

# **Improving the Accessibility of Modelling for Management Learning**

*A systems thinking approach using itthink*

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19 September 1995 

## Abstract

This thesis describes research aimed at increasing the accessibility of modelling to the general manager as a tool to promote organisational learning and improve managerial performance. An exploratory approach was adopted and a wide-ranging investigation of the whole process of modelling and its relevance to learning was carried out.

A review of individual learning, organisational learning and modelling techniques in management, led to the identification of system thinking as a modelling methodology whose role in promoting learning warranted further research.

*Two major pieces of fieldwork were conducted. Firstly, the process of training managers in systems thinking was studied. Secondly, a case study of the adoption of systems thinking by a large manufacturing company was carried out. During the course of this work, a number of training case studies and a supply chain management training workshop, based upon the use of a generic supply chain model, were developed.*

This fieldwork identified model conceptualisation as a major area of difficulty for novice modellers. In order to provide assistance in this area, a new framework for model conceptualisation, based upon the use of archetypes and generic models, was developed. During the course of this work an exploration of the relationship between qualitative and quantitative modelling was carried out. This resulted in the development of simulation models of a number of the system archetypes.

Additionally, a computerised Delphi-based knowledge acquisition tool was developed. The purpose of this tool was to allow a large group of geographically dispersed people to become directly involved in the modelling process.

In conclusion, this thesis has suggested that there are substantial benefits to be gained from encouraging managers to become modellers. It has also confirmed the potential of systems thinking to support modelling for learning.

## **Acknowledgements**

The research presented in this thesis (with the exception of chapter 7) was supported by the SERC/ESRC and in part by Cognitus Systems Ltd. The work described in chapter 7 was funded by the UK Defence Research Agency.

I would like to acknowledge the assistance that I received from my supervisors Eric Wolstenholme and Richard Thomas. I would also like to thank Alfredo Moscardini and Don Prior of the University of Sunderland for first introducing me to systems dynamics. Finally, I would like to thank Claire Monaghan for both proof reading this thesis and for providing valued support and encouragement over the last three years.

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## Thesis Overview

There is a growing recognition of a need to improve the rigor of thinking in management. The aim of the research described in this thesis is to address this need by identifying ways in which modelling techniques can be made more accessible to the general manager. Such a broad objective has necessitated a wide-ranging and exploratory approach which has investigated the whole of the modelling process and its relevance to management.

As a consequence, the material presented in this thesis does not form a simple linear progression. A number of the chapters are to a large degree free-standing and for this reason each chapter contains its own conclusions. It will help the reader to appreciate the totality of the research if, at this stage, the relationship between the chapters is clarified.

In chapter 1 and chapter 2 the theoretical background of the concept of modelling to support learning organisations is described. The need for managers to become modellers is established and the reasons for the adoption of systems thinking, as the modelling methodology for this research are given.

The next two chapters describe fieldwork that was carried out to identify what the practical difficulties were in achieving the goal of developing managers as modellers. The fieldwork looked at the process of managers becoming modellers in the context of a formal training setting (chapter 3) and 'on the job' in the work place (chapter 4). In the course of this work, a number of training case studies and a workshop on supply chain management were developed.

The remainder of the thesis is devoted to describing the research that was undertaken in response to the results of this fieldwork.

Model conceptualisation was identified as a major area of difficulty for novice modellers. In order to provide assistance in this area, a framework for model conceptualisation based upon the use of archetypes and generic models was developed (chapter 6). During the course of this work, it was discovered that there

were a number of problems with system archetypes as currently defined. In particular, there was some doubt as to whether these structures were capable of producing the behaviour that was being claimed for them.

In order to clarify the situation, research was carried out to investigate the problems that arise from moving structures across the boundary between qualitative and quantitative modelling. This research resulted in the development of a set of guidelines for the quantification of qualitative model structures and also the simulation of a number of the archetypes (chapter 5).

The work on model conceptualisation described so far, assumes that managers will be modelling in small groups. A problem arises if there are a large number of geographically dispersed people who need to be involved in the modelling exercise. In order to overcome this problem, research was carried out to identify a method that is capable of supporting group model building at a distance. The result of this research was the development of a computerised Delphi based knowledge acquisition tool (Chapter 7).

Finally the conclusions of the research are presented in Chapter 8.

# **Chapter 1**

## *Managers and Learning*

## 1.1 Introduction

The business environment is becoming increasingly complex and the pace of change is accelerating. Just how rapid change can become is shown by the fact that, during a battle for market share between Honda and Kawasaki, Honda turned over its entire product range, twice in the space of eighteen months and scored a decisive victory as a result (Stalk 1988).

Yet the majority of companies have organisational structures, the origins of which date back to the early part of this century. These structures are based upon the ideas of classical management theory (Mooney and Reiley 1931, Gulick and Urwick 1937, Fayol 1949) and scientific management (Taylor 1911), which adopt the metaphor of "the organisation as a machine" (Morgan 1986). Historically this kind of organisation has proved successful, but changes in the business environment mean that a company organised in this way will find itself at a competitive disadvantage, for reasons which will now be discussed.

In the mechanistic organisation, the role of the majority of managers is that of supervision and decision-making is the prerogative of a select group of senior managers. Consequently, such companies have an authoritarian, hierarchical and bureaucratic organisational structure.

Typically, when a problem arises, information concerning that problem travels up through the hierarchy, decisions are taken "on high" and filter down through the company and they are finally implemented by junior managers. Therefore, mechanistic organisations have difficulty in reacting quickly. The numerous layers of management create delays in both the identification of problems and the implementation of solutions to those problems. In addition to these purely physical delays, there are also likely to be delays due to the bureaucratic culture inherent in such organisations which will tend to resist change.

This mechanistic structure will also adversely affect the quality of the decision. Because decisions are necessarily made by a small group of senior managers who



are remote from the problem, they will make their decision on the basis of second or third hand information. The people who really understand the problem domain are scattered through the organisation and are isolated from each other by rigid organisational boundaries.

The old days when a Henry Ford, Alfred Sloan, or Tom Watson *learned for the organization* are gone. In an increasingly dynamic, independent and unpredictable world, it is simply no longer possible for anyone to “figure it all out at the top”.

(Senge 1990)

Limiting involvement in the decision-making process to a select few, is not only leads to poor decision being made, it is also extremely wasteful of the skills and talents within the organisation. Any company that can succeed in fully utilising the capabilities of their workforce will achieve a considerable competitive advantage.

One company in Europe has tried to estimate the average percentage of its employees’ relevant capabilities they were able to use in their work. It estimated 30 percent. If a company used any other resource that poorly, it would not survive.

(Ackoff 1994)

In summary, mechanistic management structures are unsuited to dealing with the business environment of the last decade of the twentieth century because they are too slow in responding to change and too reliant on the decision-making ability of a small subset of the organisations’ managers. Furthermore they ignore the actual and potential skills of the majority of the organisations’ workforce. New types of organisational structures are clearly required, but what form should these new structures take? In a study of the reason for success and failure in UK manufacturing companies it was found that:

There is one common denominator in high-performance plants: an ability to learn—to achieve sustained improvement in performance over a long period of time. When assessing a manufacturing organization, learning is the bottom line.

(Hays et al. 1988)

This view is supported in the USA by the chairman of Analog Devices:

I would argue that the rate at which individuals and organizations learn may become the only sustainable competitive advantage, especially in knowledge-intensive industries.

(Stata 1989)

and also by Fortune magazine:

Forget your old, tired ideas about leadership. The most successful corporation on the 1990s will be something called a learning organization.

(Domain 1989)

The idea of the learning organisation as the ideal structure for business has been developed and promoted by a wide group of organisations, practitioners and academics. (Wack 1985a; 1985b, Argyris and Schön 1987, Garratt 1994, DeGeus 1988, Hays et al. 1988, Senge 1990, Pedler et al. 1991, Morecroft and Sterman 1992; 1994, Ackoff 1994, Senge et al 1994).

In the learning organisation, decision-making is seen as an activity in which as many people as possible should become involved. There is an appreciation that the learning that occurs during the process of making a decision may be as important as the decision itself.

The learning organisation accepts the dynamic nature of its environment and the need this creates for continual organisational change and adaptation. This creates a culture in which the questioning of accepted wisdom is encouraged, being wrong some of the time is acceptable and the development of the capabilities of all individuals within the organisation is encouraged.

The attributes of traditional organisations and learning organisations that have produced success are shown in Table 1.1 (O'Brian 1994). The new attributes in the right hand column, should be regarded as being additional to the traditional organisational competencies, listed in the left hand column.

Table 1.1 Ingredients for success

1920-1990 (bureaucratic way of life)	1990-The Future (learning organisation)
<ul style="list-style-type: none"> <li>• Efficient manufacturing</li> <li>• Effective mass marketing</li> <li>• Rapid adoption of technology</li> <li>• Financial acumen</li> <li>• "Theory Y"<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Distributing power while increasing self-discipline</li> <li>• Systemic thinking skills as well developed as reductionist skills</li> <li>• Improved conversation<sup>1</sup></li> <li>• Voluntary followship<sup>2</sup></li> </ul>

If the company of the future is to be a learning organisation, then what is the role of the manager in such an organisation. Ackoff (1994) identifies three principal managerial functions:

- To create an environment in which their subordinates can do as well as they know how.
- To develop those for whom they are responsible. Managers must become educators because education is the means to development.
- To manage; the interactions of those for and to whom they are responsible, the interactions of their units with other units of the organisation and the interactions of their organisation with other organisations in their environment.

It can be seen that the manager in a learning organisation needs to both be able to learn personally and to help others to learn. This thesis describes research that has been carried out to identify techniques that can be used to help managers to learn and to communicate the insights of that learning to others.

<sup>1</sup>This refers to the removal of the defence mechanism that impede communication when controversial issues are discussed.

<sup>2</sup>The style of leadership that gets results by convincing people to act voluntarily, rather than by using coercion from a position of power.

<sup>3</sup>The adoption of a set of elementary people skills.

## 1.2 Experiential Learning

Learning is the process whereby knowledge is created through the transformation of experience.

(Kolb 1984)

This model of the learning process was developed by David Kolb. It is a consolidation of earlier work, in particular; the Lewinian model of action research and laboratory training (Lewin 1951), Dewey's model of learning (Dewey 1938) and Piaget's model of learning and cognitive development (Piaget 1970).

The theory of experiential learning, as the name suggests, places the individual's experience of the world at the centre of the learning process. There are a number of other models of learning, these fall into two categories; cognitive learning theories and behavioural learning theories, these theories do not view experience as an importance part of the learning process. Experiential learning theory does not seek to supplant these other approaches, rather the aim is to provide:

...a holistic integrative perspective on learning that combines experience, perception, cognition and behaviour.

(Kolb 1984)

Experiential learning is a cyclical process, ideas and concepts are not viewed as static constructs, but rather they are see as dynamic entities that are continually being formed and reformed through experience.

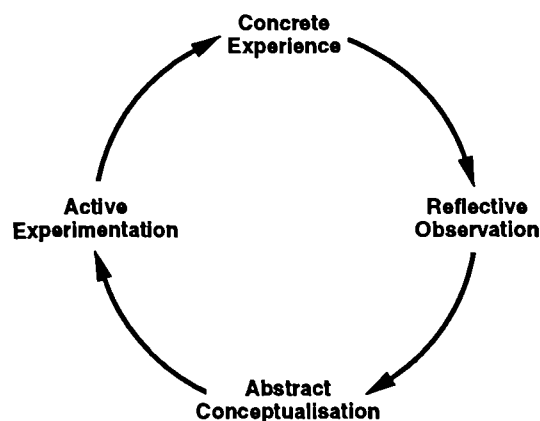


Figure 1.1 Kolb's experiential learning cycle

There are four stages in the experiential learning cycle; concrete experience, reflective observation, abstract conceptualisation and active experimentation, see Table 1.2 and Figure 1.1. For learning to occur, it is necessary that an individual experiences all of these stages.

**Table 1.2 The four stages of Kolb's experiential learning cycle**

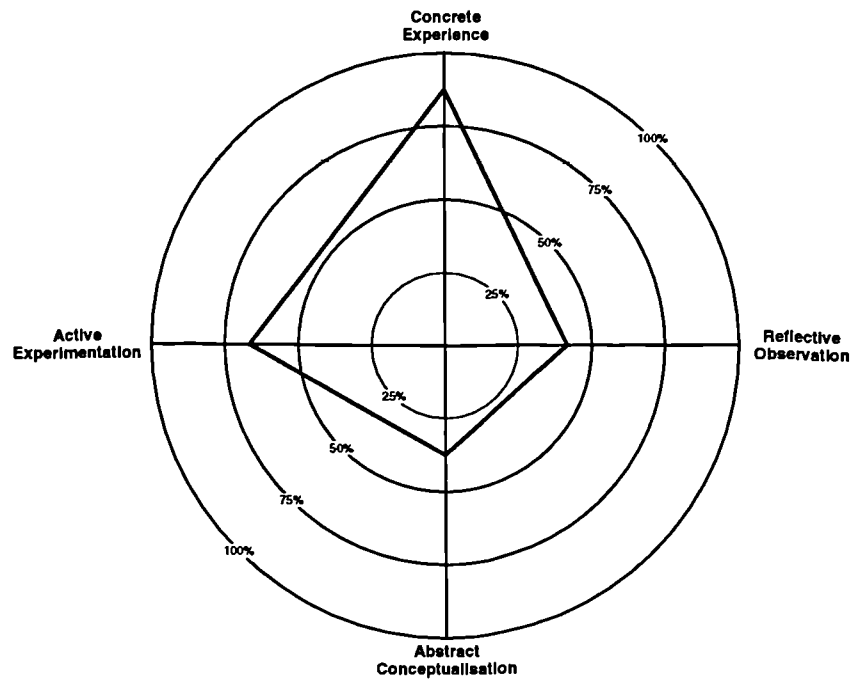
<b>Stage</b>	<b>Description</b>
1 Concrete Experience	The "raw" sensation of experience, this is unique to the person having the experience and cannot be easily communicated to others.
2 Reflective Observation	The collection of observation and data about the experience, which may entail viewing of the experience from a number of different perspectives.
3 Abstract Conceptualisation	An ordering and structuring of the raw experience into concepts and words to create logical theories of the experience.
4 Active Experimentation	Use of the theories to take action, make decisions and solve problems.

### **1.3 The Effect of Individuality on Learning**

The four stages of the experiential learning cycle require very different skills and individuals are not usually equally proficient in all of these areas. Therefore an individual will tend to focus on the stage(s) that they personally are most comfortable with. This effect of personality on learning gives us the idea of an individual learning style.

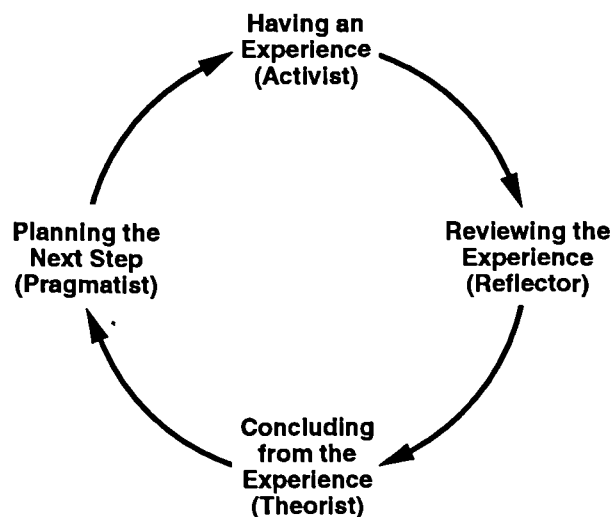
Individual learning styles were investigated by Kolb (1984). He developed an assessment procedure known as "The Learning Style Inventory". This approach uses a questionnaire to assess an individual's relative emphasis on the four learning modes. The results are displayed graphically as a "Learning Style Profile". A large number of people (almost two thousand) from a wide range of backgrounds have been assessed using this procedure, allowing norms to be

calculated. An example learning style profile is shown in Figure 1.2. It can be seen that this profile shows a distinct bias towards active experimentation and concrete experience.



**Figure 1.2** An example of a learning style profile

This approach has been developed and applied in the field of managerial development (Honey and Mumford 1986). They used a version of Kolb's learning cycle, and identified four styles of learning, see Figure 1.3 and Table 1.3.



**Figure 1.3** Honey and Mumford's learning cycle

**Table 1.3 Honey and Mumford's learning styles**

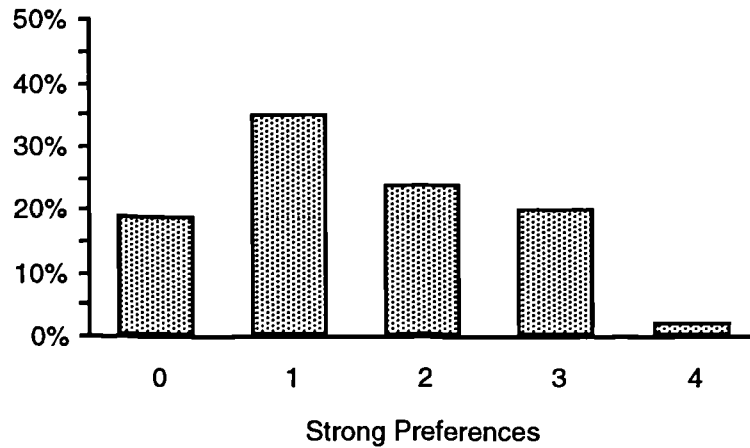
Activists	<ul style="list-style-type: none"> <li>• Try anything once</li> <li>• Tend to revel in short-term crises, fire fighting</li> <li>• Tend to thrive on the challenge of new experiences</li> <li>• Are relatively bored with implementation and longer-term consolidation</li> <li>• Constantly involve themselves with other people</li> </ul>
Reflectors	<ul style="list-style-type: none"> <li>• Like to stand back and review experiences from different perspectives</li> <li>• Collect data and analyse it before coming to conclusions</li> <li>• Like to consider all possible angles and implications before making a move</li> <li>• Tend to be cautious</li> <li>• Actually enjoy observing other people in action</li> <li>• Often take a back seat at meetings</li> </ul>
Theorists	<ul style="list-style-type: none"> <li>• Are keen on basic assumptions, principles, theories, models and systems thinking</li> <li>• Prize rationality and logic</li> <li>• Tend to be detached and analytical</li> <li>• Are unhappy with subjective or ambiguous experiences</li> <li>• Like to make things tidy and fit them into rational schemes</li> </ul>
Pragmatists	<ul style="list-style-type: none"> <li>• Positively search out new ideas or techniques which might apply in their situation</li> <li>• Take the first opportunity to experiment with applications</li> <li>• Respond to problems and opportunities "as a Challenge"</li> <li>• Are keen to use ideas from management courses</li> <li>• Like to get on with things with clear purpose</li> </ul>

The learning style of 300 managers was assessed by questionnaire, backed up observation and self-analysis (Honey and Mumford 1986). The results of this work are not encouraging:

...only 20 per cent of managers emerged with three strong preferences, i.e. could be seen as potentially good all-round learners. In contrast, 35 per cent of managers had one strong preference.

(Mumford 1989)

The full results are shown in Figure 1.4; a manager is said to have a strong preference for a learning style if they score within the top 30% for that style.



**Figure 1.4 Managers dominant learning styles (Honey and Mumford 1986)**

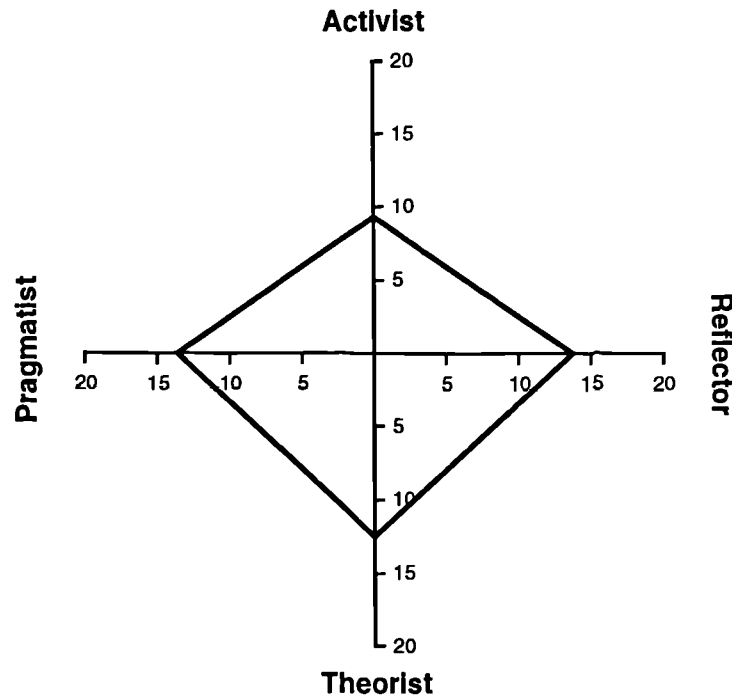
The fact that few individuals are good all-round learners need not be an insurmountable problem, provided that the management team as a whole has a broad mix of all the learning styles. This is emphasised by Bob Garratt, who uses the learning styles approach in his work in developing the decision-making skills of company directors.

...individual scores do not really concern me. It is the *group* score which is the key.

(Garratt 1994)

It will only be possible to easily form well-rounded groups of managers if the learning styles for managers as a whole is generally balanced. The results of assessing 3500 professional and managerial people from the UK are shown in Figure 1.5. The reflector and pragmatist styles are almost perfectly balanced, the theorist style is slightly lower (about 8%) and the activist style is considerably weaker (about 30% below). It can be seen that professionals and managers as a whole do have a reasonable balanced learning style, although the activist style is noticeably weaker.





**Figure 1.5** Mean learning style scores for UK managers (Honey and Mumford 1986)

This section has highlighted the fact that individuality has an important effect on learning. There are very few people who are all-round learners; the majority have a preferred learning style. It has also been shown that groups of people are much more likely to have a well-balanced mix of learning styles than the individual. Indeed the membership of a group can be specifically selected to ensure that this is the case. These facts strongly suggest that the most effective way of promoting learning within an organisation is for members of that organisation to learn together in groups.

#### **1.4 Difficulties with Managerial Learning**

Managers often fail to learn, this failure is not limited to learning from experience but may also occur in the context of more formal management training and development activities.

There are three main reasons why managers do not learn. The first is a direct consequence of the theory of experiential learning; if a manager's learning cycle is incomplete then learning cannot occur. Secondly, there may be a failure to

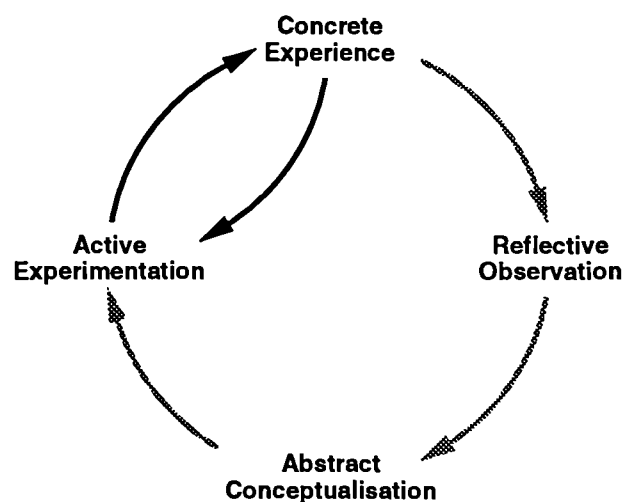
maximise learning. A complete learning cycle will guarantee learning, but the result may be an incremental gain in understanding, when the opportunity existed to gain an insight, which would deliver a large jump in understanding. Finally, the systems that managers are trying to learn about may be inherently difficult to understand. The complexity of the systems behaviour may make it impossible to learn from outcome feedback.

### 1.4.1 Failure to Complete the Learning Cycle

It has already been shown, in the section on experiential learning, that for learning to occur; it is necessary for the individual to experience all the stages of the learning cycle. If the learning cycle is short circuited then learning will not occur. Three cases of incomplete learning cycles will now be described.

#### 1.4.1.1 Reflex Decision-Making

This situation occurs when a manager responds immediately to a problem, without pausing to reflect or hypothesis. Many of the day to day decisions that managers make are likely to fall into this category.



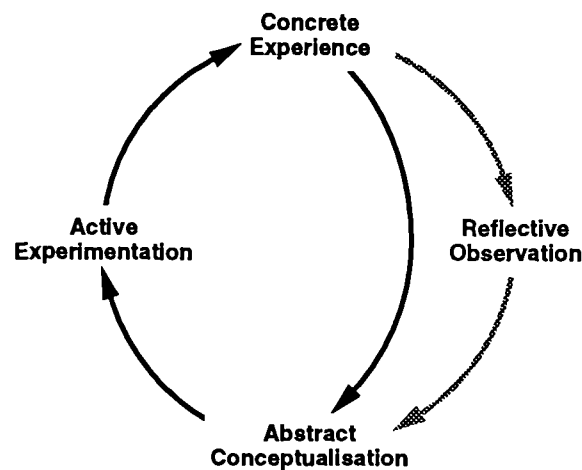
**Figure 1.6** Incomplete learning cycle due to reflex decision-making

In itself this need not be a problem, an experienced manager will already have developed a knowledge base that allows such decisions to be successfully made and there may be little that can be learned from every minor managerial decision.

The real danger is that other, more complex and important decision may be made in the same way, whether by intent or accident. This will result in not only a poor decision, but also the loss of an opportunity for learning, that would have improved the manager's subsequent performance.

#### 1.4.1.2 Action Fixation

In this case, a manager will jump straight from experiencing a problem to a hypothesis of what the problem is and what should be done about it, without pausing to reflect on either the true nature of the problem or the suitability of the solution. In this situation, the problem may be perceived in terms of a small number of stock solutions.



**Figure 1.7** Incomplete learning cycle due to action fixation

The lack of reflection reinforced by a company's culture in two ways. Firstly, tradition may dictate that certain kinds of problems must be solved by taking a specific "tried and tested" course of action. Secondly, the role of the manager may be seen to be to take action rather than to think. This action fixation has been observed in managers from a wide range of UK companies. For example:

...concentration [by managers] on task performance has been allowed to stunt the potential growth of learning experiences.

(Mumford 1988)

...first they [Directors] tend to shy away from the reflection quadrant. The process of sitting back, observing what is happening, and testing this against what is supposed to happen does not come easily to them. Second, they tend to be very strong on active experimentation and love setting out on new projects and ventures.

(Garratt 1994)

This behaviour results in:

...a lot of action inside organisations, and if it didn't work the first time the directors went into a "more of" mode and tried harder.

(Garratt 1994)

Further more it creates a culture where:

...if [Directors] they have a problem it is better to be seen to do something rather than stop and think.

(Garratt 1994)

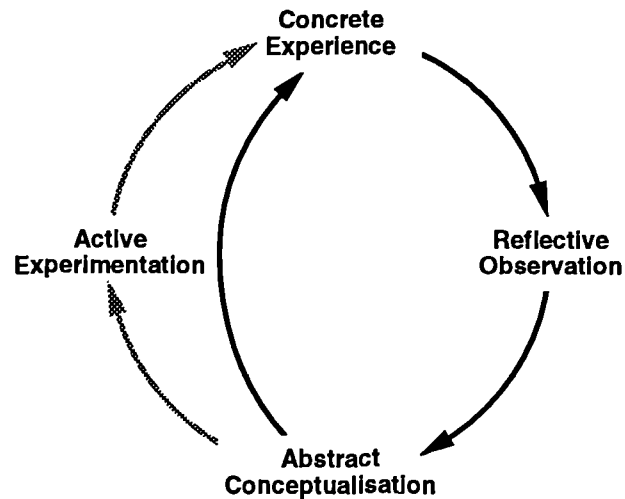
If someone is reflecting, it's considered perfectly acceptable to interrupt them, because "they're not doing anything".

(Senge et al 1994)

#### **1.4.1.3 Lack of Active Experimentation**

The previous two cases of incomplete learning cycles relate to the failure of managers to learn from their day to day work experience. This third case of an incomplete learning cycle, due to a lack of active experimentation, is associated with the failure of managers to learn in the context of formal education and training, see Figure 1.8.

The traditional approach to teaching which seeks to impart knowledge by communicating it from one person (the teacher) to another (the student) is notoriously ineffective. On average, only 25% of what is transmitted is actually received and the best that can be achieved is around 40% (Holt 1982; 1983). The reason for this is the lack of the active experimentation stage of the learning cycle.



**Figure 1.8 Incomplete learning cycle due to lack of active experimentation**

There is also a problem when it comes to applying this style of teaching to senior managers. Implicit in the approach is the assumption that the teacher has a greater degree of expertise on the subject matter than the student does; it is on the basis of this authority that the students accept what the teacher has to say. If we consider the situation where the senior management of a company is trying to increase their understanding of how their organisation functions, then there is nobody with great enough authority to teach them, because they are the experts on the subject matter (DeGeus 1988).

The case study approach to education, which is used by many business schools, is an improvement, it provides a much richer learning experience, but it still lacks the active experimentation stage of the learning cycle. Without this stage, i.e. without implementation, there is no opportunity to test out the hypothesis that has been developed during the case study.

#### 1.4.2 Limitations to Learning

The theory of experiential learning provides a model of how learning occurs; learning is defined as the creation of knowledge through the transformation of experience. The theory does not specify the nature of that knowledge or how the acquisition of that knowledge will affect a manager's performance and whether it

will promote organisational learning. In a review of the research that has been carried out in this area, Fiol and Lyles (1985) describe a lack of consensus about what learning means in the context of organisational learning.

As a result, the organisational learning literature is full of multiple interpretations of the concept.

(Fiol and Lyles 1985)

It does however emerge that a number of authors hold the view that there are two distinct kinds of learning. In particular:

First order learning and second order learning.

(Watzlawick et al 1974)

Strategy level learning and behavioural level learning.

(Duncan 1974)

Single loop learning and double loop learning.

(Argyris Schön 1978)

Learning and Adaptation.

(Hedberg 1981)

Cognitive development and behavioural development.

(Daft and Weick 1984)

Fiol and Lyles (1985) drawing on this material, summarise the two kinds of learning under the headings of lower-level learning and higher-level learning.

**Lower-level learning:** Focused learning that may be mere repetition of past behaviours—usually short term, surface, temporary, but with associations being formed. Captures only a certain element—adjustments in part of what the organisation does. Single-loop. Routine level.

**Higher-level learning:** The development of complex rules and associations regarding new actions. Development of an understanding of causation. Learning that effects the entire organisation. Double-loop learning. Central norms, frames of reference, and assumptions changed.

A overview of these two kinds of learning is given in Table 1.4. The terms single loop learning and double loop learning will be used in preference to the terms lower-level learning and higher-level learning in this thesis.

**Table 1.4** Fiol and Lyles's levels of learning

	<b>Lower-Level (Single-Loop)</b>	<b>Higher-Level (Double-Loop)</b>
<b>Characteristics</b>	<ul style="list-style-type: none"> <li>• Occurs through repetition</li> <li>• Routine</li> <li>• Control over immediate task, rules and structures</li> <li>• Well-understood context</li> <li>• Occurs at all levels in organisations</li> </ul>	<ul style="list-style-type: none"> <li>• Occurs through use of heuristics and insights</li> <li>• Non-routine</li> <li>• Development of differentiated structures, rules, etc. to deal with lack of control.</li> <li>• Ambiguous context</li> <li>• Occurs mostly in upper levels</li> </ul>
<b>Consequence</b>	<ul style="list-style-type: none"> <li>• Behavioural outcomes</li> </ul>	<ul style="list-style-type: none"> <li>• Insights, heuristics and collective consciousness</li> </ul>
<b>Examples</b>	<ul style="list-style-type: none"> <li>• Institutionalises formal rules</li> <li>• Adjustments in management systems</li> <li>• Problem-solving skills</li> </ul>	<ul style="list-style-type: none"> <li>• New missions and new definitions of direction</li> <li>• Agenda setting</li> <li>• Problem-defining skills</li> <li>• Development of new myths, stories and culture</li> </ul>

It can be seen that double-loop learning can deliver large leaps in performance, whereas single-loop learning is associated with incremental gains in performance. If managers are to maximise their potential and if organisational learning is to occur then it is necessary to achieve double-loop learning.

### 1.4.3 The Difficult Nature of the Managerial Environment

Managerial systems are intrinsically difficult to control. Further more; experience does not improve managerial performance with such systems (Sterman 1988a, Senge and Sterman 1990). Paich and Sterman (1993) cite a large body of research,

dating back to the 1960s in support of this view and provide the following examples which are drawn from a wide range of problem domains.

- Managers in a simple production-distribution system generate costly cycles of excess inventory (Sterman 1989, MacNeil/Lehrer 1989).
- Managers of simulated consumer product markets generate the boom and bust, price war, shake-out and bankruptcy characteristic of industries from video games to chain saws (Paich and Sterman 1993).
- In a simulation of People Express Airlines, students and corporate executives alike frequently bankrupt the company, just like the real management did (Sterman 1988b).
- In a publishing industry simulation, people often bankrupt their magazines even as circulation reaches all time highs, just as did a number of real publications (Hall 1976, 1989).
- In a forest fire simulation, many people allow their headquarters to burn down despite their best efforts to put out the fire (Brehmer 1989).
- In a medical setting, subjects playing the role of doctors order more tests while the (simulated) patient sickens and die (Kleinmuntz 1985).

So why is it that these systems are so difficult to manage. The problem is the complexity of managerial systems. This complexity takes two forms; detail complexity and dynamic complexity (Senge 1990). The human brain is good at dealing with detail complexity, but poor at handling dynamic complexity (Forrester 1971). Dynamic complexity arises because of the nature of managerial systems which contain multiple, delayed, non-linear feedback paths. These characteristics will now be discussed.



### 1.4.3.1 The Open and Closed Loop View of the Decision Process

Most managers will have a vague awareness that the organisation of which they are a part is a system, but very few of them appreciate the implications that this has for the decision-making process. This is highlighted by the fact that the majority of managers adopt an open loop view of the world, see Figure 1.9.



Figure 1.9 Open loop view of the decision-making process

Open loop thinking is inherently non-systemic. It assumes that a problem exists in isolation and that it is possible to take an action at a single point in time that will provide a lasting solution to that problem. A consequence of this world view is that problems are often seen as being caused by forces that are external to the manager's organisation.

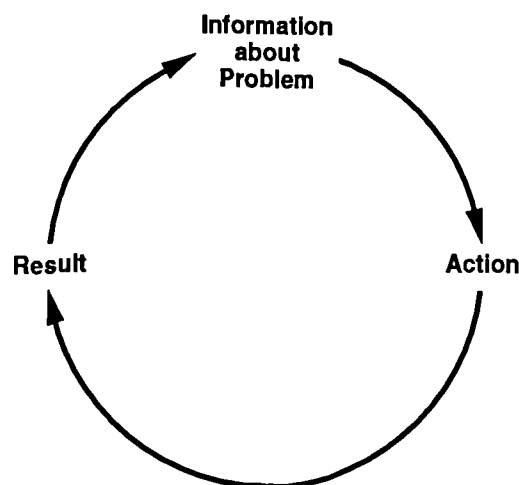


Figure 1.10 Closed loop view of the decision-making process

This view of the managerial process is erroneous. What actually happens is an iterative process whereby, the problem is continually monitored and the action being taken to solve the problem is adjusted accordingly (the classic cybernetic loop). This closed loop view of the decision process is shown in Figure 1.10. An example that illustrates the difference between these two views will now be given.

### 1.4.3.2 An Example: The Ferryboat Problem

The problem is how to steer the ferry across the river so that it reaches the landing stage on the other side. The open loop view of the problem assumes that if the ferry sets off in the direction of the opposite landing stage then it will eventually reach it and all will be well. What will actually happen is that the current of the river will sweep the ferry downstream past the landing stage, Figure 1.11a.

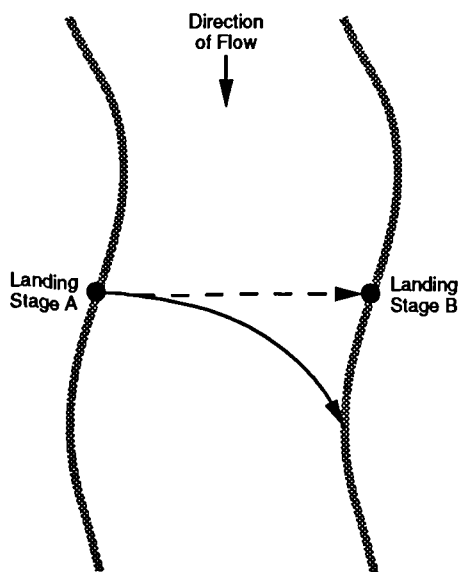


Figure 1.11a Open loop view

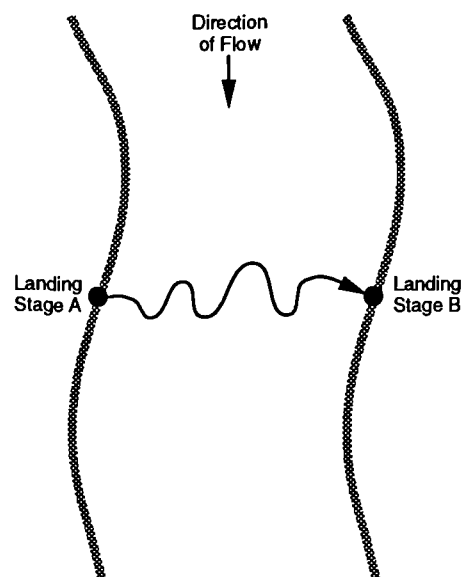


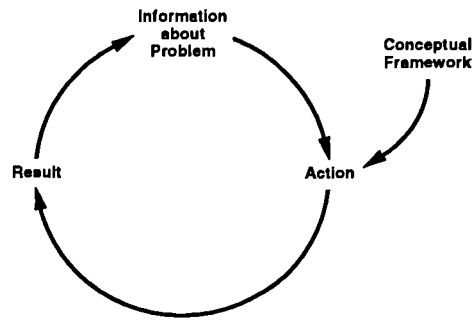
Figure 1.11b Closed loop view

Taking a closed loop view of the problem highlights the need to continuously monitor the ferry's position relative to the landing stage and to make corresponding adjustments to the course being steered, Figure 1.11b. This will ensure that the goal of reaching the landing stage is achieved.

### 1.4.3.3 Learning and the Closed Loop Decision Process

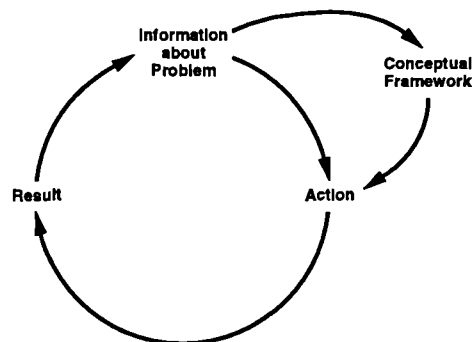
It has already been shown that there are two types of learning; single-loop learning and double-loop learning. The relationship of these two types of learning to the close looped decision process will now be described.

Single loop learning occurs when problems are solved with reference to a fixed conceptual framework. Figure 1.12 shows how the action taken depends on information about the problem and the conceptual framework.



**Figure 1.12** Single loop learning and the decision-making process

Double loop learning occurs when solving the problem causes changes to occur in the conceptual framework. In Figure 1.13, the action taken still depends upon information about the problem and the conceptual framework, but now the conceptual framework itself is influenced by information about the problem.



