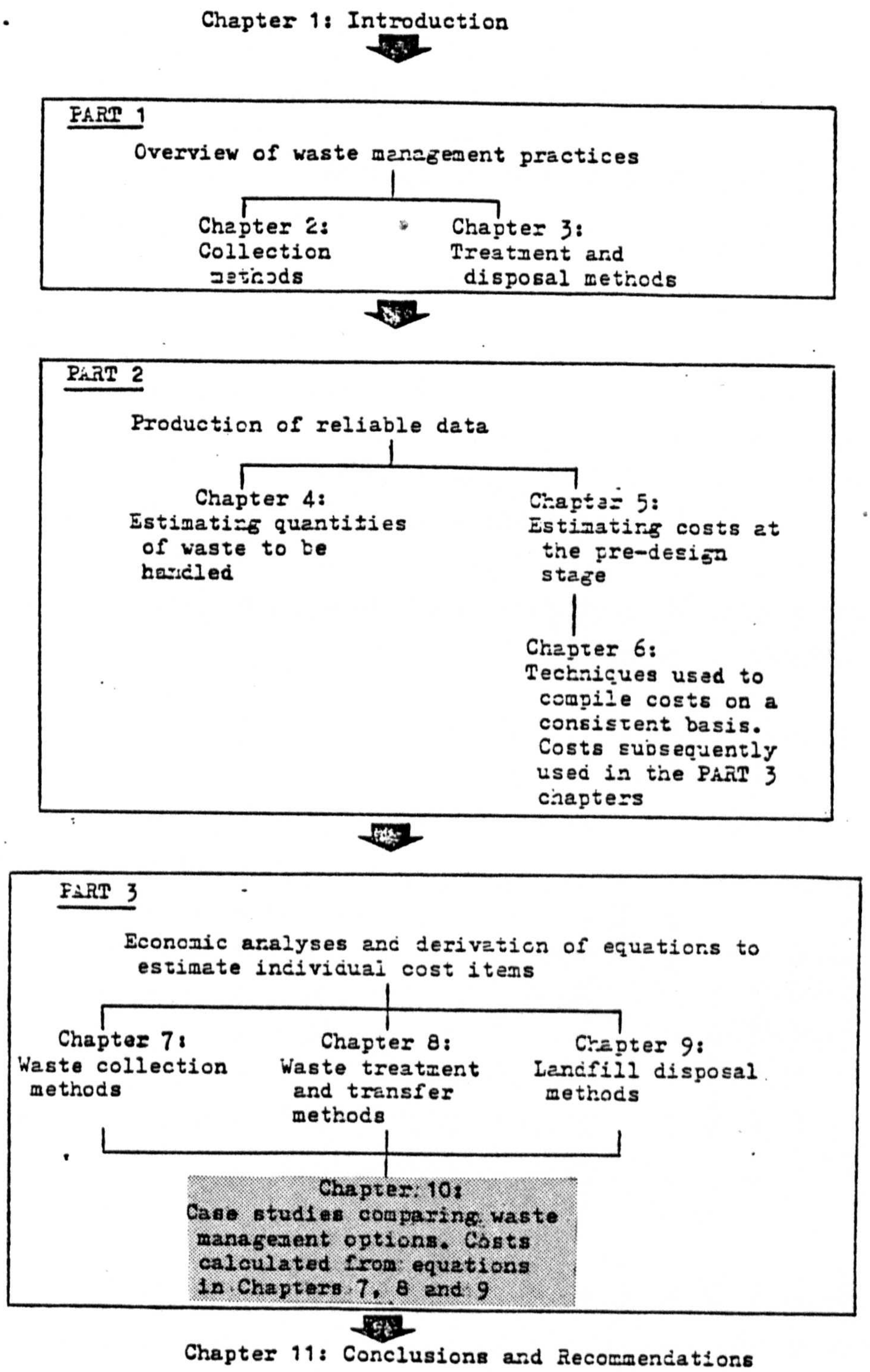
The capital costs and the corresponding capital charges were recalculated for each year based on the buildings and civils and other preparation costs. The sensitivity of site lifetimes to total operating cost are outlined in Table 9.18 and the unit costs detailed in Table 9.12.

Table 9.18 THE EFFECT OF VARIATIONS ON SITE LIFETIME

Site Lifetime \ t/d	% of total operating cost with respect to the base case operating cost			
	25	100	250	500
5	-8%	-12%	-12%	-12%
10	-7%	-12%	-11%	-11%
15	-4%	-10%	-10%	-10%

CHAPTER 10

COMPARISONS BETWEEN ALTERNATIVE WASTE COLLECTION AND LANDFILL TECHNOLOGIES USING CASE STUDIES



Chapter 10

10.1 INTRODUCTION

The principal themes of this research have been the identification of the economics of collection, transfer and landfill disposal and the demonstration of the importance of thorough and systematic financial appraisals in solid waste management. During the study, extensive variations in operational standards and accounting procedures were found in published costs and local authority records. At present these are the principal sources of economic data. As a consequence many comparisons currently made between technologies are highly ambiguous. To overcome the prevailing situation data was collected during this research from many operators and supplemented with new information. The findings then being reduced onto a consistent basis, the "base case" (described in Chapter 6), before making any comparison between alternative methods. This Chapter demonstrates how such comparisons can be made. It is stressed however that the financial information and cases presented are for illustrative purposes only and the results should not be applied uncritically to any specific operation.

Comparisons between the alternative methods presented in the illustrative case studies use the cost functions and associated information derived in the preceding chapters. In Table 10.1 a summary is presented of the total capital and operating cost functions for all of the methods considered in this work. Individual equations are referred to, where appropiate, in the case studies by quoting their "part" number. Due to the large number of cost equations for individual component expenditures it was impractical to include these in this table. Instead, they can be readily found in:

Tables 7.1 and 7.2 respectively	for urban and rural collection authorities;
Appendix 8E	for transfer methods;
Table 9.1	for landfill disposal.

Table 10.1 Summary of the total cost equations for capital and operating expenditures produced by this research (1981£)

PART	METHODS	CAPITAL COST (£)	RANGE	OPERATING COSTS (£)	RANGE
	COLLECTION		(km^2)		(km^2)
i	Urban Kerbside Sack	$y = 31000$	50-300	$y = 5.25x_{km} + 4717$	50-300
ii	Urban Backdoor Sack	$y = 31000$	50-300	$y = 7.92x_{km} + 4907$	50-300
iii	Urban Backdoor Bin	$y = 31000$	50-300	$y = 4.99x_{km} + 4520$	50-300
iv	Rural Kerbside Bin	$y = 31000$	500-2000	$y = 0.24x_{km} + 3095$	500-2000
v	Rural Backdoor Bin	$y = 31000$	500-2000	$y = 0.93x_{km} + 3803$	500-2000
vi	Collection Vehicle Haulage	-	-	$y_1 = 0.34x_k + 4.39$	(km) 0-50
	TRANSFER				
vii	Compaction without Storage	$y = 2393x_D + 20000$	(t/d) 20-200	$y = 272x_D + 23000$	(t/d) 20-200
viii	Compaction with Apron Storage	$y = 2406x_D + 54000$	20-200	$y = 295x_D + 36000$	20-200
ix	Compaction with Bunker Storage	$y = 4177x_D + 179000$	20-200	$y = 361x_D + 31000$	20-200
x	Wire-tied Baling	$y = 11698x_D - 604000$	75-300	$y = 786x_D + 26000$	75-320
xi	Dry Pulverisation	$y = 3418x_D + 256000$	20-340	$y = 7340x_D^{0.62}$	20-600
xii	Wet Pulverisation	$y = 7146x_D + 672000$	20-600	$y = 600x_D + 28000$	20-250
	Bulk Transport Vehicle Haulage:				(km/y)
xiii	Rigid 10t cc	-	-	$y = 0.239x_{ka} + 14790$	0-200000
xiv	Rigid 16t cc	-	-	$y = 0.277x_{ka} + 18250$	0-200000
xv	Artic 12t cc	-	-	$y = 0.201x_{ka} + 16460$	0-200000
xvi	Artic 14t cc	-	-	$y = 0.224x_{ka} + 17220$	0-200000
xvii	Artic 16t cc (covered body)	-	-	$y = 0.240x_{ka} + 18630$	0-200000
xviii	Artic 16t cc (flatbed trailer)	-	-	$y = 0.226x_{ka} + 17650$	0-200000
xix	Artic 22t cc	-	-	$y = 0.322x_{ka} + 24940$	0-200000
	DISPOSAL				
xx	Landfill	$y = 794x_D + 17206$ $y = 2269x_D^{0.75}$ $y = 3104x_D^{0.74}$	(t/d) 10-200 200-500 10-1000	$y = 3586x_D^{0.51}$	(t/d) 10-500

Notes

All of the equations conform to the base case conditions detailed in Chapter 6.

The operating cost equations exclude capital charges.

y represents capital or annual operating cost (1981£)

y_1 " cost per load (1981£)

x_{km} " area of authority (km^2)

x_k " return haul distance (km)

x_D " daily tonneage (t/d)

x_{ka} " annual distance (km/y)

cc " carrying capacity

Rigid " rigid chassis vehicle

Artic " articulated vehicle

These cost equations were used to estimate the capital and operating expenditures for waste handling schemes of particular sizes, as well as the corresponding unit costs (eg cost / tonne) . The latter were calculated by dividing total costs by the appropriate physical quantities.

The methodology to conduct comparisons using these models varies depending upon the information sought by the user. The case studies were specifically chosen to demonstrate the different ways in which the models are used.Consequently, at the beginning of each case the methodology to carry out the appraisal is presented.

Before an individual authority can undertake its own comparison between technologies it must either define its own base case or modify that used in this work to represent its own local situation. Once this has been done the base case total costs for each method under consideration can be calculated. Many of the sensitivity analyses undertaken in this work (in Chapters 7, 8 and 9) can then subsequently be applied to these "authority base case" values so as to identify both the effects of uncertainty on the cost estimates and the most critical component costs.

10.2 ILLUSTRATIVE COMPARISONS BETWEEN TECHNOLOGIES

Six case studies are discussed to demonstrate the versatility of the cost models derived by this research and the range of useful economic evaluations available to waste managers. The case studies are described for a hypothetical authority which conforms to the base case used in this work and draws upon the findings detailed in Chapters 7, 8 and 9. The case studies are intended to reflect the type of economic appraisals central to the informed management and future planning of municipal waste collection and disposal in every authority in Great Britain.

In brief the case studies considered are:

Case A - Calculation of the cost of four example waste management systems comprising collection, transfer, haulage and landfill operations using the cost equations presented in this work.

Case B - Comparison between three collection methods for an urban authority with the selected method to be used throughout the collection district.

Case C - Comparison between three collection methods for a rural authority where the selected method will not necessarily be used solely throughout the district.

Case D - Comparison for a rural authority between direct haul and compaction transfer over various haul distances. Three interest rates are also considered.

Case E - Comparison between direct haul and transfer to a distant landfill (100 Km return journey). Several transfer options and variations in the operating technique for landfilling untreated and treated refuse are considered.

Case F - An extensive comparison between different landfill engineering and operating techniques on the landfilling costs for untreated, baled, wet and dry pulverised refuse.

10.3 CASE A - CALCULATION OF THE COST OF A WASTE MANAGEMENT SYSTEM

10.3.1 Description and calculation

The cost equations presented in the previous chapters provide a straightforward and practical means to estimate the entire cost of a waste management system. This is a technique often sought by waste managers, especially where they have no prior in-house data, but not available in a versatile and comprehensive form until this work.

This case study demonstrates how the sequential use of these cost equations (summarised in Table 10.1) can build up the total cost for a waste management system. In addition, the cost estimates can be used to identify variations between each operation in any such system. A waste management system is defined as including all operations from the collection of wastes by a collection authority, or private operator, to their final disposal to landfill. Intermediate steps may include all, or a combination, of direct haul, bulk haul, compaction transfer and waste treatment.

In this case study four different waste management systems are costed. A hypothetical situation is presented in which four collection authorities operate within a county and each possess distinctly different operations (Fig 10.1). Two of the collection authorities are in rural districts (ie East and West Authorities) and two in urban areas (North and South Authorities). Their waste arisings are handled at two landfills, with wastes at one of these received from a compaction transfer station located near to the South and West Authorities.

When estimating the cost of a waste management system figures for collection are first calculated, followed by haulage, transfer and landfill disposal. In Table 10.2 the annual cost and cost/tonne for collection in each authority is calculated using the cost equations indicated from Table 10.1. However, before the appropiate cost equation can be selected the waste manager requires information on five physical parameters, ie:

i) area of authority;

ii) collection method used;

iii) number of rounds serviced each week by a collection vehicle;

iv) number of collection vehicles in use;

Fig 10.1. The four waste management systems considered in Case A

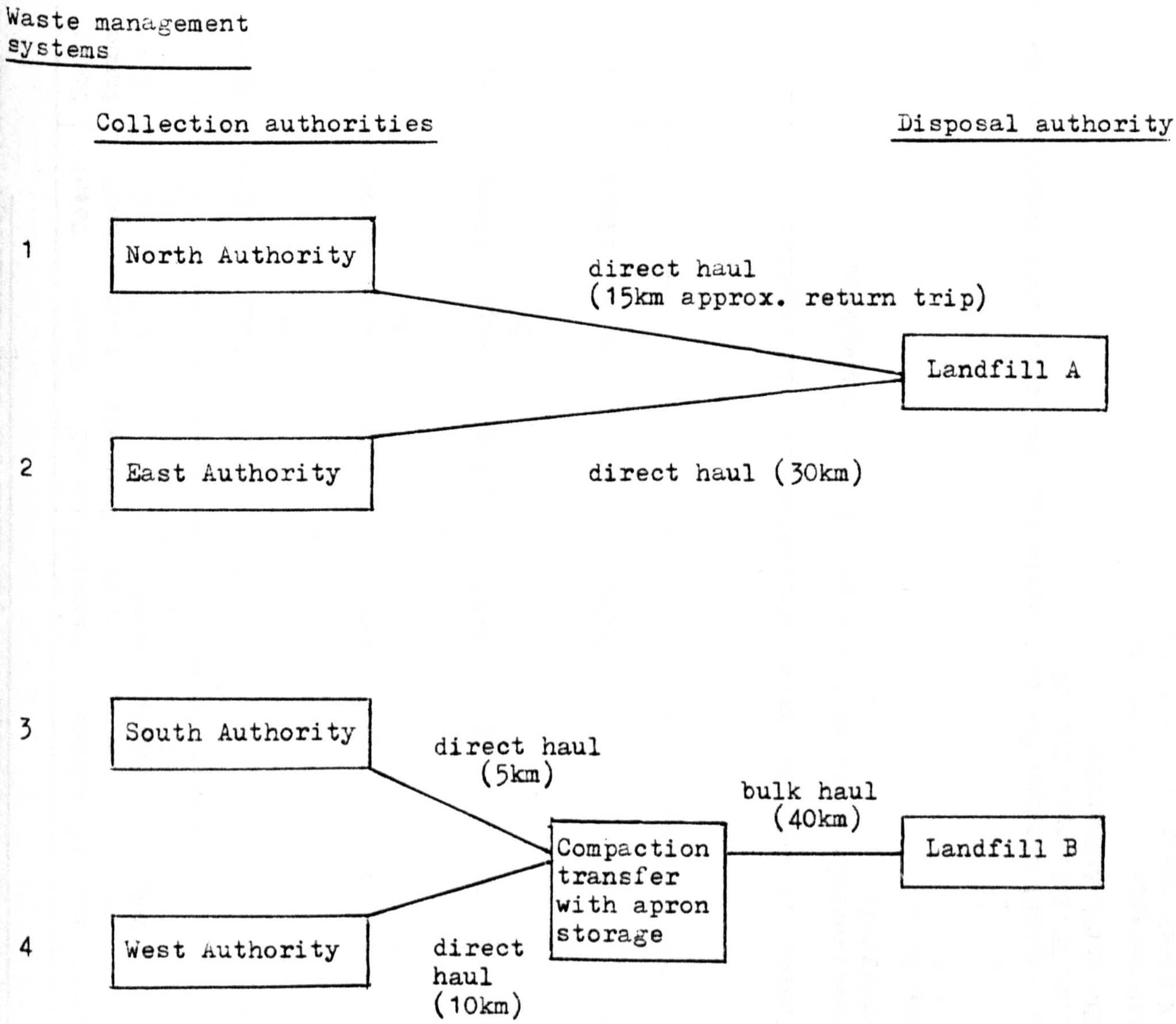


Table 10.2 Calculation of collection cost per tonne for each authority. (1981£)

Waste management system	Collection method	Rounds/ week/ vehicle 1.	Number of vehicles 1.	Tonnes/ round/ week 1.	Annual Tonneage 2.	Cost/ round (£)	Total cost (£) 7.	Cost/ tonne (£/t)
North Authority (100 km^2)	kerbside sack	10	12	3.85	24000	5242 3.	734000	30.58
East Authority (1500 km^2)	kerbside bin	5	12	2.88	9000	3455 4.	312000	34.67
South Authority (200 km^2)	backdoor bin	10	15	4.81	37500	5518 5.	959000	25.57
West Authority (2000 km^2)	backdoor bin	5	14	3.85	14000	5663 6.	519000	37.07

Notes

1. Within the data ranges in Tables 7.1 and 7.2. This information would be supplied by a waste manager.

2. Annual tonneage = Rounds/week/vehicle X No. of vehicles X Tonnes/round/week X 52 weeks/year.

3. Calculated from part i, Table 10.1.
4. " " part iv, " .
5. " " part iii, " .
6. " " part v, " .
7. Total cost includes £8738 in capital charges for each collection vehicle. Full details on the derivation of this value is given in Section 7B.1.2, Appendix 7B.

Example calculation for the North Authority:

12 vehicles X £8738/vehicle = £ 104856
(10 X 12) rounds X £5242/round = £ 629040
£ 733896 to nearest £'000 = £ 734000

v) mean annual tonneage collected on each round.

Data for each of these items should be readily available in any well managed collection authority and should not be seen as a problem. These values are used in Table 10.2 to calculate for each authority the total number of rounds and the annual tonneage collected. These values are used in turn to generate the collection cost/tonne:

		Collection (£/t)
North Authority		30.58
East	"	34.67
South	"	25.57
West	"	37.07

These collection cost/tonne values are carried forward to Table 10.3 where unit costs for direct haul, landfill disposal, and as appropiate, compaction transfer and bulk haul, are calculated using the relevant cost equations in Table 10.1. The summation of these unit costs provides a direct method of estimating the total cost for each of the four waste management systems considered. A fuller explanation of the derivation of the unit costs in Table 10.3 is given below.

Calculation of direct haul cost/tonne

Direct haul costs are calculated on a cost per load basis by the equation: $y_1 = 0.34\ X_k + 4.39$ (from part vi, Table 10.1), where y_1 is haul cost/load, X_k is return haul distance. This equation was used to calculate the cost/load for each of the haul distances noted in Figure 10.1, ie

North Authority (15km return trip)			
		0.34 x 15km + 4.39 =	£ 9.49 /load
East	"	30	£14.59 /load
South	"	5	£ 6.09 /load
West	"	10	£ 7.79 /load

The average tonneage collected on a round is different in each authority and estimates were supplied by the waste manager in Table 10.2. The cost/load values therefore can be converted into cost/tonne for use in Table 10.3 by dividing by these tonneages, eg

North Authority £9.49/load / 3.85t/load = £2.46/t

Calculation of compaction transfer cost/tonne

Compaction transfer total costs are calculated by the equation: $y = 295\ X_D + 36000$ (from part viii, Table 10.1), where y is annual transfer cost excluding capital charges, X_D is daily tonneage throughput. Before using this equation the waste manager must first estimate the daily quantity handled at the transfer station. This can be derived from

Table 10.3 Summary of the collection, transfer and landfill costs/tonne for each authority. (1981 £)

Waste management system	Collection £/t	Direct haul £/t	Transfer £/t	Bulk haul £/t	Disposal £/t	Total Cost £/t
North	30.58	2.46	-	-	2.06	35.10
(%)	(87.1)	(7.0)			(5.9)	
East	34.67	5.07	-	-	2.06	41.80
(%)	(82.9)	(12.1)			(5.0)	
South	25.57	1.27	3.59	2.02	1.73	34.18
(%)	(74.8)	(3.7)	(10.5)	(5.9)	(5.1)	
West	37.07	2.02	3.59	2.02	1.73	46.43
(%)	(79.8)	(4.4)	(7.7)	(4.4)	(3.7)	

Note

Collection cost / tonne figures are calculated in Table 10.2. The derivation of the other unit costs are discussed in the text.

Assuming all wastes from both authorities pass through the compactor,

then: annual tonneage = 37500t/y + 14000t/y = 51500t/y
daily tonneage = 51500t/y / 250 working days = 200t/d

therefore, the annual transfer cost @ 200t/d from the equation above = £ 95000
capital charges for a 200t/d plant = £ 90000 (from Appendix 8F)
£185000

cost/tonne = £185000/51500t = 3.59 £/t

Calculation of bulk haul cost/tonne

Bulk haulage is undertaken by 14t carrying capacity articulated vehicles. Each vehicle makes 4 trips/day and therefore at a 200t/d transfer station a minimum of 4 vehicles are required. Bulk haul costs are calculated for a vehicle by the equation: $y = 0.224\ X_{ka} + 17220$ (from part xvi, Table 10.1), where y is annual haul cost, X_{ka} is annual distance travelled by vehicle. Before using the equation the waste manager must first estimate the annual distance travelled by a bulk transporter, ie

annual distance = 250 working days/y x 4 trips/d x 40 km/trip (Fig10.1)
= 40000 km/y

therefore, the annual bulk haul cost @40000km/y from equation above = £ 26000
with 4 vehicles the annual cost = £104000
cost/tonne = £104000/51500t = 2.02 £/t

Calculation of the landfill disposal cost/tonne

Landfill total annual costs are calculated by the equation: $y = 3586\ X_D^{0.51}$ (from part xx, Table 10.1), where y is annual landfill cost excluding capital charges, X_D is daily tonneage handled. Before using this equation the waste manager must first estimate the annual tonneage throughput at each landfill. This is derived from the tonneages presented in Table 10.2.

North and East Authorities
annual tonneage = 24000t/y + 9000t/y = 33000t/y
daily tonneage = 33000t/y / 250 working days/y = 130t/d (Landfill A)

South and West Authorities (previously derived in transfer calculation)
annual tonneage = 51500t/y
daily tonneage = 200t/d (Landfill B)

therefore, the annual landfill cost @130t/d from equation above = £ 43000
capital charges for a 130t/d site = £ 25000 (Table 9.7)
£ 68000

cost/tonne (Landfill A) = £68000 / 33000t = 2.06 £/t

annual landfill cost @ 200 t/d = £ 53000
capital charges for a 200 t/d site = £ 36000 (Table 9.7)
£ 89000

cost/tonne (Landfill B) = £89000 / 51500t = 1.73 £/t

10.3.2 Discussion

The total system costs vary widely between the four collection areas which is indicative of the different collection methods employed and the subsequent waste disposal arrangements:

Waste management system	Total cost (£/t)	% difference
North Authority	35.10	-
East Authority	41.80	+19.1
South Authority	34.18	- 2.6
West Authority	46.43	+ 32.3

It is interesting to note in Table 10.3 that the two urban authorities (North and South) have markedly lower total costs than the more extensive rural ones. However, the proportion of the total accounted for by the collection operation is approximately equal, i.e. between 74% and 87%. The landfilling operation demonstrates a similar, though much smaller, trend at around 5% of the total cost. It is interesting to note that the cost of landfill is a relatively minor expenditure in waste management systems, and variations in the costs for collection operations are likely to have a more significant influence on overall total costs. The combined cost of transfer and bulk haul from the South Authority also approximately balances the higher cost of direct haul as undertaken by the North Authority, due to the greater distances travelled by expensive collection vehicles.

There are similarities in the total costs between each of the urban and rural authorities. The principal differences in the urban North and South being the high sack replacement cost and mode of waste haulage. In the rural East and West, where both use bin collection methods, the differences arise in labour expenditure and in the method of waste haulage. In the basis of estimation used in the work, (given in Chapter 6), rural backdoor methods (West) are costed for the driver plus three loaders, whereas rural kerbside methods are estimated for driver plus two (East).

The variations in the unit costs for each waste management system above are indicative of the complex interactions that each operation has on influencing the overall value. These interactions include differences in crew size, collection method, haul distance, economies of scale and vehicle utilization, and have been explore in depth in Chapters 7, 8 and9. The effects of some of these on the cost of waste management operations are investigated in the following case studies. The costs calculated in this study are derived according to the base case conditions and represent an estimate of expenditure for four specified sequences of operations and waste throughputs. A further development, useful to a waste manager when planning ahead, is to compare the cost of existing operations with possible alternatives. This important use of the cost equations presented in this work is also demonstrated in the following case studies.

10.4 CASE F - URBAN COLLECTION METHODS

10.4.1 Description

Consider a situation where an authority with a total area of 150 Km^2 handles annually 50,000 tonnes. At present backdoor bin collection is employed but recently the Waste Collection Officer has been asked by the Environmental Health Committee to determine whether financial savings can be made by changing over to another method. Deciding which alternative methods to consider is quite arbitrary particularly where no first-hand experience is available. However, in this case the decision is made to appraise backdoor bin against backdoor sack and kerbside sack on the grounds that sack methods are more hygienic and should enable collection to be speeded up. Faster collection ideally should result in higher tonneages per crew and per round, so reducing the number of collectors and vehicles required. The Work Study Department has subsequently estimated the manpower and vehicle requirements of the alternative methods to gather some measure of the savings in resources that may be gained. There is also the possibility of the sack methods not being able to achieve the increased tonneage expected and the financial implications of this are also investigated.