**Figure 1.13** Double loop learning and the decision-making process

#### 1.4.3.4 An Example: The Ferryboat Problem Revisited

We can extend the previous example to illustrate the difference between single-loop learning and double loop learning. In the context of this particular problem, single-loop learning could deliver the following insight:

- By steering for a point upstream of the landing stage and allowing the current of the river to bend the course of the ferry, it is possible to reach the opposite landing stage with a minimal amount of steering, Figure 1.14.

This is single-loop learning because, working within a fixed conceptual framework, what has been learned is the optimum way to steer a ferry across a river.

Double-loop learning occurs when we step outside this framework and query the basic assumptions of the situation, by ask questions such as; does the ferry need to be steered or is a ferry the best way of crossing the river. Two possible double-loop insights for this problem are:

- Eliminate the need for steering by turning the ferry into a chain ferry (a chain ferry pulls itself along by means of chains stretched across the river)
- Eliminate the need for a ferry by building a bridge.

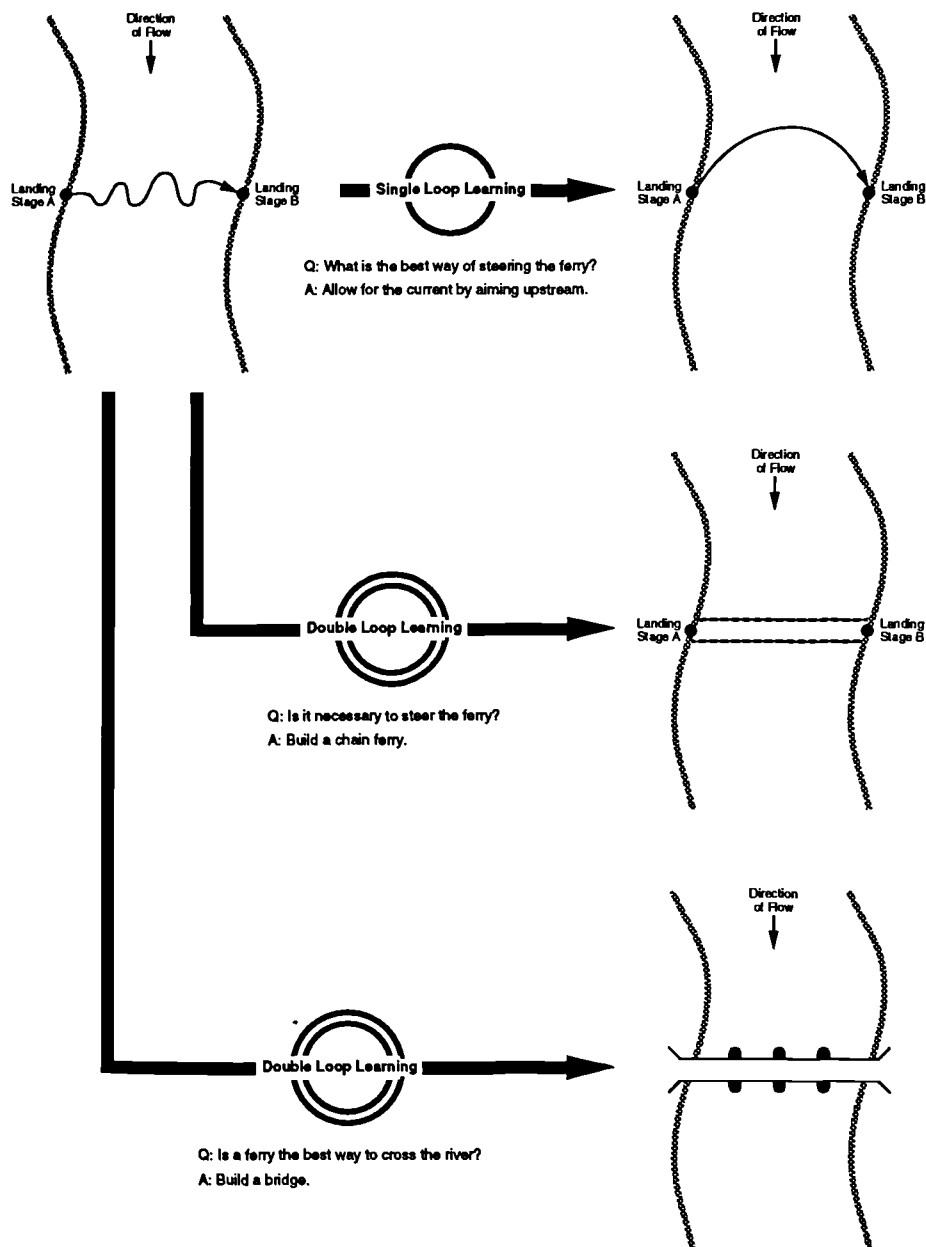


Figure 1.14 Example of single-loop and double-loop learning

### 1.4.3.5 The Unintended Consequence

Closed loop decision-making is due to the systemic nature of the organisation; another result of this is a phenomenon known as the “Unintended Consequence”. The taking of action to solve a problem in one part of the system will tend to affect other parts of the system in an unforeseen and (usually) detrimental way. In Figure 1.15, this unintended consequence of well-intended action, has been added to the basic closed loop world view.

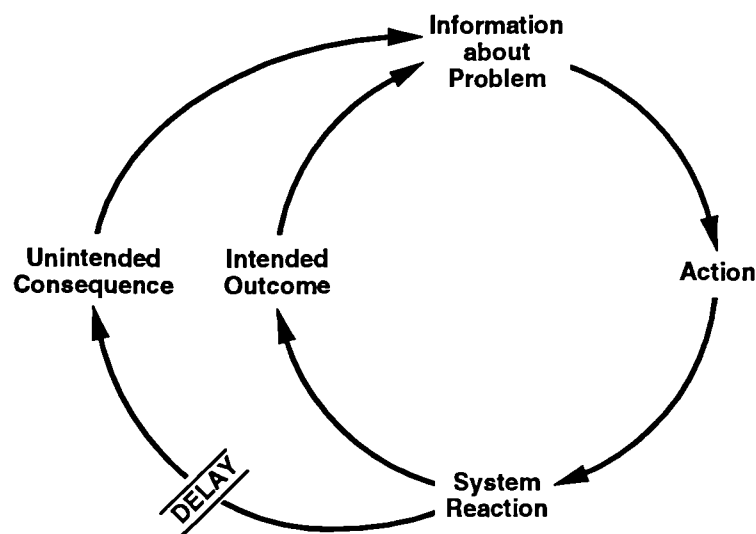


Figure 1.15 The unintended consequence

It can be seen that a delay has been marked on the diagram associated with the unintended consequence, but none has been associated with the intended consequence. The reason for this is that when an action is taken the benefit of that action will become apparent immediately, it is only after some time that the downside will make itself felt. This delay makes it difficult to learn about the system from outcome feedback, for it appears that a problem has been successfully solved and then later that another problem has appeared.

The link between the manager's own actions and the appearance of the “second” problem is very rarely made and as a consequence, the behaviour shown in Figure 1.16 occurs. This type of managerial behaviour has already been identified

with the action fixation incomplete learning cycle, so it can be seen that the continual need to take action will limit manager's ability to learn.

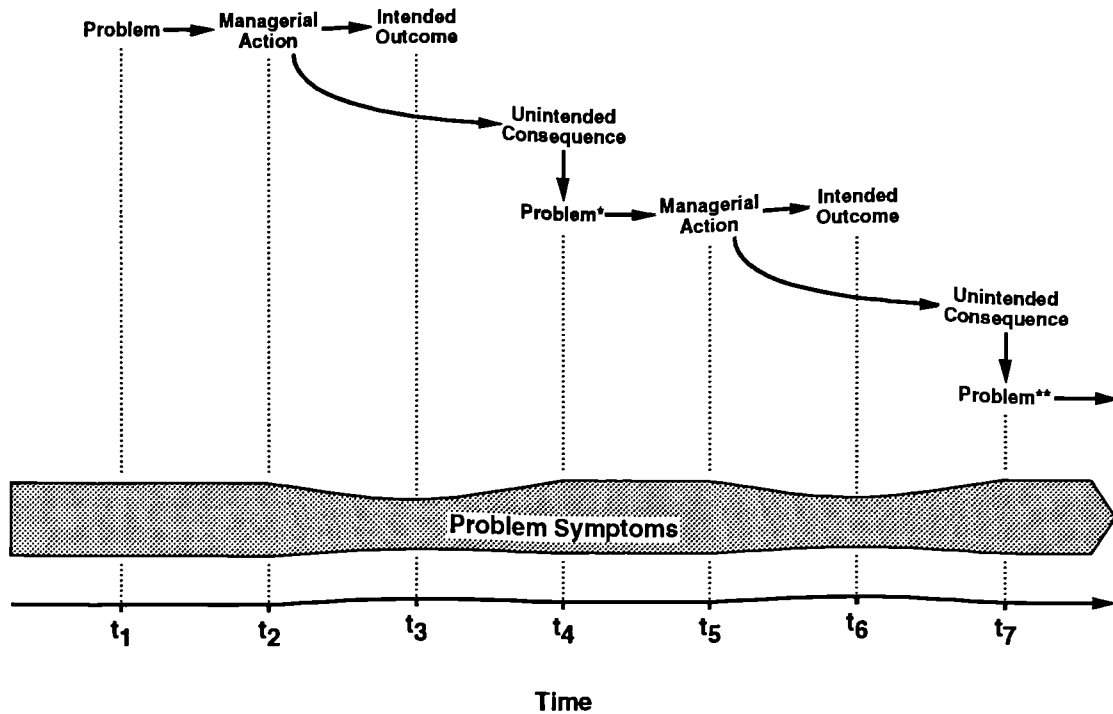


Figure 1.16 The effect of the unintended consequence

### 1.4.3.6 Delays in the Decision-making Process

The effect of delays has already been noted in the context of the unintended consequence. In fact, delays can be found everywhere within management systems. These delays are not limited to implementation, there is a delay due to the time it takes to make the decision and there are a number of much less obvious delays in the collecting and processing of information.

All the possible delays in the managerial decision-making process and the impact these delays have on the appropriateness of the implemented solution are shown in Figure 1.17. The decision implemented at time  $t_4$  was made at time  $t_3$  based on the information available to the manager at time  $t_2$  that relates to the state of the system at time  $t_1$ . If these delays are substantial compared to the rate at which the system being managed is changing then by the time the decision is implemented, it may be completely inappropriate for the current situation.

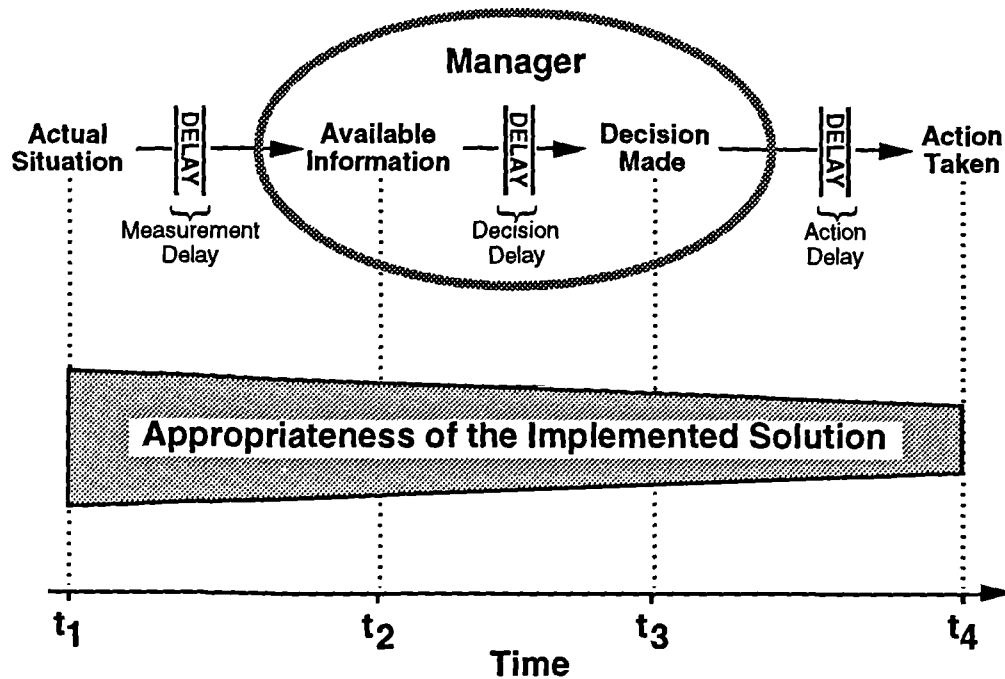


Figure 1.17 Delays in the decision-making process

These delays also make it very difficult for managers to link cause and effect and this will inhibit learning from experience.

#### 1.4.3.7 Non-Linearity in the Decision Process

Managers invariably adopt a linear view of the systems with which they work, but in fact most managerial systems are non-linear.

Almost every factor in these [industrial and economic] systems is non-linear. Much of the important behaviour is a direct manifestation of the non-linear characteristics.

(Forrester 1960/1975)

The concept of linear and non-linear systems comes from the mathematical study of dynamic systems. This section aims to describe the effect that non-linearity has in management systems, without going into the underlying mathematical details.

In a linear system, cause and effect relationships are linearly proportional, i.e. twice as much "cause" produces twice as much "effect" this implies that there is no limit on the value that "effect" can take, i.e. an arbitrarily large "cause" will produce a correspondingly arbitrarily large "effect".

In a non-linear system, cause and effect are linked in a more complex manner, i.e. twice as much "cause" may produce no extra "effect", create a huge increase in "effect" or produce a result somewhere in between.

Linear systems are relatively easy to understand; they have simple fixed modes of behaviour. In contrast non-linear systems can change between different modes of behaviour or exhibit unpredictable, chaotic behaviour. This makes them much more difficult to understand and control.

There are two main reasons why managers adopt a linear view of the world. The first is that it is the simplest, common-sense approach. The second is if the change in "cause" is small, the corresponding change in "effect" may appear to be linear, but this linearity will break down if the change in "cause" is large<sup>1</sup>.

For example, if a person who normally works a forty hour week, worked forty-four hours, it is quite likely that their weekly output would rise by ten per cent, in direct proportion to the extra hours worked. If however the same person worked an eighty hour week, it is most unlikely that they would be twice as productive; non-linear effects such as exhaustion or burnout would come into play.

A related example of linear thinking is the idea of the "man-month", which assumes that the time taken to complete a task of a given size is directly proportional to the number of people working on that task. In an insightful and witty book, Brook (1982), shows how the concept of a "man-month" has caused the downfall of many attempts to manage software engineering projects.

Non-linearity in the decision-making process, is another factor that makes it difficult for managers to link cause and effect and this will increase the difficulty of learning from experience.

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<sup>1</sup>This is known mathematically as the linearization theorem (Arrowsmith and Place 1982).



## 1.5 Organisational Learning

Organisational learning can be defined in a similar way to individual learning:

Learning in organisations means the continuous testing of experience, and the transformation of that experience into knowledge—accessible to the whole organisation, and relevant to its core purpose.

(Senge et al. 1994)

Organisations have a learning cycle (Kim 1993, Kim and Senge 1994) just like individuals, the organisational learning cycle is driven by the individual learning cycles, see Figure 1.18.

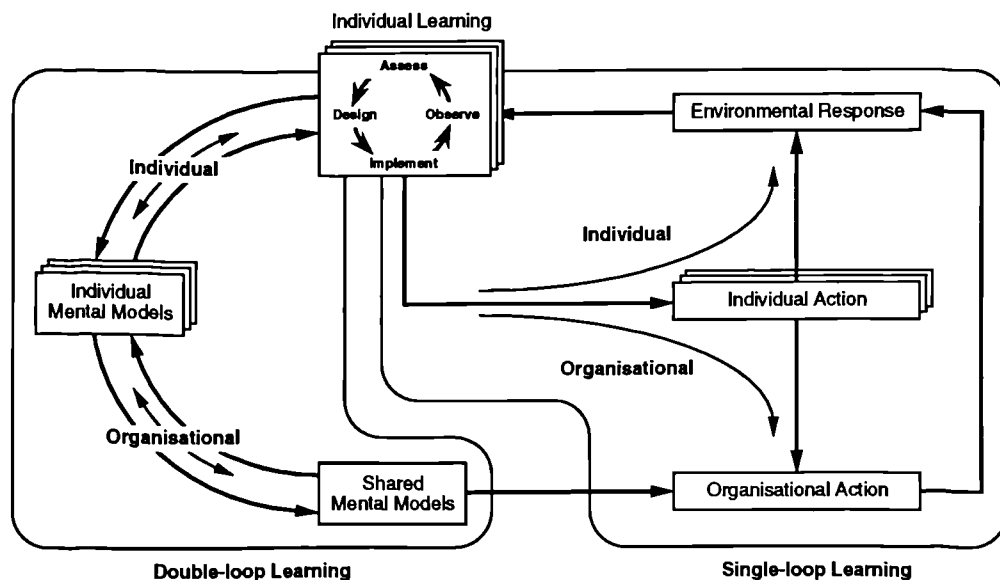


Figure 1.18 Organisational learning cycle after Kim and Senge (1994)<sup>1</sup>

Organisations can, like individuals, experience both single-loop learning and double-loop learning. These different types of learning have been identified in Figure 1.18. Organisational learning is dependant upon individual learning because if individuals are not learning then the organisation cannot learn. Individual learning in itself does not however guarantee that organisational learning will occur. The reasons for this will be discussed in the next section.

<sup>1</sup>The concept of “mental models” used in this diagram is equivalent to the “Conceptual framework” that was used in the discussion of single-loop and double-loop learning. The subject of mental model will be developed in greater detail later on in this chapter.

### 1.6 Difficulties with Organisational Learning

Kim and Senge (1994) identify six different reasons for organisational learning failure; three from March and Olsen (1975) and three from Kim (1993). Figure 1.19 shows these six breakdowns in learning superimposed upon the organisational learning cycle.

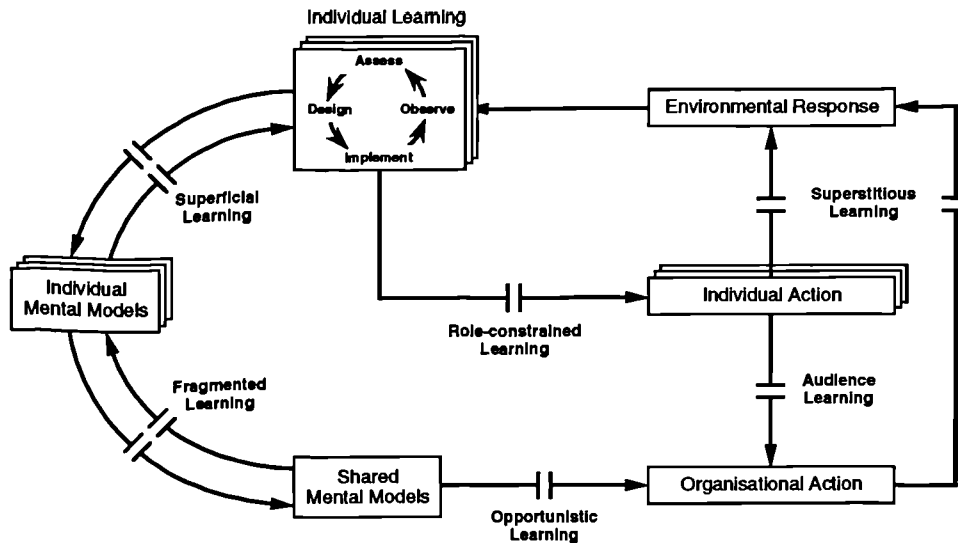


Figure 1.19 Barriers to organisational learning after Kim and Senge (1994)

These breakdowns will now be described in turn; the first three are due to March and Olsen (1975) and the last three are Kim’s (1993).

- Role-Constrained** This occurs when an individual is prevented by their position in the organisation from taking action that they believe to be necessary.
- Audience Learning** In this case, the individual succeeds in influencing organisational action but the outcome is ambiguous.
- Superstitious Learning** This kind of learning occurs when cause and effect relationships are inferred even though there is no real evidence to support the link between the action taken and the outcome achieved.
- Superficial Learning** This occurs in a situation where there was an opportunity for double-loop learning to occur, but mental models remain unchanged and only single-loop learning is achieved.

<b>Fragmented Learning</b>	This is when an individual or a small group of individuals, achieve double-loop learning, but shared mental models remain unchanged and therefore the organisation does not learn.
<b>Opportunistic Learning</b>	The need to change the organisation's shared mental models is identified by a group within the organisation. This group is not strong enough to change the shared mental model, but it is capable of bypassing it. The result is that this sub-group within the organisation achieves double-loop learning, but the organisation as a whole fails to learn. Opportunistic learning is not in itself a bad thing, part of the organisation has learned, but an opportunity to improve the performance of the whole organisation has been lost.

## 1.7 Conclusions

In this chapter the following key points have been highlighted:

- The business environment is becoming increasingly complex, the pace of change is accelerating and traditional organisational structures are no longer able to cope.
- The type of organisation best suited to this kind of environment is the learning organisation.
- The manager in a learning organisation needs to be able to both learn personally and to help others to learn.
- Learning is a dynamic, cyclical process with four stages; concrete experience, reflective observation, abstract conceptualisation and active experimentation. All of these stages have to be present for learning to occur.
- Very few people are good all-round learners. The majority have a preferred learning style; they will focus on the stages of the learning cycle with which they feel most comfortable and this can inhibit learning.

- Groups are much more likely to have a well-balanced mix of learning styles than the individual. The membership of a group can be specifically selected to ensure that this is the case.
- The culture of many organisations defines the role of the manager as a doer rather than as a thinker. This action fixation, means that managers end up with an incomplete learning cycle and hence learn little from their day to day experiences.
- Formal education techniques lack the active experimentation stage of the learning cycle and learning suffers as a result.
- There are two levels of learning, performing better within existing norms and assumptions (single-loop learning) and improving performance by redefining these norms and assumptions (double-loop learning). Double-loop learning can deliver large leaps in performance, whereas single-loop learning is associated with incremental gains in performance.
- Managerial systems are dynamically complex, they contain multiple, delayed, non-linear feedback paths. This makes such systems intrinsically difficult both to understand and to control.
- For organisational learning to occur individual learning must first take place. If organisational learning is to be double-loop learning then the individual learning upon which it is based must also be double-loop learning, but individual learning is no guarantee of organisation learning.
- Single-loop individual learning will fail to generate single-loop organisational learning, if the individual is unable to change organisational policy.

- Double-loop individual learning will fail to generate double-loop organisational learning, if the individual is unable to change the collective organisational mental models.

There is a need for techniques that can help the individual to learn and which can also be used to promote organisational learning. The use of modelling to achieve these goals is discussed in the next chapter.

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# **Chapter 2**

## *Modelling and Learning*



## 2.1 Introduction

This chapter investigates the relationship between modelling and experiential learning. A range of modelling techniques that can be used to aid managerial decision-making are reviewed and their suitability for the promotion of learning is assessed.

## 2.2 Models and Learning

There is a great deal of similarity between the of building a model and experiential learning. Figure 2.1 shows a typical depiction of the modelling process.

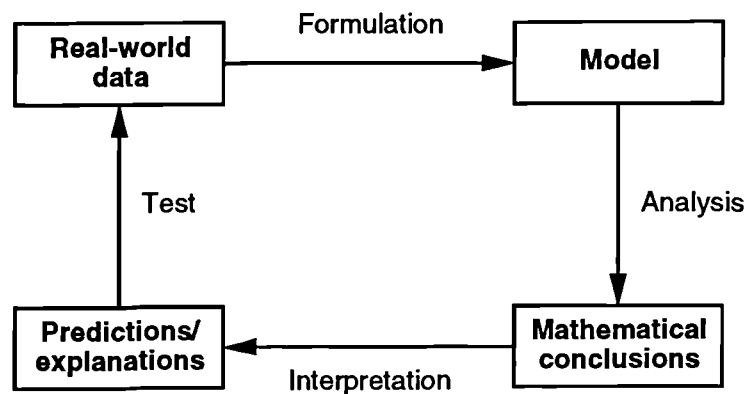
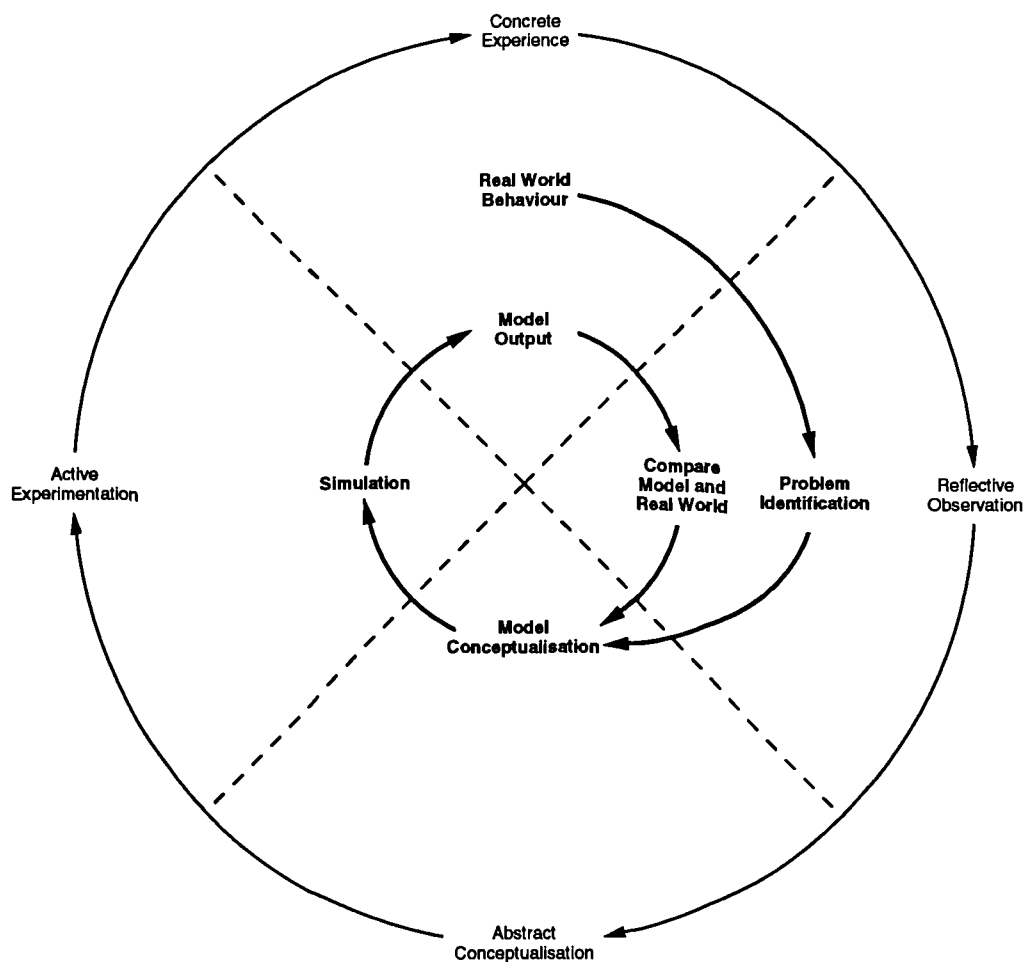


Figure 2.1 The modelling process after Giordano and Weir (1985)

It can be seen that modelling, like experiential learning, is an iterative, cyclical process. Additionally there are activities within the model building cycle that corresponds to all stages of the experiential learning cycle. Figure 2.2 shows the experiential learning cycle superimposed over the model development cycle. This suggests that modelling is a technique that can be used to promote learning. There are a number of other advantages in this approach:

- Modelling is seen as a “respectable activity” for a manager to undertake, therefore it can help overcome an action fixated company culture, by providing an excuse for managers to meet and reflect on their problems.
- Modelling provides structure and focus for the learning process.

- Modelling can be used to overcome fragmented learning in two ways. Firstly, models providing a common language that can be used to communicate ideas and insights. Secondly, the wide range of information that is needed to build a useful model will ensure that people from many parts of the organisation are involved.
- Computer simulation can be used to investigate the behaviour of systems that are far too complex for managers to understand unaided.



**Figure 2.2** The modelling process as experiential learning

There are a large number of different modelling techniques and not all of these are suitable for the promotion of learning. The next section provides an overview of these different approaches and identifies the type of modelling that is best suited to the task of promoting learning.

## 2.3 Models and Modelling

The word model has a number of different meanings, *"The Concise Oxford Dictionary of Current English"* (Allen 1990) provides seven definitions. In this thesis the following definition of a model will be used:

A model is a simplified or reduced representation of a system or object

There a large number of modelling techniques, therefore the rest of this section will be devoted to providing a classification of models. This classification will be based on the method of representation used by the model, but will also take into account the purpose of the model and the world view implied by the model. A classification of models, based on method of representation is shown in Figure 2.3.

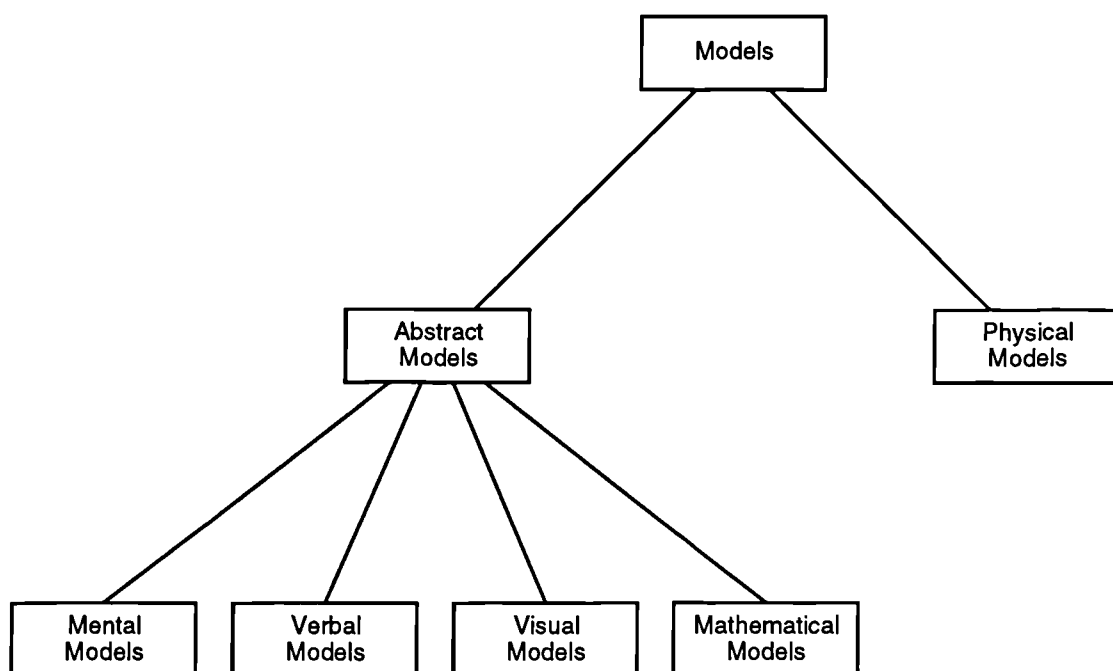


Figure 2.3 A classification of models by method of representation <sup>1</sup>

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<sup>1</sup>This diagram and the notion of a classification of models were inspired by Chapter 4 of *Industrial Dynamics* (Forrester 1961), but the emphasis of the classification described in this section is different.

### 2.3.1 Physical Models

In this approach to modelling, a real, physical, three-dimensional representation of the system under investigation is built. The model may be to scale or life-size and the purpose of the model can range from providing a static representation to the investigation of complex dynamic behaviour. Some typical examples:

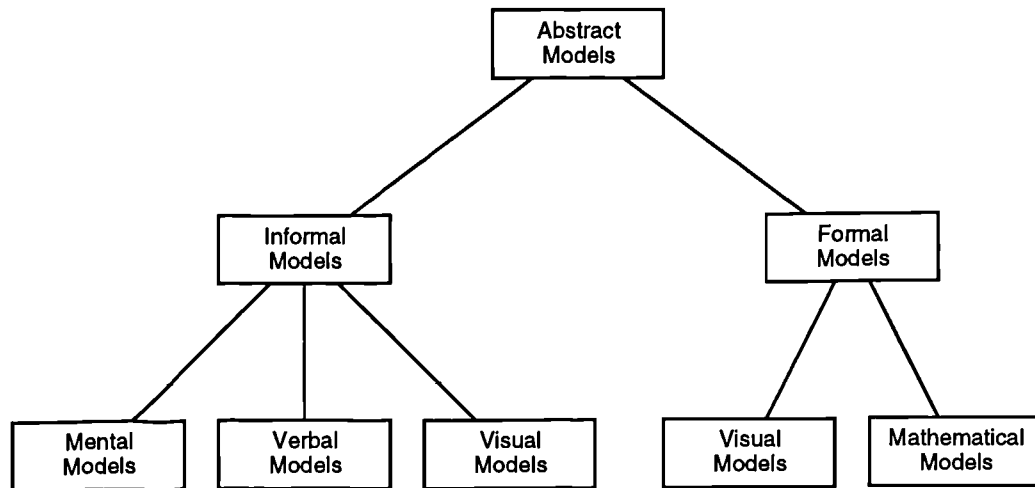
- A scale model of a proposed building.
- A prototype of a manufactured product.
- Using a scale model of a suspension bridge in a wind tunnel to test the stability of the design.
- Using a working model of a river system to investigate the impact of proposed flood control measures.

Such models are widely used in the field of engineering, but are not useful for tackling managerial problems, so they will not be further discussed in this thesis.

### 2.3.2 Abstract Models

Having disposed of the physical models, it is now possible to concentrate on the abstract models. Abstract models may be represented in one of four ways; mentally, verbally, visually and mathematically.

Before going on to discuss these categories it will be useful to add another dimension to the categorisation, that of formality. In this thesis a method of model representation is said to be formal if it provides a set of rules that define how a model is to be represented. It should be stressed that informality and formality are not synonymous with qualitative and quantitative. It is true that a quantitative model must be formal, but formal qualitative models do exist and will be described later in this section. A classification of abstract models based on methods of representation and formality is shown in Figure 2.4.



**Figure 2.4 Models classified by method of representation and formality**

### 2.3.2.1 Mental Models

The term “mental model” originated in the field of psychology (Johnson-Laird 1987). It has been adopted by those working in the area of management development in general and organisational learning in particular (Senge 1990, Senge et al. 1994, Richardson, Andersen, Maxwell and Stewart 1994, Morecroft 1992). There is a huge body of research into mental models across a range of disciplines. In this section a simple treatment of the subject will be given, based upon current usage in the fields of modelling and organisational learning.

Mental models are an individual's personal view of how the world around them functions. These models form the basis on which decisions are made. Mental models have the following characteristics; consistency, stability and simplification (Ballé 1994).

- |                       |   |
|-----------------------|---|
| <b>Consistency</b>    | An individual mental model is internally consistent, but there may be unsurfaced contradictions between the many such mental models that an individual possesses. |
| <b>Stability</b>      | An individual's world view is not easily changed. If an event contradicts a strongly held mental model then it is often either ignored or dismissed.              |
| <b>Simplification</b> | Mental models are simplifications of reality. This simplification allows the creation of generalisations, that can be applied to new situations.                  |

Mental models are more fundamental than the other kinds of model representation depicted in Figure 2.4; they are the raw stuff of modelling, behind every model there is a mental model that inspired its creation. Mental models are unique to an individual and they need to be expressed in some way if they are to be made accessible to others. This can be achieved through the use of the other types of model representation depicted in Figure 2.4.

### **2.3.2.2 Verbal Models**

A mental model can be represented in words, either written or spoken, that can be understood by any literate person. It is possible to convey qualitative and quantitative information in this manner.

The problem with this approach is that language is imprecise. If it is possible to translate a mental model into an unambiguous written description, then it will be long and unwieldy. In an organisation this inherent weakness can be exacerbated by the use of jargon terms and abbreviations that are specific to specific parts of the organisation. In such an instance, one part of the organisation will find that it cannot (literally) talk to another.

This problem can also arise in the context of groups of experts drawn from different backgrounds. An example of this is the word 'mole'; to a biologist a mole is a small burrowing mammal, to a chemist it is a specific amount of a substance, to a civil engineer it is a breakwater and to an intelligence officer it is a spy.

Examples of verbal models include: written and spoken explanations, management reports, responses at meetings.

### **2.3.2.3 Informal Visual Models**

This kind of model uses some kind of diagram to represent a mental model, it is said to be informal because there are no rules concerning the elements that make up the diagram. The informality of this approach to model representation makes it well suited to brainstorming.

This method of model representation is essentially qualitative, but is possible to convey quantitative information by means of suitable annotation. Diagrams are capable of conveying a large amount of information in a readily accessible form. For instance, it is usually much easier to find a destination from a rough sketch map than from a detailed set of written instruction.

There are two of advantages of using a diagram compared to a written description. Firstly with a diagram it is possible to gain an overall impression of the model at a glance. This is much more difficult to achieve with a written description and it may take several readings of written description to gain the same level of understanding. Secondly, diagrams are much better suited to representing spatial characteristics and the relationships between objects than words are. The disadvantage of this approach is that because there are no rules, the same problem with ambiguity arises that occurs with a written description.

Examples of informal visual models include: rough sketches, "flip charting" and "white boarding", hexagons (Hodgson 1992) and rich pictures (Checkland 1981).

#### **2.3.2.4 Formal Visual Models**

This kind of model also uses a diagram to represent a mental model, but in this case there are rules governing the elements that may form part of the diagram. This provides the additional advantage that the rules remove any ambiguity as to the meaning of the diagram, but at the price of imposing a learning overhead. It is necessary to have a knowledge of the rules and conventions of the diagramming technique before it is possible to understand the model. This method of model representation covers the whole of the qualitative to quantitative spectrum.

Examples of formal visual models include: flow charts, physical and topological maps, electronic circuit diagrams, organisational charts, influence diagrams (Miller et al. 1976), causal loop diagrams (Goodman 1974), cognitive maps (Eden 1988), activity cycle diagrams and network diagrams.

### 2.3.2.5 Mathematical Models

A model may be represented as a set of mathematical equations, this provides a high degree of precision, but a correspondingly high learning overhead. Such models are inherently quantitative in nature. The use of mathematical notation will make the model inaccessible to a large proportion of people in a typical organisation.

Examples of mathematical models include: Differential equations, computer simulation, linear programming, queuing and reliability.

### 2.3.2.6 Summary

Table 2.1 summarises and compares the different methods of model representation that have been described in this chapter.

**Table 2.1 A comparison of different methods of model representation**

<b>Model Type</b>	<b>Precision</b>	<b>Accessibility</b>	<b>Prediction</b>	<b>Suitability</b>
verbal	low	high	very low	routine communication
informal visual	low	high	very low	routine communication brainstorming
formal visual	high—high	high—high	low—high	brainstorming conceptualisation outcome generation
mathematical	high	Low	high	outcome generation

### 2.3.3 “Black Box” and “White Box” Modelling

This section looks at the mathematical models in greater detail. There are many different types of mathematical model; each based on a different branch of mathematics. These can be classified into two categories, that represent distinct modelling philosophies and world views; “Black Box” and “White Box” modelling.