The principal steps in this evaluation are:

1. Estimate for each collection method:
   (i) Tonneage likely to be collected annually on a round
   (ii) Crew size
2. Calculate from the estimates in (1) the total number of rounds, vehicles, drivers and loaders required by the authority.
3. Refer to Chapter 7 (Table 7.1) for the appropiate cost functions to calculate the annual cost per round for each method.
4. Calculate the authority's total annual collection cost for each method by multiplying the annual cost per round in (3) by the number of rounds in (2).
5. Compare the cost of each method. Perform sensitivity analyses on selected parameters such as crew sizes and also consider the costs of other collection services.

The resources required by each method assuming a 5 day week and 2 rounds per day per vehicle are estimated as:

	Crew Size	At 50,000t/year; Rounds	No. of: Vehicles	Drivers	Loaders
Backdoor Bin * 250 t/r/y (tonnes/round/year) Current method	1+4	200	20	20	80
Backdoor Sack 250 t/r/y No increase in tonneage handled on each round	1+4	200	20	20	80
Backdoor Sack 300 t/r/y Increase in tonneage handled on each round	1+4	170	17	17	68
Kerbside Sack 250 t/r/y No increase in tonneage handled on each round	1+3	200	20	20	60
Kerbside Sack 300 t/r/y Increase in tonneage handled on each round	1+3	170	17	17	51

*Example calculation of resources.

At 50000t/year collected in the authority and each vehicle carrying 5t/load the number of rounds to be serviced is:

$$\frac{50000\text{t/y}}{250\text{t/round/y}} \triangleq \underline{\underline{200 \text{ rounds}}}$$

Each vehicle services 10 rounds/week i.e. 5 day x 2 rounds/day, therefore 20 vehicles are required.

The operations in this authority conform in all other respects to the collection base case and no spare capacity in vehicles or staff is considered. Furthermore, the analysis only applies to residential collection rounds. The financial evaluation of each option is made by summating the values from each component cost function in Table 7.1, and then multiplying by the estimated number of rounds to calculate the annual cost to the authority. The annual cost of each option is presented in Table 10.4. These results and the relative increase or decrease in expenditure over the present method are conveniently summarised by a "decision tree" diagram (Figure 10.2).

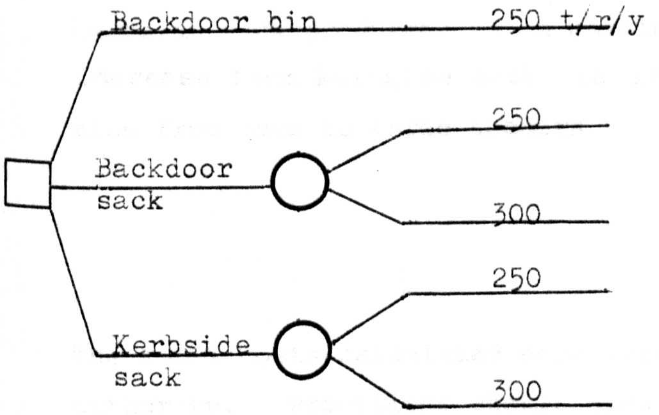
Table 10.4 TOTAL ANNUAL COST AND COST PER ROUND FOR EACH COLLECTION METHOD UNDER CONSIDERATION

Collection Method and t/round/y expected	Cost/round/year[1]		Number of Rounds	Authority Total annual cost	
	Cost from base case (£)	± 95% CI		Total cost (£)	± 95% CI[2]
Backdoor Bin 250 t/r/y	5950	340	200	1,190,000	4808
Backdoor Sack 250 t/r/y	6840	260	200	1,368,000	3677
300 t/r/y	6990	300	170	1,188,300	3912
Kerbside Sack 250 t/r/y	6100	700	200	1,220,000	9899
300 t/r/y	6160	750	170	1,047,400	9779

(1) Base case figures calculated by summating the values from the individual component cost equations in Table 7.1, using the area of authority as 150 km^2, the values for the other physical parameters presented in the previous page, and adding £874 for capital charges. The base case costs are rounded off to the nearest £10.

(2) Calculated from: Authority 95% CI $= \sqrt{\text{Round 95\% CI} \times \text{No. of rounds}}$

Fig 10.2 Diagrammatic representation of alternative collection methods and their relative difference in cost - Case B.



Method	t/r/y	Total cost (£)	% difference with respect to backdoor bin cost
Backdoor bin	250	1,190,000	-
Backdoor sack	250	1,368,000	+ 15
Backdoor sack	300	1,188,300	- 0.1
Kerbside sack	250	1,220,000	+ 2.5
Kerbside sack	300	1,047,400	- 12

10.4.2 Technical Discussion

If an increase to 300 t/r/y can be achieved with the backdoor sack and kerbside sack methods then both produce savings over the current backdoor bin method; 0.1% and 12% respectively. However, if the increased productivity from men and vehicles is not achieved and only the present 250 t/r/y is obtained, backdoor sack then exhibits a net increase in collection expenditure (+ 15%) and kerbside sack produces a marginal rise of 2.5%. This small increase from kerbside sack is inspite of the reduction in crew size from four to three loaders.

The total costs calculated here represent the minimum cost to an authority. Provisions should also be made for spare vehicles, and perhaps, spare men, bulky and special waste collections, commercial and trade collections, and street sweeping.

The cost of spare vehicles or labour can be readily incorporated into the total collection costs using the following rates:

1 loader	£6,900/y
1 driver	£7,500/y
1 collection vehicle	£8,740/y capital charges + operating cost (dependent upon size of authority and collection method)

Decisions over the collection methods employed are not made on purely financial grounds but are strongly influenced by unquantifiable social, environmental and political considerations. It is important not to ignore the effect of these on the decision whether to change collection methods.

Influence exerted by trade unions are of particular note. Frequently they can completely thwart an effort to change a collection practice especially where there is an inherent increase in productivity with no increase in wages, or where a reduction in the workforce will result. Both of these factors are included in this case study. Where a change of method is accepted by the unions, invariably their agreement will result in an increase in the wages of those men retained. This will consequently reduce the financial savings (if any) that can be expected from such a change. Therefore, an estimate of the expected increases in labour cost must be included in the decision process. To avoid a great deal of management time being wasted it is important to bring this cost in as soon as possible. The involvement of the unions early in the decision process could improve relations, may smooth the way for a change of method, and will enable this extra labour cost to be estimated sooner.

10.5 CASE C - REORGANISING RURAL COLLECTION METHODS

10.5.1 Description

There has been a gradual trend since local authority reorganisation in 1974/75 to standardise each new collection district onto one collection method. While a large majority of the authorities have achieved this, several either have not yet done so or decided they are not going to and instead operate two or more methods. In 1976/77, 26% of English and Welsh authorities employed more than one collection method, decreasing only slightly to 25% in 1979/80 (Table 10.5).

This Case Study compares a situation where both single and multiple collection methods are under consideration. A hypothetical rural authority of 1500Km^2 handles 20000t/y; 10000t from country rounds and 10000t from town rounds. The current collection method is backdoor bin throughout the entire district (ie 100% backdoor bin) and the Waste Collection Officer has been instructed to financially appraise alternative collection methods. He decided to consider not only a change to 100% kerbside sack or 100% kerbside bin, but also the operation of different methods in different parts of the authority since perhaps fewer staff would be lost. A mixed collection method may therefore be more attractive to the unions, while still achieving a cost saving.

The kerbside sack and kerbside bin methods were chosen for evaluation as they confer the potential advantage of a faster collection rate, leading to higher tonneages per crew or per round and a

Table 10.5 PERCENTAGE OF AUTHORITIES OPERATING MORE THAN ONE COLLECTION METHOD

Authorities	1976/77	1979/80
English	27%	25%
Welsh	16%	24%
Combined	26%	25%

Source: CIPFA Waste Collection Statistics Actuals 1976/77 and 1979/80.

reduction in the number of vehicles and manpower required. The financial implications of the kerbside methods not being able to achieve this increase in tonneage are also investigated.

The principal steps in this evaluation are:

1. Estimate for each collection method:
   - (i) Tonneage likely to be collected annually on a country round and a town round.
   - (ii) Crew size.
   - (iii) Daily number of rounds possible by a vehicle on a country round and a town round.
2. Calculate from estimates in (1) the total number of rounds, vehicles, drivers and loaders required by the authority.
3. Determine those combinations of collection methods which could operate together and calculate the number of rounds required by each.
4. Refer to Chapter 7 (Table 7.2) for the appropiate cost functions to calculate the annual cost per round for each method.
5. Calculate the authority's total annual collection cost for each method or combination of methods by multiplying the annual cost per round in (4) by the number of rounds in (3).
6. Compare the cost of each method. Perform sensitivity analyses on selected parameters such as crew sizes and also consider the costs of other collection services.

As in Case B the Work Study Department has estimated the resources required by each individual method and also that for several combinations of them:

(N.B. a 5-day working week is assumed for all options)

		No. of Rounds/ Day/ Vehicle	Crew Size	At 20,000t/d, No. of: Rounds	Vehicles	Drivers	Loaders
A	Backdoor Bin						
	Town Rounds 200 t/r/y	2	1+3	50	5	5	15
	Country rounds 200 t/r/y	1	1+3	50	10	10	30
	Current method		1+3	100	15	15	45
B	Kerbside Bin						
	Town 200 t/r/y	2	1+2	50	5	5	10
	Country 200 t/r/y	1	1+2	50	10	10	20
	No increase in tonneage handled on each round		1+2	100	15	15	30
C	Kerbside Bin						
	Town 250 t/r/y	2	1+2	40	4	4	8
	Country 225 t/r/y	1	1+2	45	9	9	18
	Increase in tonneage handled on each round		1+2	85	13	13	26
D	Kerbside Sack						
	Town 200 t/r/y	2	1+2	50	5	5	10
	Country 200 t/r/y	1	1+2	50	10	10	20
	No increase in tonneage handled on each round		1+2	100	15	15	30
E	Kerbside Sack						
	Town/part Country 250 t/r/y	2	1+2	40	6	6	12
	Part Country 225 t/r/y	1	1+2	45	5	5	10
	Increase in tonneage handled on each round		1+2	85	11	11	22

Each option is evaluated by summating the values from each component cost function in Table 7.2, and then multiplying by the estimated number of rounds to calculate the annual cost to the authority. In this instance the authority's operation closely resembles the base case criteria derived in this research. Where another authority may differ an apprppriate addition, or subtraction, must be made to the annual cost per round. Each annual cost per round is subsequently multiplied by the weekly number of rounds so as to calculate the cost to the authority (Table 10.6).

10.5.2 Technical Discussion

Each collection option is summarised in Figure 10.3. On financial grounds the cheapest option would be to convert the authority over to 100% kerbside bin collection. While from an operational point of view 100% kerbside sack requires the least number of rounds (saving of 17) whereas both 100% kerbside sack and 75% kerbside sack/25% backdoor bin involve the lower number of staff and vehicles (savings of 27 staff and 4 vehicles).

Should either of the 100% kerbside methods not achieve the higher tonneage expected they will still produce a financial saving to the authority. 100% kerbside bin, the cheapest option at > 200t/r/y (40% savings), remains the lowest cost even if no improvement in tonneage is achieved (29% saving). This saving is due entirely to the expected reduction in crew size from 1+3 to 1+2. Should this reduction not be possible then no financial saving will be obtained. Union agreement in staff reduction is therefore crucial and if not forthcoming during the decision stage then to pursue this option is very risky. The savings from 100% kerbside sack (21%) handling > 200t/r/y are lower than kerbside bin however if no improvement in tonneage per round occurs a similar drastic effect on the economics results. This strategy also relies solely on a reduction in labour costs.

Table 10.6

TOTAL ANNUAL COST AND COST PER ROUND FOR EACH COLLECTION METHOD UNDER CONSIDERATION

(a) Detailed Calculations

Collection method	t/round/y	Cost/round/year (1): Costs from Collection base case (£)	Cost/round/year (1): 95% CI	Number of Rounds	Annual tonnage and %age of total	Authority total annual cost: Total Cost (£)	Authority total annual cost: 95% CI (2)	Crew Sizes	Work Study data from text
[CURRENT METHOD]									
100% Backdoor bin (town and country)	200	6070	210	100	20000 (100)	607000	2100	1 + 3	Calc. A
100% Kerbside bin (town)	250	4260	245	40	10000 (50)	170400		1 + 2	Calc. C
(country)	225	4260	245	45	10000 (50)	191700		1 + 2	"
						362100	2259		
100% Kerbside bin (town & country)	200	4330	245	100	20000 (100)	433000	2259	1 + 2	Calc. B
50% Backdoor bin (country)	200	6070	210	50	10000 (50)	303500		1 + 3	Calc. A
50% Kerbside bin (town)	250	4260	245	40	10000 (50)	170400		1 + 2	Calc. C
						473900	2146		
100% Kerbside sack (town/part country)	250	5760	NK	60	15000 (75)	345600		1 + 2	Calc. E
(part country)	225	5760	NK	23	≃5000 (25)	132480		1 + 2	"
						478080	NK		
100% Kerbside sack (town & country)	200	5760	NK	100	20000 (100)	576000	NK	1 + 2	Calc. D
75% Backdoor bin (town/part country)	200	6070	210	75	15000 (75)	455250		1 + 3	Calc. A
25% Kerbside sack (part country)	225	5760	NK	23	≃5000 (25)	132480		1 + 2	Calc. E
						587730	NK		
75% Kerbside sack (town/part country)	250	5760	NK	60	15000 (75)	345600		1 + 2	Calc. E
25% Backdoor bin (part country)	200	6070	210	25	5000 (25)	151750		1 + 3	Calc. A
						497350	NK		

(b) Summary of total costs

Collection method and t/r/y expected			Authority Total Annual Cost: Total Cost (£)	Authority Total Annual Cost: 95% CI	Percentage Savings with respect to backdoor bin
[CURRENT METHOD] 100% Backdoor bin		200 t/r/y	362100	2100	-
100% Kerbside bin,	town country	250 t/r/y 225 t/r/y	368050	2259	39
100% Kerbside bin		200 t/r/y	433000	2259	29
50% Backdoor bin 50% Kerbside bin	country town	200 t/r/y 250 t/r/y	473900	2146	21
100% Kerbside sack	part country rest	225 t/r/y 250 t/r/y	478080	NK	21
100% Kerbside sack		200 t/r/y	576000	NK	5
75% Backdoor bin 25% Kerbside sack	town, part country part country	200 t/r/y 225 t/r/y	587730	NK	3
75% Kerbside sack 25% Backdoor bin	town, part country part country	250 t/r/y 200 t/r/y	497350	NK	18

For key, see overleaf

Table 10.6 TOTAL ANNUAL COST AND COST PER ROUND FOR EACH COLLECTION METHOD UNDER CONSIDERATION (contd.)

Key:

(1) base case figures calculated by summating the values from the individual cost equations in Table 7.2, using the area of authority as 1500 km^2, the values for the other physical parameters in the text, 10 rounds per vehicle per week, and adding £874 for capital charges. The base case costs are rounded off to the nearest £10.

(2) Calculated from:

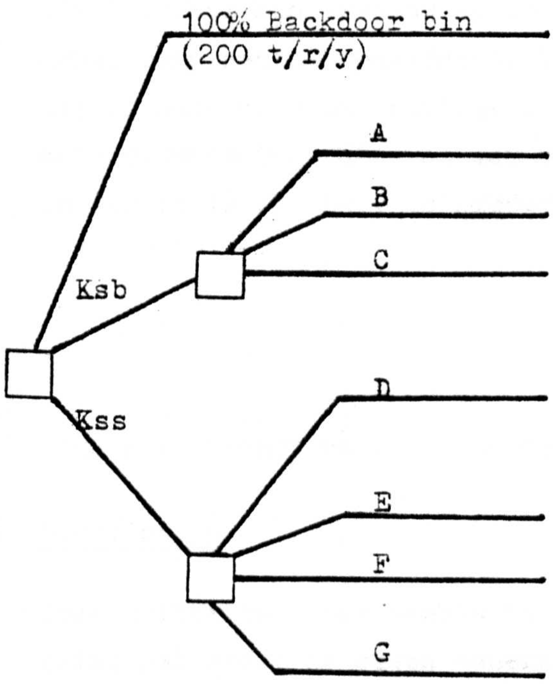
$$\text{Authority 95\% CI} = \sqrt{\text{Round 95\% CI} \times \text{No. of rounds}}$$

NK not known

* Example calculation:

	Tot. Ann. cost per round (sum of indiv. eq in Table 7.2) (£)		Number of rounds		Authority tot. cost (£)
50% backdoor bin 200 t/r/y	6070	x	50	=	303500
50% kerbside bin 250 t/r/y	4260	x	40	=	170400
					473900

Fig 10.3 Tree diagram of alternative collection methods and their relative difference in cost - Case C.



	Total cost (£)	% diff wrt Bkd bin	Cost rank -ing	No. of round	drivers	loaders	vehicles
100% Backdoor bin (200 t/r/y)	607000	-	8	100	15	45	15
A	362100	-40	1	85	13	26	13
B	433000	-29	2	100	15	30	15
C	473900	-22	3	90	14	38	14
D	478080	-21	4	83	11	22	11
E	576000	- 5	6	100	15	30	15
F	497350	-18	5	85	11	22	11
G	587730	- 3	7	98	13	34	13

Key

Ksb Kerbside bin options
Kss Kerbside sack options

A 100% Kerbside bin (200t/r/y)
B 100% Kerbside bin (200t/r/y)
C 50% Kerbside bin
50% Backdoor bin

D 100% Kerbside sack (200t/r/y)
E 100% Kerbside sack (200t/r/y)
F 75% Kerbside sack
25% Backdoor bin
G 25% Kerbside sack
75% Backdoor bin

Bkd Backdoor bin

All of the other options can be considered less sensitive since they incorporate not only a reduction in the workforce but also a reduction in vehicles. Consequently if the shedding of labour is not possible the effect is less dramatic as some savings will accrue from lower vehicle running costs. The two "double-method" options which appear to offer the best likelihood of significant savings in vehicle and labour resources, even after some compromise with the unions, are 75% kerbside sack/25% backdoor bin (saving up to 4 vehicles and 27 staff) and 50% kerbside bin/ 50% backdoor bin (saving up to 1 vehicle and 8 staff). The other combination considered, 25% kerbside sack/75% backdoor bin, offers only marginal savings (3%) over the present backdoor bin method, and after adding on set-up costs and negotiating with the unions it is unlikely to produce any overall saving.

10.6 CASE D - DIRECT HAUL VERSUS COMPACTION TRANSFER

10.6.1 Description

Some authorities are unable to obtain landfills close to their principal areas of waste generation, so by necessity must develop them further away. This increases the distance over which the collected refuse has to be transported. Haulage can be undertaken either directly to the landfill in the collection vehicle, or indirectly in a bulk transporter via a transfer station close to the town. The economics of direct haul were considered in Chapter 7 and bulk haul in Chapter 8.

The principal steps in this evaluation are:

1. Determine the return haul distance to each disposal site, the methods of transfer envisaged, tonneage per load in collection vehicles and bulk transporters, daily number of return journeys a collection vehicle and bulk transporter can make.
2. Refer to Table 10.1 (or Section 7.6.2) for the collection vehicle haul cost function to calculate transport cost in collection vehicles at each selected distance.

3. Refer to Table 10.1 (or Section 8.6.2 and Table 8.2) for i) the bulk transporter haul cost function to calculate transport cost at each selected distance; and ii) the operating cost of the transfer method.
4. Compare the cost of direct and bulk haul with distance. Perform sensitivity analyses on selected parameters such as:
   (i) Financial effects on the cost of collecting refuse.
   (ii) Variations in interest rate.
   (iii) Number of loads per day achieved by a bulk transporter.
   (iv) Average tonneage per load carried in a collection vehicle.

To illustrate the economics of direct and bulk haulage consider a hypothetical rural collection authority handling about 150t/d, which will be required to discharge at one of three potential landfill sites all at different distances from the main area of waste generation (30, 60 and 80 Km return journey). This authority's operations conform initially to the base case (Chapter 6) and in particular capital is charged at 14% interest p.a.

The collection vehicles have been estimated by sample weighings to carry between 3 and 4 t/load and a suitable transfer arrangement is apron storage of refuse, compaction and bulk haulage in 16t capacity rigid chassis vehicles. Bulk transporters usually carry at or near their maximum payload and the dominant factor on the number required is the return distance between the transfer station and landfill. For this comparison where four return journeys are possible in the working day, three vehicles are required (150t/d ÷ (16t x 4 loads) = 3 vehicles, and where only three journeys are possible four vehicles would be employed (150 ÷ (16 x 3) = 4).

At each of the distances considered, the unit haul cost (in cost/tonne) for both direct and bulk haul is calculated to identify the relative cost of each alternative.

	Return Haul Distance (Km)	0	30	60	80
1.	Direct Haul - 4t/load	1.10*	3.65	6.20	7.90
	3t/load	1.46*	4.86	8.26	10.53

Return Haul Distance (Km)	0	30	60	80
Bulk Haul:				
2. Transfer		3.99		
3. Bulk Transport - 16t Rigid				
4 loads/day	1.14*	1.66	2.18	2.53
	5.13	5.65	6.17	6.52
3 loads/day	1.52*	2.04	2.56	2.91
	5.51	6.03	6.55	6.90

Notes

1. Collection vehicle haul cost equation: from Table 10.1 (part vi) for a vehicle carrying 4 tonnes/ load over 60 km return trip.

$(0.34 \times 60) + 4.39 = £\ 24.79\ /\ \text{trip}\ \div$

$4\ t\ /\ \text{load}$

$£\ 6.20\ /\ \text{tonne}$

2. Compaction with apron storage operating cost equation: from Table 10.1 (part viii) for a 150t/d plant

$(295 \times 150) + 36000 = £\ 80250\ +$

capital charges (App 8F) £ 69358

annual cost £149608 ÷

annual tonneage 37500

£ 4.99 / tonne

3. 16t rigid bulk transport cost equation:

annual distance - 4load/d x 80 km/load x 250 d = 80000

annual tonneage - 4load/d x 16 t/load x 250 d = 16000

from Table 10.1 (part xiv) for an 80 km return haul

$(0.277 \times 80000) + 18250 = £\ 40410\ \div$

annual tonneage = 16000

£ 2.53 / tonne

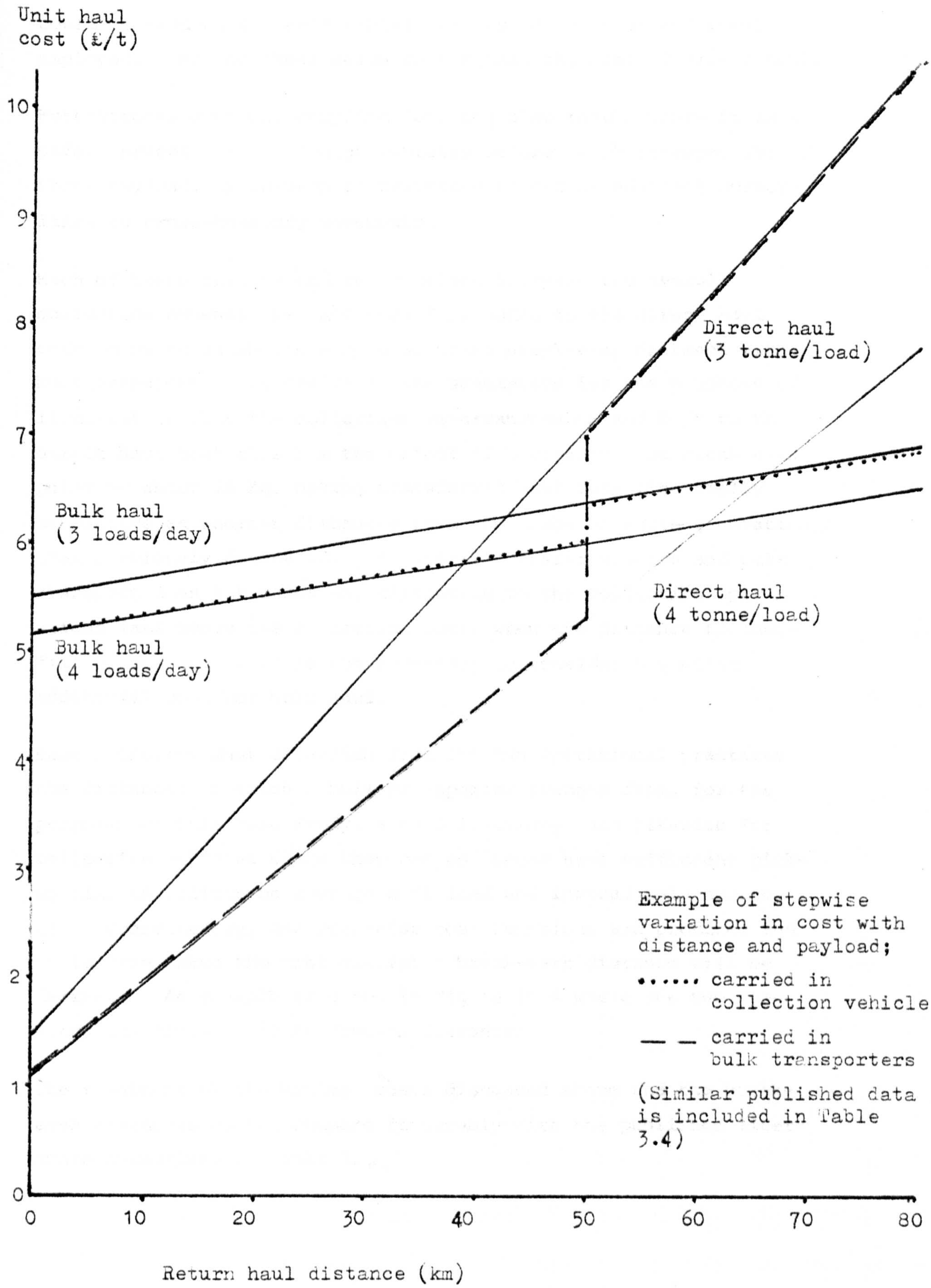
* Vehicles would be required to haul refuse to the site even if the distance is very small. This unit cost represents the fixed costs only.