<b>White Box</b>	This approach to modelling is knowledge-based. The equations of the model articulate real world cause and effect relationships and the parameter values of the model relate to real world objects. The model is a representation of its builders understanding of how the system being modelled functions. This kind of model can be used to test out theories of how the modelled system function and to predict the future state of the modelled system.
<b>Black Box</b>	This approach to modelling is data-based. The model is built using statistical estimation techniques. The equation structure and parameter values are chosen so that the model will fit the data set of the system being modelled. This means that the equation and parameter values have no real world interpretation. This kind of model can only be used for prediction.

It can be seen from the above descriptions that black box models are unsuitable for use as an aid to learning. It may be possible to accurately predict the future state of a system using a black box model, but it cannot be used to understand why that system state came about. In contrast, white box modelling allows the representation of knowledge in such a way that it is possible to test it against reality. Consequently it is possible to learn from building a white box model.

An addition point in the favour of white box modelling is that it generates an accumulated body of knowledge, including universal insights, that can provide a starting point from which to tackle new problems. The black box approach to modelling does not provide a similar body of accumulated knowledge and therefore each new problem has to be started from scratch.

**Table 2.2 The uses of models**

<b>Black Box</b>	<b>White Box</b>
Prediction	Prediction
	Test of theories
	Generate universal insights

An example will now be presented to show the differences to these two approaches to model building.

### 2.3.4 An Example: Modelling A Pendulum

This section describes the modelling of a simple physical system, the pendulum, using the black box and the white box approaches. The aim is to contrast the two procedures and compare the insights that are generated. A simple physical system was chosen for two reasons. Firstly, these modelling techniques were developed in the physical sciences and only later applied to socio-economic systems. Secondly, the simplicity of the chosen system makes it is easier to appreciate the difference between the two approaches.

The system to be modelled is shown in Figure 2.5. The aim of the investigation is to determine what factors affect the period of oscillation of the pendulum.

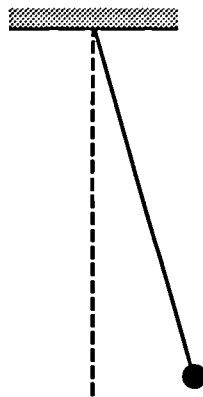


Figure 2.5 The pendulum

#### 2.3.4.1 White Box Modelling

The model derivation described in this section assumes a knowledge of basic calculus. The first step is to make a number of simplifying assumptions. A pendulum consists of a point mass attached to a rigid support by an inextensible string of zero mass. This system is shown in Figure 2.6.

The next step is to apply our knowledge of the interaction between the different parts of the system. In this particular case we look at the forces acting on the pendulum bob, there is a downward force on the pendulum bob due to gravity and an equal and opposite tensional force due to the string.

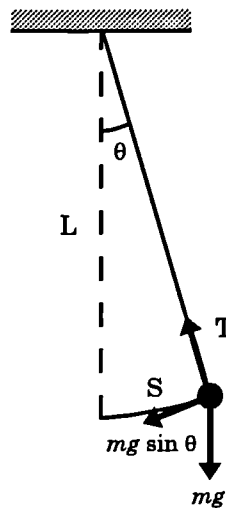


Figure 2.6 The simple pendulum

The resultant force on the bob is given by

$$F = -mg \sin \theta \quad (1)$$

The force can also be calculated using Newton's second law of motion:

$$F = ma \quad (2)$$

From the diagram it can be seen that:

$$a = \frac{d^2 S}{dt^2} \quad (3)$$

and

$$S = L\theta \quad (4)$$

Substituting (1),(3) and (4) into (2), gives:

$$\frac{d^2 \theta}{dt^2} = -\frac{g}{L} \sin \theta \quad (5)$$

The final step is to solve this second order ordinary differential equation, to provide a complete description of system behaviour. This particular equation is non-linear and is not therefore amenable to analytical solution, but it can be solved numerically for a specific case. An alternative way forward is to make another

simplifying solution, that is the amplitude of the pendulum's swing is small. If this is the case then it can be assumed that:

$$\sin \theta \approx \theta \quad (6)$$

Applying (6) to (5) gives

$$\frac{d^2\theta}{dt^2} = -\frac{g}{L}\theta \quad (7)$$

This simplified model is known as "Simple Harmonic Motion" and its equation may be solved using standard analytical techniques to give

$$\theta = K \sin \left[ \left( \frac{g}{L} \right)^{\frac{1}{2}} t + \varepsilon \right] \quad (8)$$

and the period of oscillation is given by

$$T = 2\pi \sqrt{\frac{L}{g}} \quad (9)$$

The desired aim has been achieved; an equation that can be used to calculate the period of a pendulum has been obtained. In addition a number of other insights have been gained:

- The period of oscillation of the pendulum is independent of the mass of the pendulum bob.
- The pendulum's period of oscillation depends on the acceleration due to gravity. Therefore it is possible to use a pendulum to measure the strength of gravity.
- An idealised model of oscillation has been developed (Simple Harmonic Motion) that can be used to investigate other systems.
- The basis for further work has been created. For example, the existing equations can be modified to take into account the effect of air resistance.

The capability of this approach to generate universal insight is shown in Figures 2.7a-2.7d (Pain 1993). It might appear at first sight, that these four physical, have little in common. In fact all of these systems produce the same dynamic behaviour; simple harmonic motion. The equations of motion for these systems all have the same form.

$$\frac{d^2x}{dt^2} + \omega^2x = 0 \quad (10)$$

The unique nature of each physical system is taken into account by the definition of the  $\omega^2$  term.

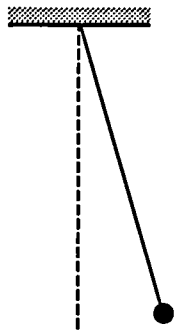


Figure 2.7a Pendulum

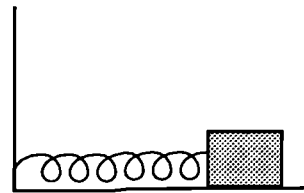


Figure 2.7b Sliding mass on a spring

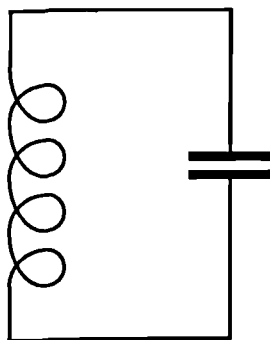


Figure 2.7c Inductor capacitor circuit

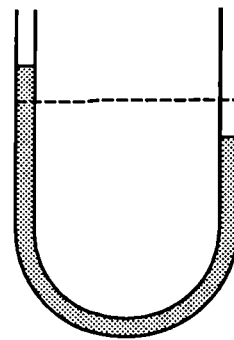


Figure 2.7d Column of water in a u-tube

This demonstrates how the modelling of one system can give insights into the behaviour of a number of other systems.

### 2.3.4.2 Black Box Modelling

The first step is to gather data. In this case it is necessary to measure the period of a number of pendulums. It would not be known that the period of oscillation was independent of the mass of the bob, so it would be necessary to measure the period of pendulums of different lengths and of different masses.

Looking at the first of these data sets, Figure 2.8, it can be seen that the period of oscillation is independent of the mass of the pendulum bob.

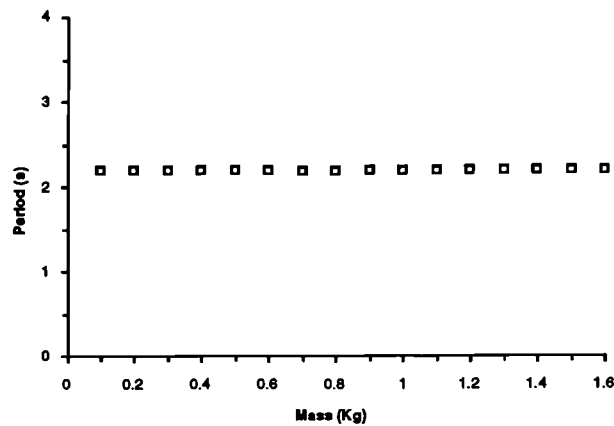


Figure 2.8 Effect of mass of pendulum bob data set

The second set, showing the relationship between pendulum period and length is more interesting, Figure 2.9.

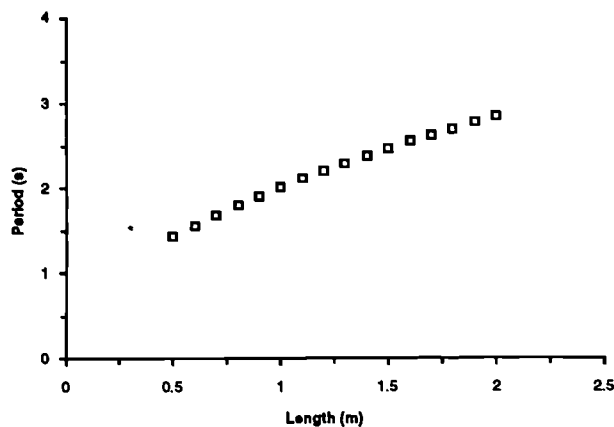


Figure 2.9 Effect of length of pendulum bob data set

The next step is to fit a model to the data set. Using the standard method of a Least Squares Estimator we can fit a curve to provide a predicted value for a given value of  $x$ .

$$\hat{y} = a + bx \quad (11)$$

Applying this technique to the above data set, the following result is obtained:

$$T = 0.93L + 1.04 \quad (12)$$

$$r = 0.996 \quad (13)$$

$$r^2 = 0.992 \quad (14)$$

The correlation coefficient ( $r$ ) is 0.996 which indicates a good linear relationship between  $L$  and  $Y$ . The value of  $r^2$  0.992 shows that over 99% of the variation is accounted for by the linear model. Figure 2.10 shows the regression line and the original the data set.

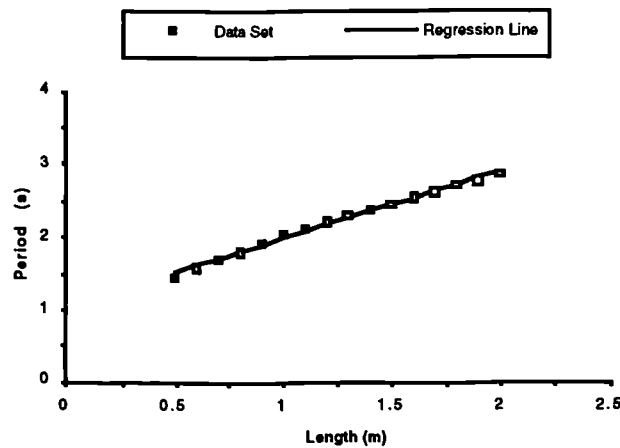


Figure 2.10 The regression model

If we had a larger data set the deficiency of the linear model would become apparent and a non-linear regression mode could be applied. Assuming a good enough data set, it would be possible to arrive at the same relationship obtained by the analytical approach:

$$T = 2.01\sqrt{L} \quad (15)$$

The desired aim has been achieved; an equation that can be used to calculate the period of a pendulum has been obtained. There is however, a hidden assumption implicit in equation (15); that the force of gravity is constant. Using a black box approach to modelling, there is no way of attaching any meaning to the constant in equation (15). The model can give no idea as to what this constant term represents in the real system or indeed if it had any physical meaning at all. If we refer to the previous model and rearrange equation (9) to give:

$$T = \left( \frac{2\pi}{\sqrt{g}} \right) \sqrt{L} \quad (16)$$

It can be seen that the constant is equal to:

$$\frac{2\pi}{\sqrt{g}} \quad (17)$$

The presence of  $g$  in the equation, shows that the period of a pendulum depends on the force of gravity. This fact is hidden to the black box modeller, who would, for instance, be unaware that a pendulum has a longer period on the Moon compared with its period on the Earth or that the pendulum's period would be slightly different at a north pole as compared with the equator.

The result that has been obtained for the pendulum is of no help in investigating the behaviour of the systems shown in Figure 2.7. In order to be able to calculate the period of oscillation for any of these systems it would be necessary to repeat the whole process of data collection and analysis.

### 2.3.5 Traditional Modelling in Management

This section looks at the types of modelling that are in common usage for management problem-solving. The aim is to look at the world view inherent in these modelling techniques, rather than to describe each in detail. There are two broad categories of model in use within organisations. Those developed by specialists, using the techniques of operational research and management science and those developed by managers themselves, using spreadsheets.



### **2.3.5.1 Operational Research and Management Science<sup>1</sup>**

This is a grouping of a wide range of mathematical modelling techniques that are used to tackle problems in management. Typical examples of these techniques are: forecasting, decision trees, linear programming, stochastic modelling, queuing theory, network analysis, markov chains and discrete event simulation.

The key ideas in OR are optimisation and forecasting. An optimisation model has three components, an objective function, a set of constraints and a set of decision variables. The purpose of the model is to determine the values of the decision variables that maximises the objective function, while satisfying all the constraints. The purpose of a forecasting model as the name implies is to forecast the future state of the system being studied.

### **2.3.5.2 Problems with using OR Modelling Techniques to Promote Learning**

The shortcomings of forecasting as a method of promoting learning have already been described in the previous section. Optimisation models suffer from a similar handicap; they are by nature, black box models and provide no way of gaining specific or general insights from the model output.

The idea of optimisation is inherently a single loop learning concept. What optimisation delivers is the best solution, given a set of constraints. For double-loop learning to occur, it necessary to question these constraints, a task that an optimisation model cannot help with.

The mathematical nature of OR modelling makes it inaccessible to the non-technical, who become excluded from the model building process. This results in the “back room” school of modelling, where the model is built by an analyst in isolation from the users of the model. The result of this is that the analyst achieves a complete learning cycle while the intended audience for the model does not. If the individuals do not learn, then organisational learning cannot occur.

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<sup>1</sup>The abbreviation OR will be used to refer to both operational research and management science in this thesis.

A further problem is that the type of models used in OR are only capable of solving well-posed problems; they are unable to tackle the 'unstructured messes' that confront managers. Yet this is the very situation where the need to learn and the need for help with learning is the greatest.

### **2.3.5.3 Problems with using OR to Promote Learning**

The nature of the models used in OR is not the only problem; there is a problem with OR itself. The history of OR is such that many organisations either do not see any need for the technique or if they do, they believe it can only be of use at the operational level. It would seem that organisations have reached by experience the same conclusion as suggested by theory in the previous section.

OR began in the 1930s and grew strongly in the 1950s and 1960s to establish itself as both an academic discipline and a practical management technique (most large companies had at this time a dedicated OR department). OR was seen as a tool that could help guide company policy at the highest level.

But by the late 1970s and early 1980s, there was a feeling that OR had lost its way (Ackoff 1979, Dando and Bennett 1981). In most companies OR had lost its reputation as a tool for strategic decision-makers, instead it was seen as a technique that was only of use at an operational level within the company.

A number of reasons for this fall from grace have been proposed, Ackoff's (1979) diagnosis of the problem was that OR has become an academic discipline that was too remote from the needs of managers, that was inward looking and obsessed by mathematical techniques:

...OR came to be identified with the use of mathematical models and algorithms rather than the ability to formulate management problems, solve them, and implement and maintain their solutions in turbulent environments.

(Ackoff 1979)

The effect of this has been that:

...practitioners decreasingly took problematic situations as they came, but increasingly sought, selected and distorted them so that favoured techniques could be applied to them.

...its (OR) mathematical techniques can easily be taught by those who do not know where, when and how to use them.

...those who either practise or preach it (OR) have come to be more and more like each other. The original interdisciplinary nature of OR has completely disappeared.

(Ackoff 1979)

Support for the view that OR has become predominately an academic discipline is provided by a study that compared the Journal of the Operational Research Society for the year 1968 with the year 1978. It revealed that while the authors in 1968 came from both the academic and the practitioner communities, in 1978, the authorship was almost totally academic (Dando and Bennett 1981).

At a more fundamental level, OR has been criticised for being positivist and lacking a grounding in a (sociological) theory of knowledge (Mingers 1992, Tacket and White 1993, Jackson 1993). The topic of epistemology is still being hotly debated within the OR community (Checkland 1994, Tacket and White 1994) and in the wider systems community. A summary of the arguments can be found in Lane (1993a; 1993b; 1994) and the current views of many of the protagonists are discussed in Richardson, Wolstenholme and Morecroft (1994). This ideological debate will be discussed further later on in this chapter.

Forrester has long argued (1960/1975) that the problem with OR was not its use of mathematical models as a way of understanding social and economic system, but the fact that it used the wrong type of mathematical models.

These mathematical methods (those used in OR) are all essentially static and linear in character and are not able to capture the dynamic nature of important processes in the real world.

He also identifies the academic nature of OR as a problem.

...OR became an academic discipline rather than a practical profession. In its academic setting, hard OR drifted toward continued refinement of the very theories that kept it from engaging the real world.

(Forrester 1994)

OR has sought to overcome these problems by reinventing itself as "soft OR", as distinct from the traditional approach to OR, which is now dubbed "hard OR". The subject of soft OR will be discussed later in this chapter.

#### **2.3.5.4 Spreadsheets**

The most dangerous, hideously misused and thought-annihilating piece of technology invented in the past 15 years has to be the electronic spreadsheet. Every day, millions of managers boot up their Lotus 1-2-3s and Microsoft Excels, twiddle a few numbers and diligently sucker themselves into thinking that they're forecasting the future.

(Schrage 1991)

The language of the above quote may be rather excessive, but the view it provides of the typical spreadsheet user is unfortunately all too accurate. Spreadsheets are by far the most popular managerial modelling tool. The use of spreadsheet dates right back to the earliest days of personal computing. The first spreadsheet program VisiCalc sold more than 700,000 copies and the program has been identified as the major reason for the success of the Apple II computer (Pfaffenberger 1991).

Spreadsheets are good at storing and manipulating large amounts of data. In addition, most spreadsheets now provide the facility to perform sophisticated data analysis, without the need to program formulas. They also provide a wide range of facilities for the displaying and presentation of data.

#### **2.3.5.5 Problems with using Spreadsheets to Promote Learning**

Models built using spreadsheets are of little use in promoting learning for a number of reasons.

Spreadsheet models are invariably open loop, there is a very good reason for this; a closed loop in a spreadsheet model will generate an error known as a “circular reference”. This open loop world view inhibits learning.

The variables used in a spreadsheet model are predominately financial; everything is represented in terms of money. This is a useful way of calculating the financial implications of a course of action, but it ignores the underlying real world interactions that are driving the financial outcomes. Little can be learned from a model that does not seek to model what is happening physically as well as financially within the organisation and its environment. Such a structurally deficient model is unlikely to perform well, particularly if the organisation’s environment is subject to change.

Spreadsheet models are black box in the extreme. It is very difficult to obtain an impression of the structure of a spreadsheet model, simple by looking at it. This will be particularly the case if the model is large or multiple worksheets have been used. Finally, the majority of spreadsheet models are used to for forecasting and it has already been established that this particular modelling technique does not promoting learning. It is a worrying fact that the modelling technique most commonly used by manager is of little use for promoting learning.

#### **2.3.5.6 Modelling to Predict**

The traditional approach to modelling in management that has just been described can be summarised as “modelling to predict”. The process of modelling to predict is shown in Figure 2.11.

The result of this analyst driven approach to problem solving is that the analyst is the one who learns from building the model. The management team can only learn at second hand from the analyst, because they have not participated in the model development process.

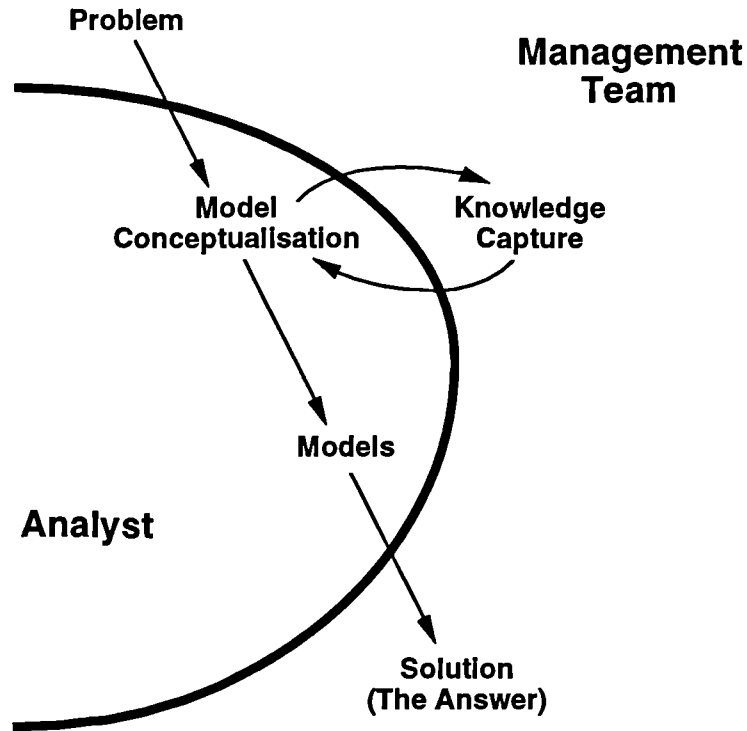


Figure 2.11 Modelling to predict

It should be apparent that the management team are very unlikely to have a complete learning cycle under these circumstances. The result is the knowledge gap shown in Figure 2.12, which represents a lost opportunity for organisational learning.

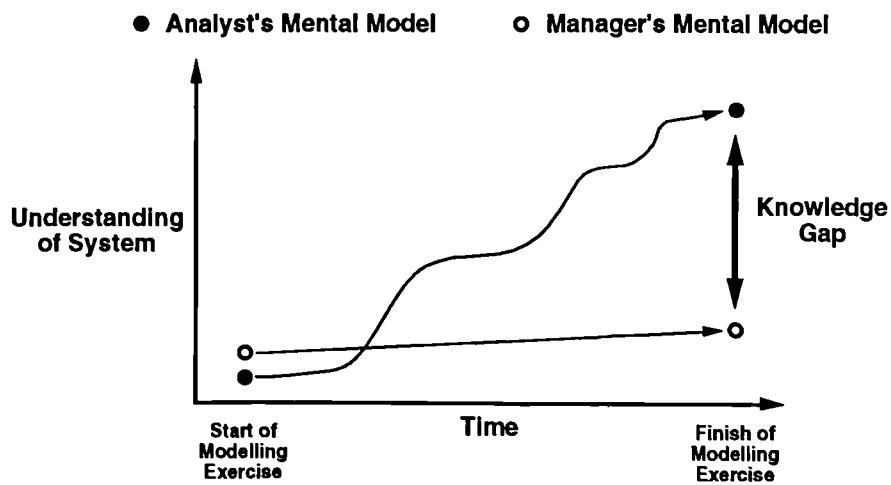


Figure 2.12 The effect on mental models of traditional modelling

### 2.3.6 Modelling for Learning

The alternative to modelling to predict is modelling to learn, this approach will be first be described and then its development will be discussed. The process of modelling for learning is shown in Figure 2.13.

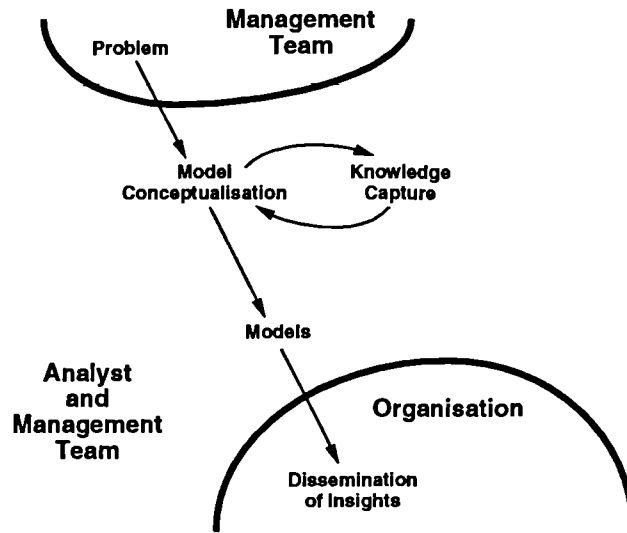


Figure 2.13 Modelling for learning

The role of the analyst is now that of a facilitator, who helps the management team build a collective model. The managers are fully involved in the modelling process and so both the analyst and the managers learn together. This results in the elimination of the knowledge gap, see Figure 2.14.

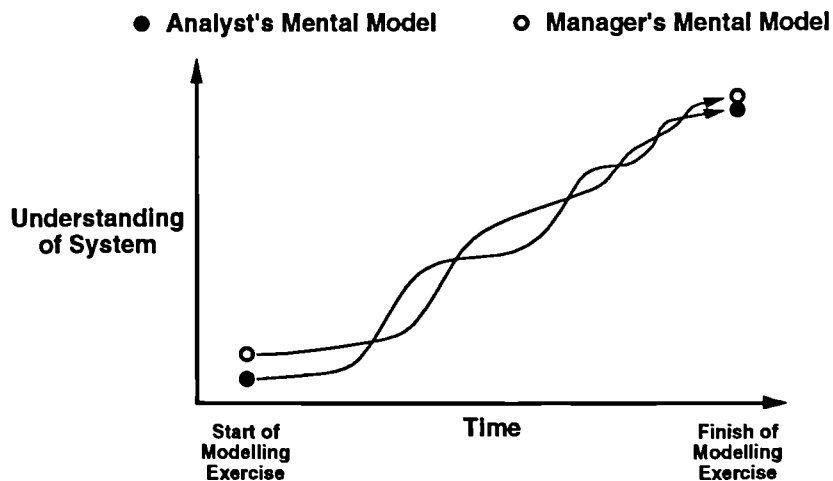


Figure 2.14 The effect on mental models of modelling for learning

During the modelling exercise the managers will learn from each other by sharing their mental models. Before the modelling exercise, managers will have varying degrees of knowledge about different aspects of the organisation. The group as a whole will have no consistent, shared mental model. After the modelling exercise, managers will have gained knowledge about aspects of the organisation with which they were unfamiliar and passed on their knowledge of the organisation to others. The group as a whole will have evolved a much more consistent shared mental model, see Figure 2.15.

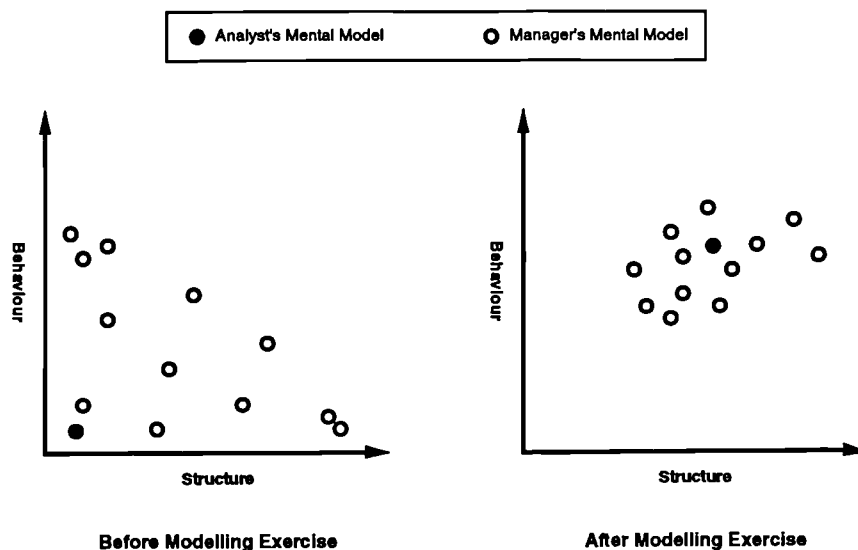


Figure 2.15 The organisational effect of modelling for learning

### 2.3.6.1 The Development of Modelling for Learning

The idea of modelling to learn came about because a gap had emerged between the quantitative techniques of operational research and the qualitative techniques of strategic planning.

At the quantitative end of the spectrum, it had become apparent that OR was incapable of providing tools that were able to facilitate strategic debate. At the other end of the spectrum, there are a large number of techniques that can support strategic debate, but which due to their qualitative nature, were incapable of testing policy recommendation against reality.



An example of this is the work of Porter (1985), who provides a widely used set of tools for analysing strategy and competitive advantage; Porter's generic strategies and value chain analysis. The latter is a method of mapping and then analysing an organisation's activities. The problem arises in the analysis stage because of the nature of the value chain system. Porter recognises its complexity:

...the value chain is not a collection of independent activities but a system of interdependent activities.

(Porter 1985)

and he is undoubtedly correct when he states that:

Linkages can lead to competitive advantages in two ways: optimisation and co-ordination. Linkages often reflect trade-offs amongst activities to achieve the same overall result.

(Porter 1985)

But he provides no methods for achieving this. The value chain will contain multiple delayed feedback paths; the difficulty of understanding and controlling such systems has already been established. If modelling tools were available to aid the task of understanding and redesigning the value chain, then the power of Porter's approach would be greatly enhanced.

This is true in the general case. There is a need for an approach that combines the best of both worlds; that provides the accessibility of the qualitative techniques combined with the capacity of quantitative modelling to generate understanding of complex dynamic systems.

Work was carried out by Shell during the 1980s to investigate the role of strategic planning within the organisation. The result of this work was a realisation that the purpose of planning should be the improvement of managers understanding of their organisation and its environment. This approach to strategic planning became known as "planning for learning"

...planning means changing minds, not making plans

(DeGeus 1988)

To achieve this, the use of scenarios as a tool to promote strategic debate was developed (Wack 1985a; 1985b). The advantage of using scenarios instead of basing planning upon a single forecasting future, is that a number of possible futures can be explored. If a modelling methodology could be found that was capable of being integrated into this approach to planning then it would be possible to test out the scenarios for internal consistency and permit decision makers to experiment with alternative futures. This would greatly enhance the potential for learning.

Modelling for learning is an amalgamation of the idea of “planning for learning” with system dynamics modelling. This came about because both disciplines had reached the same conclusions as to the purpose of modelling. From the mid 1980s onwards there was a growing awareness in system dynamics (Morecroft 1988, Senge 1983; 1985, Wolstenholme 1983) that, to paraphrase DeGeus:

Modelling means changing minds, not making predictions.

A more detailed account of the emergence of modelling for learning is given by Morecroft and Sterman (1992; 1994).

During the last decade, system dynamics has increasingly seen its role as modelling for learning in general and the promotion of organisational learning in particular. A good impression of this work can be found in Morecroft and Sterman (1992; 1994), which contains papers by most of the leading proponents in the field.

In embracing organisational learning, system dynamics has both changed and grown. A new name been applied to this broader discipline; systems thinking (Senge 1990, Kim and Lannon-Kim 1990, Senge et al. 1994).

There are many reasons why this metamorphosis of system dynamics occurred, but a major one must be that the discipline has always been sympathetic to the

ideas associated with the modelling for learning viewpoint. In fact, it is undoubtedly true that many practitioners of system dynamics were modelling for learning long before the phrase itself existed.

In the next section systems thinking will be described and its relationship to system dynamics will be clarified.

## **2.4 System Dynamics and Systems Thinking**

The aim of this section is to provide an overview of system dynamics and systems thinking. Additional information is provided in Appendix 1, which describes the basic modelling techniques and provides a bibliography of introductory texts on system dynamics and systems thinking.

### **2.4.1 System Dynamics**

System dynamics<sup>1</sup> as the name implies, is concerned with the study of dynamic systems. It was developed by Jay Forrester at the Massachusetts Institute of Technology (Forrester 1958; 1961). Forrester applied the concept of feedback as used in control engineering to the study of managerial systems.

In addition he identified the non-linear character of such systems and built a modelling technique that could cope with this, through the use of computer simulation. This was a radical stance to adopt at a time when most other modelling techniques dealt solely with linear systems. Indeed in many ways it still is for although the study of non-linear dynamic system has become common in some disciplines, there are many other disciplines particularly within the social sciences in which linear models are the norm.

System dynamics models a system in terms of causal links which connect individual model elements. These links may form closed loops known as feedback loops which are responsible for the dynamic behaviour of the system. It can be

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<sup>1</sup> System dynamics was originally known as industrial dynamics.

seen from this that structure and behaviour are closely linked. In order to change the behaviour of system it is necessary to redesign the system's structure.

In system dynamics modelling the emphasis is on investigating problems (undesirable dynamic behaviour) and solving these problems by system redesign. System dynamics has over the years been used to model a wide range of socio-economic, ecological and physical systems (Lebel 1982).

Originally, system dynamics was seen as a simulation-based modelling technique, but by the mid 1970s, the use of qualitative diagramming had evolved (Goodman 1974, Morecroft 1982). In the early 1980s, the use of qualitative diagramming as a method of modelling in its own right, known as qualitative system dynamics was developed (Wolstenholme and Coyle 1983, Wolstenholme 1985). These two aspects of system dynamics modelling will now be described.

### 2.4.2 Qualitative System Dynamics

Qualitative system dynamics is based upon the use of causal loop diagrams to build a map of the system being investigated. The "language" of causal loop diagrams is quick and easy to acquire, so this method of modelling is very accessible.

Qualitative system dynamics can be used at the beginning and the end of a system dynamics modelling exercise. At the beginning of a modelling exercise it is used as a mapping tool for group model building. At the end of a modelling exercise, it is used as a method of summarising the structure and behaviour of the models used during the quantitative modelling phase.

The insights provide by the qualitative mapping phase may be such that the management team does not wish to progress to the quantitative phase. It is more likely that it will be necessary to build a quantitative model to gain an in-depth understanding of system behaviour.

### 2.4.3 Quantitative System Dynamics

Quantitative system dynamics is based upon the use of computer simulation to investigate the dynamic behaviour of the system being investigated. The skills required to build a quantitative system dynamics model are not easy to acquire and consequently quantitative modelling is not as accessible as qualitative modelling. Modern simulation packages are however very good at communicating model structure and are user friendly enough to permit interactive experimentation by the non specialist.

#### 2.4.3.1 Simulation Tools

The traditional modelling tools such as DYNAMO (Pugh-Roberts 1986) or DYSMAP (Dangerfield and Vapenikova 1987) are essentially customised programming languages, in which the model is represented as a list of equations. This style of model representation and the compiled nature of these packages inhibits interactive experimentation and limit the use of such packages to those with a technical orientation. The appearance of the STELLA (Richmond 1985) and ithink (Richmond, Peterson & Charyk 1993) simulation software changed all this. These packages are graphically based. The model is built up on the computer screen using a set of tools. The software is very easy to use, so the average person can carry out interactive experimentation with an existing model, with little or no training.

### 2.4.4 Systems Thinking

System dynamics has developed considerably since its inception. The following changes can be identified (Wolstenholme 1993, Wolstenholme & Corben 1994):

- A recognition of the need to build models interactively with participants (managers, owners and associated actors) of problem situations.
- A recognition of the relevance and importance of both qualitative and quantitative modelling approaches to analysis.

- A move to explicitly incorporate organisational boundaries into qualitative models as a means of highlighting the demarcation of culture, power and politics between participants.
- The development of the concept of microworlds to help the dissemination of modelling insights.
- The use of simple archetypal structures by which to express insights from complex models.

The effects that these changes have had on the practise of system dynamics is shown in Figure 2.16.

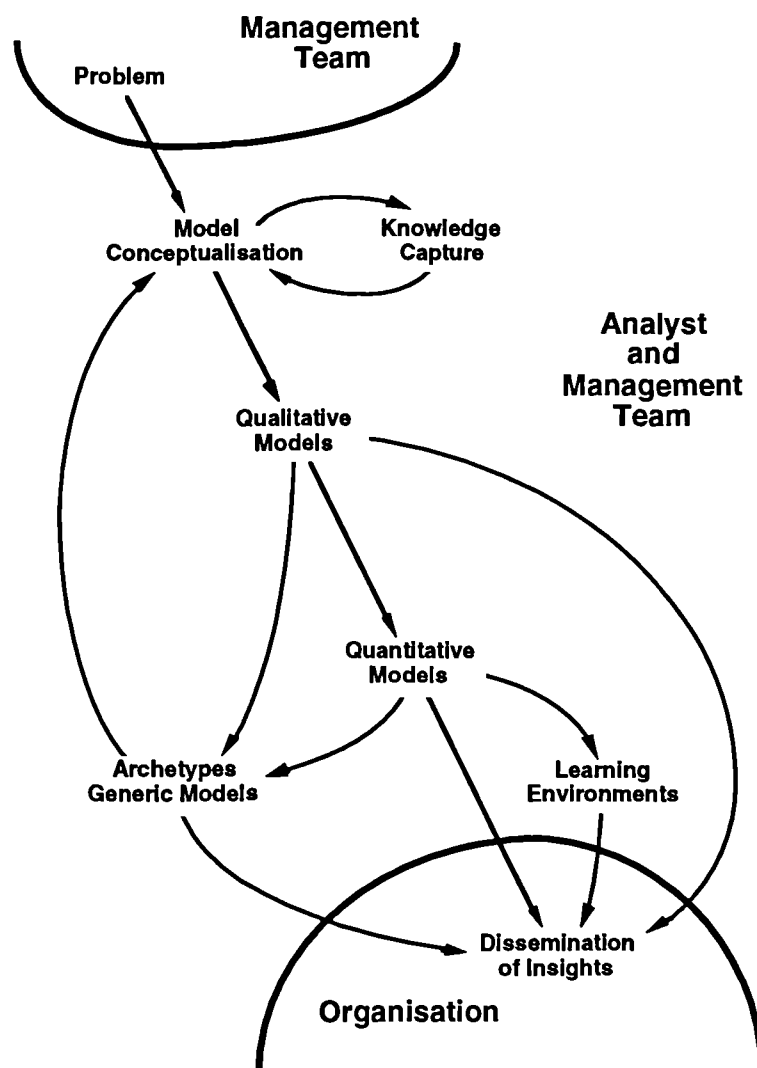


Figure 2.16 Modelling for learning using system dynamics

This change have occurred gradually through a process of evolution. If however we look at the totality of these changes then it is apparent that a revolution has occurred. This fact has not generally been appreciated by those outside system dynamics. Even those working in other systems disciplines seem unaware of the transformation. Flood and Jackson's (1991) description of system dynamics provides a striking example of this. They like many other people believe system dynamics to be simply a continuous systems simulation technique.

In an attempt to unite the new and the old under a distinct banner, Peter Senge (1990) coined the name system thinking, which he sees as:

The fifth discipline<sup>1</sup>: The cornerstone of organisational learning  
(Senge 1990)

The huge success of the book "The Fifth Discipline" (Senge 1990) and its successor "The Fifth Discipline Fieldbook" (Senge et al. 1994) has created a great deal of interest in systems thinking and the name has achieved a wider recognition.

System thinking has not been without its critics. The use of the name systems thinking to refer to one specific systems methodology has been questioned (Checkland 1994) and the prominence given to qualitative modelling by systems thinking, in particular the use of archetypes has been criticised (Peterson and Eberlein 1994, Forrester 1994).

This is reminiscent of the response to qualitative system dynamics (Richardson 1986). It is true that qualitative modelling can be misused, but then so can qualitative modelling (Peterson and Eberlein 1994). There is a danger of an artificially polarised debate developing over what is in reality, a continuum. Both of these approaches to modelling can prove useful and when used together, in true systemic fashion, the whole is greater than the sum of the parts.

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<sup>1</sup>The other four are; personal mastery, mental models, shared vision and team learning.

There has also been a debate as to the relationship between systems thinking and system dynamics; is system thinking part of system dynamics or is the converse true? Forrester (1992; 1994) equates systems thinking with qualitative system dynamics and therefore sees it as a small part of system dynamics. In contrast, Senge sees system dynamics as underpinning certain parts of systems thinking.

In systems thinking the tool of system archetypes is based on a general methodology, ...called system dynamics.