10.6.2 Technical Discussion

Figure 10.4 summarises the unit cost for each and indicates that at particular distances direct haul becomes more expensive than bulk haul. This break-even point varies depending on the number of loads/day a bulk transporter can make and the tonneage collected on a round by a collection vehicle. Where each bulk transporter can make 4 loads/day and the collection vehicles 4t/load break-even is about 60 Km (return journey). This drops dramatically to 37 Km where only 3t/load are achieved in the collection vehicle and correspondingly direct haulage becomes more expensive.

If for some reason the bulk transporters can only achieve three journeys a day break-even with direct haul at 3t/load increases slightly to 42 Km and at 4t/load to 66 Km. Therefore solely on the financial evidence of haulage costs, the transport of refuse below the break-even distance is cheaper by collection vehicles and above this distance by bulk transporters. However, where direct haul is operated the transport of waste to and from the landfill cannot be considered in isolation. The further a site is from the collection area the time spent travelling will increase while that available for collecting refuse will reduce. At longer distances the time for collection will have reduced to such an

Fig 10.4 Unit cost for direct haul and bulk transport at a 14% per annum interest rate - Compaction with apron storage compared against direct haul to landfill.



extent that it would become impossible for each vehicle to maintain its daily number of rounds (and hence tonneage/load) without overtime or relay working. Alternatively, the daily number of rounds could be reduced for each vehicle and extra vehicles and crews employed. All of these serve to increase the cost of direct haul.

Furthermore, economic complications can also result where it is a safety practice to discharge vehicles before lunch irrespective of their payload, or through restrictions placed by adjacent authorities on cross-boundary movements.

Each of these options and restrictions increase the overall collection expenditures and should be added to the direct haul cost so as to establish a more accurate break-even distance with bulk transport. If one makes the assumption for the purposes of illustration that the collection re-arrangements add £1/t to the direct haul cost this has the effect of decreasing the break-even point by about 15 Km, making transferred haul more financially attractive at shorter distances from the areas of waste generation than previously discussed. A central transfer station and bulk transport does not cause any disruption to the collection operations (and hence the collection cost) when the distance to landfill alters and so it is not necessary to consider a similar additional cost for bulk haul.

Each authority must establish from its own operational practices the distances at which a bulk transporter changes from, for the purposes of this Case Study, 4 to 3 loads/day, and likewise for collection vehicles where they can no longer have sufficient pick-up time to collect on average a 4t load and instead only manage 3t. Consequently, two step-wise cost functions are produced and it is from these the most realistic break-even distance will be derived. An example is given in Figure 10.4 where the two step functions cross at 50 Km (return distance).

The treatment of the haulage costs discussed above and the break-even distances quoted compare favourably with the published literature summarised in Table 3.4.

10.6.3 Variation in Interest Rate

The economic study of waste transfer methods (Chapter 8) demonstrated that these are highly capital intensive and therefore very sensitive to changes in interest rate. At the present time of fluctuating interest rates it is prudent in any financial study to consider the effect of their variation. This has been undertaken for one example of both direct and bulk haul at two interest rates, 10% and 20%; one above and one below the base case rate of 14% already considered.

		10% interest rate				20% interest rate			
	Return Haul Distance (Km)	0	30	60	80	0	30	60	80
2.	Direct Haul 4t/load (£/t)	1.06	3.60	5.30	7.80	1.16	3.71	5.41	7.96
	Bulk Haul:								
1.	Transfer (£/t)		3.66				4.53		
2.	Bulk Transport 4 loads/day (£/t)	1.09	1.61	2.13	2.48	1.21	1.73	2.25	2.60
		4.75	5.27	5.79	6.14	5.74	6.26	6.78	7.13

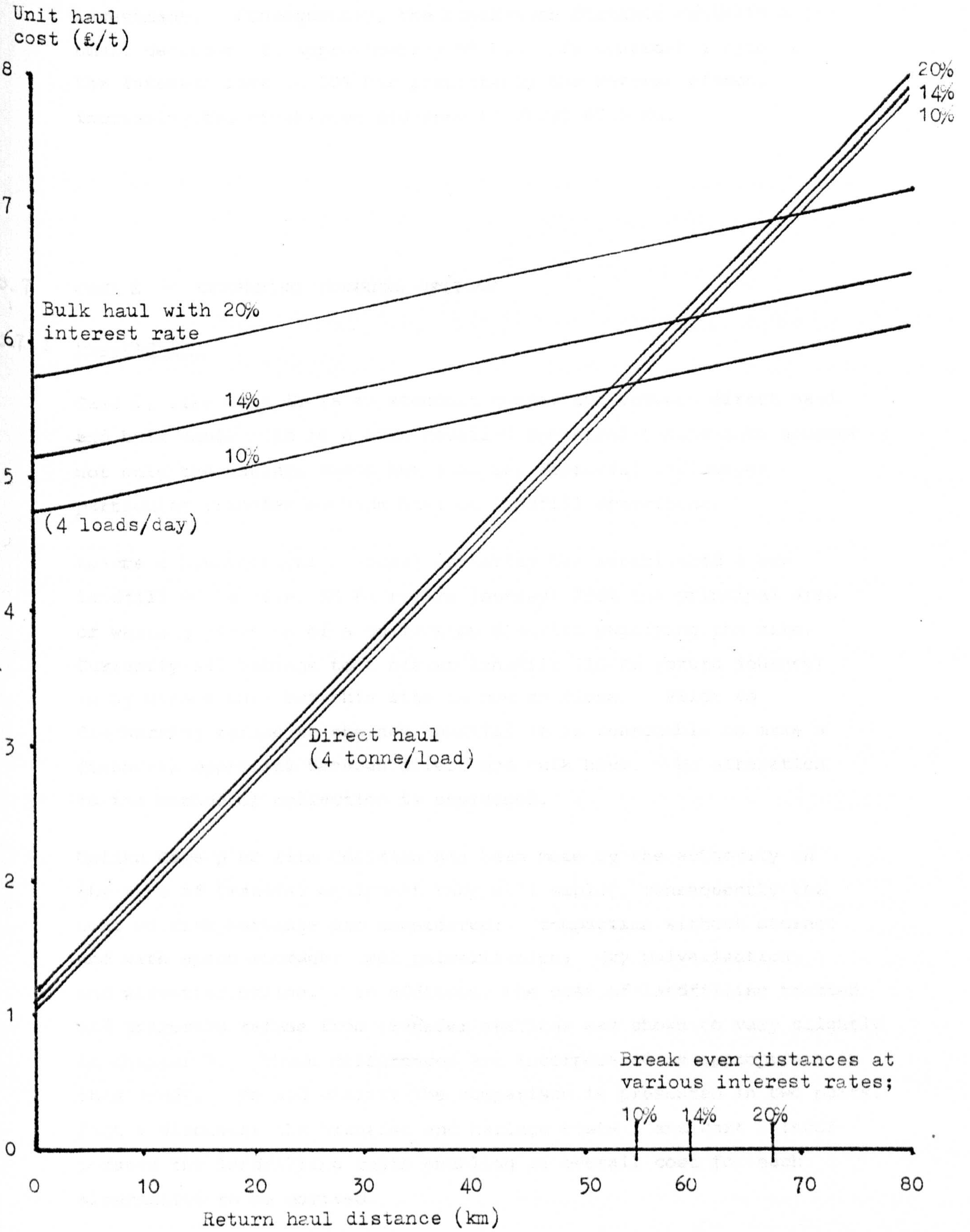
1. Derivation of transfer cost/tonne:

Capital Charges @:	10% = £56,830	20% = £89,597
Summated total operating cost	£137,172	£169,939
Cost per tonne: 137,172 ÷ (150t/dx250 days)	£ 3.66	£ 4.53

2. Cost functions recalculated to account for the changes in capital charges, in a similar manner to (1).

The interest rate calculations for 10%, 14% and 20% bulk haul (4 loads/day) and direct haul (4t/load) operations are detailed in Figure 10.5. Bulk haul is far more sensitive to variations in interest than direct haul and as a result some fluctuation of the break-even distance will occur. Overall, the effect of a variation in the interest rate is not large but its influence should be appreciated.

Fig 10.5 Unit cost for direct haul and bulk transport at various interest rates; 10%, 14%, 20% - Compaction with apron storage compared against direct haul to landfill.



The base case rate of 14% as already shown in Figure 10.4 has a break-even distance of 60 Km (return journey), a decline of 4% to 10% interest has the effect of making capital-intensive options cheaper to operate relative to those requiring less investment. Consequently, the break-even distance exhibits a small decrease, to approximately 55 Km. In contrast a rise in the interest rate to 20% has predictably the reverse effect, increasing the break-even distance to about 67.5 Km.

10.7 CASE E - COMPARING TRANSFER OPTIONS

10.7.1 Description

Case E, like Case D, is an economic comparison between direct haul and bulk haul. It is a more detailed appraisal taking into account not only the haulage costs but also the financial influences particular transfer methods have on landfill operations.

Assume a hypothetical disposal authority has established a new landfill 40 Km (i.e. 80 Km return journey) from the principal area of waste generation of a collection district supplying the site. Currently all haulage to a nearer landfill (10 Km return journey) is by direct haul but this site is due to close. Prior to discharging refuse at the new landfill it is reasonable to make a financial appraisal between direct and bulk haul. No alteration to the method of collection is envisaged.

Unlike Case D no firm decision has been made by the authority on the type of transfer equipment they will employ, consequently the cost of five variants are considered: compaction without storage and with apron storage; wet pulverisation; dry pulverisation; and wire-tied baling. In addition, the cost of landfilling treated and untreated refuse from transfer stations was shown to vary slightly in Chapter 9. These differences are incorporated as appropriate in this study. To aid clarity the comparison is presented in two parts: Part 1 discusses the transfer and haulage costs; and Part 2 incorporates the landfilling costs enabling an overall cost for each alternative to be derived.

The principal steps in this evaluation are:

1. Determine the return haul distance to the disposal site, the transfer methods to be considered, the bulk transport vehicle types most suited to each transfer method, tonneage per load in collection vehicles and bulk transporters, daily number of return journeys a collection vehicle and bulk transporter can make.
2. Refer to Table 10.1 (or Section 7.6.2) for the collection vehicle haul cost function to calculate transport cost in collection vehicles at each selected distance. Add to each estimate a unit cost to account for disruption to the collection of wastes.
3. Refer to Table 10.1 (or Section 8.6.2 and Table 8.2) for i) the bulk transporter haul cost function to calculate transport cost at each selected distance; ii) the operating cost functions to calculate the expenditure on each transfer method under consideration.
4. Calculate and compare the cost of direct and bulk haul with distance.
5. Identify differences between the base case landfill operation and the authority base case.
6. Calculate the landfill cost per tonne for both treated and untreated refuse, incorporating the costs of variations to the base case operation (presented in Table 6.11), from values given in Table 9.12.
7. Combine the direct and bulk haul costs with their appropriate landfill cost. Compare each method. Perform sensitivity analyses on selected parameters such as:
   - (i) Financial effects on the cost of collecting refuse.
   - (ii) Variations in interest rate.
   - (iii) Number of loads per day achieved by a bulk transporter.
   - (iv) Tonneage per load carried in a collection vehicle.
   - (v) Other variations to the landfill operation not considered in (6).

10.7.2 Part 1: Transfer and Haulage Cost Discussion

The collection authority receives about 200t/d of waste and from sample weighings collection vehicles are known to carry between 3 and 4t/load. Each vehicle makes on average two rounds a day, therefore between 25 and 34 collection vehicles are employed; i.e.

200t/d ÷ (4t/load x 2 loads/day/vehicle) = 25 vehicles
200t/d ÷ (3t/load x 2 loads/day/vehicle) = 34 vehicles

Certain bulk transport vehicles are suited to particular transfer methods; rigid chassis vehicles for compaction and wet pulverisation, covered articulated vehicles for dry pulverisation and flatbed trailers for baled refuse. In this comparison all vehicles have a 16t carrying capacity and at a return distance of 80 Km, after considering turn-round time and other work breaks, each can make these complete journeys daily. Consequently, 5 vehicles would be employed in a transfer operation, i.e.

200t/d ÷ (16t/load x 3 loads/day/vehicle) = 5 vehicles

Table 10.7 and Figure 10.6 summarise the transfer and haulage costs for all options under consideration using the cost functions previously detailed in Chapter 7 and 8. No major departures from the base case in Chapter 6 are expected by the authority, with the exception of a collection round reorganisation cost for direct haul (assumed for illustration to be 0.25£/10 Km travelled), and hence the base case costings were used.

If in another case study specific cost items were outside the base case they could be readily incorporated in Table 10.7 as an incremental cost (or saving).

Wet pulverisation and wire-tied baling are both far more expensive than direct haul carrying 4t/load over the 80 Km distance. These two methods are however commonly selected for reasons other than purely financial ones, where perhaps political or social pressures to ensure "tidy and neat" refuse are strong, or on technical grounds where one of these methods in the view of the Disposal Officer or elected Councillors is more efficient to operate.

Table 10.7 UNIT COST PER TONNE FOR DIRECT HAUL AND SEVERAL BULK HAUL OPTIONS (£/t)

Method	Transfer or Treatment Cost (£/t)	Haul Distance (Bulk Transport Annual Distance)		
		0KM (0KM)	50KM (37500KM)	80KM (4) (60000KM)
(1) Direct haul @ 4t/load		1.10	5.35	7.90
@ 3t/load		1.46	7.13	10.53
ADD				
(2) Disruption to collection operations estimated as: @ 3 and 4t/load (i.e. 0.25£/10KM haul)		0	1.25	2.00
@ 4t/load		1.10	6.60	9.90
@ 3t/load		1.46	8.38	12.53
(3) Compaction without storage	2.97	1.52	2.39	2.91
*Bulk Transport		4.49	5.36	5.88
(3) Compaction with apron storage	3.73	1.52	2.39	2.91
*Bulk Transport		5.25	6.12	6.64
(3) Wet Pulverisation	9.77	1.52	2.39	2.91
*Bulk Transport		11.29	12.16	12.68
(3) Dry Pulverisation	6.36	1.55	2.30	2.75
**Bulk Transport		7.91	8.66	9.11
(3) Wire-tied Baling	8.47	1.47	2.18	2.61
***Bulk Transport		9.94	10.65	11.08

Notes: (1) Equations in Table 10.1. Calculations similar to the examples given in the Case D text.

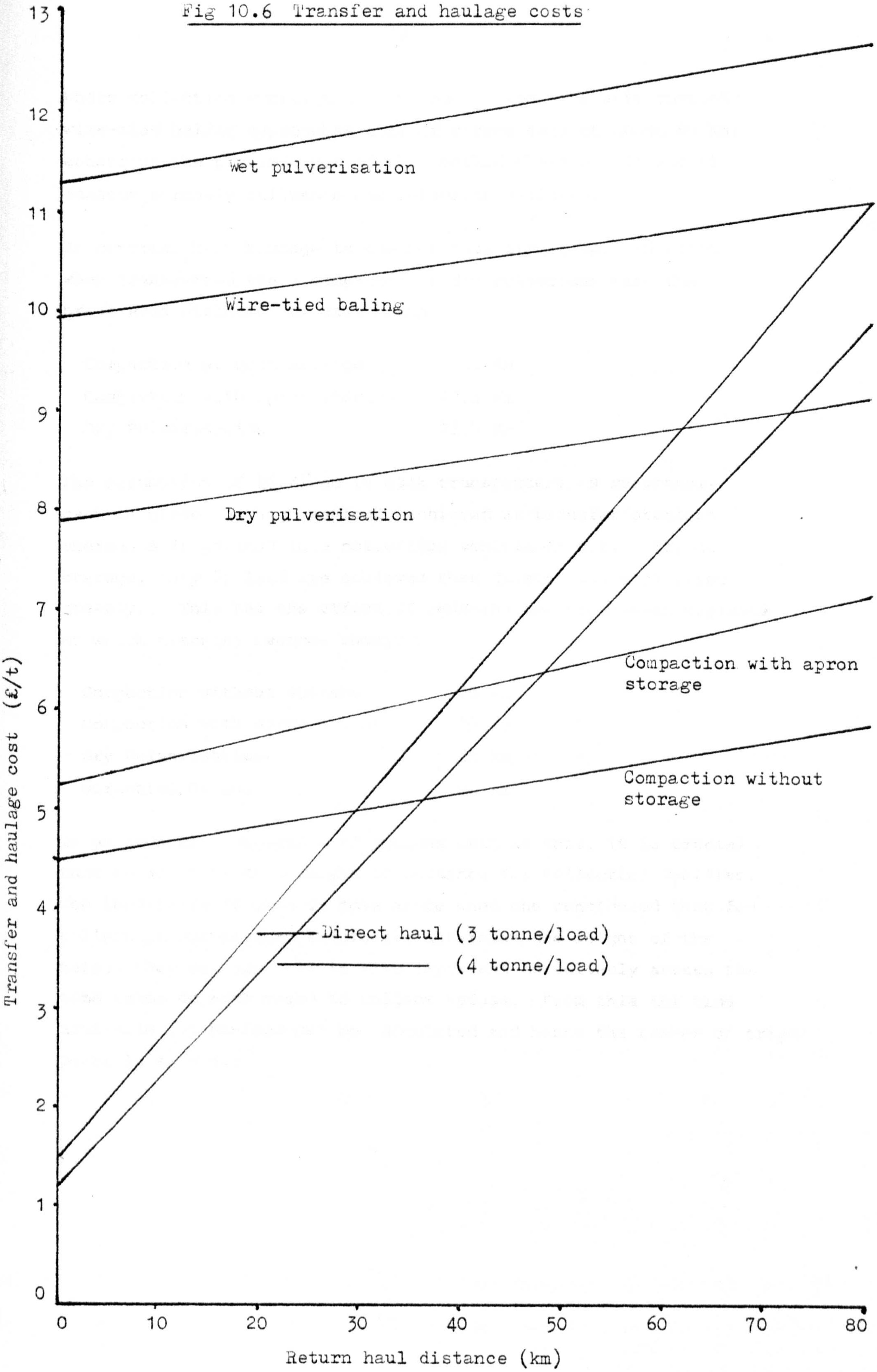
(2) Estimated additional cost arising from rearrangements to the collection operations. For example, overtime payments, extra vehicles and crews, relay working. More fully discussed in Case D.

(3) Calculated from the total operating cost function for each transfer method, plus capital charges at 14% p.a. and the bulk transport haul cost models for the vehicle types considered. Cost functions in Table 10.1, capital charges in Appendix 8F.

(4) It is unrealistic to expext direct haul vehicles to achieve 2 trips per day unless overtime is worked.

Vehicle types:
- * Bulk transporters: 16t carrying capacity rigid, each vehicle 3 loads/day, 16t/load
- ** 16t carrying capacity covered artic., " "
- *** 16t carrying capacity flatbed artic., " "

Fig 10.6 Transfer and haulage costs



Where collection vehicles only manage 3t/load the unit cost of wire-tied baling approaches that of direct haul at about 80 Km, enhancing the possible use of this method where non-financial reasons strongly influence the selection decision.

In contrast bulk haulage is cheaper than direct haul (@ 4t/load) when transferred via a compactor or dry pulveriser with the break-even distance for each being:

Compaction without storage	36 Km
Compaction with apron storage	47.5 Km
Dry Pulverisation	71.5 Km

The assumption of 16t/load in bulk transporters is reasonably certain given the high payloads achieved at transfer stations whereas a 4t payload in a collection vehicle is not. If, on average, only 3t/load are achieved then direct haul cost rises steeply. This has the effect of reducing the break-even distance at which transfer becomes cheaper:

Compaction without storage	29 Km
Compaction with apron storage	39 Km
Dry Pulverisation	61 Km
Wire-tied baling	80 Km

In an economic comparison of options such as this, it is crucial that an accurate mean weight is obtained for collection vehicles. The importance of this is more acute when one considered that few collection authorities accurately determine the weight of the refuse they collect. It is also important to reliably assess the time taken on each round to collect refuse. From this the time available for haulage can be calculated and hence the number of trips possible each day.

10.7.3 Part 2: Landfill Discussion

The physical form of the refuse which passes through a pulveriser or baling transfer station is altered and correspondingly so is the cost of its final disposal at the landfill. Therefore when considering the financial aspects of each transfer method their effects on the landfill operation should also be included.

In Chapter 9 the economic analysis of landfill disposal is only applicable to the emplacement of untreated waste at a site conforming to the base case standard of operation and design. Several aspects of the 200t/d landfill considered in this case study do not match the base study and consequently the direct use without modification of the landfill cost functions (Table 9.1b) is not possible. Instead, added to the base case cost are several incremental values each accounting for a specific variation from the base case. Several such variations having been discussed at length in Section 9.5 and evaluated in Table 9.12.

In brief, the differences between the base case and the hypothetical authority's basis of operation are:

	Base Case (Chapter 6)	Authority's Basis
1.	Only untreated refuse considered.	Untreated and treated refuse considered.
2.	All cover won on site.	Half the cover required for untreated and dry pulverised refuse must be purchased. Wet pulverised and baled refuse are considered not to require cover.
3.	Site not divided into "cells" (See Chapter 3 for definition of cells)	Extensive cell construction.
4.	No site drainage required.	Limited site drainage installed.
5.	No leachate treatment measures.	Limited leachate treatment installed.
6.	No gas alleviation measures.	As base case.
7.	No revenues.	Some revenues received, variable depending on the physical form of the refuse and resource recovery.
8.	Site life, 20 years.	As base case.
9.	Interest rate, 14% p.a.	As base case.

The effect on the landfill cost from these variations to the base case are listed in Table 10.8. This table concludes by indicating that the emplacement of untreated and dry pulverised refuse are the most expensive forms of waste to handle, followed by wet pulverised material (approximately 12% lower) and bales, 40% below untreated refuse.

The addition of the landfill cost to the Part 1 transfer and haulage costs produces an overall total unit cost for each alternative method (Table 10.9), graphically represented in Figure 10.7. Comparison with Figure 10.6 shows that the break-even distances between direct and bulk haul have been reduced. This is primarily due to the landfilling of untreated, directly hauled waste being more expensive than the landfilling of treated refuse. Overall the break-even distances for direct haul (assuming 2trips/day) at 4t/load are almost identical to those described earlier for transfer and haulage costs only. However, for direct haul at 3t/load the effect of cheaper landfilling for treated refuse is more apparent, i.e.

	Break-even distances	
	Transfer, haulage and Landfill (Km)	Transfer and haulage (Km)
Compaction without storage	29	29
Compaction with apron storage	37	39
Dry pulverisation	61	61
Wire-tied baling	71	80

In conclusion, in this purely economic appreciation of a landfill 80 Km return journey from the main waste generating area, bulk haul with transfer by compaction or dry pulverisation are both cheaper than direct haul in a collection vehicle with 4t/load and 2 loads/day. If this payload slips to 3t/load then wire-tied baling is also a financially attractive option over direct haul. It is emphasised that strategic decisions such as the replacement of direct haul with bulk haul are not made solely on economic grounds. The decision must also include social, operational, union and political considerations. This can and often does lead to a compromise option not necessarily the lowest in cost.

Table 10.8 LANDFILL COST PER TONNE FOR TREATED AND UNTREATED REFUSE (£/t)

Landfill Components[1]	Untreated Refuse	Dry Pulverised Refuse	Wet Pulverised Refuse	Baled Refuse
Base Case	1.76	1.75	1.73	1.47
Soil Cover - ½ purchased - steel wheeled	0.39	0.39	-	-
- no cover	-	-	(0.12)	(0.20)
Cell construction - intermediate cost	0.29	0.29	0.29	-
Drainage - low cost	0.06	0.06	0.06	0.06
Leachate - low cost	0.25	0.25	0.25	0.25
Gas Measures	None			
Revenues - intermediate income	(0.44)	(0.44)	-	-
- low income	-	-	(0.18)	(0.18)
Site lifetime - 20y	No adjustment to base case			
Interest rate - 14% p.a.	"			
TOTAL LANDFILL COST/TONNE	2.31	2.30	2.03	1.40

(1) All extensions to the base case are detailed in Table 9.12.

Table 10.9 TOTAL COST PER TONNE FOR TRANSFER, HAULAGE AND LANDFILL [1] (£/t)

Method	0KM	50KM	80KM
Direct Haul @ 4t/load	3.41	8.91	12.21
@ 3t/load	3.77	10.69	14.84
Compaction without storage	6.80	7.67	8.19
Compaction with apron storage	7.56	8.43	8.95
Wet pulverisation	13.32	14.19	15.71
Dry pulverisation	10.21	10.96	11.41
Wire-tied baling	11.34	12.05	12.48

(1) For each method the Transfer and Haulage cost from Table 10.7 is ADDED to Total Landfill cost from Table 10.8.