(Senge et al. 1994)

A position closer to the middle ground is taken by Richmond (1994) who sees systems thinking being larger than system dynamics, but only larger in the sense that:

...system thinking is system dynamics with an aura.

(Richmond 1994)

This is a good metaphor because:

...systems thinking is not quite the same as system dynamics. But the overlap is very substantial, and the difference is more in orientation and emphasis than in essence.

(Richmond 1994)

The latter is the viewpoint that should be adopted. The observation about orientation and emphasis is important because many of the differences are not as large as they seem. The discipline as a whole must avoid becoming involved in a pointless internal argument. The systems thinkers with their new ideas which have come from their links with other academic disciplines and the system dynamic traditionalists with their cautious good sense have much to learn from each other.



## 2.5 The Choice of Systems Thinking

The research described in this thesis was carried out using systems thinking. The reasons for this will now be discussed. The most important reason for this choice was that system thinking has a proven track record as an approach that is useful in promoting organisational learning.

Secondly, system thinking supports both qualitative and quantitative modelling. This allows a single method to be used all the way through a modelling exercise from brainstorming to knowledge dissemination. This flexibility has another advantage in that it allows the individual manager to use techniques from the part of the qualitative to quantitative continuum with which they feel most comfortable.

Finally, systems thinking is able and willing to tackle the kind of real world problems that confront managers. There are strong links between the academic and practitioner communities; indeed many of the top academics in the field are also amongst the top practitioners. The aim of most of the research carried out within the discipline is to improve its effectiveness in problem solving and as tool to promote organisational learning.

## 2.6 Soft OR

Before concluding this chapter a mention must be made of soft OR and its suitability as a vehicle for organisational learning. Soft OR is a broad term which covers a wide range of methodologies most of which are older than soft OR itself. Soft OR has sought to distance itself from hard OR. In doing this it has put itself in grave danger of repeating the same mistakes made by hard OR.

The problem is that in rejecting abstract mathematics; soft OR has embraced abstract epistemology. Soft OR is rapidly becoming an academic discipline that is remote from the real world concerns of managers. The warning signs were apparent early on in soft OR's development. Eden and Graham (1983) criticised Jackson (1982) for using:

...a conceptual abstraction of higher order than those of systems theorising, viz. the "interpretative paradigm", to argue that Churchman, Ackoff and Checkland do not demonstrate that their systems thinking can produce radical or fundamental change.

(Eden and Graham 1983)

They argue that the stakeholders should be the arbitrators of whether change is radical or not:

By 'radical' we mean that those involved and many of those being acted upon have defined the action as *radical*. *We do not really care too much* whether Jackson, Checkland, Ackoff, Churchman et al. see it as not radical.

(Eden and Graham 1983)

Three soft OR modelling methodologies will now be discussed; total systems intervention (TSI), soft systems methodology (SSM) and Strategic Options Development and Analysis (SODA).

### 2.6.1 Total Systems Intervention (TSI)

Total Systems Intervention was developed by Flood and Jackson (1991). The idea of TSI is to provide a system of system methodologies. Problem situations are analysed to determine which methodology or combination of methodologies should be applied. There are six methodologies; system dynamics, viable systems diagnostics, strategic assumption testing, interactive planning, soft systems methodology and critical system heuristics.

The idea of a system of system methodologies is initially attractive, but there are difficulties of applying it in practice. These will now be discussed with emphasis on the problem of using TSI to promote organisational learning.

It is unrealistic to expect a working manager to become conversant with a system of system methodologies. Indeed, I feel that it is unrealistic to expect any one person to become expert in six system methodologies<sup>1</sup>. This creates three problems.

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<sup>1</sup>The chapter on system dynamics contained in *Creative Problem Solving* reinforces this point. It is clearly written by someone who has an extremely limited grasp of system dynamics.

Firstly, applying TSI will of necessity require the resources of a team of experts which will limit the applicability of the approach to large organisation that will be able to support the cost of this. Secondly, there seems to be an inherent contradiction in a methodology that talks about emancipation and empowerment, yet is too complicated for individual managers to practise without using external experts. Finally, if no one person has in-depth understanding of all the available methodologies, on what basis is the choice of methodology to be made?

The large number of methodologies is likely to prove a source of confusion to those on the receiving end of them. One of the key aims of system thinking is the transfer of skill from modelling experts to managers. Systems thinking is an on going process during which managers should start to develop their own systems thinking skills. This is unlikely to occur with TSI because managers will continually be presented with new systems methodologies.

Another problem with using TSI to promote organisational learning is that TSI will only be able to provide both qualitative modelling and quantitative modelling if system dynamics is one of the chosen methodologies. All the other methodologies in the system of system methodologies are purely qualitative.

### 2.6.2 SSM and SODA

It would be unfair to give the impression that all the techniques of soft OR are more concerned with methodological correctness than the ability to solve problems. Two methods in particular have a long track record of successful application to real world problems; soft systems methodology (SSM) (Checkland 1981, Checkland and Scholes 1990, Patching 1990) and Strategic Options Development and Analysis (SODA) (Eden 1988). Both of these methodologies are qualitative in nature; they use mapping techniques to structure problems. They have many characteristics which are suitable for promoting organisational learning, but the lack of a qualitative modelling capability which can be used to provide the experience stage of the learning cycle, is a serious handicap.

This problem can be overcome through the use of system dynamics modelling. SODA is more open to this approach, its qualitative mapping tool; cognitive mapping is closely related to the influence diagrams in system dynamics. The use of SODA with both qualitative and quantitative system dynamics is accepted by its originator (Eden 1994).

In the case of SSM, while it is certainly possible to use SSM as a “front end” to system dynamics modelling, this goes against the underlying philosophy of SSM. This is because in SSM, the role of the system is as an aid to thinking, systems are not real world phenomena that can be modelled.

## **2.7 Conclusions**

This chapter has shown how modelling can be used to facilitate management learning. It has also identified systems thinking as a modelling methodology whose role in promoting learning is worthy of further research.

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# **Chapter 3**

## *Training Managers in Systems Thinking*



### 3.1 Introduction

This chapter describes the design and assessment of a management training program in modelling for learning. This research has identified a number of barriers to the adoption of systems thinking by managers. Over the period of three years, the author has in collaboration with Cognitus Systems Ltd been involved in the delivery of a number of three day training courses in systems thinking.

The participants were mostly practising managers approximately one third were analysts or consultants. The background of the participants was highly varied. The following kinds of organisations were represented: manufacturers of electronics, computers, vehicles, pharmaceuticals and the oil industry; service industries such as communications, retailing, financial institutions and management consultants; and the public sector including, a government department, a *government research* institute, the police and educational institutions.

The author has participated in seventeen training courses. Twelve of these were conducted in house for specific organisations and the remaining five were public workshops in which managers from a number of different organisations participated. The typical in-house workshops consisted of four to six participants and two trainers. The public workshops were larger with twelve to twenty participants and three to four trainers. It was often the case that small groups of participants from a particular organisation would attend the public workshops.

The author therefore has had the opportunity to observe a representative cross-section of both managers and organisations that have shown an interest in adopting system thinking in the UK.

### 3.2 Training Course Overview

The structure of the training course is shown in Table 3.1. The course aims to develop both qualitative and quantitative modelling skills in parallel, it is “hands-on” in nature; the emphasis is on learning by doing. The in-house training courses

and the public training courses have the same structure for the first two days. The in-house course devotes the third day to tackling a real problem of interest to the host organisation whereas the last day of the public workshop is devoted to another case study.

**Table 3.1 Structure of training course**

<b>Cognitus Systems 3-Day Training Workshop</b>	
<b>Day 1 AM</b>	
1.1	Introduction to workshop
1.2	Introduction to systems thinking
1.3	Introduction to itthink
1.4	Itthink hands-on exercise
<b>Day 1 PM</b>	
1.5	Presentation of community care case study
1.6	Itthink exercise with community care model
1.7	Introduction to archetypes
<b>Day 1 Evening</b>	
1.8	Overnight exercises
<b>Day 2 AM</b>	
2.1	Debrief of overnight exercises
2.2	Modelling guidelines
2.3	MGI qualitative modelling exercise
2.4	MGI quantitative modelling exercise
<b>Day 2 PM</b>	
2.4	MGI quantitative exercise (continued)
2.5	MGI debrief
2.6	Archetypes
<b>Day 3 AM/PM</b>	
3.1	Modelling projects or case study
3.2	Workshop wrap-up session

The training course structure, in particular its emphasis on qualitative modelling, is based upon that developed by E. F. Wolstenholme at the Bradford Management

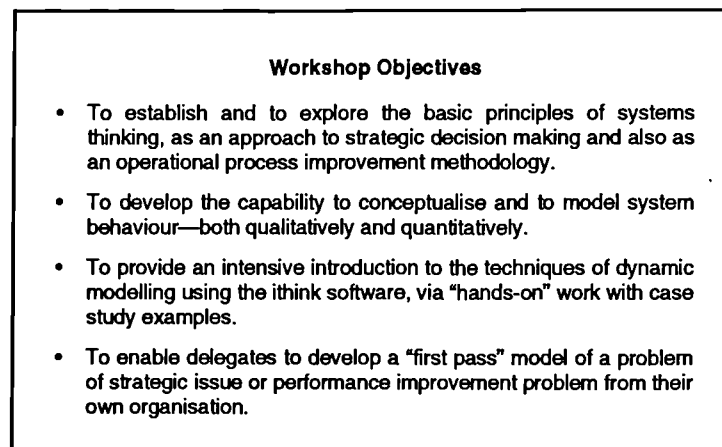
Centre. The specific content of the course has evolved over time. The Author has been responsible for the development of four major case studies; MGI, CHIPS, Rocket Powered Flight and Zanadu. The remaining material has been developed by E. F. Wolstenholme, R. W. Stevenson of Cognitus Systems and the author.

### 3.3 Training Course Day One

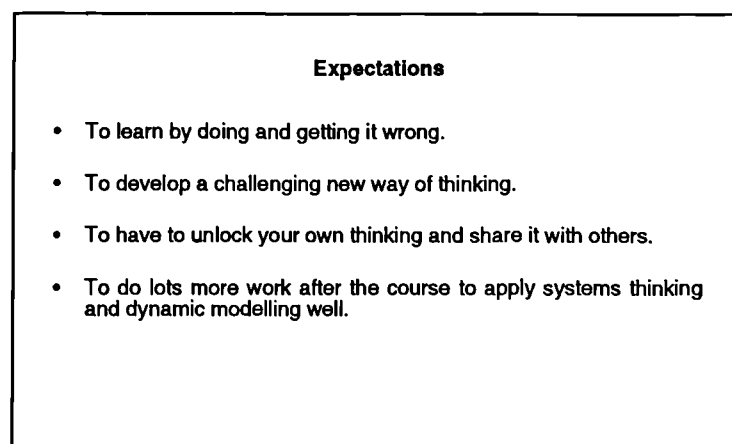
This section provides an overview of the first day of the training course.

#### 3.3.1 Introduction to Workshop

This session gives an overview of the training course and sets out the workshop's objectives and expectations, see Figures 3.1 & 3.2. It also provides an opportunity for the participants to introduce themselves to each other and to the trainers.



**Figure 3.1** Overhead slide setting out the workshop's objectives



**Figure 3.2** Overhead slide setting out the workshop's expectations

### 3.3.2 Introduction to Systems Thinking

The first part of the session introduces the idea of a system, contrasts the open and closed loop world views and introduces feedback loops and causal loop diagramming, as described in chapter 1.

**Table 3.2 Skills summary for the introduction session**

<b>Area</b>	<b>Skills</b>
Qualitative modelling	Link signing Loop signing

The second part of the session is a short hands-on exercise in which the participants working in small groups, are required to produce examples of reinforcing loop, balancing loop and a pair of reinforcing and balancing loops. In the debrief each group present their examples in turn and have it commented on by the trainers.

### 3.3.3 Introduction to Ithink

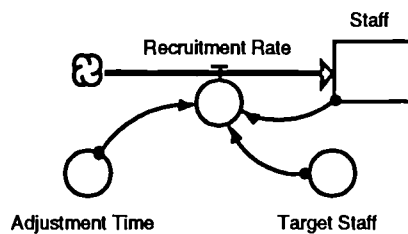
This session introduces the concepts of stocks, flows and delays and describes their representation in itthink. The session ends with the demonstration of a simple itthink model. The model is of a simple inventory system and it contains all the basic model elements. (Richmond et al 1987).

### 3.3.4 Ithink Hands-On Exercise

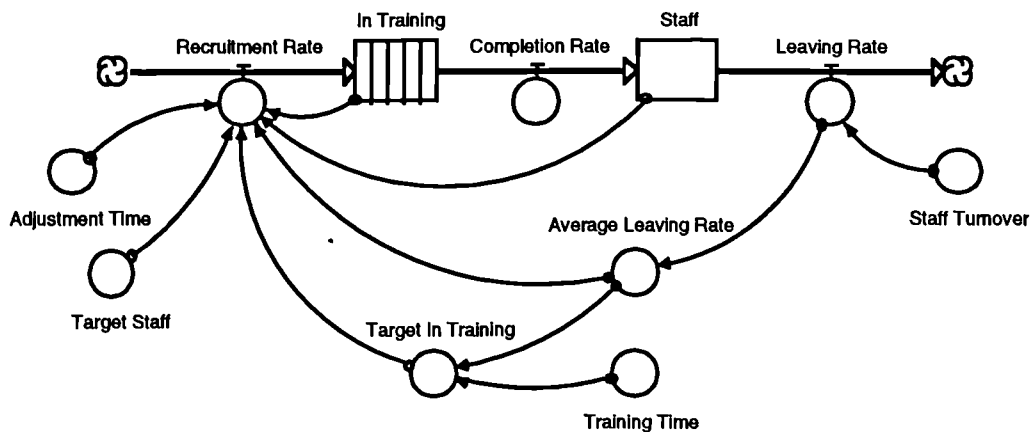
This is the participants first exposure to the itthink software. They are talked through the incremental development of a simple model of staff turnover. The first model is shown in Figure 3.3 and the final model in the sequence is shown in Figure 3.4. The models are a variant of the models developed by Wolstenholme (1990). The aim of this exercise is to introduce all the main features of the itthink software and to provide a demonstration of the modelling process, see Table 3.3.

**Table 3.3 Skills summary for the staff models hands-on session**

Area	Skills
Ithink Interface	Model construction Create graphs and tables Run a model Change a model parameter Carry out a sensitivity analysis Modify a model
Model Elements	Stock Conveyor Flow Convertor Graphical function
Built-in Functions	Introduce concept Use specific examples SMTH3() STEP()
Modelling	Build a model from verbal instructions Equilibrium run Test inputs



**Figure 3.3 The initial staff model**



**Figure 3.4 The final staff model**

### 3.3.5 Community Care Case Study

This session is based upon a real case study (Wolstenholme 1993). It has two objectives, firstly to provide an example of an application of systems thinking to a real problem and secondly to reinforce the managers' skills with the software and provides the opportunity to perform "what if" simulations with a larger and more realistic model.

The first part of the session is a presentation of the community care modelling project, which provides background information on the problem domain, describes how modelling was used to tackle the problem and discusses the insight generated by the process. The second part of the session is a hands-on exercise during which participants build the community care model from an itthink map and equation listing. They then are required to experiment with the model to see if they can, by changing management policies, improve the systems behaviour. The itthink map of the community care model is shown in Figure 3.5.

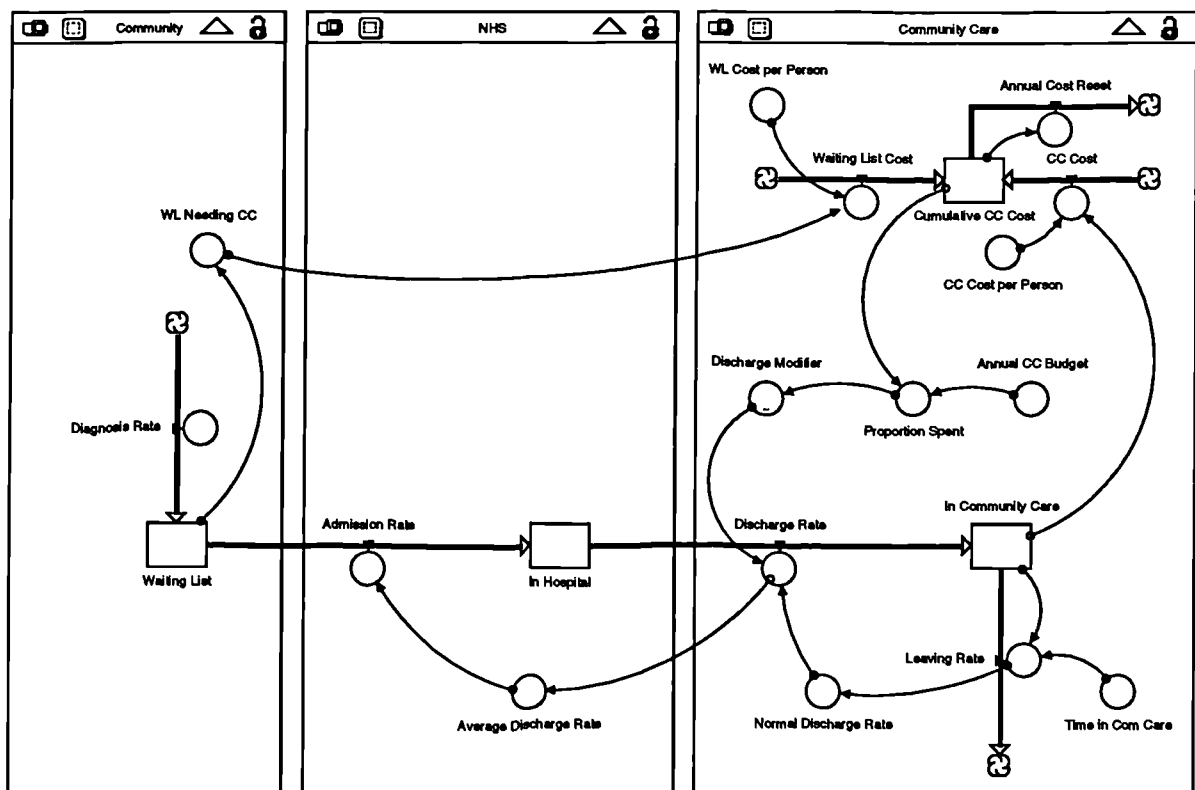


Figure 3.5 The community care model

**Table 3.4 Skills summary for the community care case study**

<b>Area</b>	<b>Skills</b>
Model Elements	Sectors
Built-in Functions	PULSE()
Modelling	Build a model from diagram and equation listing Interactive experimentation with model Use of model for policy design

The session is wound up with a short debriefing during which participants can discuss their findings. This leads straight on into the next session.

### 3.3.6 Introduction to Archetypes

This session introduces the subject of archetypes. It is shown that the behaviour of the community care model can be reduced down to two loops; an intended balancing loop and an unintended reinforcing loop. The generic nature of this structure; the 'Fixes That Fail' archetype is then described.

### 3.3.7 Overnight Exercises

Participants are given a series of modelling exercises, that require participants to produce causal maps and/or itink maps from written descriptions. Some of these are reasonably transparent descriptions of simple models, but others are based on problem descriptions taken from newspapers are much more open-ended.

## 3.4 Training Course Day Two

This section provides an overview of the second day of the training course.

### 3.4.1 Debrief of Overnight Exercises

Day two starts by looking at the participants' answers to the overnight exercises. The aim of this session is to provide an opportunity to discuss alternative ways of formulating models and to correct any misconceptions that participants may have.

### 3.4.2 Modelling Guidelines

This session describes two techniques for model conceptualisation; the feedback loop approach and the modular approach (Wolstenholme 1990). Guidelines for the modelling process are covered (Richmond et al 1993).

### 3.4.3 The Major Case Study

Four major case studies were developed; MGI, CHIPS, Rocket Powered Flight and Zanadu. The first three of these case studies share the same basic structure so of these, only one; the MGI case study will be described in detail. The Zanadu case study is different in that it was specifically developed for use on the third day of the training course and it will be described in detail later on in this chapter.

#### 3.4.3.1 The MGI Case Study

The majority of the second day is devoted to this major case study which is based upon the market growth model (Forrester 1968). The documentation that accompanies this exercise is shown in Appendix 2. The case study consists of two parts; a qualitative mapping exercise and a qualitative itthink modelling exercise.

In the qualitative mapping exercise, participants work in small groups to create a causal map from a problem description and they are also required to suggest a possible solution to the problem. A facilitated debriefing session follows in which the problem and proposed solutions are discussed.

**Table 3.5 Skills summary for the MGI qualitative modelling exercise**

<b>Area</b>	<b>Skills</b>
Modelling	Model conceptualisation

The second part is a quantitative modelling exercise. The participants work on the computers in pairs. They are provided with an itthink map of the base case (as is) MGI model and parameter values, but this time, they are required to create their



own equations. A written description of operation policies is provided to assist with this task. When the model has been built, the participants are required to modify it to incorporate the solution that was identified in the qualitative exercise, but no additional help or information is given with this task. A number of open ended exercises with the model are available to those who have completed the first two parts of the exercise.

**Table 3.6 Skills summary for the MGI quantitative modelling exercise**

<b>Area</b>	<b>Skills</b>
Built-in Functions	DELAY() FORCST() IF()THEN()ELSE() MIN()
Modelling	Equation writing Conceptualising extensions to existing model

The case study is wound up with a short debriefing during which participants can discuss their findings. This leads straight on into the next session on archetypes.

### **3.4.3.2 The Chips Case Study**

The CHIPS model is based on the “Futures Electronics” case (Goodman 1974). The model has the same basic loop structure and similar reference mode of behaviour, but the detailed models are different. The structure of the case and the layout of the documentation are very similar to the MGI case and so they will not be described separately.

### **3.4.3.3 The Rocket Case Study**

This case study was developed for training those interested in modelling physical systems using ithink. The rocket model was developed by the author from the first principles of Newtonian Mechanics. The documentation that accompanies this exercise is shown in Appendix 3. This training case has only been used on one occasion at the present time.

### 3.4.4 Archetypes Revisited

This session returns to the subject of archetypes. The first part of the session looks at the archetypes within the MGI case study. The growth producing and growth inhibiting behaviour of the MGI model is captured in two loops; an intended reinforcing loop and an unintended balancing loop. The generic nature of this structure; the 'Limits to Success' archetype is then described. A solution for this archetype is then presented which corresponds to the solution found in the MGI case study. The problematic behaviour exhibited by the MGI system is then shown to be an erroneous 'Limits to Success' solution archetype. The generality of this structure as an archetype in its own right; 'Growth and Under Investment' is then established.

The second part of the session looks at some of the other archetypes. The participants have now seen the 'Fixes That Fail' and 'Limits to Success' archetypes which consist of a pair of opposing loops, they are now introduced to the archetypes that are based upon pairs of similar loops (Wolstenholme and Corben 1993).

## 3.5 Training Course Day Three: In-House Workshops

The final day is devoted to a modelling project that tackles a problem of real interest to the host organisation. The exact structure of the project varies, but that shown in Table 3.7 is typical.

**Table 3.7 Structure of the modelling project**

### **Day Three: Modelling Projects**

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Introduction to problem domain

Facilitated group mapping

Hands on modelling

Debrief

---

The session starts with one or more of the participants making a presentation to the group on the problem domain that is to be modelled. This is to ensure that the trainers and all of the participants have an appreciation of the issues that the model is to address. The session ends with a brief discussion, the aim of which is to clearly defined the purpose of the modelling exercise.

The next stage is to facilitate the group to a first-pass qualitative model. The trainers will usually have had advanced notice of the kind of problem that is to be modelled and so may have some generic models available to start the process off. The whole group works around a white board or flip chart to develop the model. The session ends when a qualitative model that is capable of acting as a starting point for quantitative modelling has been developed.

The quantitative modelling takes place in small groups. The size of the groups varies —the ideal is one trainer to two participants, but one trainer to three participants is possible, beyond this number it becomes very difficult for the group to work successfully around one computer.

The debrief provides an opportunity for the groups to share their insights and to discuss how the modelling may be further developed.

### 3.5.1 Workshop Wrap-Up Session

This final session is common to both the in-house workshops and the public workshops. It provides an opportunity for participants to ask questions about any aspect of systems thinking. It also allows participants to informally discuss their first impressions of systems thinking and comment on how they hope to use systems thinking in the future.

## 3.6 Training Course Day Three: Public Workshops

The structure of the third day of the public workshop has evolved considerably over the last three years; the reasons for this will now be discussed.

### 3.6.1 The Problem

In the public workshop, the final day is devoted to another case study. It is not possible to provide individual modelling projects for two main reasons. Firstly the ratio of trainers to participants is too large and secondly many participants would be unwilling to discuss details of their modelling project with other participants for reasons of commercial confidentiality.

In the early workshops, individual modelling projects were tried out. It was found that one trainer cannot adequately supervise two modelling groups. The problem is that the groups need the undivided attention of a trainer for a considerable period of time, particularly when they are first starting to build a model. While the trainer is helping one group, the other group will often get stuck and then frustration sets in. Such a session can easily end up in complete chaos.

### 3.6.2 Alternatives to Individual Modelling Projects

The initial response to this problem was to replace the individual modelling project with another case study and to provide each of the participants with an opportunity to discuss their modelling interests with a trainer.

The aim of these sessions was to provide the participants with a starting point for their modelling when they returned to their own organisation. These sessions lasted for approximately thirty minutes and by the end it was usual for the participants to have a sketch of the basic loop structure of a model or a basic set of itthink stock and flow structures.

The case study that was initially used was the CHIPS case study, this was chosen because it was already available. The problem with the CHIPS case study is its similarity to the MGI case study. The subject of the case study is different, but its structure and the content, in terms of the modelling skills needed to complete it are identical. The case study was therefore useful in reinforcing the lessons from the previous day's case study, but lacked any new challenges to stimulate the participants.

It became apparent from talking to the participants that a number of them were interested in the modelling of supply chains systems. It was therefore decided to give participants the option of working with the generic supply chain model. The supply chain model and the exercises that accompany it are described in detail in Chapter 4 and Appendix 5.

The CHIPS case study and the Supply Chain Model provided a workable interim solution for day three. It was felt however that a more challenging case study should be developed for use on the final day.

### 3.6.2.1 The Zanadu Case Study

This exercise is based upon a real case study (Corben et al. 1995). It was developed to satisfy two objectives. Firstly to provide a qualitative mapping exercise of a system with greater complexity and more of a process orientation than that found in the day two case study. Secondly to demonstrate and provide an opportunity for participants to experiment with the advanced features<sup>1</sup> (Richmond 1993a) and the authoring capabilities of the ithink software (Richmond 1993b). The case study consists of two parts; a qualitative mapping exercise and a qualitative modelling exercise based on the use of the Zanadu model. The structure of the case is shown in Table 3.8.

**Table 3.8 Structure of the zanadu case study**

#### **Day Three: Zanadu Case Study**

Qualitative exercise	Process mapping exercise Debrief of mapping exercise
Qualitative exercise	Introduction to Zanadu model Exercises with Zanadu model <ul style="list-style-type: none"> <li>• Experimentation with model</li> <li>• Advanced ithink features</li> <li>• Authoring features</li> </ul> Debrief of hands-on exercises

<sup>1</sup>The new features added to version 3 of ithink.

In the qualitative mapping exercise, participants work in small groups to create a model from a problem description. They are asked to produce a causal map, a high level map and an itthink representation of the main stocks and flows within the model. A facilitated debriefing session follows in which the problem and proposed solutions are discussed. The solution to this exercise is shown in Figures 3.6 & 3.7.

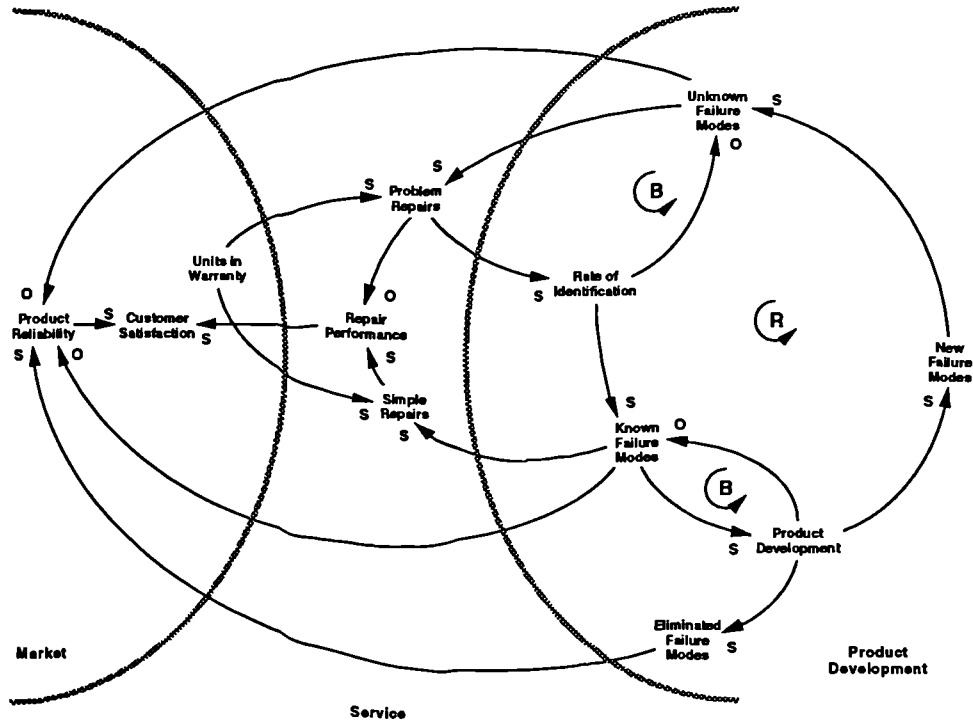


Figure 3.6 Zanadu causal map

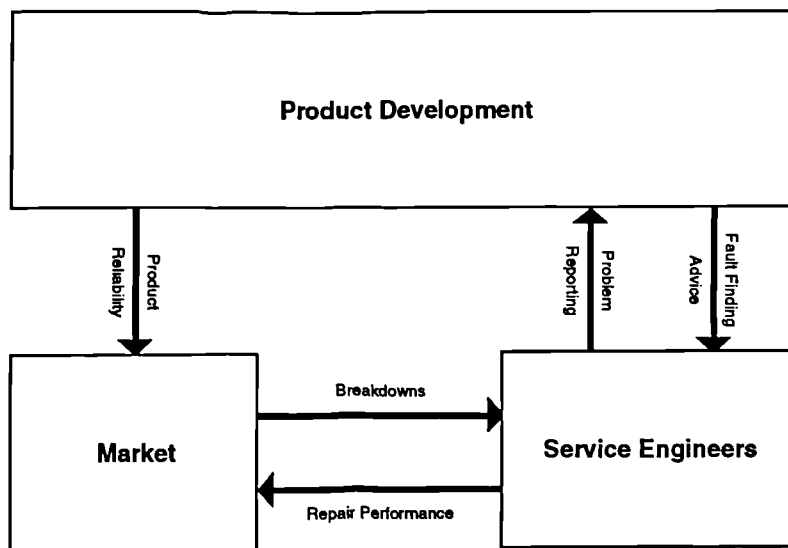


Figure 3.7 Zanadu high level map

The first part of the quantitative exercise is devoted to introducing the participants to the Zanadu model. The participants are talked through a hands-on exploration of the model, using the computer and a base run simulation of the model is performed and the resulting behaviour is discussed. The itthink map of the base Zanadu model is shown in Figure 3.8.

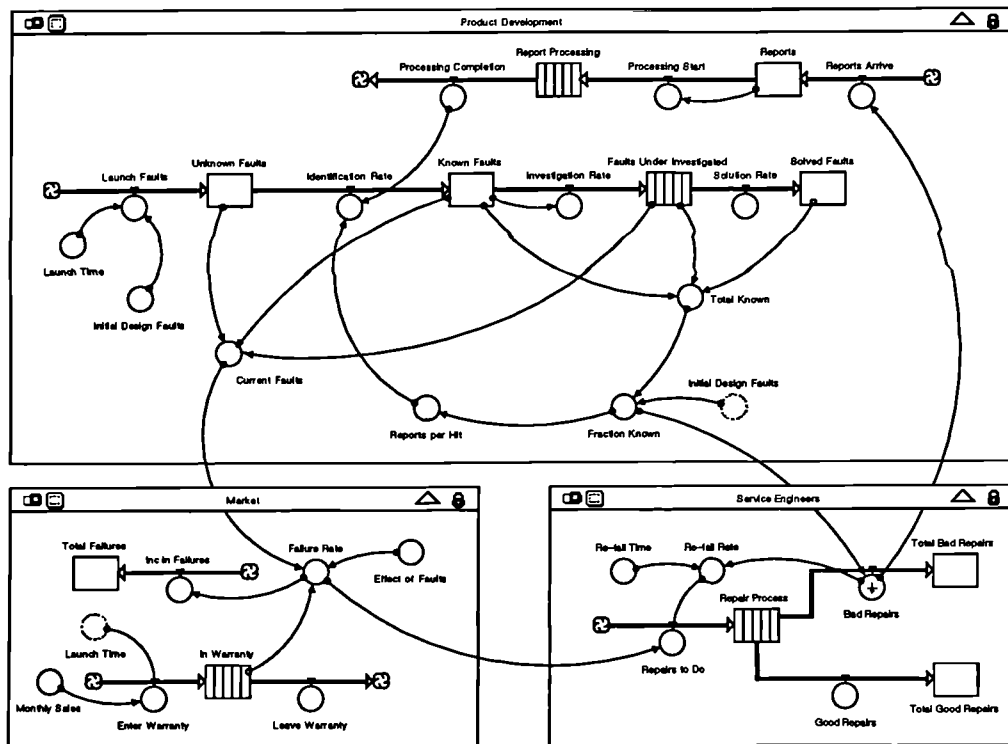


Figure 3.8 Zanadu base model

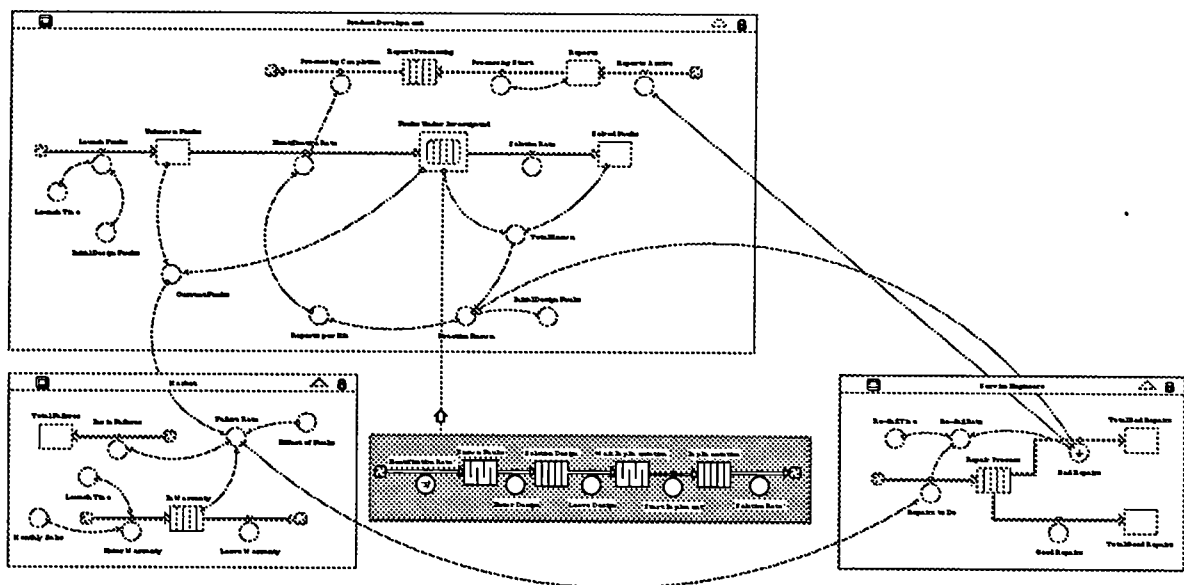
Next the participants carry out a sensitivity analysis to investigate the effect of alternative strategies for allocating limited engineering resources. This includes the use of the model for the investigation of system behaviour. In the remainder of the exercises the model is used as an example model on which to test out additional software features.

The first set of exercises introduces a number of new building blocks that can be used to create itthink models. Figure 3.9 shows the modified Zanadu model. The second set of exercises covers the use of itthink’s authoring features; these allow an itthink model to be used as an interactive learning environment. Figure 3.10 shows the Zanadu model with a high level control panel. The features covered by these

exercises are listed in Table 3.9. The case study is wound up with a short debriefing during which participants can discuss any aspect of the case study.

**Table 3.9 Skills summary for the Zanadu quantitative modelling exercise**

Area	Skills
Advanced ithink features	High level map Pinned graphs Queues Conveyor parameters Conveyor leakage Drill-down and sub-models Cycle time calculation
Authoring capabilities	Authoring preferences Slider device Graphical function and display device Numerical display device Message posting



**Figure 3.9 Zanadu enhanced model with drill-down**



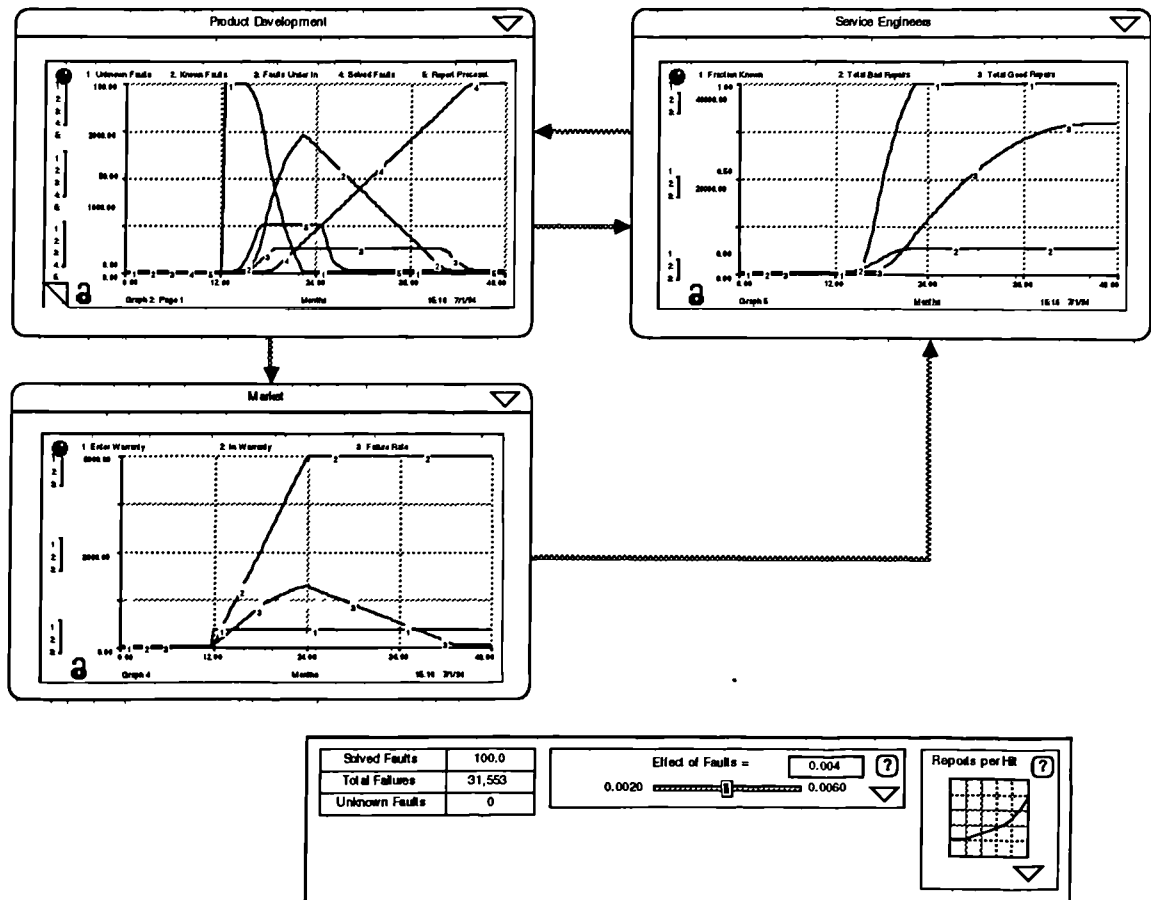


Figure 3.10 Zanadu enhanced model with high level control panel

### 3.6.3 Workshop Wrap-Up Session

This final session is common to both kinds of workshops and it has already been described in the section on the in-house workshops.