Economic appraisal provides the necessary framework for discussion. All parties then decide if the least cost option is to be selected, or if it is more appropriate to pay the extra cost for a more labour intensive or sophisticated disposal technique.

In this case study bulk haul via compaction without storage is the cheapest option. A compromise could be to undertake dry pulverisation transfer, or perhaps maintain direct haul but take major operational steps to obtain on average 5t/load and 2 trips/day (Figure 10.7).

10.8 CASE F - ALTERNATIVE LANDFILL ENGINEERING AND OPERATING TECHNIQUES

10.8.1 Description

The aim of Case F is to demonstrate the flexibility of the landfill disposal cost model described in Chapter 9, and noted in Table 10.1 (part xx). This is done by examining the effect of different standards of operation on the landfilling costs for untreated, baled, wet and dry pulverised waste. Consider a situation where a Waste Disposal Officer is investigating the financial implications of several modes of operation at a 400 t/d site.

The authority and site differ markedly from the base case criteria used throughout this research (Chapter 6). Therefore the first step is to identify these differences and calculate the authority's base case unit cost (Table 10.10):

	Research Base Case	Authority Base Case
1.	No trade revenues.	As research base case.
2.	20 year lifetime	15 year lifetime - untreated and dry pulverised waste. 20 year baled and wet pulverised.
3.	Site not divided into "cells". (See Chapter 3 for definition of cells).	All refuse emplaced in cells, except baled waste.
4.	No site drainage required.	Extensive drainage construction required.

Fig 10.7 Transfer, haulage and landfill costs

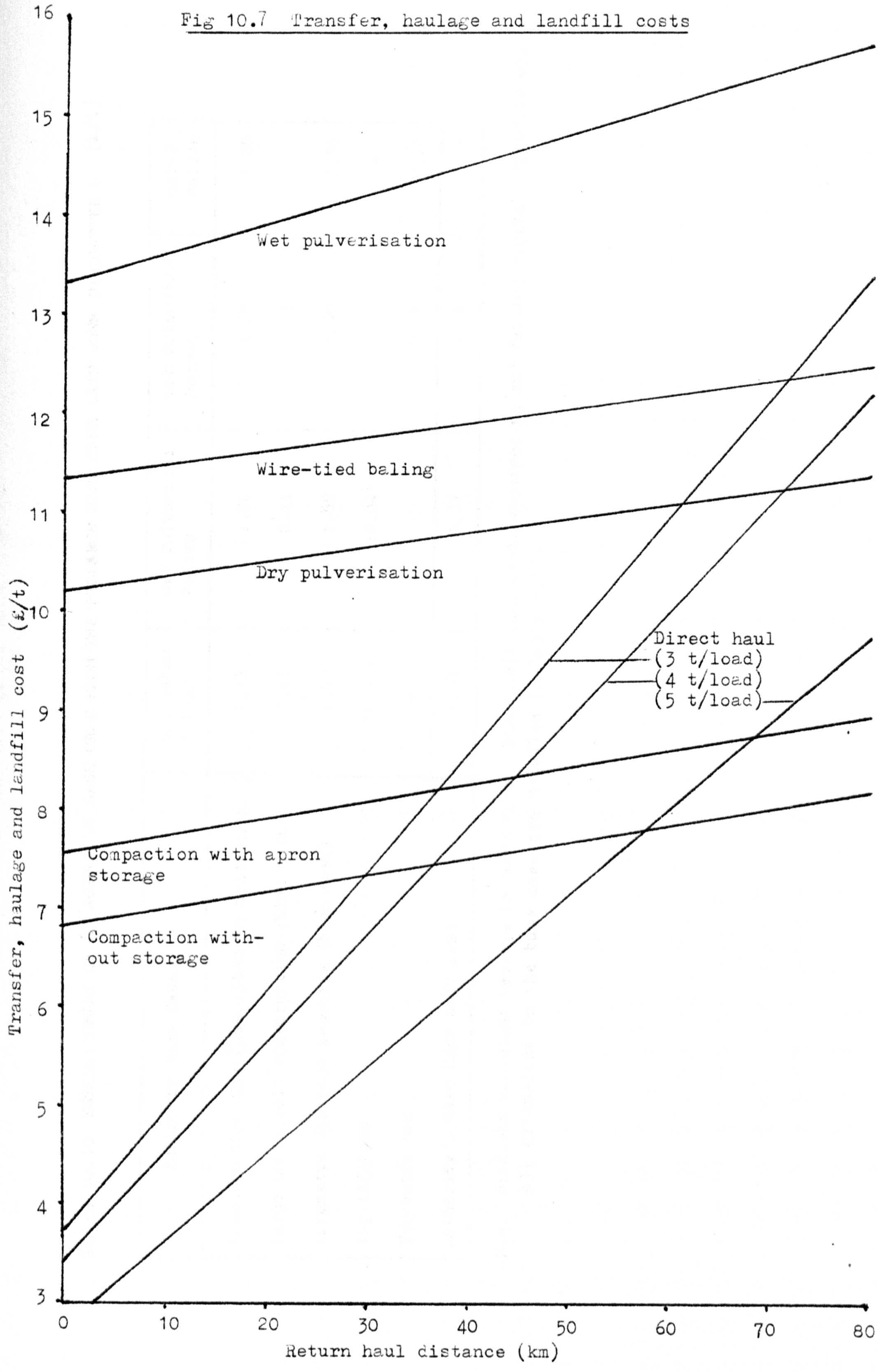


Table 10.10 ESTABLISHMENT OF AN 'AUTHORITY' BASE CASE FROM THE RESEARCH BASE CASE LAID DOWN IN CHAPTER 6 (£/t)

Authority Base Case	Untreated Refuse	Dry Pulverised Refuse	Wet Pulverized Refuse	Baled Refuse
Research Base Case(described in Section 6.3)	1.22	1.20	1.18	1.09
Large scale cell construction (high cost)	0.41	0.41	0.41	-
Extensive drainage measures (high cost)	1.50	1.50	1.50	1.50
15y lifetime	(0.04)	(0.04)	-	-
Two extra men	-	-	0.14	0.14
Authority's Base Case unit cost	3.09	3.07	3.23	2.73

N.B. Brackets represent savings in costs from lower building, civil engineering and fencing capital expenditures. All extensions to the base case are detailed in Table 9.12

	Research Base Case	Authority Base Case
5.	No leachate treatment measures.	Leachate treatment required.
6.	No gas alleviation measures.	Gas alleviation required.
7.	All cover won on site.	As research base case.
8.	400t/d base case = 4 men.	Two additional men for wet pulverised and baled refuse, i.e. (£6900x2) ÷ (400t/d x 250 days) = 0.14 £/t.

The unit cost of each change to the research base case criteria is derived from Table 9.12. All changes are summated to derive the authority base case costs, given in Table 10.10. Having now established this new base case the second step in this appraisal is to review the possible operational variations he envisages could be undertaken at the site. These are treated as extensions, the cost of which are added to the authority base case.

The variations considered are:

1. Compare between 100% purchased soil cover, foam cover and no cover.
2. Compare between gas alleviation and gas collection measures.
3. Compare between on-site leachate treatment and recirculation through the landfill.

Again these variations are estimated from figures in Table 9.12 and are summarised in Table 10.11. There are 44 possible permutations of these three variations and the four types of refuse under review. The most convenient way of exhibiting each permutation and evaluating any selected one is with a decision tree (Figure 10.8). The cost of each permutation is calculated by summating all values along each branched pathway. For example:

Wet pulverised refuse - Authority Base Case	3.23 £/t	(From Table 10.10)
Foam cover	0.26)	
Gas collection	(0.14))	(From Table 10.11)
Leachate recirculation	0.18)	
Total £/t	3.53	(as given in Figure 10.8)

Thus, using a decision tree enables any combination of these variations to the landfill operation to be easily and quickly evaluated.

Table 10.11 COST OF SPECIFIC VARIATIONS TO AN "AUTHORITY" BASE CASE (£/t)

Variations - 400t/d site	Untreated Refuse	Dry Pulverised Refuse	Wet Pulverised Refuse	Baled Refuse
Intermediate Cover				
100% purchased soil	0.39	0.39	0.39	0.39
100% purchased foam	0.26	0.26	0.26	0.26
No cover	-	(0.05)	(0.06)	(0.12)
Gas Measures				
Alleviation (low cost)	0.08	0.08	0.08	0.08
Collection (intermediate)	0.16 } (0.14)	0.16 } (0.14)	0.16 } (0.14)	0.16 } (0.14)
Revenue (intermediate)	(0.30) }	(0.30) }	(0.30) }	(0.30) }
Leachate Measures				
Recirculation (low cost)	0.18	0.18	0.18	0.18
On-site treatment (high cost)	2.06	2.06	2.06	2.06

The unit cost for each variation is taken from Table 9.12.

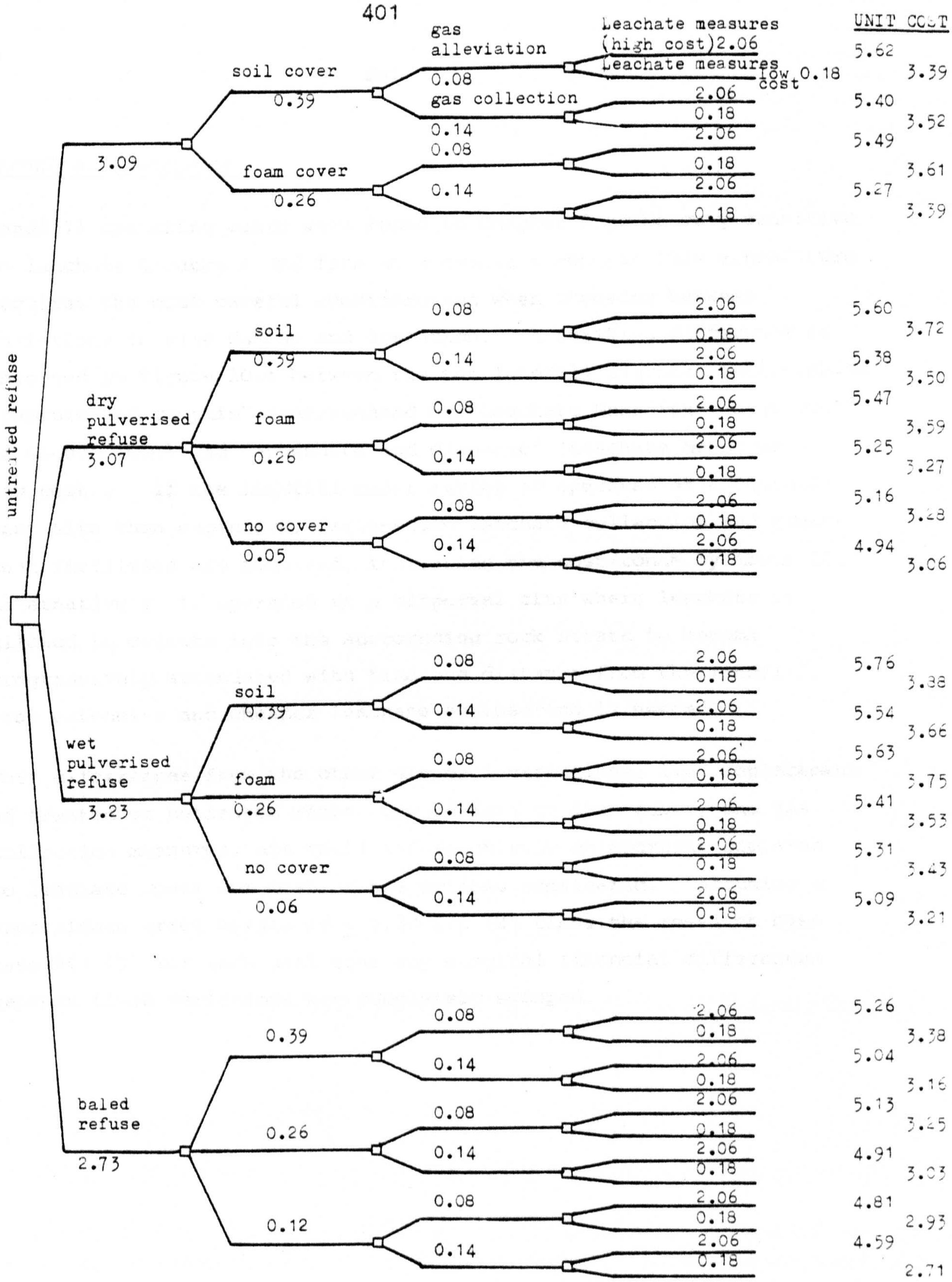


Fig 10.8 Tree diagram of the alternative landfill options

10.8.2 Technical Discussion

Landfill operating costs were found in Chapter 9 to be very sensitive to leachate treatment and from an economic viewpoint this expenditure requires the most careful consideration when choosing between variations in site design and operation. A striking difference is observed in Figure 10.8 between the two landfill leachate philosophies; "capture and contain" (represented by "Leachate Measures - high cost" in Figure 10.8) and "attenuate and disperse" (Leachate Measures - low cost). If the landfill under review is operated as a containment site then expensive, large-scale leachate collection and treatment facilities are required, increasing the cost/tonne by about £2. Alternatively, if operated as a dispersal site where leachate is allowed to migrate into the surrounding rock strata to become progressively attenuated with time and distance from the landfill, less extensive and cheaper leachate engineering is needed.