## 3.7 Modelling in the Training Course

The modelling exercises within the training course are designed to form a progression in which participants are required to increase their own contribution to the modelling process. This progression is shown in Figure 3.11. In the first exercise participants are given explicit instructions on what to do, by the time they reach the final modelling exercise, they are expected to attempt a simple modelling project unaided.

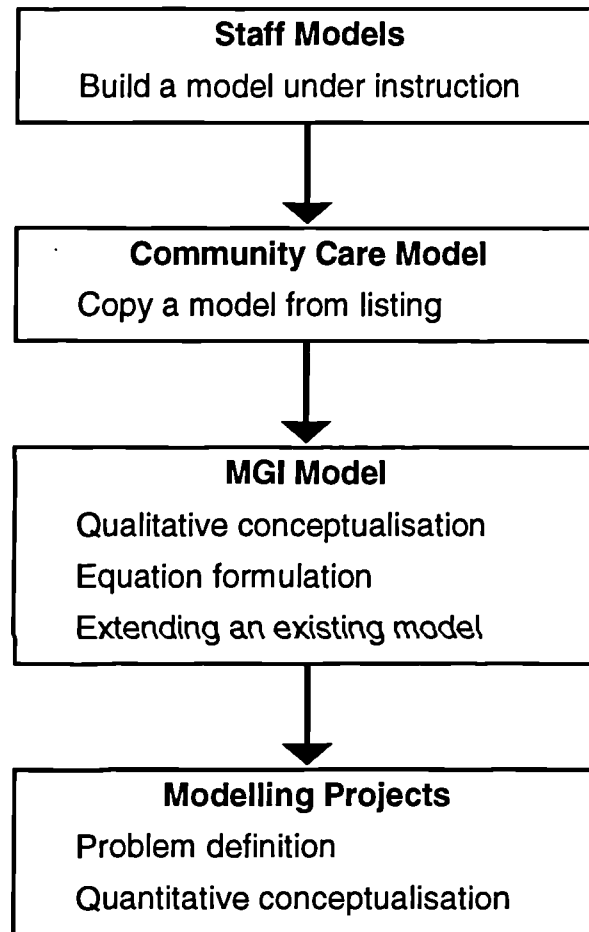


Figure 3.11 Progression of modelling in the training course

### 3.8 Methods for Assessing Participant's Performance

The emphasis of the research that has been carried out into managers and modelling has so far concentrated on assessing the effect that the use of computer model based learning environments has on managerial learning (Sterman 1988, Bakken 1989; 1992). The aim of the research described in this chapter was to assess the performance of managers who were trying to become modellers and in particular to identify where the blockages were in this learning process. The choice of method to achieve this aim will now be discussed. A number of factors needed to be taken into account when deciding the best approach to adopt.

The content of the training course was far from constant over the study period. There were two main reasons for this. Firstly the course was being continually improved and new sessions or case studied were being added all the time.

Secondly in the case of the in-house workshops it was consciously decided to be flexible in the choice of material that was delivered so as to tailor the course to suit the needs and interests of the individual group. Also a number of the in-house workshops were of two days duration rather than the usual three and a condensed version of the standard course was delivered.

This variation in training course content over time has meant that only small groups of the total number of participants have experienced exactly the same training course. The public workshops have been subject to less variation than the in-house workshops.

The participants had a huge range of previous experience. At one extreme some of them had never modelled before and had only ever used a computer to query a data base. At the other extreme there were people had already been using itthink for several months. Again there was much greater variety in previous experience amongst the participants of the in-house workshops as compared to the public workshops.

The variation in course content, coupled with the large range of the participants previous experience, makes assessment difficult. It was decided to adopt a two pronged approach of direct observation of participants while they were taking part in the training course, backed up by self assessment by the participants through the use of a questionnaire. The use of a formal test to assess participants' knowledge was rejected because the workshop already had an intensive workload and there was insufficient time within the workshop in which to carry out a test.

The high trainer to trainee ratio made it possible for the author to spend a considerable amount of time with each participant and so observe their modelling performance. It was also possible, through informal discussions with participants to gain an insight into their thinking and view of the training course. The observation of participants' performance was based upon all of the workshops that the Author attended, both in-house and public. The third day of the in-house

workshops provided a valuable opportunity for the author to observe managers who were making their first attempt to model a real problem.

It was decided to limit the analysis of the course evaluation questionnaires to the public workshops. This was because the public workshops were much more consistent in terms of content and duration compared with the in-house workshops. Also the participants were far more evenly matched in terms of their previous experience of systems thinking and *ithink* than was the case for the participants of the in-house workshops.

### 3.9 The Course Assessment Questionnaire

The course assessment questionnaire is shown in Figure 3.12. This questionnaire was developed by Cognitus Systems Ltd for training course appraisal. A number of questions concerning the location of the training course and the facilities offered by the venue have been omitted from Figure 3.12. The results from the analysis of ninety questionnaires completed by public workshop participants will now be described.

#### 3.9.1 Question 1

The participants were asked to assess a number of aspects of the training course on a five point scale (1 = poor, 5 = excellent). The mean scores for question 1 are shown in Table 3.10 and the distribution of responses is shown in Figure 3.13.

**Table 3.10 Average scores for question 1**

<b>Question</b>	<b>Mean Score</b>	<b>Median Score</b>	<b>Modal Score</b>
Course content	4.18	4	4
Course handouts	4.22	4	4
Course material	4.07	4	4
Length of course	3.89	4	4
Presenters	4.44	4.5	5
Overall impression	4.21	4	4

## Questionnaire

We would be grateful if you could spend a few minutes of your time to give us your reactions to the workshop.

Name:

Position:

Organisation:

1 Please tick the appropriate box:

	Excellent			Poor	
Course Content	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Handouts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Presentation Material	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Length of Workshop	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Presenters	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Overall Impressions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2 Did the course meet your needs?

Yes       No       Partly (Please Comment)

3 a) Were there any topics omitted that you were hoping would be included?

b) Were there any topics included that, in your opinion, should be omitted?

4 a) How would you rate your prior knowledge of business modelling?

b) How would you rate your prior knowledge of modelling with itthink?

5 Do you feel adequately equipped to undertake your modelling project?

6 Any final comments?

**Thank you for answering this questionnaire**

**Figure 3.12 The course assessment questionnaire**

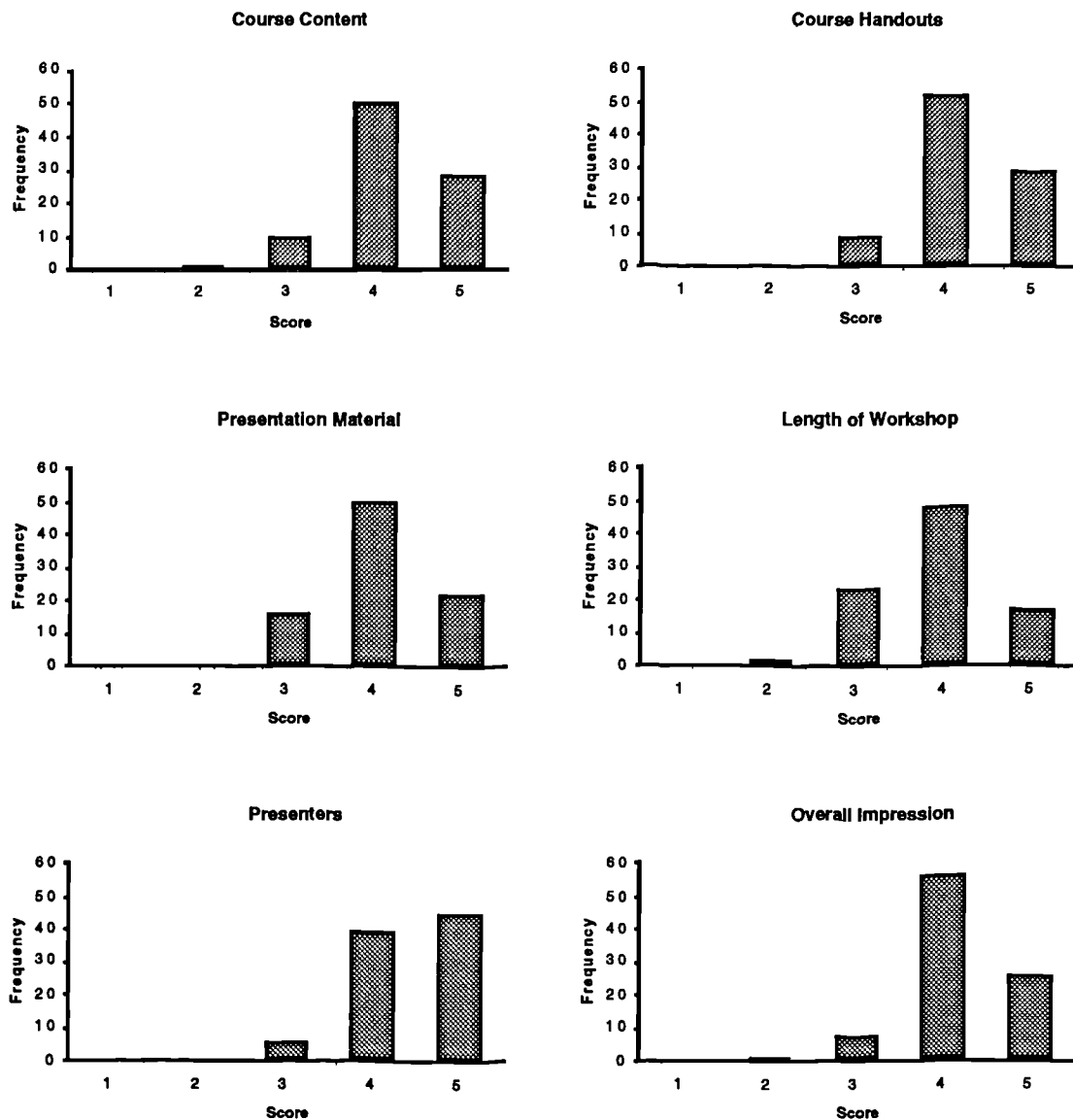
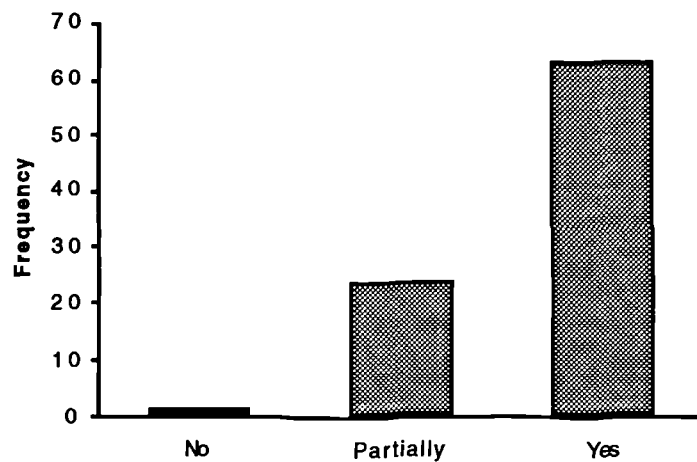


Figure 3.13 Response to question 1

It can be seen that the training course achieved very high ratings in all of the categories. The aspect of the training course with which the participants were least satisfied was its length, but even this scored well into the top half of the scale. The main complaint was that the course was too short; thirteen participants (fifteen per cent) specifically stated that they would prefer a longer course and a number of these participants also suggested that this longer course should be split in two parts; an introductory course and an advanced course.

### 3.9.2 Question 2 and Question 3

These questions are closely related and so they will be discussed together. In question 2, the participants were asked to indicate whether the course met their needs with responses on a three point scale (1 = No, 2 = Partly, 3 = Yes). The mean score for this question was 2.70. Figure 3.14 shows the distribution of responses.



**Figure 3.14** Response to question 2 (did the course meet the participants needs)

Again the level of satisfaction was high; seventy-two per cent were satisfied, twenty-seven per cent were partially satisfied and only one person was unsatisfied. The reasons that participants gave for being only partially satisfied with the training course fell into two main categories. The first was that the models used during the training course did not cover the participants particular area of interest. The second was that the balance between qualitative and quantitative modelling was wrong.

These themes were repeated in question 3 which asked respondents to list topics; that had been omitted but which should have been included and those which had been included but which should have been omitted. The following discussion therefore draws on responses to both questions 2 and 3 and also question 5 which some participants used to comment generally on course content.

### 3.9.2.1 Model Subject Area

A number of participants requested that the training course should include the modelling of the following specialist areas:

- Scenario planning and market system mapping.
- Better balance between public and private sectors [too much public sector].
- Supply chain management case study very relevant.
- Models in our own areas of interest.
- Modelling softer issues.
- More financial applications would have been helpful.

This problem only occurs in the public workshops, participant of the in-house training courses, spend the majority of the final day tackling a problem of their own choosing. In the case of the public workshop, it is simply not possible to include case studies from every problem domain in a three day course.

One possible solution to this problem would be to expand the range of problem domains covered by the overnight exercises. The problem with this approach is that as the subject of the exercises becomes more specialised, less of the participants will be able to tackle the problems. The subject matter of the exercises has been specifically chosen so that no specialist knowledge is required and everyone can participate. There does not seem to be a practical solution to this problem within the context of the public workshop that aims to provide a general introduction to systems thinking. It would be possible to devise themed workshops<sup>1</sup> that focused on particular problem domains, but such courses might well have difficulty in attracting enough participants to prove viable.

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<sup>1</sup>One such workshop that covers supply chain management is described in Chapter 4.



### 3.9.2.2 The Balance between Qualitative and Quantitative Modelling

A number of participants (eighteen per cent) commented on the balance between qualitative and quantitative modelling in the training course. These comments were evenly divided between those who wanted more systems thinking and those who wanted more itthink, typical comments are shown in Table 3.11.

**Table 3.11 Comments on the balance between qualitative and quantitative modelling**

More Qualitative Modelling	More Quantitative Modelling
<ul style="list-style-type: none"> <li>• Less computer.</li> <li>• More time spent on causal loops and systems thinking.</li> <li>• More practise developing maps.</li> <li>• A mapping only case study.</li> <li>• Need more time mapping.</li> <li>• More time on systems thinking.</li> </ul>	<ul style="list-style-type: none"> <li>• I didn't get deep enough into the software.</li> <li>• More detail on itthink functions.</li> <li>• Archetypes; much less emphasis.</li> <li>• I did not benefit from the review of the archetypes.</li> <li>• I would have preferred more on itthink.</li> <li>• More baseline knowledge of the software.</li> </ul>

The fact that the course content was equally criticised for being both too qualitative and too quantitative suggests that the balance is about right for an introductory training course. However this divergence of opinion suggests that there is a need for more specialist training courses. It would be possible to devise two courses that focused on qualitative modelling and quantitative modelling respectively. The problem with this approach is that the qualitative and quantitative aspects are complimentary and any system thinker should have an understanding of both kinds of modelling.

In view of this, it would be better to let participant specialise after a basic introduction to both qualitative and quantitative techniques. One way of achieving this would be to have a common day one followed by two days on either qualitative or quantitative modelling. Another way of achieving this would to add two further options to day 3; a day spent on qualitative mapping, exploring the

archetypes and discussing the use of systems thinking to promote organisational learning and a day spent in an in-depth exploration of itthink's features.

### 3.9.3 Question 4

The first part of this question asked participants to assess their previous modelling experience. The majority responded with single word answers, but a few, the more experienced, named particular modelling techniques or software packages with which they were familiar. The responses to this question are shown in Figure 3.15. It should be noted that nearly half of the participants (forty-seven per cent) said they had no previous modelling experience and less than one quarter (twenty-four per cent) said they possessed good business modelling skills.

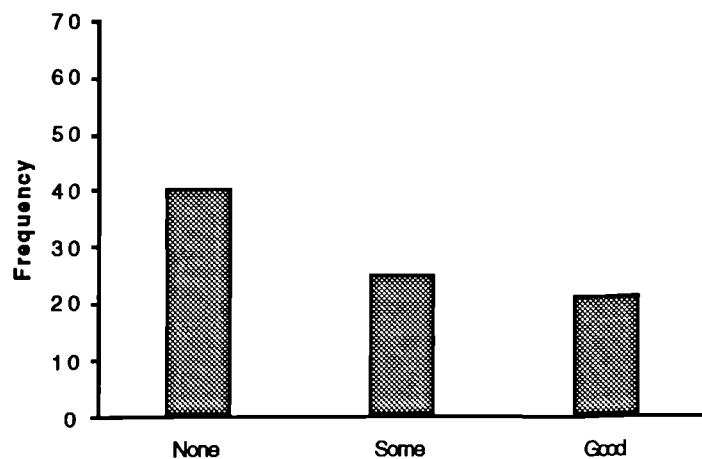
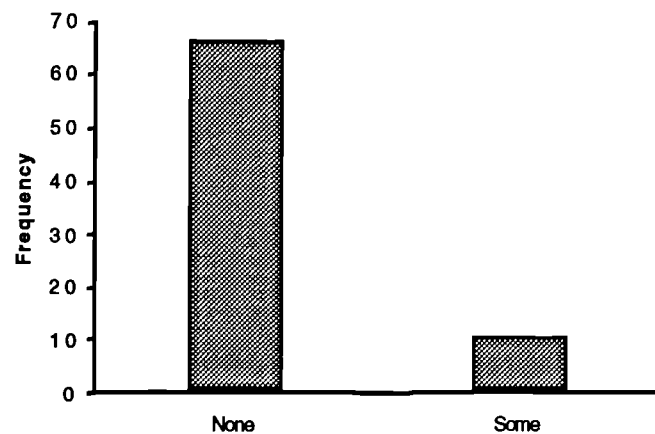


Figure 3.15 Response to question 4a (previous modelling experience)

In the second part of question 4, participants were asked to assess their prior knowledge of itthink. The vast majority (eighty-seven per cent) said that they had no previous experience of the software, see Figure 3.16. Those with prior knowledge of itthink generally described it as basic or minimal, although there were three participants who described their experience as average or better.



**Figure 3.16** Response to question 4b (previous itthink experience)

### 3.9.4 Question 5

This question asked if participants felt that they were capable of undertaking a modelling project on their own. The responses were varied, a number answered with definite yes (twenty-five per cent) or a definite no (sixteen per cent) the majority (fifty-nine per cent) were circumspect about their abilities, see Figure 3.17. Typical comments from this group were:

- Enough to make a start.
- Ready to start but expect problems.
- Require more practise to gain confidence.
- Yes and No, I need to go and try.
- I am well equipped to make a start.
- Broadly, but will probably want help.

This majority group had a very realistic view of their abilities. They were confident enough to start to apply systems thinking, but were aware of the difficulties they

would face. They also appreciated that they still had a lot to learn; that there was a need to practise the techniques that they had learned during the training course.

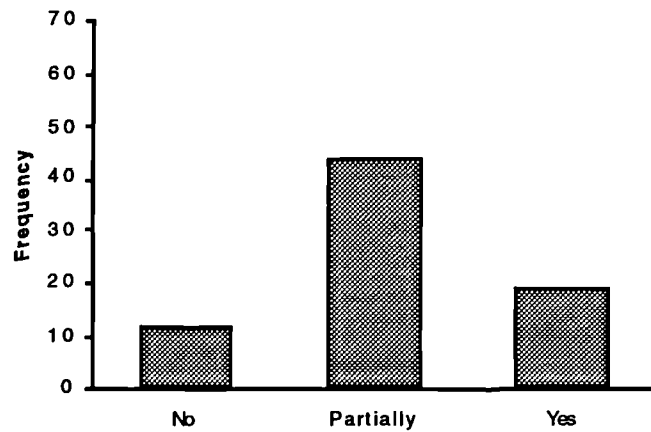


Figure 3.17 Response to question 5 (equipped to tackle a modelling project)

### 3.9.5 Question 6

This question asked for any additional comments on the training course. As would be expected there was a wide range of responses to this question. A good number of the participants (twenty-six per cent) took the opportunity to praise the training course and some wrote glowing endorsements:

- Course pitched at the right level, and the knowledge of the presenters was impressive. I would change very little.
- Excellent insight to the subject and a great booster of self confidence.
- Keep preaching the word.
- I found the three days very useful.
- A very good course, hard work for the novice, but I learnt a lot.
- A very stimulating three days.
- Enjoyed the course immensely.

Some participants reiterated the points that they had already made in their responses to previous questions. Finally there were a number of minor criticisms and suggestions, often concerned with general aspects of the training course which do not warrant further discussion here.

### **3.10 Observation of Participants Performance**

The observations have been summarised into a number of categories.

#### **3.10.1 The Debrief of the Overnight Modelling Exercises**

Participation is usually very high in this session. The interactions that take place during this session are broadly of two types. Firstly there are specific technical questions. These take the form of a one to one dialog between a trainer and the participant that asked the questions, but occasionally other member will join in the dialog by raising a related question.

The other type of interaction that occur is a group debate on the actual models themselves. The discussion provoked by the models is often very wide ranging and thought provoking. The participants start to use the model to make points and propose solutions to the problem. A number of extensions to the model are usually put forward. The participants usually become so engrossed in these discussions, that it is difficult to move the group on to the next problem and the session has a marked tendency to overrun its allotted time.

It is interesting to note that a session that was envisaged as a way of providing an introduction to model conceptualisation and answering technical questions has become in practise a group modelling session. The participants' discussions clearly indicate that they see more to this session than a set of simple modelling exercises, that they are interested in the examples as problem in their own right. This behaviour demonstrates the power that simple models have to provoke debate. The choice of subject for the models is also a contributory factor. The problems are based upon topical issues from the Criminal Justice System and the National

Health Service; subjects about which all the participants will have a reasonable amount of background information and on which many will hold strong opinions.

### 3.10.2 Use of Software

Training managers how to use the *ithink* software is relatively easy. Most managers can be taught how to “fly” the software in a couple of hours (the time it takes to complete the first *ithink* hands-on exercise). There were a few participants who had very little computing experience but even this group was able to use the software competently by the end of the first day.

### 3.10.3 Qualitative Modelling

It was noticeable that participants often created loops that contained very few variables. In particular the type of loop shown in Figure 3.18 that consists of a pair of variables was very popular, the more complex multiple variable loops, as shown in Figure 3.19 for example, was much less common.

This was true both in the first session on system thinking and later on in the training course. It might be expected that simple loops would be used early on in the course, particularly because the examples that had participants had see up to this point were simple two or three element loops. However later on in the course they have seen the community care qualitative model and the solution to the MGI qualitative exercise both of which have numerous model elements.

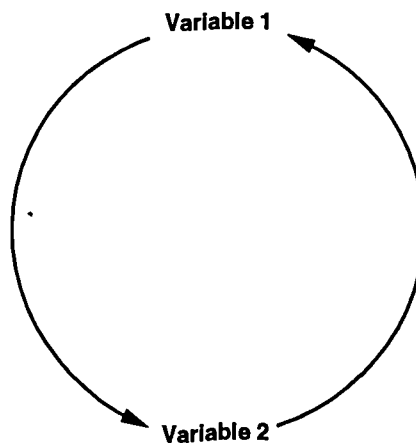


Figure 3.18 A simple loop pair

It is interesting to note that the types of loop structure that managers used to express their ideas were of the same order of complexity as that found in the system archetypes (Senge 1990). It is also consistent with the view that individuals carry around ideas in the form of “chunks” of information (Richardson et al 1994).

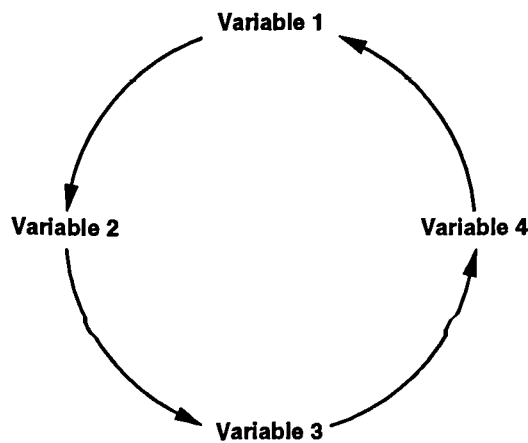


Figure 3.19 A multiple variable causal loop

The problem with such simple loop structures is that the omission of detail in the links between the key variables, can obscure important causal relationships and it may also lead to ambiguity in the signing of causal links. An example of this is shown in Figure 3.20. Here there is doubt as to the sign of the causal link between “Variable 1” and “Variable 2”. The participant will comment that the link is both same and opposing and provide two scenarios that support this assertion.

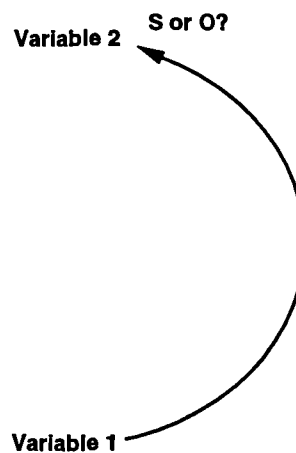


Figure 3.20 An ambiguous causal link

The reason for this confusion is that there is too big a causal jump between the two variables. If some intermediate variables are introduced, it soon becomes apparent that there are actually two paths, of opposite sign, from “Variable 1” to “Variable 2” via the intermediates “Variable A” and “Variable B”, Figure 3.21.

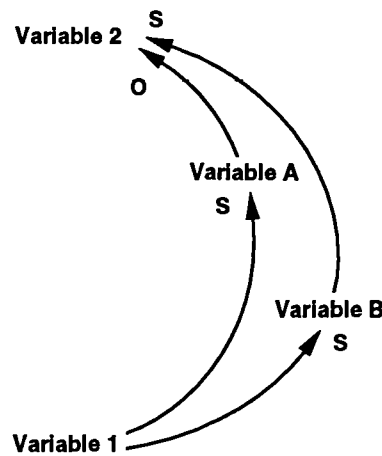


Figure 3.21 The resolution of an ambiguous causal link

This existence of two paths between “Variable A” and “Variable B” has the effect of creating two loops where originally there was only one, Figure 3.22.

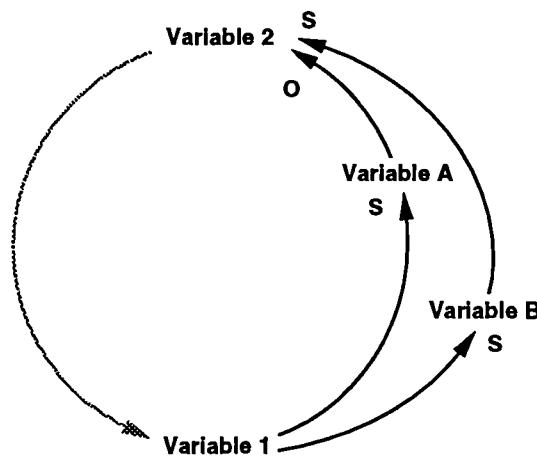


Figure 3.22 The effect of resolving an ambiguous causal link

This mechanism can be used as a technique for incrementally developing a model. The procedure is to question each link in the model and ask if there is an alternative path between the two variables with opposite causality to the current link. If this is the case then another loop can be added to the model.



### 3.10.4 Quantitative Modelling: Equation Formulation

The material presented in this section is based upon the observations of participants' performance during the MGI quantitative modelling exercise. This exercise requires participants to formulate equations from a given set of variables.

The participant performance in this area was very varied. This was due to the participants having a wide range of mathematical ability. Some participants were experienced mathematicians whilst others were uncomfortable working with numbers and equations.

The participant with little mathematical background found the process of writing equations difficult. A guide to equation formulation is that equations should be dimensionally consistent, but the non-mathematical participants did not find this technique to be of help. In contrast, participants with an engineering background were familiar with this method and used it widely. One way to help those with little mathematical background to formulate equation is to ask them to first perform the calculation for a specific case, using nominal numbers, then apply the procedure that they have just used to the general case of the equation. For example, consider the formulation of the equation for Lead\_Time in the MGI case study. The required equation is:

$$\text{Lead\_Time} = \text{Order\_Backlog} / \text{Production\_Rate}$$

The participant who is struggling to reach this equation can be helped by being asked a specific question:

If the order backlog is 500 units and the average production rate is 100 units per week then what is the order lead-time?

They will usually give the correct answer of 5 weeks. The process of calculating this answer for a specific case, provides the participant with the form of the required equation for the general case.

The participants who were used to formulating equations found the standard systems dynamics equation formulation rather strange at first, for example:

The calculates of a current value of a variable as a base value multiplied by some normalised multiplier:

$$\text{Order\_Rate} = \text{Effect\_On\_Sales} * \text{Base\_Productivity} * \text{Sales\_Force}$$

or the formulation for the outflow of a first order delay:

$$\text{Staff\_Leaving} = \text{Sales\_Force} / \text{Length\_of\_Stay}$$

A number of participants commented on the use of a graphical function as a multiplier in the MGI case that:

I would have never have thought of modelling it that way

The problem seemed to be that of unfamiliarity; this type of equation does not usually arise in spreadsheet modelling.

### 3.10.5 Model Conceptualisation

This is the most difficult modelling skill for managers to acquire. Participants often stated that they found conceptualising the hardest part of the workshop and this was confirmed by their actual performance.

Participants find conceptualisation easier if it was carried out within some kind of framework. A good example of this, can be found in the second day case study. The task of incorporating the qualitative solution into the base case quantitative model is usually carried out very successfully, with little need for facilitator intervention. In contrast the less transparent of the overnight conceptualisation exercises and the freeform modelling, were found to be much more difficult.

Participants confronted with a blank sheet of paper, find it difficult to start off the modelling process. If however they can be facilitated to build a working first pass model (this can be a very simple model), then they usually have the confidence to

incrementally develop this model, with only occasional need for facilitator assistance.

### 3.10.6 Use of Models

Experimenting with a model comes naturally to most managers, but some need some prompting to experiment methodically and interpret simulation output.

A number of participants were motivated to conceive and implement their own extensions to the model used in the MGI case study. It was noted with some interest that it was the managers who were most likely to want to extend the model, analysts tended to regard the case study simply as an exercise to be carried out and soon lost interest in the completed model. However the analysts were in general better at implementing such extensions.

This suggests that it is best if workshops are attended by mixed groups of managers and analysts. This has been confirmed by experience. The workshops where managers and analysts worked together, were all very successful and useful models of the managers own problems were developed on the final day.

### 3.10.7 Modelling Projects

In all of these sessions it was possible to achieve a simple first pass model. In a few cases this was more of the trainer's model than the participants, but usually the participants took the initiative and the trainer's role was that of providing help and advice. There were two main areas of difficulty for participants in carrying out this exercise. The first problem area was that of model conceptualisation; this has already been discussed in this chapter. The second problem was the tendency that participants had of trying to build the whole model in one step.

The participants showed a marked reluctance to stop mapping and start simulating. They wanted to "finish" the map of the whole model before attempting any simulations. The problem is that this "Big Bang" approach to modelling usually leads to failure. The solution is to adopt a top-down, iterative approach to

modelling (Richmond et al 1993). The trainers had to insist, often quite firmly, that the participants adopt this approach. A rule of thumb that; the number of “not yet defined” elements in a model should be six or less (Richmond et al 1993), proved to be useful in enforcing incremental model development.

The author has also come across this problem while working as a consultant on three separate occasions. In each of these cases, the client had the basis of a good model, but because they had not developed the model incrementally, they were unable to make such a large model function correctly.

*A number of the models that came out of these sessions were, to the author’s knowledge, further developed by the participants after the workshop. In one case the model was used virtually unchanged to summarise the findings of a major piece of business process re-engineering and so facilitate the negotiation of changes in supply chain policy between a major high street retailer and its suppliers.*

### 3.10.8 Alternatives to Individual Modelling Projects

In the public workshops the participants did not undertake modelling projects on the final day, instead they tackled another case study.

#### 3.10.8.1 CHIPS

The CHIPS case study was the first alternative to individual modelling projects. It was eventually replaced with the Zanadu case study.

The minority of participants who experienced difficulty with the previous day’s case study, welcomed the chance to undertake a case study of similar difficulty. The majority quickly completed the case study and did not appear to find it challenging.

#### 3.10.8.2 Zanadu

The author has observed the use of this case study on three occasions. The qualitative mapping exercise will be described first, then the quantitative exercise.

The qualitative part of the case study is more difficult than its equivalent in the MGI case study. There are a number of reasons for this; the problem is intrinsically more complicated, the model is larger (it has almost twice the number of stocks and conveyors), the model contains a mix of low level processes and high level aggregate concepts. The effect of the increased difficulty was varied.

Some groups rose to the challenge and after a very intense modelling session produced some good and interesting solutions.

Other groups clearly found the problem too difficult and became dispirited. These groups needed a considerable amount of help to get to a model. Part of the problem with these groups was that there seemed to be an unwillingness to commit something to paper, as a starting point, instead they would talk themselves round and round in circles.

This wide variation in performance may be simply because some groups contained better modellers than others. The author felt that another factor which may be important is the way in which each group functioned as a group.

The facilitation and group working experience of the participants was highly varied and this was not taken into account when splitting the participants into groups for the case study. It was noticeable that some groups seemed to function as a whole whereas in others there was a tendency for one or more individuals to work on their own instead of participating in the group. It would be useful to carry out some further research in this area to determine what effect group behaviour has on the modelling process.

If it is proven that group modelling is not working in some cases then it will be necessary to take steps to remedy this situation. One possible solution is to assign participants to groups based on previous experience and so create more evenly balanced groups. Another possible approach is to improve the structure of group working by assigning specific roles (facilitator, modeller, etc.) to group members.

The quantitative part of the Zanadu case study, which introduces additional features of the itthink software, was completed without great difficulty by most of the participants.

### **3.10.8.3 Difficulties with Case Studies**

It is very difficult to recreate the richness of experience that results from modelling a problem of personal concern in a case study. This is due to the artificial nature of case studies; the participants have no personal experience of the system being modelled on which to draw for guidance. This lack of experience with the system is a problem for the author attempting to create a case study that will stretch participants modelling skills.

The problem description in the MGI case study is essentially the description of the solution model. It is therefore reasonably transparent to the participants and they do not need to prove much in the way of additional information. The problem description in the Zanadu case is purposely further removed from the solution model and this requires the participants to make more assumptions and modelling choices. The lack of experience of the system being modelled to guide makes this task difficult.

## **3.11 Conclusions**

The training course received very high overall approval ratings from the participants. There was a body of opinion that expressed a wish for both a longer training course and a variety of training courses which would allow qualitative modelling, quantitative modelling and a number of problem domains to be explored in more detail.

The training material with the exception of the third day case study was well received in general. If a case study could be developed that delivered a large part of experience that results from the modelling projects then the training course would be considerably enhanced.

Observation of the participants in training courses has confirmed the value of training practising managers in modelling. The great enthusiasm shown by many of the managers on being able to model for the first time has made a lasting impression on the author.

The area of the modelling process that causes most difficulty to new modellers has been identified as that of model conceptualisation. The managers' conceptualisation performance clearly shows that there is a need to improve the conceptualisation process. The crux of the problem would appear to be the lack of any model structure to work with in the early stages of the conceptualisation process. What is required therefore is a framework for model conceptualisation that will help managers move easily to a simple working model as early as possible in the conceptualisation process. This identification of model conceptualisation as a problem area has inspired the work that is described in chapter five of this thesis.

Finally the results of this exploratory research into the training of managers in systems thinking, described in this chapter, provides a foundation for further research in this area.

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## **Chapter 4**

### *A Case Study of the Adoption of Systems Thinking*

## 4.1 Introduction

This chapter provides a longitudinal case study of the introduction of systems thinking to an organisation. In addition, the design and delivery of a model based logistics workshop is described and evaluated.

### 4.1.1 Commercial Confidentiality

The work described in this chapter was carried out for a company that wishes to remain anonymous. To protect commercial confidentiality, the name of the company and the nature of the industry have been changed. The inclusion of model output has been limited to that produced by two generic models for the same reason.

This restriction in no way reduces the value of the material presented, because the emphasis in this chapter is on investigating the adoption of systems thinking by an organisation, rather than describing the output or structure of a specific model.

### 4.1.2 Background

UKCO manufactures trucks for the domestic, European and world markets. An important feature of UKCO as far as this study is concerned, is that they have strong collaborative and financial links with OSCO, a foreign truck manufacturer. It is also relevant to note that at the time of this case study, UKCO was in the process of re-engineering a number of its key business processes and that the launch of a major new product was imminent.

### 4.1.3 Overview and Timetable

The first contact with UKCO was a request to facilitate the building of a high-level model of UKCO's supply chain, that would illustrate the consequences of some proposed changes in logistics policy. A model was built in two intensive sessions and was used to support the decision making process at the highest level within the company.

The success of this work persuaded and encouraged UKCO to invest time and resources to increase their understanding of how they might use systems thinking. To widen the exposure of the methodology, a logistics workshop built around the previous modelling work was designed and delivered to a group of managers. This work identified several possible problem areas that would benefit from the application of systems thinking and UKCO decided to send two of their managers on a systems thinking training course.

The first in-house application of systems thinking was made by one of these managers who was working on a project to re-engineer UKCO's product improvement process. A model was developed with a minimal amount of outside help and the project was successfully completed without further external intervention. Subsequently UKCO has trained a further two managers who are currently involved in a redesign of UKCO's European distribution network.

**Table 4.1 Timetable of events**

<b>Date</b>	<b>Duration</b>	<b>Activity</b>
12/92	4 days	Modelling
4/93	4 days	Modelling
5/93	2 day	Logistic Workshop
6/93	3 day	Staff Training
8/93	2 days	Modelling
9/93	3 day	Staff Training

A timetable of these events is shown in Table 4.1 and the relationship between these activities and the spread of systems thinking within the company is shown in Figure 4.1.

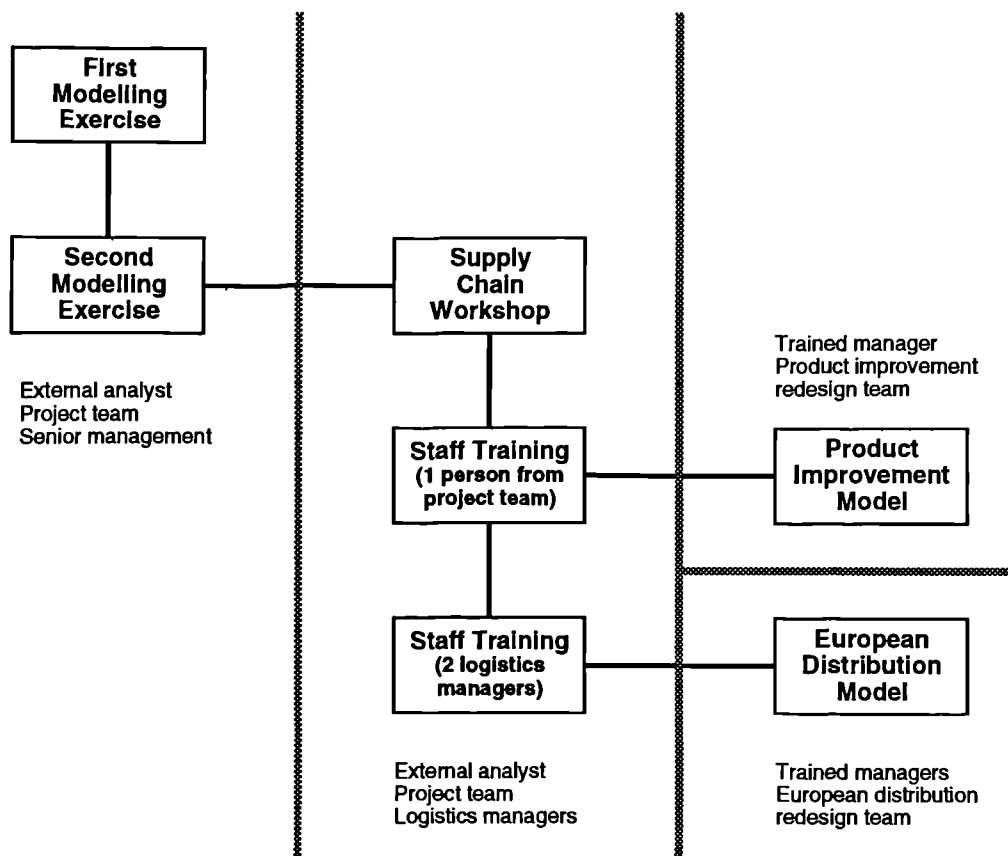


Figure 4.1 The spread of systems thinking within UKCO

#### 4.1.4 Chapter Structure

This chapter in addition to describing an application of systems thinking, provides a review of the literature on techniques for disseminating the insights gained through modelling. In order to clarify relationship between this material, a brief overview of the chapter’s contents will now be given.

The next two sections describe the first and second modelling exercises. This is followed by a discussion of the issues involved in disseminating the insights of modelling exercises. The design and delivery of a logistics workshop is then described, this section is supported by two appendices that provide background information on the Beer game and the itthink supply chain model, both of which were used during the workshop. The next section describes how UKCO developed an in-house capacity to apply systems thinking. Conclusions are drawn in the final section.

## 4.2 First Modelling Exercise

This was UKCO's first exposure to systems thinking and the *ithink* software. The author acted as a consultant to a small team of managers from UKCO Information Technology Department (the project team). The team consisted of the head of the Information Technology Department, his deputy and two more junior members of staff. The modelling took place over an intensive four day period. This tight schedule was necessary because the model was to be used, as the basis for a presentation to senior management, during an imminent strategy review event.

### 4.2.1 The Problem

UKCO was about to introduce a major new product range and it was proposed to take this opportunity to introduce a new approach to production logistics. UKCO was already using just in time and the current practice was to schedule production one month in advance. The proposal was to set a production schedule of fixed batches for five months in advance, based on a forecast of demand.

This change was expected to provide major benefits in terms of improved product quality, reduced production costs and improved relationship with suppliers. The main problem with this strategy was the demands it made upon forecasting performance. Any error in forecasting demand would cause costs to be incurred either as the result of holding excess stock or through the loss of sales due to long delivery times. UKCO's forecasting performance was variable; at an aggregate level it was good but at individual product level errors approached plus or minus forty per cent.

There was a 'political' dimension to this proposed change in that the new policy was strongly backed by OSCO, UKCO's collaborator because it mirrored OSCO's own practice. There were two main reasons that OSCO had adopted this approach. Firstly, OSCO manufactured off shore and the long shipping delay implied by this did not permit sudden reaction to changes in demand. Secondly, OSCO had a much smaller product range than UKCO (by a factor of 10) and demand between

different products was therefore much less variable. These two approaches can be categorised by stating that UKCO's was pursuing a marketing strategy that was driven by demand whereas OSCO's marketing was driven by production.

The project team were well aware of these differences between the two companies and had reached the conclusion that the proposed policy might create severe problems for UKCO, a view that was shared by many within the organisation.

The project team had spent a considerable amount of time working on the problem before the author became involved and there was already a good understanding of the main issues within the group. This work had included the use of simulation tools; Witness (Istel Ltd 1986), but the group were dissatisfied with the results.

The reason for this is that discrete modelling packages, such as Witness, are designed to model the detail complexity of systems; they can model individual components moving around a production facility for instance. This kind of model is very good at answering specific, detailed questions about the system, for example; machine utilisation, maximum queue length, cycle times, etc. If the model and data it is based upon are good then this kind of information can be calculated with a high degree of accuracy.

This type of model is much less useful at providing insights at the strategic level; the big picture gets lost in amongst all the complexity. The method of model representation which involves a large number of icons, representing complex "black box" sub-systems is intimidating to those unfamiliar with the modelling package.

The reason for the author's involvement was that the group was looking for an alternative approach to modelling that would allow them to express their insights in a way that would be comprehensible to senior management.

## 4.2.2 Model Development

The first task was to establish the aim of the modelling exercise and the requirements for the model.

### 4.2.2.1 Purpose of the exercise

- To build a high level simulation model of UKCO's supply chain.
- To develop a presentation based on the model.

### 4.2.2.2 Objectives for the model

To establish the impact of the proposed logistics policy and forecasting of varying accuracy in terms of:

- Levels of stock
- Customer delivery times
- Levels of lost sales
- Cost of distressed selling of excess stocks

### 4.2.2.3 Timetable

The time available for the exercise was short therefore it was decided that a maximum of two days should be spent on model development. This allocation of time ensured that an appropriate amount of time could be devoted to experimentation with the model and the preparation of the presentation. The use made of the available four days is shown in Table 4.2. The exercise was completed on time and the project team were very satisfied with what had been achieved in the time available.

**Table 4.2 Breakdown of effort for first modelling exercise**

<b>Activity</b>	<b>Duration</b>
Model building	2 days
What if simulations	1 day
Preparing model for presentation	1 day

### 4.2.3 The Logistics Model

An overview of the model will now be given. The map of the model is shown in Figure 4.2.

#### 4.2.3.1 Structure

The model is in essence a main chain structure; that is a sequence of linked stocks and flows. A forecast of demand volume is used to drive component scheduling (components are ordered as “kits” that contain all of the components to make a particular product). Demand is highly seasonal and so it is necessary to plan to produce stock in advance to cover the time of peak demand, this is modelled by the Production\_Policy converter.

Component kits take 1 month or 5 months to pass through the component schedule delay depending on the scenario being modelled. Manufacturing starts as soon as the components arrive and the finished product accumulates in Finished\_Stock until it is required.

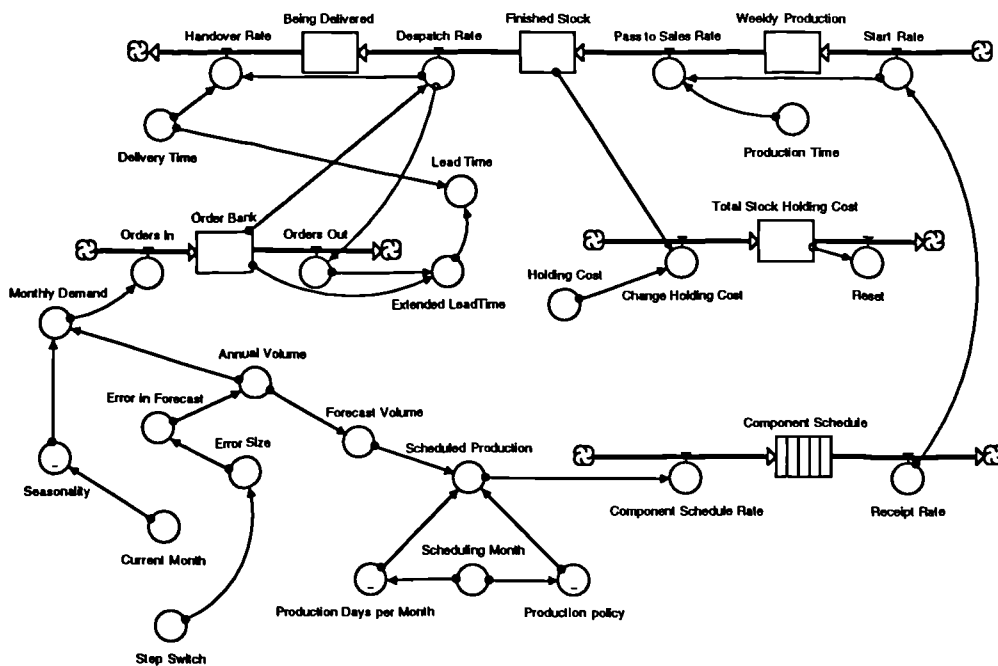


Figure 4.2 First pass logistics chain model

Customers place orders that enter an order bank, if stock is available the order is filled and after a delivery delay, the customer receives their goods.



There is nothing particularly unusual about the model; the structures and equation are all fairly standard. The only complicating factor is the use of a scheduling time that is offset from the current simulation time to drive the component scheduling.

#### **4.2.3.2 Simulation Specifications**

The model used a unit of time of months and the simulation length was twenty-four months (two years).

#### **4.2.3.3 Seasonality**

This was an important issue as far as UKCO was concerned and a number of variables were modelled using graphical functions so that seasonal factors could be taken into account. These are listed below:

- (Demand\_)Seasonality
- Production\_Days\_per\_Month
- Production\_Policy

The UK and European markets have significantly different patterns of seasonality. Two versions of the model, incorporating different demand seasonality profiles were developed to model these markets.

The introduction of seasonality makes it more difficult to see the detrimental effects that an error in forecast has on the system. If constant demand and production patterns had been used, these effects would be more clearly seen, but it was felt that for the sake of credibility that seasonality must be modelled.

#### **4.2.3.4 Test Input**

- Error\_Size

The model is started in equilibrium with actual demand and forecast demand being equal. The system is then shocked by introducing a step into demand in

month sixteen. The adjustment of sales forecast in response to this change in demand was modelled using a smoothing function.

This timing of the shock to week sixteen was chosen for two reasons, firstly it allows a comparison to be made with a steady state year (the first half of the simulation) and secondly it provides sufficient time for the consequences of the step to become apparent.

#### **4.2.3.5 Performance Measures**

The following performance measures were created:

- Total\_Stock\_Holding Cost
- Lead\_Time
- Finished\_Stock

If these score keeping variables are compared with the list of objectives for the model it can be seen that “Lost Sales” and “Cost of Distressed Selling” are missing. During the course of the model development it was decided that these performance measures were more difficult to quantify than the three listed above and did not warrant the effort necessary to include them in the model.

#### **4.2.3.6 Model Output**

To protect commercial confidentiality, no model output will be presented, but the insights gained from experimentation with the model will be summarised in the next section.

### **4.2.4 Insights from Modelling Exercise 1**

Experimentation with the model clearly showed that the consequences of introducing a five month production commitment was likely to be both very long delivery times for models that were unexpectedly popular and large amounts of distressed selling for models that did not achieve their expected popularity. The

effect of the three month production commitment was less extreme, but the implications in terms of costs and customer satisfaction were still considered to be unacceptable. The model showed that for longer production commitments to be feasible, then forecast accuracy needed to be improved.

#### 4.2.5 The First Presentation

The presentation was made by the head of the project team and it think was used interactively throughout. In total, seven different versions of the model were used during the presentation, see Table 4.3.

**Table 4.3 The models used in the first presentation**

No	Market	Model Volume	Committed Production	Test Input	Output
1	UK	High	5 Months	Steady State	Demand Stock Production Order Backlog
2	UK	High	5 Months	Forecast Error -25%, 0, 25%	Stock Holding Cost Lead Time
3	UK	High	1 Month	Forecast Error -25%, 0, 25%	Stock Holding Cost Lead Time
4	Europe	High	5 Months	Forecast Error -25%, 0, 25%	Stock Holding Cost Lead Time
5	UK	Low	5 Months	Steady State	Demand Stock Production Order Backlog
6	UK	Low	5 Months	Forecast Error -25%	Stock Holding Cost Lead Time
7	UK	Low	1 Month	Forecast Error -25%	Stock Holding Cost Lead Time

It was decided to use a different version of the model for each parameter and policy run. This eliminated the need to manually change model variables and

therefore produced a shorter, smoother presentation and eliminated the possibility of human error. This second point was particularly important because the presenter had only limited “hands on” experience with itthink.

#### **4.2.5.1 Model 1**

This model was used to introduce the basic structure of the model to the audience. A steady state simulation run was made to show the software in action and to establish a base run case.

#### **4.2.5.2 Models 2 & 3**

These models compare the effect of forecast error on a high volume product being sold in the UK market for production commitments of one and five months. These simulation runs establish the adverse effects of the longer production commitment (overstocking and stock-outs).

#### **4.2.5.3 Model 4**

This model is the same as model two except that it uses European seasonal patterns. This demonstrates that the problematic behaviour occurs in both markets.

#### **4.2.5.4 Model 5**

This model was used to introduce the low volume product model to the audience. A steady state simulation run was made to show the effect of batches and the need to build up stock in advance of peak demand.

#### **4.2.5.5 Models 6 & 7**

These models compare the effect of forecast error on a low volume product being sold in the UK market for production commitments of one and five months. This establishes the adverse effects of the longer production commitment (overstocking and stock-outs).

#### **4.2.5.6 Other “Models”**

In order to allow all of the presentation to be made from within a single application, a number of other “models” were used. These “models” used the text and graphing capability of itthink to present summary points and supporting information. This novel use of itthink as a stand-in for a presentation package worked well although a dedicated presentation package would of course have offered many additional facilities.

#### **4.2.6 Outcome of the First Presentation**

The presentation was very successful on two counts, firstly the views of the project team were endorsed by the senior managers and secondly the modelling approach itself created much interest and favourable comment. It was decided that the model should be further developed and used at a joint meeting between the senior managers of UKCO and OSCO to present UKCO’s case for opposing the proposed changes in production scheduling policy.

### **4.3 Second Modelling Exercise**

This work took place four months after the first modelling exercise. In the intervening period, the project team spent time experimenting with the model. In addition, a number of minor changes were made to the model during this period.

#### **4.3.1 Model Development**

The result of the time spent using the model was that the project team now had a much clearer idea of the changes that they would like to see in the model. The proposed changes were all enhancements of the basic model; there was no wish to change the basic model structure.

##### **4.3.1.1 Features for the Enhanced Model**

- Sectors
- Improve the model’s ease of use by making more parameters available as converters and creating policy switches

- Incorporate European and UK seasonal effect in one model
- Model batches for all product volumes

### 4.3.1.2 New Model Development

- Semi-generic model without seasonal effects

In addition to these extensions to the existing model it was felt that it would be useful to have a semi-generic model of the supply chain available, that could be used to demonstrate the basic dynamics of the system.

### 4.3.1.3 Timetable

Four days were made available for this work. The way in which this time was used was very similar to the first modelling exercise (see Table 4.2) but the general pace of work was considerably less hectic.

## 4.3.2 The Logistics Model

An overview of the changes made to the model will now be given. The map of the model is shown in Figures 4.3a - 4.3c.

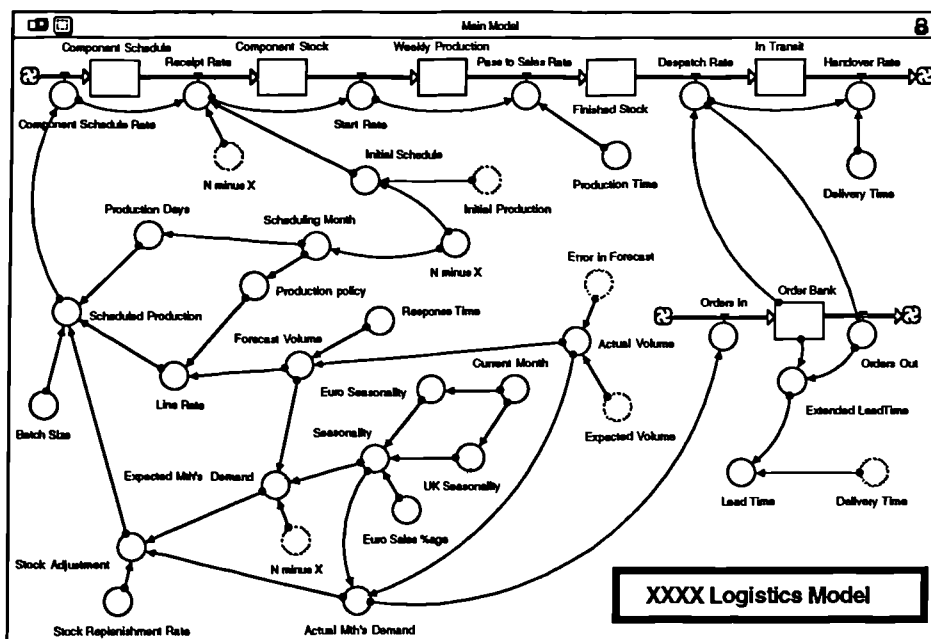


Figure 4.3a Final logistics chain model: main model

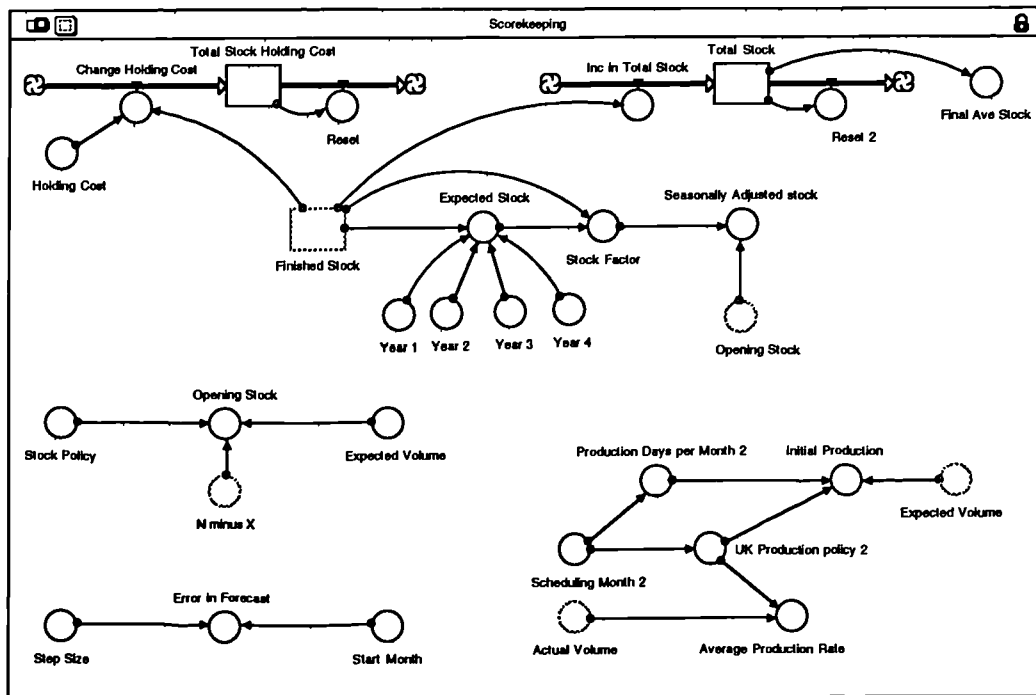


Figure 4.3b Final logistics chain model: score keeping

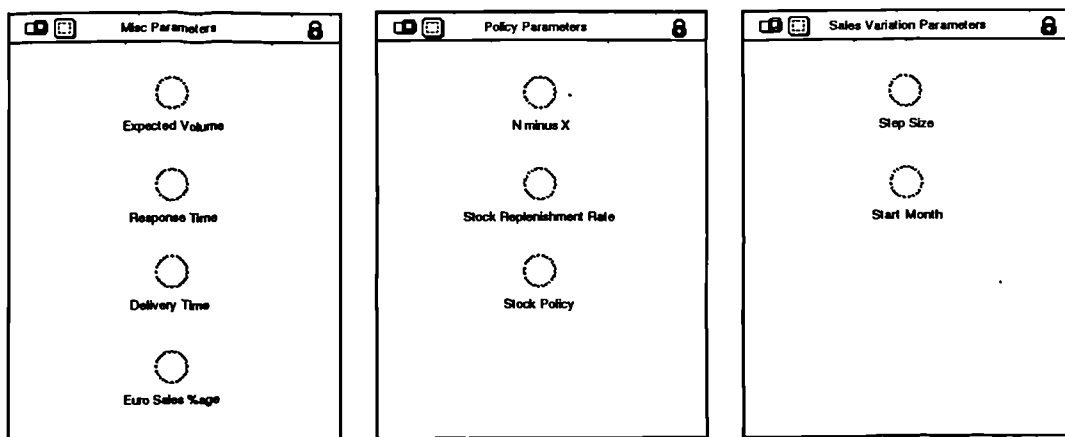


Figure 4.3c Final logistics chain model: control panels

### 4.3.2.1 Structure

The only change made to the basic model structure was to extend the logistics main chain backwards so that it included the component schedule pipeline. The direction of flow of the main chain in the diagram was switched from “right to left” to “left to right” for aesthetic reasons.

### 4.3.2.2 Sectors

The most noticeable difference between the first pass model and the second model is the use of sectors. Five sectors were created; these are listed in Table 4.4. The main model is the only sector that the target audience see; the other sectors were developed for the convenience of the project team.

**Table 4.4 List of model sectors**

<b>Sector Name</b>	<b>Type</b>
Main Model	Model
Score keeping	Score keeping
Sales Variation Parameters	Control Panel
Policy Parameters	Control Panel
Misc. Parameters	Control Panel

### 4.3.2.3 Control Panels

To improve the model's ease of use, a number of control panels were built, that allowed operating policies and parameters to be changed. The ability to alter the length of the production commitment by changing a single parameter ( $N_{\text{minus}}X$ )<sup>1</sup> proved to be particularly useful. In the previous version of the model it was necessary to make a number of changes in different parts of the model to achieve the same result.

A number of parameters that had been hidden in equations, for example *Response\_Time*, were made explicit on the diagram and hence available to the user in the control panels.

### 4.3.2.4 Combining European and UK Seasonal Effects

The model incorporates the seasonal effects from both the UK and European versions of the previous model. A converter *Euro\_Sales\_%age* allows the model to be run in three modes; UK only, European Only, UK and European mixed.

<sup>1</sup> "N minus X" was the way that UKCO expressed production commitment; the "N" standing for now and the "X" representing the length of the production commitment. For example, using this notation, the one month and five month production commitments are written as "N-1" and "N-5" respectively.



### 4.3.2.5 Modelling Batches

This was modelled in a simplified manner; desired production being rounded to an integer number of batches.

### 4.3.2.6 Model Output

To protect commercial confidentiality, no model output will be presented, but the insights gained from experimentation with the model will be summarised in the next section.

### 4.3.3 Insights from Modelling Exercise 2

The experimentation with the second model confirmed the finding of the first model. The introduction of fixed batch sizes for large and medium volume product had little effect.

### 4.3.4 The Semi-Generic Logistics Models

In the process of designing the first presentation, it had become apparent that the inclusion of seasonal effects tended to make it more difficult to appreciate the fundamental dynamic behaviour of the logistics supply chain.

The requirement was for a way of demonstrating the typical behaviour of supply chains; stock-outs and over-stocking and their causes; delays in the flow of information and material. The delays that occur in managing this particular supply chain are shown in Figure 4.4, this diagram is a specific case of the generic diagram of delays in the management process, that was presented in Chapter 1.

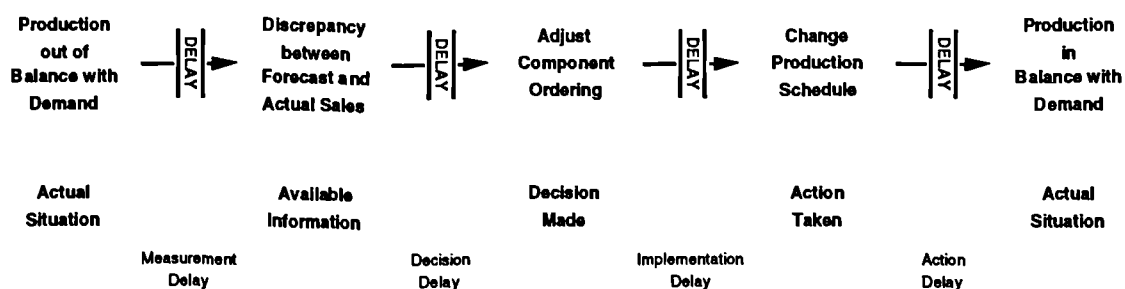


Figure 4.4 Delays in managing the logistics supply chain

If an error in forecasting occurs, then it will eventually become apparent that there is a discrepancy between forecast demand and actual demand. In response to this the management will want to adjust the production schedule, but this cannot be done directly because of the component scheduling commitments that have already been made. Therefore management adjusts the current component ordering rate and after a delay equal to the production commitment (1 month or 5 months) production will be adjusted to match actual demand.

To demonstrate this type of behaviour it was decided to build a semi-generic model of the logistics supply chain. Two versions of the semi-generic model were developed. The first model shows the delay in reacting to a forecast error and the effect this has on stock levels. The second model was more sophisticated in that it modelled the adjustment of stockholding to take into account the new level of demand.

#### 4.3.5 Semi-Generic Logistics Model A (without stock recovery)

An overview of the model will now be given. The map of the model is shown in Figure 4.5.

##### 4.3.5.1 Structure

This model used a simplified version of the main chain structure found in the full logistics model. It consisted of three elements; a component schedule delay, a production delay and inventory of finished stock.

The model contained three versions of this main chain, with production commitments of one month (N-1), five months (N-5) and zero months (N-0). This allowed the effect of using different lengths of production schedule commitment to be compared. The zero month production schedule was included so that the effect of eliminating the pipeline delay could be demonstrated.

The adjustment of sales forecast in response to changes in demand was modelled using a smoothing function.

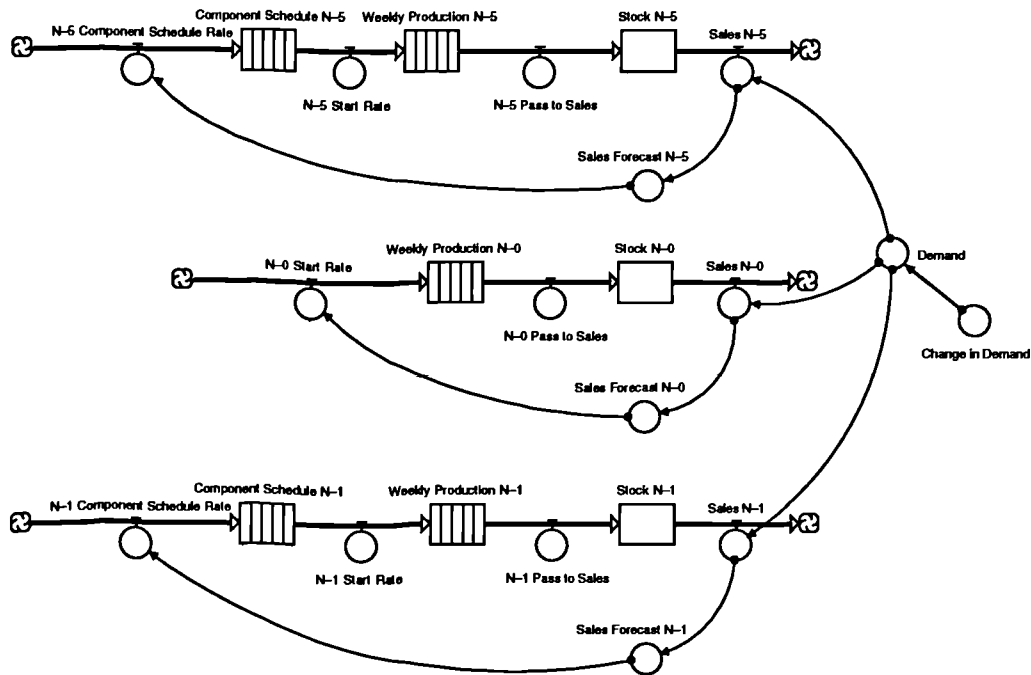


Figure 4.5 The semi-generic logistics model A

#### 4.3.5.2 Test Input

- Error\_Size

The model is started in equilibrium with a constant demand; the system is then shocked by introducing a step change into demand. Two steps sizes were use;

- A 40% increase in demand
- A 40% decrease in demand

#### 4.3.5.3 Model Output

The output of this model is completely generic and so it can be presented here. The effect of running the model with a 40% step increase in demand is shown in Figures 4.6a - 4.6b and the effect of a 40% step decrease in demand is shown in Figures 4.6c - 4.6d.

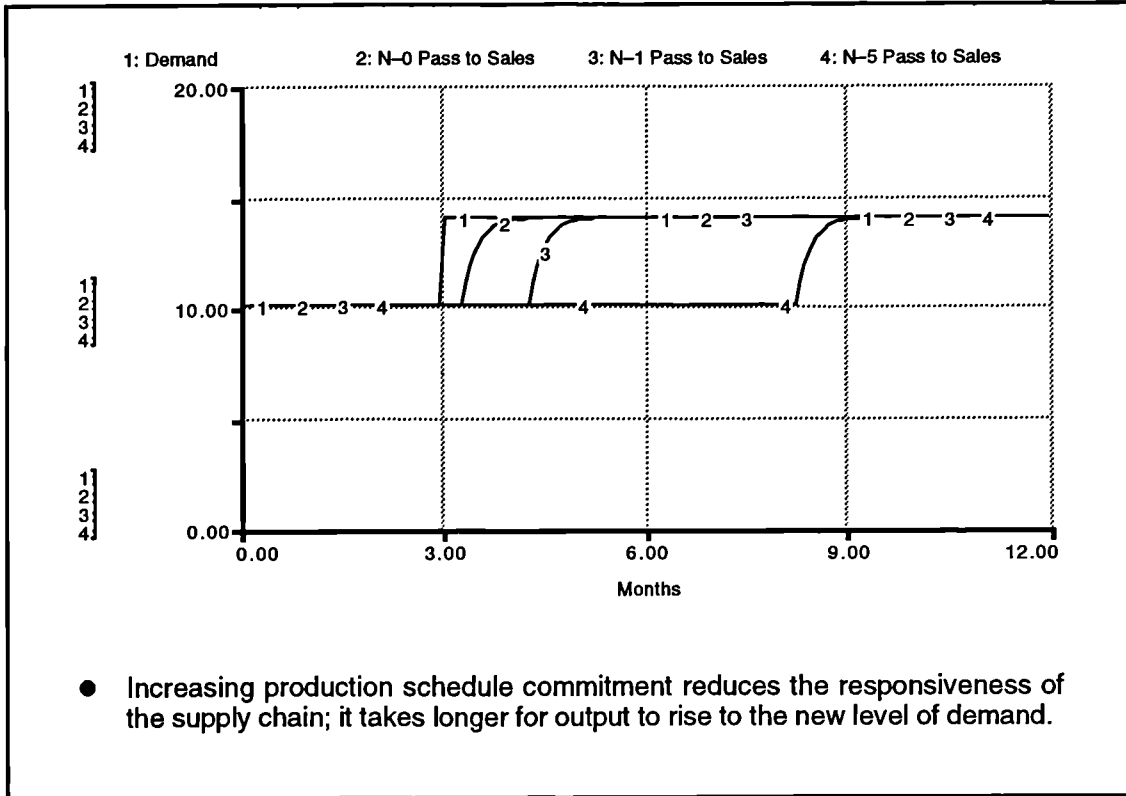


Figure 4.6a The response to a 40% increase in demand

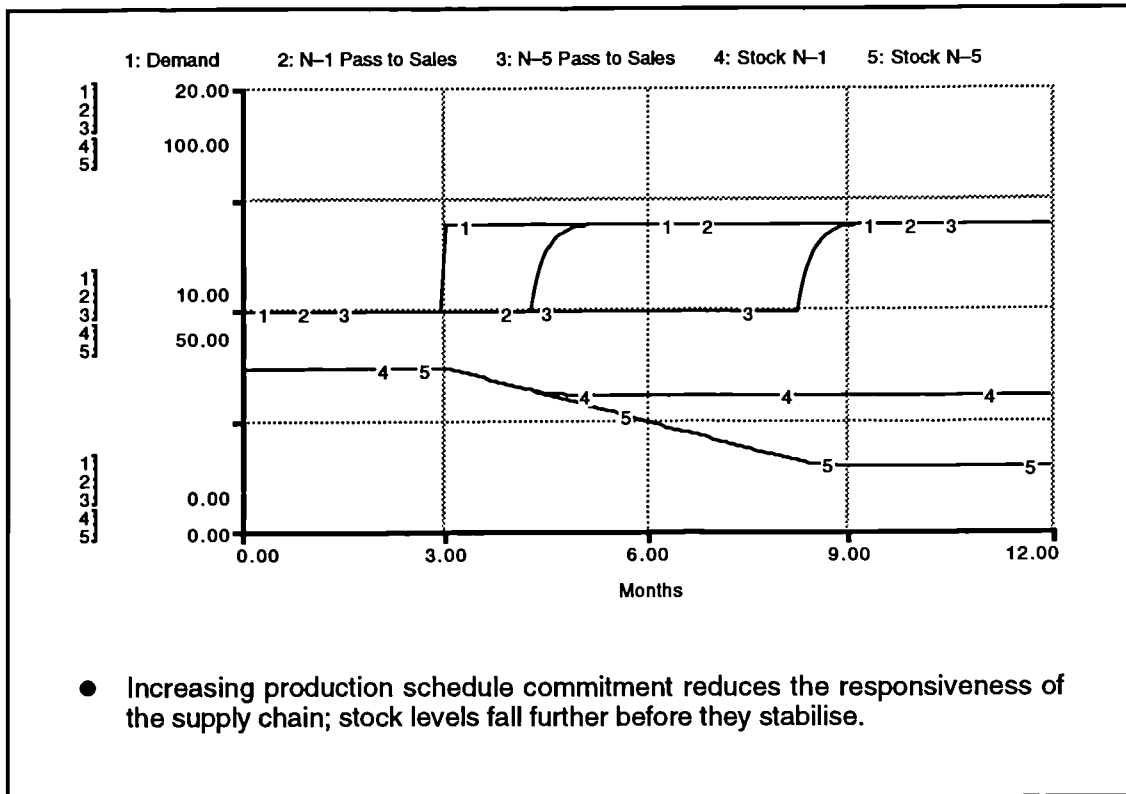


Figure 4.6b The effect of a 40% increase in demand

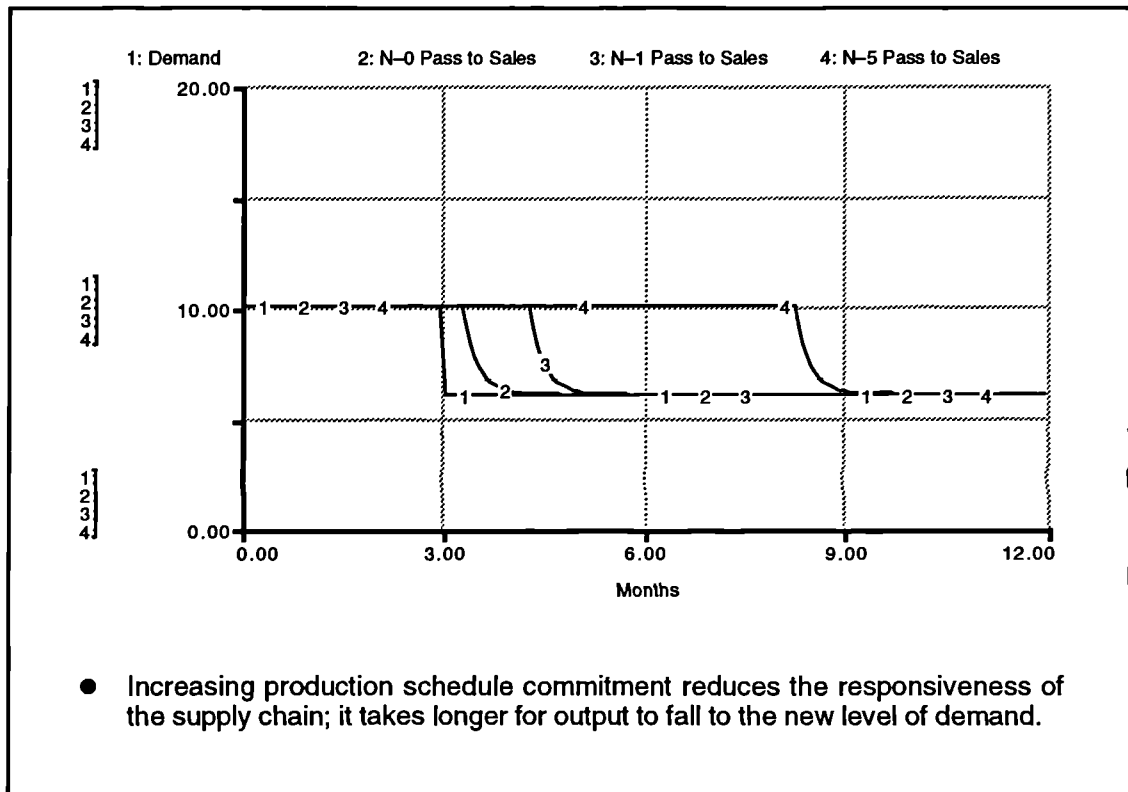


Figure 4.6c The response to a 40% downturn in demand

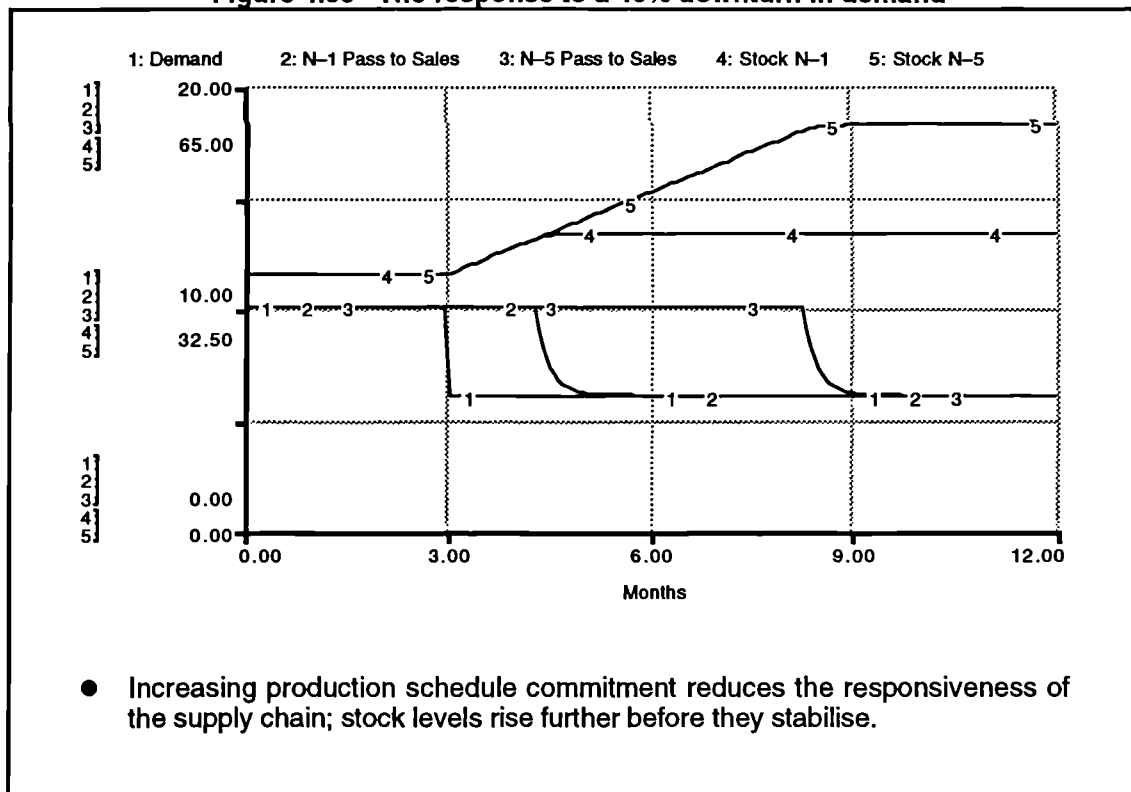


Figure 4.6d The effect of a 40% downturn in demand

### 4.3.6 Semi-Generic Logistics Model B (with stock recovery)

An overview of the model will now be given, the model map is given in Figure 4.7.