Cost differences from the other disposal variations, i.e. emplacement of treated or untreated waste, use of soil or foam cover, and gas collection measures, are small and relatively unimportant compared to leachate costs for most of the options considered. Assuming an approximate error margin of $\pm$ 0.30 £/t (2½ times the research base case 95% CI) for each unit cost any marginal financial differences between these variations are completely swamped.

CHAPTER 11

CONCLUSIONS

11.1 Contribution to waste management planning

A major priority of waste management is to plan for the future. It is a task complicated by several areas of uncertainty that must be resolved before a waste manager can produce a useful and workable plan, ie:

i) estimate reliably the quantity, composition and distribution of the wastes to be collected;

ii) compare technically the range of available methods for handling wastes;

iii) weigh up the competing pressures on land use;

iv) satisfy the increasing public concern and curiosity in waste management operations;

v) compare economically the alternative options by producing accurate estimates of their costs;

vi) establish the relative merits of trade-offs between methods (eg direct haul in collection vehicles against bulk haulage).

Without the careful consideration of each of these issues the decisions taken on future waste management practices may be founded on weak or ill-conceived technical and financial grounds. The ability of a waste manager to address these areas of uncertainty is critically dependent upon the resources available within a waste disposal or collection authority. Some large county departments in England have separate sections solely dedicated to planning for the future with the purpose of maintaining a continuity to the disposal operation. Conversely, in the majority of public sector operations elsewhere departments are small and all too often the waste manager relegates the planning of waste management to a subordinate position, on the grounds that there are insufficient manpower and financial resources to undertake such an exercise. The provisions of the 1974 Control of Pollution Act requiring waste disposal authorities to produce a plan has done little to change this situation.

In contrast to legal complusion a more constructive approach is to provide waste managers with better tools to evaluate, quickly, reliably and cost-effectively, the uncertainties encountered in the development of a plan. The purpose of this research has been to provide such tools for the waste manager. It does not represent a comprehensive approach to waste management planning. No single work could satisfactorily achieve such a task. However, it has concentrated upon three key areas, ie

i) producing a reliable method to estimate the quantities of wastes to be collected;

ii) generating sound economic information on several "popular" collection, transfer and landfill operations;

iii) assessing the effect on costs from changes in a wide number of parameters including, operating procedures, plant design, throughput, and interest rate fluctuations.

This information can then be used to make rational apprasials between alternative options at the appropiate stage in the planning process.

Waste management planning can be viewed as a series of stages from which a workable and properly considered plan evolves. The stages are presented sequentially, though this need not be the case in practice for all situations. The initial stage is to set out the objectives of the study. These should define the level of detail sought and address local political concerns, social attitudes, national legislation, other local government plans, and financial constraints.

The next stage is to define the "boundary" of the system under consideration. Figure 5.1 is an example of a system boundary, and was used in this work to delineate the individual collection, transfer and disposal operations. The greater the detail to be included in a plan then the greater the depth to which the financial and technical aspects of each operation in the system are reviewed.

The third stage involves the collection of technical and economic information from existing and potential operations, and the subsequent comparison and evaluation of alternative options. It is at this stage in the planning process that the methods and techniques presented in this thesis are designed to be used.

The final stage is one of public consultation, where the draft plan is laid open for comment. Once these have been received it then falls to the waste manager to reconcile any differences with the ultimate aim of producing a plan based on the concensus opinion. However, sometimes it may prove impossible to successfully satisfy opposing viewpoints.

11.2 Specific conclusions

Collectively, the methods and economic information contained in in this thesis represent a significant contribution to waste management planning in five principal areas.

1. A workable statistical model has been demonstrated in Chapter 4 which accurately estimates the tonneages arising in a collection area from a very small, but representative, sample size. Potentially, this could have a major influence in improving the quality of the tonneage statistics currently used by authorities to plan disposal facilities.

2. New capital and operating cost estimating equations have been produced to replace those adopted from other, more distantly related, fields of engineering. These equations in Chapter 5 are a straightforward method of quickly assessing the cost of an option when only indicative, lower accuracy, values are sought. This is known as the "pre-design" level and typical accuracies are about an order of magnitude (ie $\times/$ 2.0).

3. More accurate cost functions were derived in Chapters 7, 8 and 9. These go further than the estimating equations in 2) and enable more comprehensive cost estimates to be produced. These would be suitable for situations where a limited

number of favourable options are to be investigated further by a waste manager. This is known as the "preliminary design" level of cost estimation and the accuracy achieved by the cost functions is between $\stackrel{\times}{/}$1.3 and 1.5.

4. Also in Chapters 7, 8 and 9, for the first time detailed capital and operating costs have been established for all of the "popular" collection and disposal methods. The sensitivity of the total costs to each of their component expenditures is also explored in depth. The cost estimates produced are accurate to between $\stackrel{\times}{/}$1.1 to 1.2 and are useful where rigorous economic assessments are required on a preferred option prior to tendering or seeking capital sanctioning.

5. A new basis for calculating capital and operating cost indices has been laid down for waste management to inflate forward costs from earlier years. This breaks the reliance on the possibly less-representative Wholesale Price Index or the general engineering indices. Additionally, Chapter 5 also has a new break-even analysis technique suitable for commercial waste disposal operators which can assess likely revenues for planned waste treatment plants.

Five case studies are also documented in Chapter 10 to demonstrate the methodology by which the costs for collection, transfer or landfill disposal, or any combination thereof, can be estimated, and the economic trade offs between alternative methods or standards of operation can be readily calculated.

The production of an extensive set of capital and operating costs, all compiled on a consistent basis, as described in 4. above has enabled a detailed investigation to be made into the economics of each method. A number of interesting conclusions have been identified from this analysis.

Collection:

1. Collection costs vary markedly between urban and rural areas. This is primarily due to lower travelling distances and a higher number of households served by a vehicle and crew in urban authorities. Principal operational differences were found in crew sizes, fuel consumption and frequency of maintenance.

2. Overall, the operating costs for each collection method are most closely related to the area of each authority.

3. Capital expenditures are dominated by the cost of the collection vehicle.

4. In the base case the cheapest collection method to operate is kerbside bin, and conversely the most expensive is backdoor sack. This situation remains even when the number of loaders is increased for the kerbside methods or reduced for the backdoor methods.

5. The largest operating expenditures are labour costs and capital charges. Together these comprise upto 77% of the total cost for the urban backdoor bin collection method.

6. The cost for replacement sacks is a significant expenditure for the sack collection methods (> 10% of the total cost). This represents the additional cost that must be borne by the community if it favours this more aesthetic method of collection.

7. Vehicle running costs, which include fuel costs, in contrast to 5. and 6. above are relatively insignificant expenditures, accounting for ≤6% of the total cost. This is an interesting finding given the large element of travelling associated with collection.

8. A cost function has been produced to estimate the cost of

hauling wastes in a collection vehicle to a disposal point. The typical return haul distance found from operators in urban authorities is 10km, and in rural ones, 30km. The corresponding haul costs are around 7.80 and 14.60 £/load respectively.

Transfer:

9. The use of compactors to transfer wastes is the cheapest method compared to treatment by wire-tied baling, dry or wet pulverisation.

10. The two largest capital expenditures for all methods are building construction and installation of transfer equipment.

11. Bunker storage increases the capital investment required for a transfer station by 50 to 75%.

12. Wet pulverisation is the most capital intensive of the alternatives to compaction costed in this work.

13. The capital cost of wire-tied baling plants at increasing sizes of operation rises more steeply than the cost of dry pulverisation. At 50t/d there is little difference between the costs, at 100t/d wire-tied baling is 20% higher, and at 300t/d it is over 125% larger.

14. The largest annual expenditures are capital charges and labour costs which account for upto 83% of the total operating cost at a 25t/d wet pulverisation plant.

15. Other notable expenses are:

electricity costs - compaction without storage and dry pulverisation (≤7.5 and <9% respectively)

crane costs - compaction with bunker storage (5 to 8 %)

mobile plant costs - compaction with apron storage (~8%)

pulveriser maintenance - dry pulverisation (6 to 11%). This expense is primarily due to the regular need for costly hammer refacing.

16. Models to estimate the haulage costs for seven distinctly different bulk transport vehicles have been produced. These represent the types of vehicles typically used to carry wastes from transfer stations. Over short distances (<30000 km/y, or 120 km/d) the annual cost of all the vehicles, with the exception of 22t articulated units, are within £5000 of each other. At twice this distance the range increases to around £7000.

17. At distances of over 60000km/y the operating cost of articulated vehicles is lower than the corresponding rigid chassis vehicles with the same carrying capacity.

Landfill disposal

18. The largest capital expenditures are the provision of mobile plant and civil engineering preparatory works. The need to construct a more substantial access road at sites over 200 t/d is also an increasingly significant cost item.

19. Manual labour is the largest operating cost on small sites (≤50t/d), but is superseded by capital charges on larger sites. Together they represent upto 64% of the total operating cost.

20. The running costs of emplacement and support vehicles are also significant expenses (upto 22%). Interestingly, vehicle maintenance and tyre cost dominate over the fuel component.

21. Site rent (or void cost) is also an important cost (~10%) at sites with high rates of input (>350t/d).

22. Several variations and extensions to the landfill base case were also costed. From these it is evident that the cost of leachate alleviation measures, if on-site treatment is necessary, could more than double the landfill operating cost. Gas alleviation and drainage measures at small sites have similarly large influences. The provision of off-site

cover, cell construction, changes in interest rates or site lifetime, are insignificant by comparison.

23. Notable economies of scale have been identified for three sets of total costs:

dry pulverisation operating costs, scale factor 0.62;
landfill capital costs, 10-1000t/d, scale factor 0.74;
landfill operating costs, 10-500t/d, scale factor 0.51.

Economies of scale were not identified in this research for the other methods. However, a number of economies were found for component expenditures and are given in Table 5.15.

11.3 Recommendations for further studies

The research reported in this thesis has elucidated the economics of waste management in a number of areas far more comprehensively than achieved in earlier studies. However, uncertainty still exists and several topics would benefit from further investigations. Accordingly, some suggestions are presented:

1. The economic implications of the privatisation of collection operations.

2. Further refinement of the estimation of haul costs in collection and bulk transport vehicles.

3. Detailed study into the compilation of the components of waste management cost indices with the view to producing regularly updated values for use by waste managers and researchers.

4. Further economic analyses would greatly improve the accuracy in several areas of landfill costing:

    i) gas extraction and alleviation measures;
    ii) site lining, grouting, dynamic consolidation and other ground improvement techniques;
    iii) capping, restoration measures, aftercare and post-closure monitoring;

iv) on-site leachate treatment facilities.

5. Considerable opportunities exist for the expanded use of interactive computer models to optimise waste management plans. At present, a selection by a waste manager between several alternative methods is rarely an optimum solution. His manual comparisons can only consider a limited number of parameters and has to ignore, or make non-limiting assumptions for, all others. The use of optimisation techniques, such as linear programming, can consider more variables than simple inspection, and by complimenting these solutions with the experience of the waste manager marks a significant breakthrough in the development of waste management plans. It is of crucial importance that optimisation techniques use reliable cost information. Therefore, the data provided in this thesis is one such source for future use.

6. A review of the economics of incineration, refuse-derived fuel and resource recovery options would be an important piece of work, complementary to the topic of this thesis. Comparisons between landfill disposal and the methods mentioned above would provide waste managers the first thorough, consistent and unambiguous analysis of these options.

7. A study, similar in nature to this work, to assess the economics of hazardous waste collection, treatment and disposal would be very timely.

11.4 Waste management economics in a new perspective

In future years the waste manager will increasingly take on the role of a waste planner. In some respects this is a field traditionally alien to him. This research has sought to provide the tools to enable such a person to estimate reliable economic data during the process of constructing a coherent waste management plan. It is appreciated that costs should not be the only criterion against which projects are selected; social, environmental and technical issues also have important influences. However, the establishment of consistent economic data at an early stage in the planning process serves to put these other considerations into better perspective. This should not only lead to more informed planning decisions in the future but also ultimately improve the quality of the service offered.

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