#### 4.3.6.1 Structure

This model has the same basic main chain structure as the previous model, see Figure 4.6. The only difference between the two models is that the second semi-generic model incorporates a stock control policy which aims to maintain stock at some target level. This target level is defined as a number of weeks worth of cover of forecast sales. In addition to setting a target for stock, the policy also takes into account current forecast of sales and the material already in the supply chain. This gives the following four part the ordering policy:

$$\text{Sales\_Forecast} + \text{Stock\_Correction} + \text{Component\_Schedule\_Correction} + \text{In\_Production\_Correction}$$

The adjustment of sales forecast in response to changes in demand was modelled using a smoothing function.

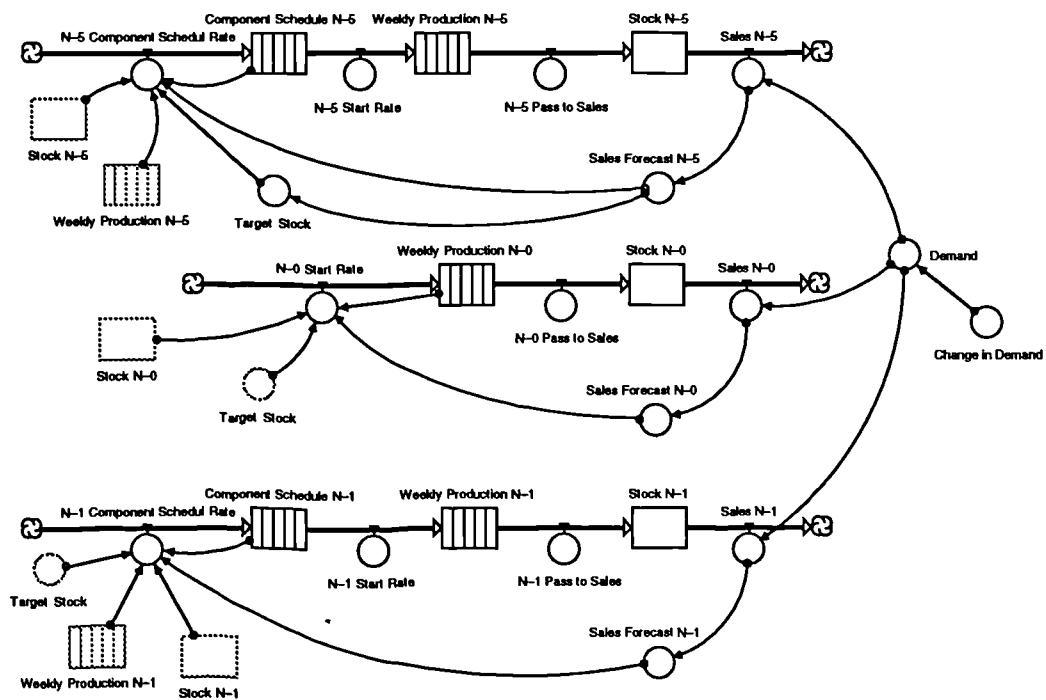


Figure 4.7 The semi-generic logistics model B

### 4.3.6.2 Test Inputs

The same test inputs were used as in both versions of the semi-generic model; a 40% step increase in demand and a 40% step decrease in demand.

### 4.3.6.3 Model Output

The output of this model is completely generic and so it can be presented here. The effect of running the model with a 40% step increase in demand is shown in Figures 4.8a - 4.8b and the effect of a 40% step decrease in demand is shown in Figures 4.8c - 4.8d.

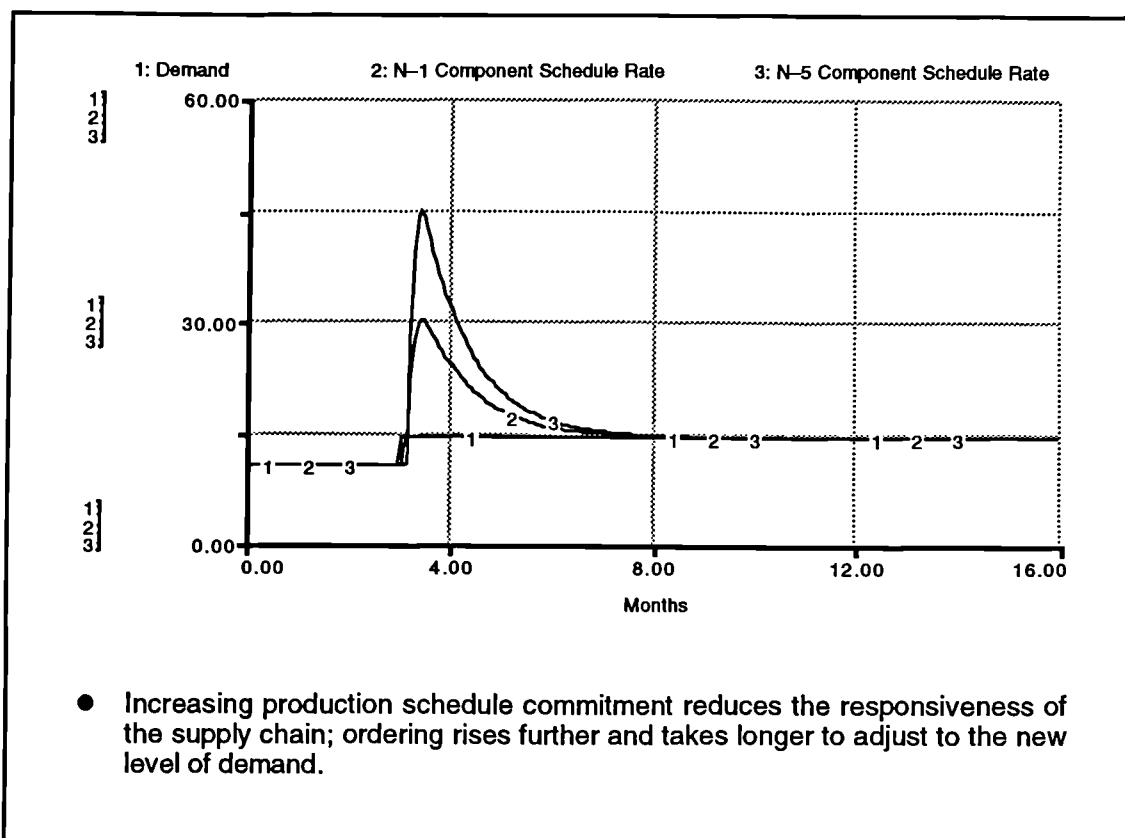


Figure 4.8a The response to a 40% increase in demand

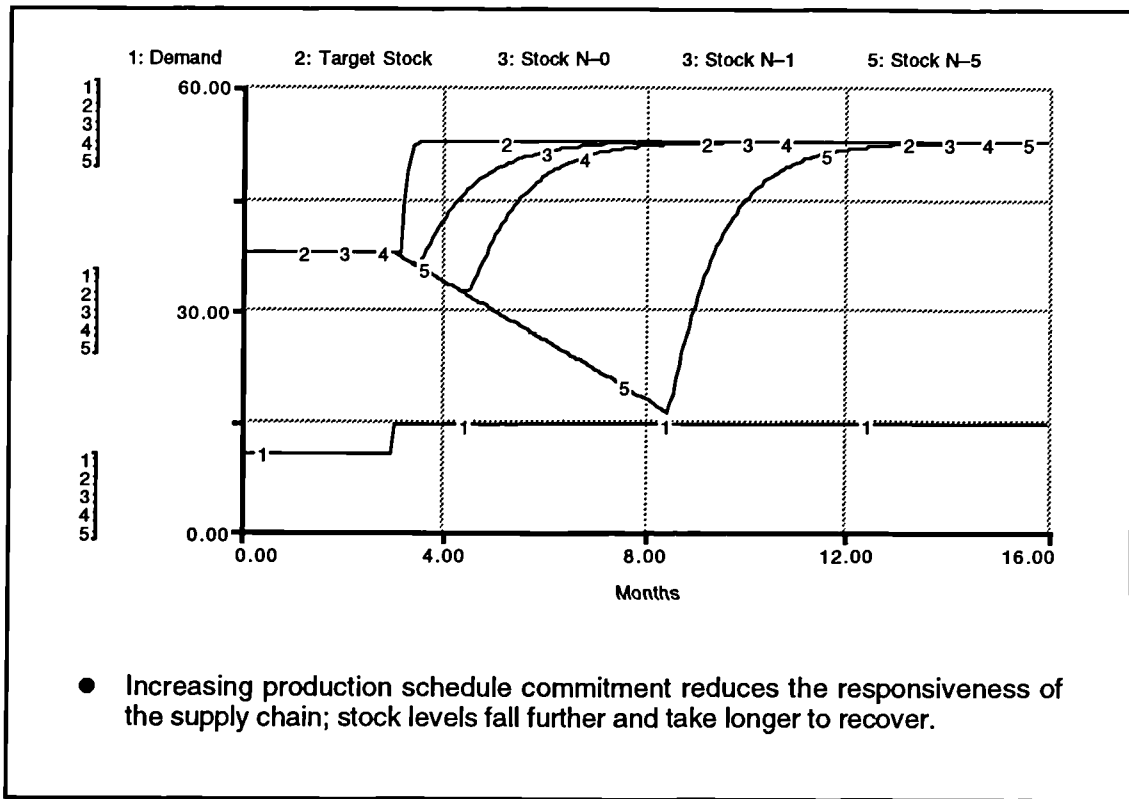


Figure 4.8b The effect of a 40% increase in demand

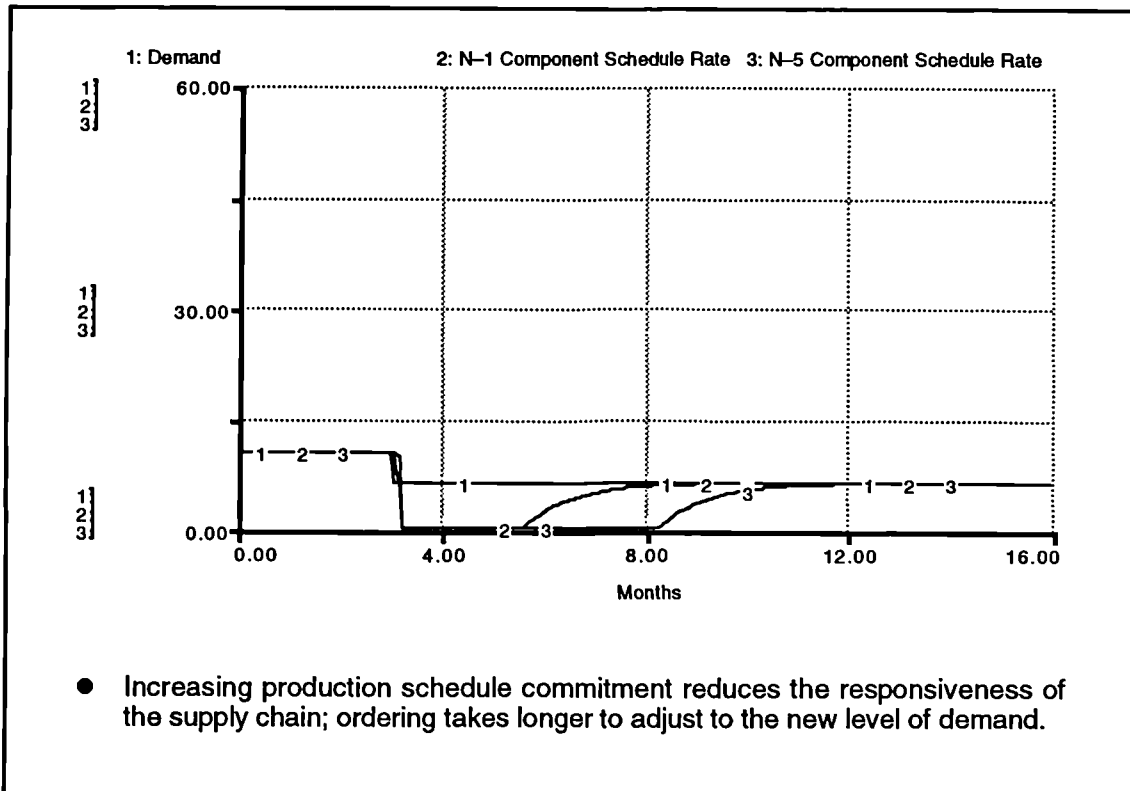


Figure 4.8c The response to a 40% decrease in demand



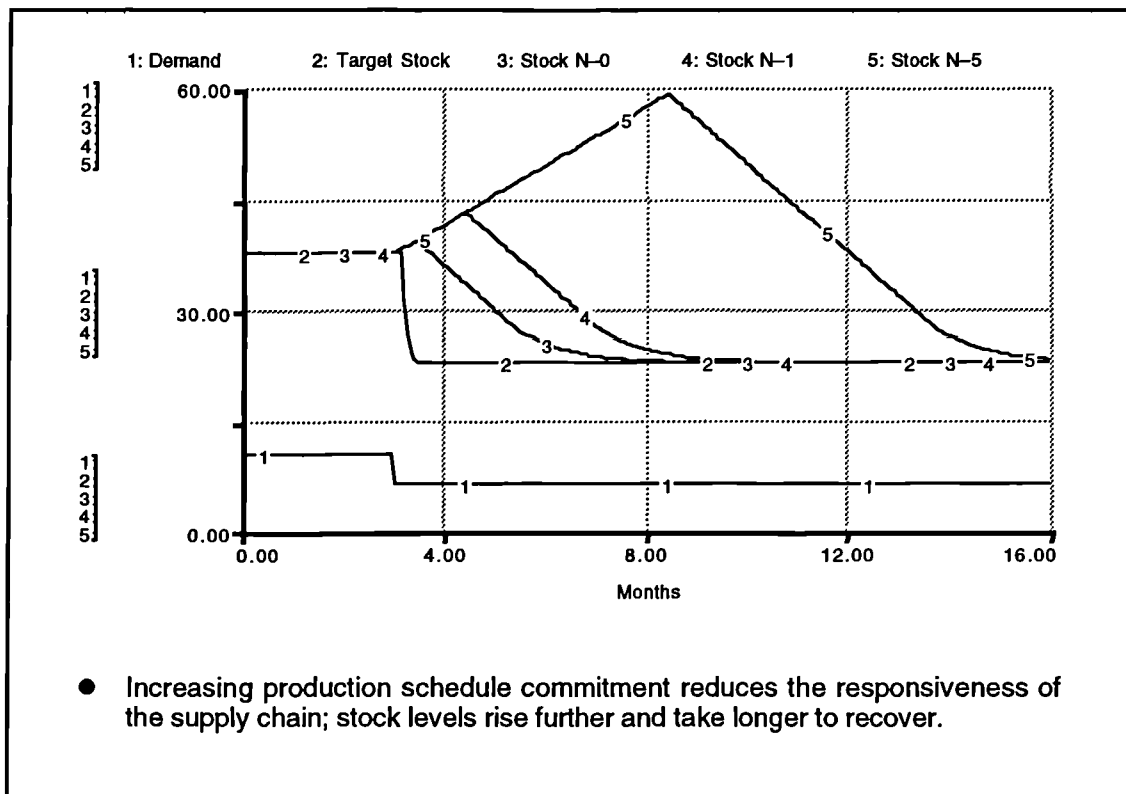


Figure 4.8d The effect of a 40% downturn in demand

### 4.3.7 The Second Presentation

This presentation was made by the head of the project team to an audience made up of senior managers from UKCO and OSCO.

The format of the presentation was not changed significantly from the previous one, but the emphasis was different. The first presentation had two aims, firstly to transfer the project team’s insights and secondly to establish the credibility of the modelling approach. To this end, the models used in the first presentation were chosen to show that widest range of scenarios that could be modelled.

The second presentation was focused on the policy issue itself and therefore the models were chosen so that a smaller number of scenarios were explored in greater detail. In total eight different versions of the model were used, see Table 4.5.

Table 4.5 The models used in the second presentation

No	Market	Model Volume	Committed Production	Test Input	Output
1	UK	High	5 Months	Steady State	Demand Stock Production Holding Cost
2	UK	High	5 Months	Forecast Error +40%	Demand Stock Lead Time
3	Semi-Generic Model (without recovery of stock position)		0 Months 1 Months 5 Months	Forecast Error -40% +40%	Demand Production Stock
4	Semi-Generic Model (with recovery of stock position)		0 Months 1 Months 5 Months	Forecast Error -40% +40%	Demand Production Stock Target Stock
5	UK	High	0 Months 1 Months 5 Months	Forecast Error -40% +40%	Stock Lead Time Holding Cost
6	UK	High	1 Months	Batch Size 2/5/15	Stock
7	UK	Low	1 Months	Batch Schedule preferred/required	Production Demand Stock Holding Cost
8	UK/Euro	-	1 Month	Volume low/high	Stock Production Demand

#### 4.3.7.1 Model 1

This was used to introduce the basic structure of the model to the audience. A steady state simulation run was made to show the software in action and to establish a base run case.

#### 4.3.7.2 Model 2

This model showed the effect of forecast error on a high volume product being sold in the UK market for production commitments of five months.

#### 4.3.7.3 Models 3 & 4

These models were used to show the generic nature of the systems behaviour and to demonstrate the causes of that behaviour. In particular, they emphasise the detrimental effect of longer production schedule commitments.

#### **4.3.7.4 Model 5**

This model moves the argument from the generic to the specific. The same set of sensitivity runs used with the semi-generic models are simulated using the full model.

#### **4.3.7.5 Model 6**

The effect of batch size on the level of finished stock for a high volume product is investigated by this model. The output shows that batch size has little effect on stock levels for high volume products.

#### **4.3.7.6 Model 7**

This model looks at the effect of batch scheduling on low volume products. The model contains two different production patterns. The first is what the company would like to do (the preferred schedule), where all of the low volume batches are made just before peak demand. The second is what the company has to do (the required production schedule), where because of capacity constraints on production, many of the batches have to be made in advance. The model generates comparative graphs of stock holding and stock holding costs for the two production schedules, which clearly show the extra costs incurred by the required production schedule.

#### **4.3.7.7 Model 8**

This model was set up to show the effect of UKCO's preferred option.

#### **4.3.7.8 Presentation Summary**

The presentation ended with the following summary points:

- A one month production schedule commitment is essential to prevent excessive levels of finished stock.
- Most high volume product lines can be built with batch sizes of fifteen or more.

- Smaller batches are required for low volume product lines to avoid excessive stock holding.

#### 4.3.8 Outcome of the Second Presentation

The outcome was a success on two counts. Firstly OSCO accepted UKCO's point of view on the issue of production schedule commitment. Secondly, OSCO were very impressed by the work carried out by the project team and they were satisfied that UKCO had a through understanding of the issues involved in managing the supply chain. Consequently, OSCO stated that they would not make any further attempt to influence UKCO's logistics policy.

### 4.4 Disseminating the Insights of the Modelling Exercise

This section describes the traditional approach to disseminating the results of a modelling exercise. The limitations of this approach are discussed and the use of microworlds as a method of knowledge dissemination is described.

#### 4.4.1 The Traditional Approach

If this case study had been written before the advent of systems thinking then there would not be much more to say, because the point has already been reached where a traditional (consultant centred) system dynamics modelling project would stop. A satisfactory outcome has after all been achieved and the desirability of disseminating the insights of a modelling project, to promote organisational learning, was not generally appreciated at this time.

It would be wrong to imply that no attempt would have been made to make the results of the modelling project known, to a wider group of managers within the company. But both the choice of information to impart and the means chosen to achieve this, would be very different from current practise. The emphasis would have been on presenting the results and recommendations of the modelling exercise, some model output would undoubtedly be included, but there would have been little if any discussion about the details of the model itself.

#### 4.4.2 Difficulties in Implementing the Results of Modelling Projects

The traditional approach to implementation, will only work if the recommendations of the modelling project are not too radically different from current management practise. If this is not the case, then there will be difficulties in implementation, particularly if the recommendations contradict managers' strongly held beliefs as to the nature of the problem facing the organisation.

A case study from the insurance industry, illustrates this problem (Senge and Sterman 1990). A modelling project had been set up to investigate the company's claim handling process. A small group of managers were closely involved in the development of the model and as a result they gained a number of important insights into how the company could improve its claims handling operation.

They (the managers) could articulate the policy implications of the model with clarity and conviction

[But]...the results of the model were virtually unimplementable

This was because the policy changes suggested by the model were both counterintuitive and contradicted long held company beliefs:

"The model suggested the need for investment in [loss] adjuster capacity at a time when the firm and the entire industry, is under intense pressure to cut costs"

"...the model implied that the responsibility for the insurance crisis rested in part with established management practices, when most within the firm regarded the problem as externally caused"

"...the model suggested that established policies had produced declining quality and increasing claim size"

Another barrier to implementation was that it required the co-operation of a large number of managers, who made decisions at a local level, this was only likely to be forthcoming if they could be convinced of the effectiveness of the proposed changes.

This problem is not unique to implementing the results of a modelling exercise. Many attempts at organisational change fail because of a lack of support and co-operation from the people within the organisation (Carnall 1990).

This problem with implementation and the recognition of the importance of organisational learning has resulted in a considerable amount of research being carried out into identifying methods for disseminating the insights of modelling exercises.

A consensus has emerged that the best way to disseminating the insights of a modelling exercise throughout an organisation is by means of a particular kind of workshop, known as a learning laboratory. (Morecroft 1988; 1992, Kim 1989; 1990, Senge and Sterman 1990, Bakken, Gould and Kim 1992, Senge et al 1994)

#### 4.4.3 Learning Laboratories

The purpose of a learning laboratory is to provide a framework for promoting organisational learning by disseminating the insights of a modelling exercise. It aims to recreate, for a wider audience, the learning experience of the participants in the original modelling exercise

Learning laboratories are also known as "Learning Environments" (Moorcroft 1992) and "Computer-Based Learning Environments" (Isaacs and Senge 1992).

#### 4.4.4 Microworlds

A microworld is a simulation model to which a user interface has been added to permit interactive experimentation with that model. Microworlds are also sometimes called "Management Flight Simulators" (Sterman 1988b).

In a microworld, the way in which the user can interact with the model is controlled by the interface designer; the user will usually be allowed to change a limited number of model parameters and will be provided with selected model output. The underlying model may or may not be visible to the user.

The sophistication of the interface can vary widely; the early microworlds used a simple text based interface (Pugh, Hunter and Stephens 1985). The latest multimedia based microworlds that have been developed (Langley and Larsen 1993), include the use of text, conventional computer graphics, photographic images, video clips, audio sequences and animation. The vast majority of microworlds have interfaces that fall somewhere in between these two extremes. A typical example of a microworld is the Peoples Express microworld (Serman 1988b), this was implemented using the MicroWorld Creator software (Diehl 1992).

#### 4.4.5 Issues in Designing Learning Laboratories and Microworlds

It may appear at first sight that all a learning laboratory need consist of, are hands-on sessions with a microworld based on the model developed during the modelling exercise. This is not in fact the case. It has been known for a long time, that it is very difficult to learn about a system by gaming with it (Forester 1961). There are two main reasons for this; firstly the nature of the model means that it is difficult to learn from outcome feedback (Andersen et al 1990, Bakken 1989, Serman 1988a) and secondly people in a gaming situation do not behave in a way that is conducive to learning.

Feedback model are capable of generating complex behaviour; there are likely to be appreciable delays in both space and time between action being taken and the effect of that action becoming apparent, this makes it very difficult for learning to occur (Bakken 1992).

If a user is to learn anything from the use a microworld, then they must experiment with it in a reflective and methodical manner. The evidence suggests that if participants are left to their own devices this will not be the case. They will certainly be stimulated by the microworld, it will be played with enthusiasm, but this is because the participants are trying to beat the computer at all costs, not because of the insights they are gaining. In an early test of a microworld it was observed that;

They (the managers) were, literally, on the edges of their seats...But afterwards none could articulate a significant new insight

(Senge and Sterman 1990)

This is the so called "video game syndrome" (Morecroft 1992, Peterson 1990a; 1990b, Senge and Sterman 1990). Other symptoms of this syndrome are;

- No effort is made to develop and test out theories about the causes of problematic behaviour exhibited by the system.
- A lack of method in experimenting with the microworld, there is a marked tendency for users to simultaneously change multiple factors.
- The quitting of games that are going badly, users were not prepared to see a strategy through to the end if it looked like they were going to "lose".
- The lack of any attempt to relate experiences with microworld to the real world system.
- Not taking advantage of the freedom to try out new strategies in a risk free environment, participants behave the same way as they do in real life.

If we relate this behaviour back to the theory of experiential learning (Argyris and Schön 1978, Kolb 1984), which was described in Chapter One, then we can see why little learning occurs; the participants are stuck at the "having an experience" stage, they never close the learning loop. The challenge is to design a learning laboratory that will promote learning by taking participant through all stages of the learning cycle. This goal also provides a way of distinguishing a microworld from a learning laboratory.

A microworld is a way of enhancing the user friendliness of a model so that it could be used for interactive experimentation. In this view, microworlds are seen to be just one of the many elements that go to make up a learning laboratory, albeit an important one. The clear cut distinction between a microworld and a learning



laboratory is blurred because some microworlds take on tasks that would normally be considered part of the learning laboratory, to become in effect computerised learning laboratories. These systems use multimedia to; introduce the background to the model and describe the model loop structure; guide user experimentation and provide explanations of system behaviour (Peterson 1990a; 1990b).

#### 4.4.6 Structures for Learning Laboratories

A number of structures have been proposed for learning laboratories; these are summarised in Table 4.6.

**Table 4.6 Structures for learning laboratories**

<b>Bakken et al (1992)</b>	<b>Morecroft (1992)</b>	<b>Kim (1990)</b>
Context setting	Pre-game briefing that recreates the original model conceptualisation process	The first crucial hour <ul style="list-style-type: none"> <li>• Buy-in</li> </ul>
Conceptualising the issues	Develop scenarios	Current reality <ul style="list-style-type: none"> <li>• Where are we?</li> </ul>
Experimentation & reflection <ul style="list-style-type: none"> <li>• “Flying the flight simulator”</li> </ul>	Informed experimentation	Introducing the tools <ul style="list-style-type: none"> <li>• Causal loop diagrams</li> </ul>
	Post game debrief	Using the tools <ul style="list-style-type: none"> <li>• Conceptualising</li> </ul>
		Introducing the game model
		Planned scenarios <ul style="list-style-type: none"> <li>• Holding the reins</li> </ul>
		Free plays <ul style="list-style-type: none"> <li>• Cutting the reins</li> </ul>
<b>Peterson (1990)</b>	<b>Senge (1989)</b>	<b>Senge and Sterman (1990)</b>
Preparing for play <ul style="list-style-type: none"> <li>• Visit the cast</li> <li>• Mission statement</li> <li>• Simulation set-up</li> </ul>	Importance of conceptualisation	Focus on conceptualisation
Playing	Designing in reflection	Design opportunities for reflection
Understanding why	Beware the computer	Beware the computer

The structures proposed for learning laboratories contain many similarities and it was decided to adopt the same general approach in designing a structure for the learning laboratory used in this study. In addition to these structures a number of guidelines have also been proposed. (Peterson 1990a; 1990b, Kemeny and Kreutzer 1992, Andersen et al 1990) that need to be considered. Many of these are concerned with microworlds and concentrate on issues such as interface design, but three general points emerge:

### **Group Size**

Participants should not work singly. Group working stimulates debate and so promotes learning. The groups should be small, a maximum of three, with two being the ideal number (Kim 1989).

### **Principle of Parsimony**

The number of performance indicator variables and policy levers that are provided to participants by the microworld should be small (six or less of each). The provision of more performance measures will cause information overload and the addition of extra policy levers will make reflective experimentation less likely (Peterson 1990a; 1990b).

### **Putting a Stake in the Ground**

In order to promote reflective experimentation, participants are required to follow a three stage procedure when using the microworld (Peterson 1990a; 1990b, Senge 1989). For each scenario that they wish to test out, participants must:

- 1 Predict the outcome of the scenario, by sketching a graph of the behaviour of key model variables.
- 2 Perform the simulation experiment.
- 3 Compare predicted behaviour to the simulated behaviour and account for any discrepancy, in systemic terms.

### 4.4.7 Learning Laboratory Content

It is impossible to set a structure that can be used in all circumstances, the exact content of a learning laboratory will depend on many factors; the time available, the background of the participants, the nature of the microworld, etc. Table 4.7 provides a check list of activities that should be considered for inclusion.

**Table 4.7 Elements of learning laboratories**

<p><b>Introduction to the workshop</b></p> <ul style="list-style-type: none"> <li>• Provide an overview of the workshop and state it's aims</li> </ul>
<p><b>Introduction to the modelling project</b></p> <ul style="list-style-type: none"> <li>• Introduce the background of the original modelling project</li> </ul>
<p><b>Introduction to systems thinking</b></p> <ul style="list-style-type: none"> <li>• Basic concepts of systems thinking</li> <li>• Methods of model representation               <ul style="list-style-type: none"> <li>◆ Causal maps</li> <li>◆ Archetypes</li> <li>◆ <i>ithink maps</i></li> </ul> </li> <li>• Hands on experience of itthink</li> </ul>
<p><b>Model Conceptualisation</b></p> <ul style="list-style-type: none"> <li>• Recreate the model conceptualisation process</li> <li>• Explain the basic loop structure of the model</li> <li>• Scenario generation</li> </ul>
<p><b>Introduction to the model/microworld</b></p> <ul style="list-style-type: none"> <li>• Explain how user will interact with the microworld</li> </ul>
<p><b>Using the model/microworld</b></p> <ul style="list-style-type: none"> <li>• Guided experimentation               <ul style="list-style-type: none"> <li>◆ Predict</li> <li>◆ Simulate</li> <li>◆ Explain</li> </ul> </li> <li>• Free experimentation</li> </ul>
<p><b>Debrief</b></p> <ul style="list-style-type: none"> <li>• What learned about system</li> <li>• Identify other areas of applications</li> <li>• How useful was the workshop</li> </ul>

This checklist was used in the design of the for the learning laboratory that was developed for used in this study.

#### **4.5 The Logistics Workshop**

The successful outcome of the two modelling exercises created a great deal of interest within UKCO about the models themselves and the modelling methodology that had been used to create them. The sponsors of the two modelling exercises, the Information Technology Department were keen to increase the exposure of managers within UKCO to systems thinking and to investigate other potential areas for application.

The idea of running an in-house training course in system thinking was considered, but rejected. It was felt that what was required at this stage was to create greater awareness of the method and so stimulate interest in further applying systems thinking. If UKCO needed to acquire the ability to support systems thinking in-house, then personnel could be trained at a later date.

To achieve this aim, it was decided to create a learning laboratory, which would focus on the issue of supply chain management. The choice of supply chain management had several advantages:

- 1 Work had already been carried out in this area and the existing logistics models could be integrated into the learning laboratory.
- 2 Supply chain management was a live issue within UKCO.
- 3 There was a reasonably large number of managers involved in logistics planning and control, so there would be no shortage of participant for the learning laboratory.

### 4.5.1 The Aims of the Logistics Learning Laboratory

The learning laboratory was designed to function on two different levels, satisfying two distinct but compatible aims:

- 1 To promote the adoption of systems thinking within UKCO.
- 2 To provide participants with a thorough understanding of the issues involved in the design and management of supply chain systems.

It had been decided at the outset that an itthink-based generic supply chain model<sup>1</sup> should be built to form the centre piece of the learning laboratory. Therefore there would be a need to train participants in the basics of using itthink. It should be stressed however that the learning laboratory was not intended to be an itthink training course.

**Table 4.8 The training objectives of the logistics learning laboratory**

<b>Subject Area</b>	<b>Skills Taught/Knowledge Acquired</b>
Systems Thinking	Awareness of the basic ideas of systems thinking Read a causal map Read an itthink map
Itthink Modelling	Perform "what if" simulation runs with an existing itthink model Perform sensitivity analysis simulation runs with an existing itthink model Create graphs and tables
Supply Chain	Supply chain structures and their generic nature Typical behaviour of supply chain systems; amplification and oscillation Effect of system structure, delays, operating policies and organisational boundaries on supply chain behaviour Resonance effects in supply chains and the creation of false seasonality

<sup>1</sup>The supply chain model is described, in detail in Appendix 5.

## 4.6 The Logistics Workshop Structure

The structure of the logistics workshop is shown in Table 4.9. Each stage of the workshop will now be briefly described and the reasons for its inclusion in the workshop will be given. The Beer game and the supply chain model are described in greater detail in following sections.

**Table 4.9 The logistics workshop program**

<b>UKCO 2-Day Logistic Workshop</b>	
<b>Day 1 AM</b>	
1.1	Introduction
1.2	The beer game
1.3	Beer game debrief
1.4	Introduction to systems thinking and itthink
<b>Day 1 PM</b>	
1.5	Itthink hands on Development of staff models, under supervision
1.6	The supply chain model session 1 <ul style="list-style-type: none"> <li>a) Introduction and overview</li> <li>b) Experimentation with different ordering strategies</li> <li>c) Discussion of results</li> </ul>
<b>Day 2 AM</b>	
2.1	The beer game revisited Beer game video
2.2	The supply chain model session 2 <ul style="list-style-type: none"> <li>a) Experimentation with seasonal and other test inputs</li> <li>b) Discussion of results</li> </ul>
2.3	Presentation of the UKCO logistics model <ul style="list-style-type: none"> <li>a) Development and application to date</li> <li>b) Discussion of model development options</li> </ul>
<b>Day 2 PM</b>	
2.3	The strategic perspective <ul style="list-style-type: none"> <li>a) MGI qualitative case study</li> <li>b) Demonstration of MGI quantitative models</li> </ul>
2.4	Open forum

### 4.6.1 The Beer Game<sup>1</sup>

It was decided that playing the Beer Game would be the first activity of the workshop. This starting point was chosen for the following reasons:

- 1 The Beer Game shows the difficulty of managing a supply chain system, even when it has been highly simplified.
- 2 Playing the game would help to “break the ice” between the participants.
- 3 The debrief after the game provides an opportunity to introduce some of the ideas of systems and so leads on into the following session.

### 4.6.2 Introduction to Systems Thinking

This session was designed to introduce the basic ideas of systems thinking and the itthink “language”. The participants are set some simple mapping exercises to give a hands on experience of qualitative modelling. This session was a shortened version of the introductory session of the standard itthink training course<sup>2</sup>

### 4.6.3 Itthink Hands On Exercise

This session was also derived from the standard itthink training course. It consists of talking participants through the building of a series of six models. These models are concerned with staff recruitment and departure<sup>3</sup>.

#### 4.6.3.1 Aims of the Exercise

It was decided to include this session for three main reasons. Firstly to provide participants with an overview of the modelling approach and the itthink software and in particular, to introduce the various facilities that they will need to use during the following exercises with the supply chain model; graphs, tables, sensitivity analysis and the ability to change the value of a parameter.

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<sup>1</sup>The Beer Game is described, in detail, in Appendix 4.

<sup>2</sup> See Chapter 3 for more details.

<sup>3</sup> This is part of the standard training course and is described in Chapter 3.

Secondly to reinforce the lessons that participants should have learned from playing the Beer game. The exercise shows how structure causes behaviour and demonstrates the need for appropriate control policies. For example “staff model 5” produces amplification and oscillation because its ordering policy fails to take the staff that are in training into account. This provides an exact parallel with the Beer game where problems occur because the players forget about the goods that are in the pipeline when they make their ordering decision. The ability of the models to reproduce and explain such recently experienced problematic behaviour, will help to increase participants’ confidence in the modelling approach.

The third aim of the session is to introduce participants to the type of structures that occur in supply chains. The debrief that follows the exercise was used to achieve this.

#### **4.6.3.2 The Debrief**

The debrief had two purposes. The first part of the debrief was designed to reinforce the learning that should have occurred during the hands-on exercises.

In the second part of the debrief the emphasis is on exploring the relationship between the staff models and the type of structures that can be found in supply chains. The final staff model, see Figure 4.9 is taken as a starting point and by changing the names of the model elements it is shown to be a simple single stage supply chain, see Figure 4.10. This structure is then further generalised to become the stock management system shown in Figure 4.11. The completely generic nature of this structure is demonstrated by the list of specific cases shown in Table 4.10.

The final part of the debrief takes the map of the supply chain model (see Appendix 9) and show how it is essentially three of the generic stock management system structures connected end to end.



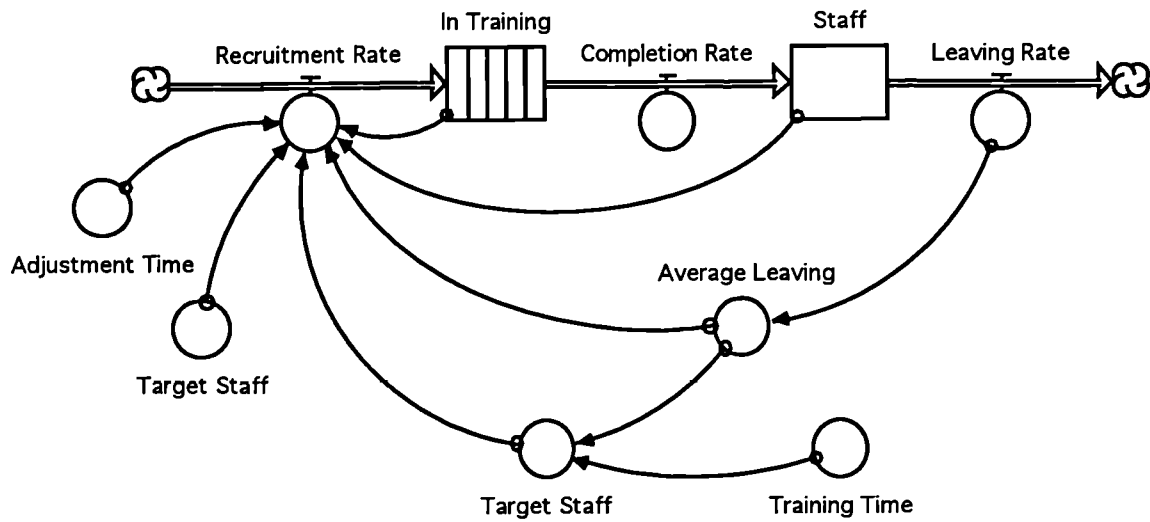


Figure 4.9 The final staff model

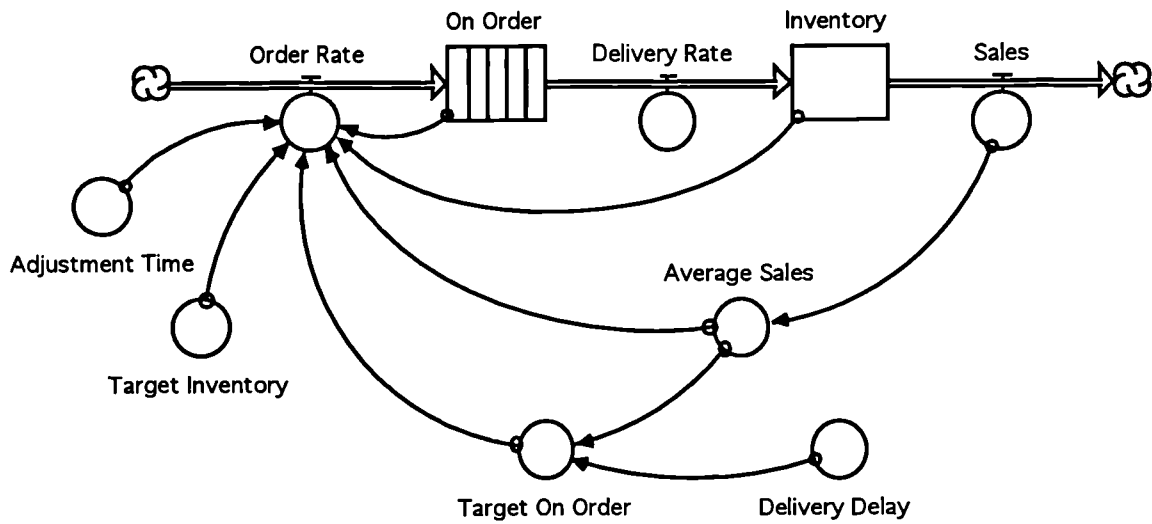


Figure 4.10 Single stage supply chain model

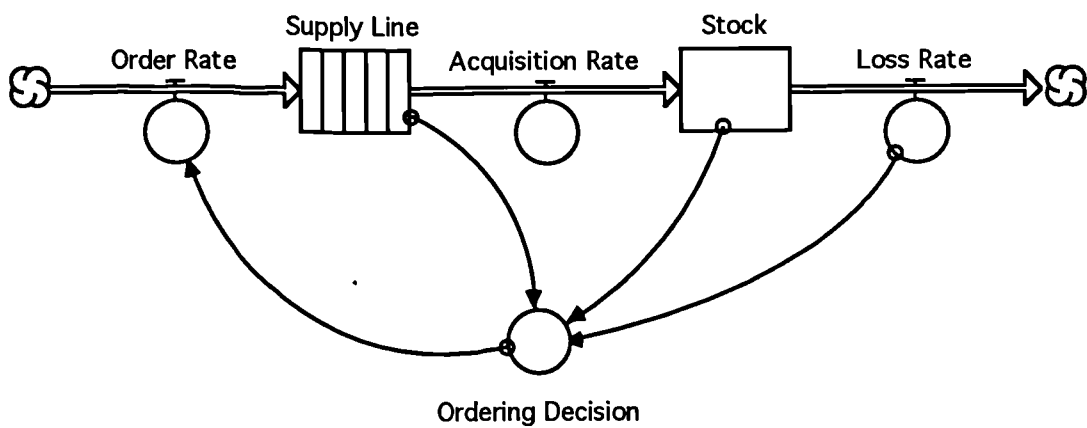


Figure 4.11 Generic stock management system

**Table 4.10 Example of stock management systems after (Sterman 1988a)**

System	Stock	Supply Line	Loss Rate	Gain Rate	Order Rate
Inventory Management	Inventory	Goods on Order	Shipments to Customers	Deliveries from Supplier	Orders for Goods
Staff Management	Employees	Recruiting and Training	Leaving and Redundancy	Training Completion	Vacancy Creation
Marketing	Customer Base	Prospective Customers	Defection to Competitors	Recruitment of Customers	New Contacts
Property Development	Buildings	Under Construction	Demolition	Construction Completion	Development Starts
Agriculture	Food	Crops in Fields	Consumption	Harvesting	Crop Planting
Social Drinking	Alcohol in Blood	Alcohol in Stomach	Metabolism of Alcohol	Absorption from Stomach	Drinking

#### 4.6.4 The First Supply Chain Model Session

The aim of this session is to introduce the supply chain model to the participants and show the effect that different ordering policies have on the behaviour of the supply chain system. In particular that the model is capable of producing the type of behaviour that the participants experienced earlier whilst playing the Beer game.

##### 4.6.4.1 The Exercises

Participants are first talked through a hands-on exploration of the supply chain model, which includes a demonstration of how to select test inputs and ordering policies. Next they are given workbooks<sup>1</sup> to guide their experimentation with the model. The experiments contained in the workbooks are listed in Table 4.11.

The first run is with a constant demand and this demonstrates that the model is in equilibrium. The remainder of the runs use a step change in demand to shock the system.

The step test was chosen for two main reasons. The first reason was for its' familiarity; participants will have already seen the step test in the Beer game and

<sup>1</sup> An example exercise from the Supply Chain Workbook is presented in Appendix 5.

the staff models. The second reason was for ease of interpretation of system behaviour. The single shock of the step test will in general stimulate system behaviour that is less complex than that produced by the other available test inputs. For example, the sinusoidal and random test inputs, which are continually changing will usually generate a more complex system behaviour that is correspondingly more difficult to interpret.

**Table 4.11 Simulation runs performed during session 1**

<b>Run</b>	<b>Demand</b>	<b>Ordering Policy</b>	<b>Behaviour</b>
1	Constant	<ul style="list-style-type: none"> <li>• Average Orders</li> </ul>	<ul style="list-style-type: none"> <li>• Equilibrium run.</li> </ul>
2	Step	<ul style="list-style-type: none"> <li>• Average Orders</li> </ul>	<ul style="list-style-type: none"> <li>• Amplification of orders up the supply chain.</li> <li>• Inventory levels decline.</li> </ul>
3	Step	<ul style="list-style-type: none"> <li>• Average Orders</li> <li>• Inventory Control</li> </ul>	<ul style="list-style-type: none"> <li>• Amplification of orders up the supply chain.</li> <li>• Inventory levels Oscillate.</li> </ul>
4	Step	<ul style="list-style-type: none"> <li>• Average Orders</li> <li>• Inventory Control</li> <li>• Pipeline Control</li> </ul>	<ul style="list-style-type: none"> <li>• A smooth transition to new inventory levels, but with some overshoot and amplification.</li> </ul>
5	Step	<ul style="list-style-type: none"> <li>• Retail Orders</li> <li>• Inventory Control</li> <li>• Pipeline Control</li> </ul>	<ul style="list-style-type: none"> <li>• A smooth transition to new inventory levels, with no amplification.</li> </ul>

The second, third and fourth model runs build up the ordering policy from a simple replacement policy to a fully balanced ordering decision that takes into account loss rate, inventory and pipeline. The final model run shows the effect of feeding information on customer demand forward up the supply chain. When using this policy, the wholesaler and factory base their ordering and production decisions upon actual retail sales, in the previous runs the orders received from the preceding sector in the supply chain were used as a basis for this decision.

#### 4.6.4.2 The Debrief

The debrief compares the effect of the different ordering policies and relates the behaviour of the model back to that experienced during the Beer game. The following points are stressed:

- 1 There is a need to monitor and control all the accumulations of material within the supply chain and in particular the material in the pipeline must be taken into account.
- 2 Reductions in delays within the supply chain will improve the system's performance.
- 3 Improving the quality of the information used in the ordering-decision will have a beneficial effect on the system's performance.

#### 4.6.5 Beer Game Revisited

The second day begins with the showing of the Beer Game Video (MacNeil-Lehrer Report 1989). The video shows the playing of the Beer game and the following debrief. It then goes on to provide some real examples of problematic supply chain behaviour in the automotive and property development industries.

It was decided to show the video at this point to reinforce the learning that should have occurred during the previous day and to get the participants thinking about the issue of supply chain management again. Finally it was felt that the video would provide an entertaining and undemanding start to the day.

#### 4.6.6 The Second Supply Chain Model Session

The aim of this session is to explore some of the more complex behaviour modes of the supply chain model. In addition it provides an opportunity for participants to experiment with the full range of the test inputs. The exercises contained in this session are listed in Table 4.12.

Table 4.12 Simulation runs performed during session 2

Run	Demand	Ordering Policy	Behaviour
1	Random	<ul style="list-style-type: none"> <li>• Average Orders</li> <li>• Inventory Control</li> <li>• Pipeline Control</li> </ul>	<ul style="list-style-type: none"> <li>• Pseudo seasonal behaviour in levels of inventories.</li> </ul>
2	Sine Wave Sensitivity (13, 26, 52 weeks)	<ul style="list-style-type: none"> <li>• Average Orders</li> <li>• Inventory Control</li> <li>• Pipeline Control</li> </ul>	<ul style="list-style-type: none"> <li>• Resonance; the 26 week sine wave causes greater oscillation of inventories than either the 13 week or 52 week sine waves.</li> </ul>
3	Random	<ul style="list-style-type: none"> <li>• Average Orders</li> </ul>	<ul style="list-style-type: none"> <li>• No pseudo seasonal behaviour in levels of inventories.</li> </ul>

#### 4.6.6.1 The Exercises

The first exercise aims to demonstrate that the supply chain model can generate counterintuitive behaviour. A random test input in which demand fluctuates about a fixed value is used. It might be expected that this input will cause inventory levels to fluctuate slightly about a constant value. However what actually happens is that relatively large changes in inventory levels occur; some of which are reminiscent of seasonal behaviour.

The second model run aims to help participants explain the behaviour that they have just witnessed in the previous exercise, by demonstrating that the supply chain model has a resonant frequency. A sine wave input is used and a sensitivity analysis is carried out in which the period of the sine waves are varied. The model output shows resonance; the medium frequency sine wave input produces larger oscillations in inventory levels than either the low frequency or high frequency inputs.

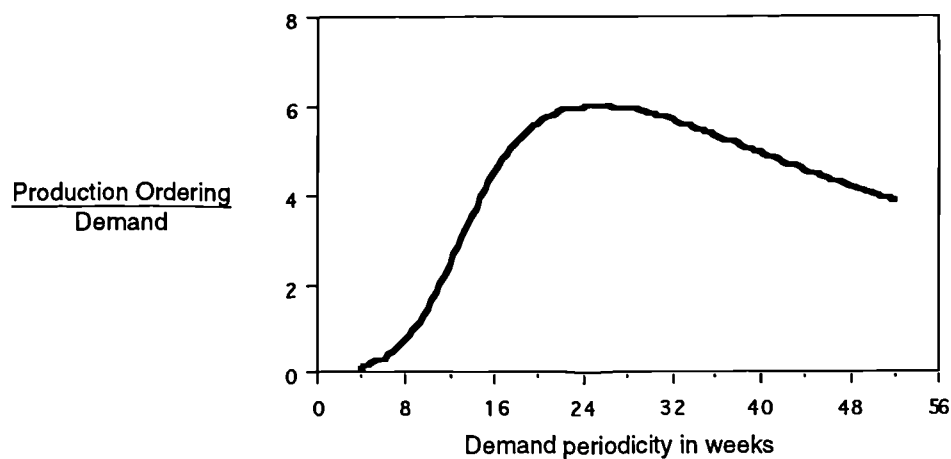
The final run demonstrates that the resonance effect is due to the ordering decision policy. The random test input is used, but this time with ordering policy 1 (simple

replacement of sales). The model output shows inventory levels that fluctuate slightly about a constant value.

After participants have finished these exercises they are free to use the remaining time to devise their own experiment with the supply chain model. In particular it is suggested to participants that they might like to run the model with some of the test inputs that they have not yet used.

#### 4.6.6.2 The Debrief

The debrief introduces the idea of system resonance by using the analogy of some simple physical systems; a vibrating string, a playground swing and a suspension bridge. The sensitivity run is then discussed and the results from a more extensive sensitivity run are presented in the form of a frequency response, see Figure 4.12. This clearly shows that the production sector is most sensitive to disturbances with a period of around twenty-five weeks.



**Figure 4.12** Frequency response of the production sector

Moving back to exercise one, it is explained that the random test input contains a large number of different frequencies and the supply chain is selectively amplifying those frequencies to which it is most sensitive. This leads into a discussion of how the market might react to these supply chain dynamics and so create false seasonal patterns of demand.

The behaviour of run three is then explained. The reason resonance does not occur is that the ordering policy makes no attempt to correct inventory or pipeline levels. The policy tracks sales that are fluctuating about a constant value therefore inventories will also fluctuate about a fixed point.

The final task of the debrief is to cover any points that have arisen out of participant own experiments with the supply chain model.

#### 4.6.7 The UKCO Logistics Model

The aim of this session was to introduce the UKCO logistics model to the workshop participants. It was decided that the majority of the session should be taken up by a presentation made by a manager from the project team who had been closely involved in the development of the UKCO model (and was one of the workshop participants), supported where necessary by the author.

The presentation started by describing the background of the project, the model development process and the use to which the models had been put. Then there was a hands-on presentation of the models. Participants were talked through an exploration of the various versions of the model and then encouraged to experiment with the models for themselves.

The session was wound up by a question and answer session, in which the author and the manager from the project team provided extra information on the models and their development.

#### 4.6.8 The Strategic Perspective

The UKCO model although a fairly high level and aggregated model, was essentially addressing an operational problem in logistics. In order for the workshop participants to appreciate the full range of problems that systems thinking was capable of tackling, it was felt important that they had experience of a strategic case study.

It was therefore decided to use the MGI<sup>1</sup> case study in the workshop. There was only sufficient time available to tackle the qualitative part of the exercise. In any case the second quantitative part of the exercise, which is essentially an itthink model building exercise, was not felt to be in keeping with the objectives of the workshop. The participants were however given a limited amount of time to explore and experiment with the finished quantitative itthink models.

#### 4.6.9 Open Forum

The final session was an open discussion it was included to satisfy the following objectives:

- 1 Provide the participants with the opportunity to raise any remaining problems that they had with systems thinking or the itthink software with the author.
- 2 Generate feedback from the participants on the benefits (if any) they gained through participating in the workshop.
- 3 Generate feedback from the participants on the usefulness of the systems thinking approach in general.
- 4 Discuss further areas of application of systems thinking within UKCO.

### 4.7 The Delivery of the Logistics Workshop

The logistics workshop was attended by nine managers, who came from a number of different companies from within the UKCO group. All of the managers were working in the area of logistics and production planning. The workshop began with a brief overview of the workshop program and aims. This was followed by the participants introducing themselves to the rest of the group. It was necessary to do this, because not all of the participants were known to each other.

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<sup>1</sup> The Market Growth and Investment (MGI) case study has already been discussed in Chapter 3 and is presented in full in Appendix 2.



### 4.7.1 The Beer Game

There were nine participants at the logistics workshops so one game was played with the extra person allocated to the factory position. The time available for the game allowed it to be played for the full 50 weeks, but participants were told that the game would last for 100 weeks to avoid end effects.

One of the participants had prior knowledge of the Beer game, although he had not actually played it. This manager had also been a member of the modelling project team and initially it had been decided to make him sit the game out. However he was very keen to play and his participation was allowed, with a degree of trepidation, by the author. It was felt that it would be a worthwhile experiment to see what effect one knowledgeable player would have on the course of play. In order to minimise his influence it was decided not to place him at either end of the chain, therefore he was assigned to the wholesaler position.

The game was played with enthusiasm by the participants, with many 'in' jokes being made. The results of the game will now be presented.

#### 4.7.1.1 Ordering

The orders placed by the four sectors are displayed in Figure 4.13. It can be seen that the amplification of orders increases up the supply chain, see Figure 4.14 and Table 4.13. The gain of the wholesaler is close to that of the retailer, so it seems that the wholesaler was using his prior knowledge of the game, but it can be seen from the gains of the distributor and factory sectors that the retailer's actions have had little effect on the behaviour of the system as a whole. Comparing the teams' performance to the average values shown in Table 4.13, it can be seen that the retailer's and wholesaler's performances are very close to the average (+5% and +7% respectively). In contrast the distributor and factory performed much worse than average (+19% and +25% respectively).

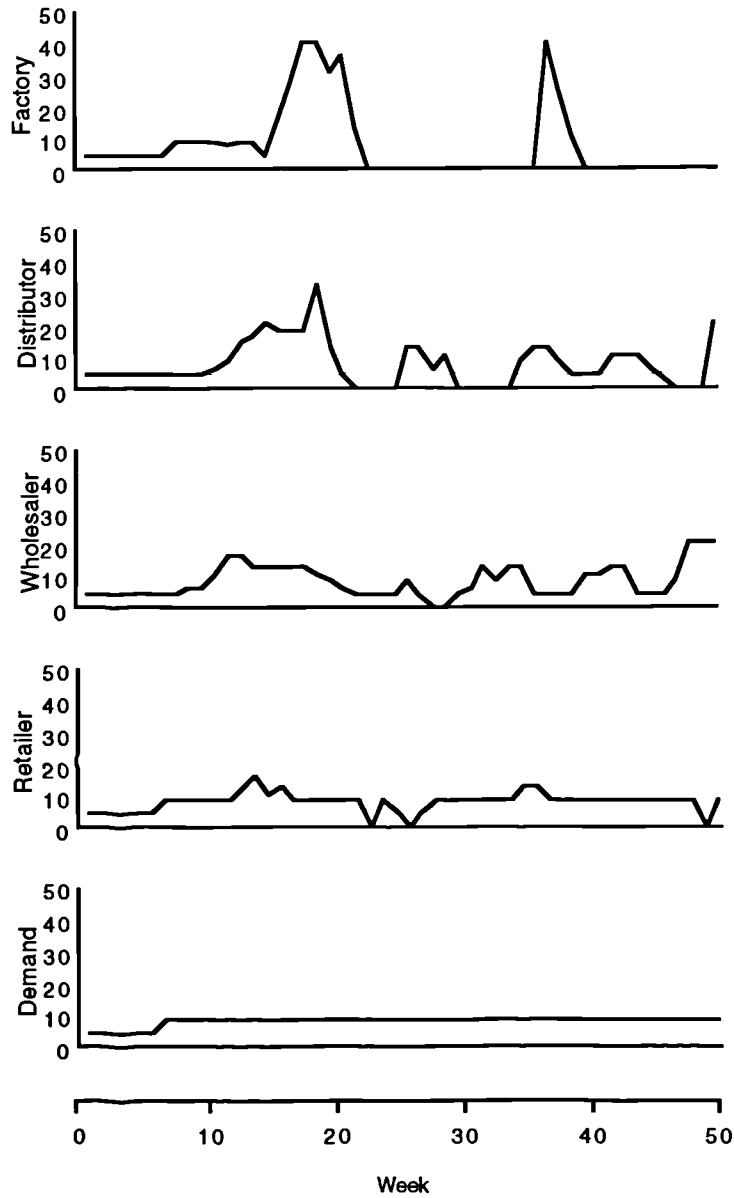


Figure 4.13 Graph of ordering by sector

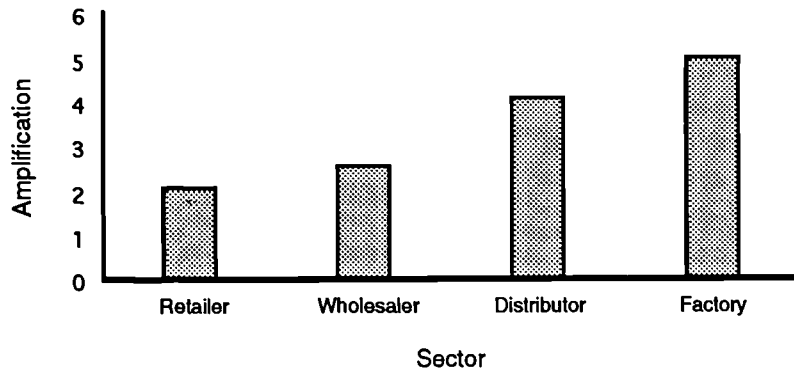


Figure 4.14 Graph of amplification in ordering by sector

Table 4.13 Ordering data

Sector	Min Order	Max Order	Gain <sup>1</sup>
Demand	4	8 (8)*	—
Retailer	0	16 (15)	2.0 (1.9)*
Wholesaler	0	20 (19)	2.5 (2.4)
Distributor	0	32 (27)	4.0 (3.4)
Factory	0	40 (32)	5.0 (4.0)

\* The figures in bracket are the averaged results of 11 games (Sterman 1988a)

#### 4.7.1.2 Inventory

Inventory levels are shown in Figure 4.15. It can be seen that the range of the swings in inventory increases up the supply chain, see Figure 4.16 and Table 4.14.

Table 4.14 Inventory data

Sector	Min Inventory	Max Inventory	Range
Retailer	-18 (-25)*	24 (20)	42 (45)
Wholesaler	-28 (-46)	12 (41)	40 (88)
Distributor	-24 (-45)	59 (49)	83 (94)
Factory	-21 (-23)	98 (50)	119 (73)

\* The figures in bracket are the averaged results of 11 games (Sterman 1988a)

Comparing the teams' performance to the average values shown in Table 4.14, it can be seen that the Retailer's performance is slightly better than average (a 7% reduction). The Wholesaler's figures show a massive performance improvement with a range that is only 55% of the average value, demonstrating the advantage of prior knowledge. The Distributor, with a 12% reduction in range, also shows a modest improvement over the average results.

<sup>1</sup>Gain is defined as:  $\frac{\text{Maximum Ordering}}{\text{Maximum Demand}}$

In contrast, the Factory turned in a very bad performance, with the range in inventory 63% above average. Most of this increased range is due to a much larger maximum inventory level (98 compared with the average of 50), the minimum inventory levels were similar (minus 21 compared to the average of minus 23).

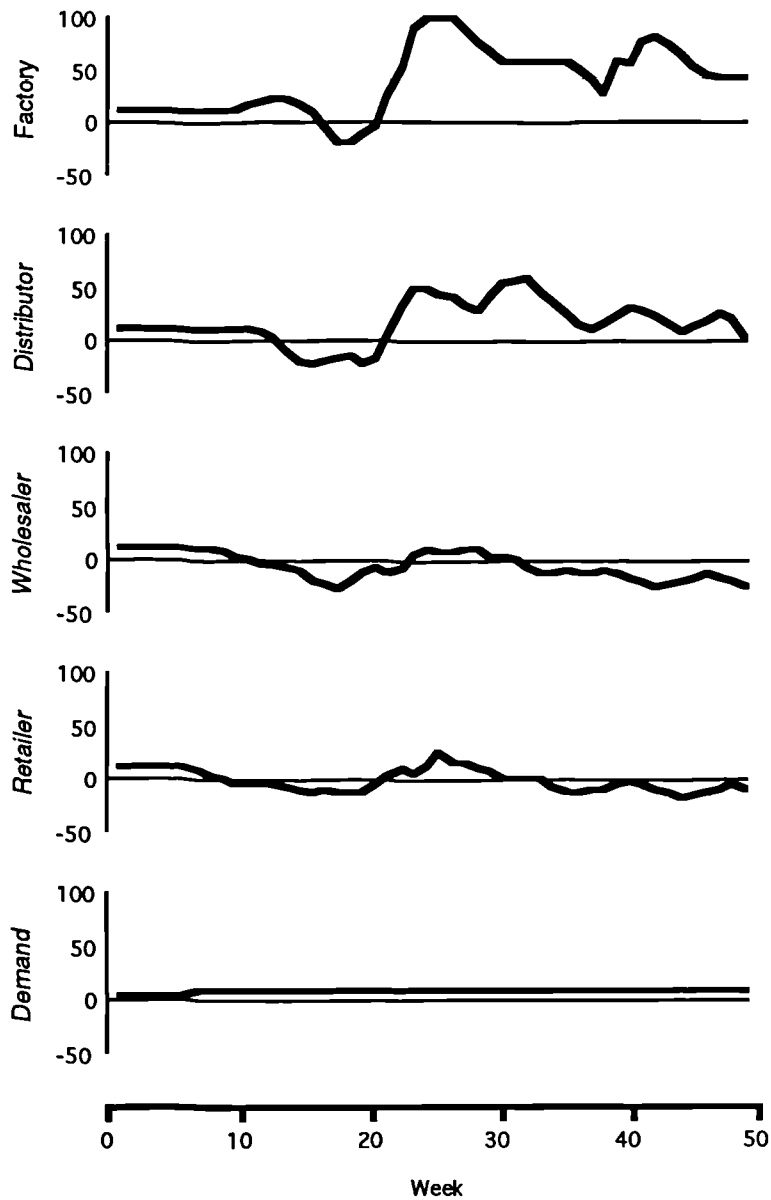


Figure 4.15 Graph of inventory by sector

The most likely explanation for this behaviour is that the managers manning the Factory position were transferring their normal behaviour over into the Beer game. The managers were used to working in a highly seasonal market, in which it was necessary to built up stocks in advance of the seasonal peak. The oscillatory

behaviour generated by the other participants would of course confirm their misconception that they were dealing with a highly seasonal market.

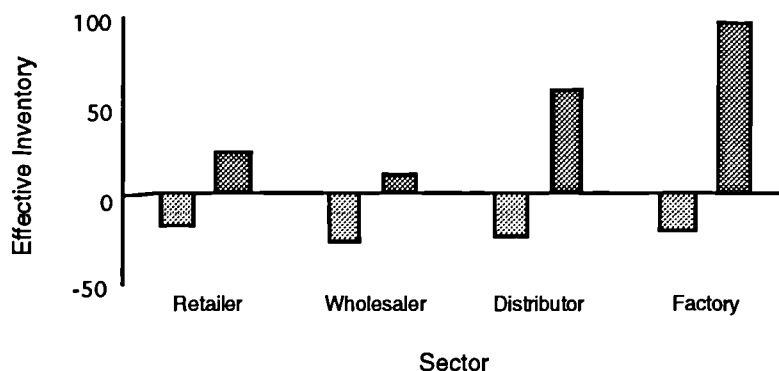


Figure 4.16 Graph of maximum and minimum inventory by sector

#### 4.7.1.3 Costs

Total costs for each sector are shown in Figure 4.17. It can be seen from Figure 4.18 and Table 4.15, that the total sector cost increases up the supply chain; this is the result of the corresponding increase in inventory fluctuations. If these costs are compared to the average performance achieved in the Beer game, it can be seen that the Retailer achieves a modest improvement with costs that are 5% below average, the Wholesaler, again does better with a 13% reduction in total cost. The Distributor fares slightly worse with costs that are 3% above average. The Factory costs are huge, a 179% increase on the average, because of the large maximum inventory level that was discussed in the preceding section.

Table 4.15 Total costs

Sector	Total Costs	Average
Retailer	362.5	(383)*
Wholesaler	554.0	(635)
Distributor	646.5	(630)
Factory	1059.0	(380)

\* Averaged results of 11 games (Sterman 1988a)

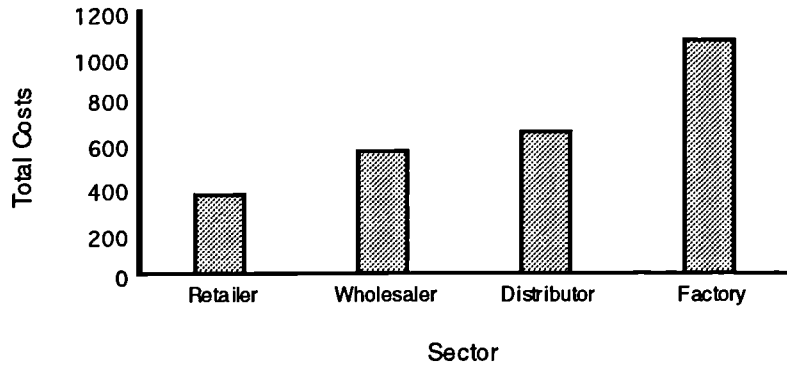


Figure 4.17 Graph of total costs by sector

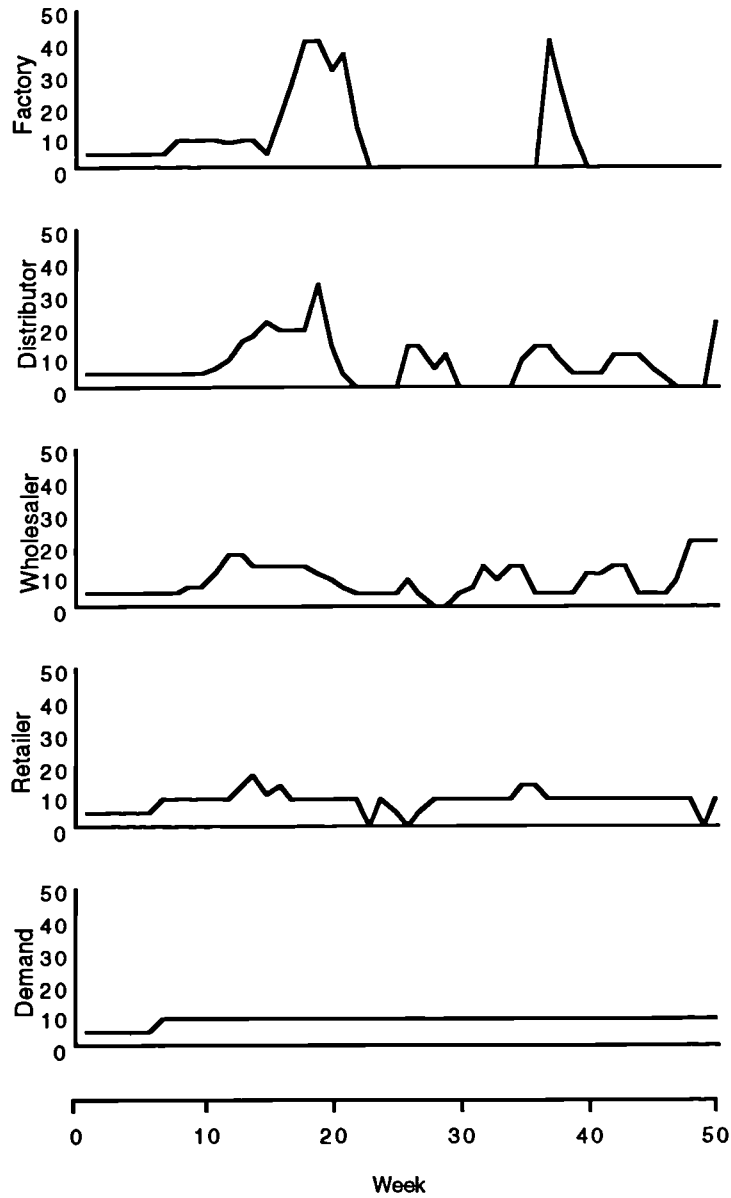


Figure 4.18 Graph of costs by sector

#### 4.7.1.4 Beer Game: Observations

The results of the Beer game show that experienced logistics managers find it difficult to manage what is after all a relatively simple system. Participation in the game by the manager who knew the actual demand pattern shows that the actions of one player with perfect information cannot, on their own, prevent amplification and oscillation in ordering from occurring. This manager did however achieve a better performance for his own sector, see Figure 4.19, this may not just be because he had prior knowledge of the game, he was also the only manager who appeared to be carrying out any mental calculations during the game.

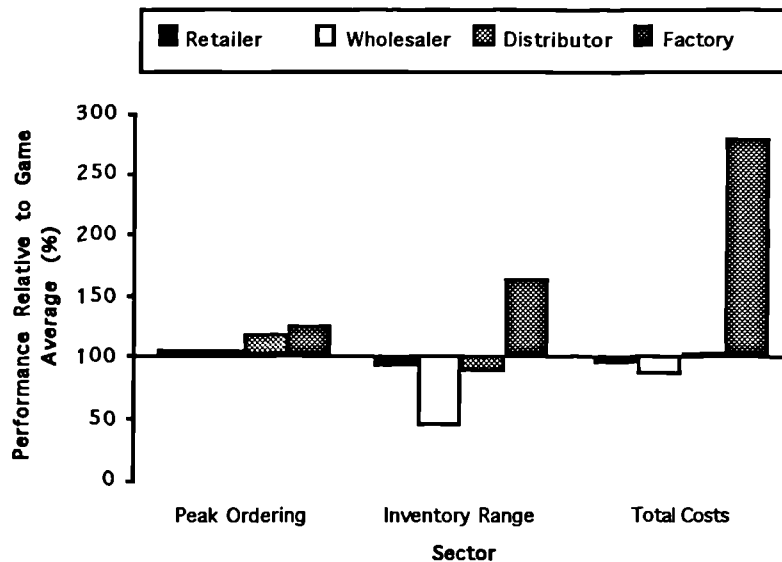


Figure 4.19 Graph of relative performance by sector

#### 4.7.2 Introduction to Systems Thinking

This session was successfully delivered and well received. Nothing occurred during the session that is worthy of further comment or discussion.

#### 4.7.3 I think "Hands on"

The participants were split up into small groups to carry out this exercise; three groups of two and one group of three were used. All of the participants were computer-literate; they used computers in the normal course of their work. The

session followed its usual course<sup>1</sup>, the mechanics of using the software were quickly learned, but policy design was found to be a more difficult task.

In particular, only one group managed to implement an ordering policy that eliminated the problematic behaviour of Staff Model 5 without help. The required solution is an ordering policy that takes into account the number of staff in training, i.e. one that manages the pipeline. That so many of the groups found this task difficult, despite the fact they had all claimed to be aware of the importance of managing the pipeline in the Beer game debrief, show how difficult it is for managers to transfer insights between problem domains.

#### 4.7.4 The Supply Chain Model Session 1

This session was also conducted with participants working in small groups, the make up of the groups was unchanged from the preceding session.

This session went very smoothly, by now participants were becoming familiar with the various ordering policies. All of the groups did well in their prediction of system behaviour, with the exception of one group who got themselves into a muddle over the first exercise (ordering equal to averaged sales, step test input); they couldn't understand why inventory didn't recover.

The final exercise (feeding retail demand up the supply chain) sparked off an interesting discussion about the accuracy and timeliness of information that was available to the managers. This lead on to a more technical discussion as to how the quality of information available to the decision makers could be modelled using *ithink*.

#### 4.7.5 Beer Game Revisited

The participants enjoyed watching the video and found it stimulating. Nothing occurred during the session that is worthy of further comment or discussion.

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<sup>1</sup>The conduct of this session is described in Chapter 3



#### 4.7.6 The Supply Chain Model Session 2

Participants worked in their usual groups for this session. The fact that a random test input produced pseudo seasonal behaviour, surprised all of the participants, who were at a loss when asked to give reasons for this behaviour. This made it a challenging session for most of the participants.

The sine wave sensitivity exercise did not seem to help the majority of the managers to understand what was going on. Two of the managers did realise that the supply chain was selectively amplifying input of certain frequencies, but neither of them explicitly mentioned resonance or could give reasons why this selective amplification occurred.

In the debrief when the subject of resonance was raised, it emerged that all the participants were familiar with the phenomena, from their engineering background, but they had not expected such behaviour to occur in a non-mechanical system. This provides another example of the difficulty that managers have in transferring knowledge from one problem domain to another.

In the second part of the session, the unstructured use of the model, all the participants, after a little experimentation with the other test inputs, focused in on using the user defined test input to enter the company's own seasonal demand pattern. The model did not perform well with this rather extreme demand pattern and a discussion was facilitated on the need to use forecasting to improve supply chain performance.

One group became interested in how a limited production capacity at the factory would affect supply chain behaviour. The author quickly modified their version of the supply chain model to allow a limit to be placed on production. The managers then used this model to carry out a number of sensitivity runs on production capacity with different demand patterns. They became so engrossed in this work, that it was difficult to persuade them to stop for the debrief.

#### 4.7.7 The UKCO Logistics Model

The group was joined by the head of the modelling project team for this session. The presentation on the model and its development was well received and a stimulating question and answer session followed.

There were a number of questions on the details of the model; what assumptions had been made, how particular features had been modelled. This was followed by a more general discussion on the future of the logistics model. A consensus soon emerged that there was no point in developing the model further, it had been built for a particular purpose and it had fulfilled that purpose very successfully.

The group felt that to expand the model so that it could be used to tackle other supply chain problems would be counterproductive; they should not be afraid to move on and build new models. This was a viewpoint that was strongly supported by the author. It was felt however that the existing model could have a useful role to play within the company as a device for promoting interest in systems thinking amongst a still wider group of managers.

#### 4.7.8 The Strategic Perspective (MGI Case Study)

To carry out this exercise the participants were split up into three groups of three. The results were average. The groups all got to a solution, which was represented in the usual hybrid mix of influence diagrams and itthink maps.<sup>1</sup> The only observation that will be made about this session is that the managers all seemed very pleased to be given an opportunity to take part in a debate that was at a strategic as opposed to an operational level.

#### 4.7.9 Open Forum

In general the comments of the participants were very positive about the workshop and the systems thinking approach. Several areas within the company where systems thinking could be beneficially applied were described. In particular it was

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<sup>1</sup> See Chapter 3 and Appendix 2 for a more detailed description of the MGI case study.

felt that the approach should be applied to two of the company's systems that were currently being redesigned; the product improvement system and the European distribution system.

The head of the project team said that there was a need to be careful how any further work was managed. The success of the logistics model had gained a great deal of credibility for the approach and it was important not to jeopardise this; an unsuccessful follow up project could be very damaging.

The managers clearly wanted to be involved in further use of itthink and wanted additional training or access to trained people who could help them use the tool.

The workshop ended with the head of the project team making a commitment that the company would provide resources so that they could move forward on the use of systems thinking and itthink.

## **4.8 The Development of an In-House Modelling Capability**

This section describes the efforts that UKCO made to develop an in-house capacity to practise systems thinking.

### **4.8.1 Staff Development**

Two members of staff attended a three day public workshop in systems thinking that was held one month after the logistics workshop. Both of these people were from the Information Technology Department, they had been involved in the initial modelling exercises and had also attended the supply chain workshop. During the training course, the author had a brief discussion on the subject of producing a model of UKCO's product improvement systems with one of the participants. In the course of this discussion a main-chain structure that modelled the life cycle of a fault was sketched out.

### 4.8.2 The First In-House Modelling Project

On return to the company, this person further developed the model and came up with the causal map shown in Figure 4.20. He then attempted to move the model onto itthink and created three sectors. In addition to the fault life cycle main chain, there was a units in warranty main chain and a fault diagnosis and repair main chain. At this point he ran into difficulty and the author became involved in the modelling project.

The modelling was very good for a first attempt. In particular the causal map showed a good understanding of the problem domain, it identified the key feedback loops and provided a sound basis for a model. It should be mentioned that loop 4 in Figure 4.20 is a rather dubious construct, but the modeller was aware of this and he had placed a question mark next to the loop sign in the diagram.

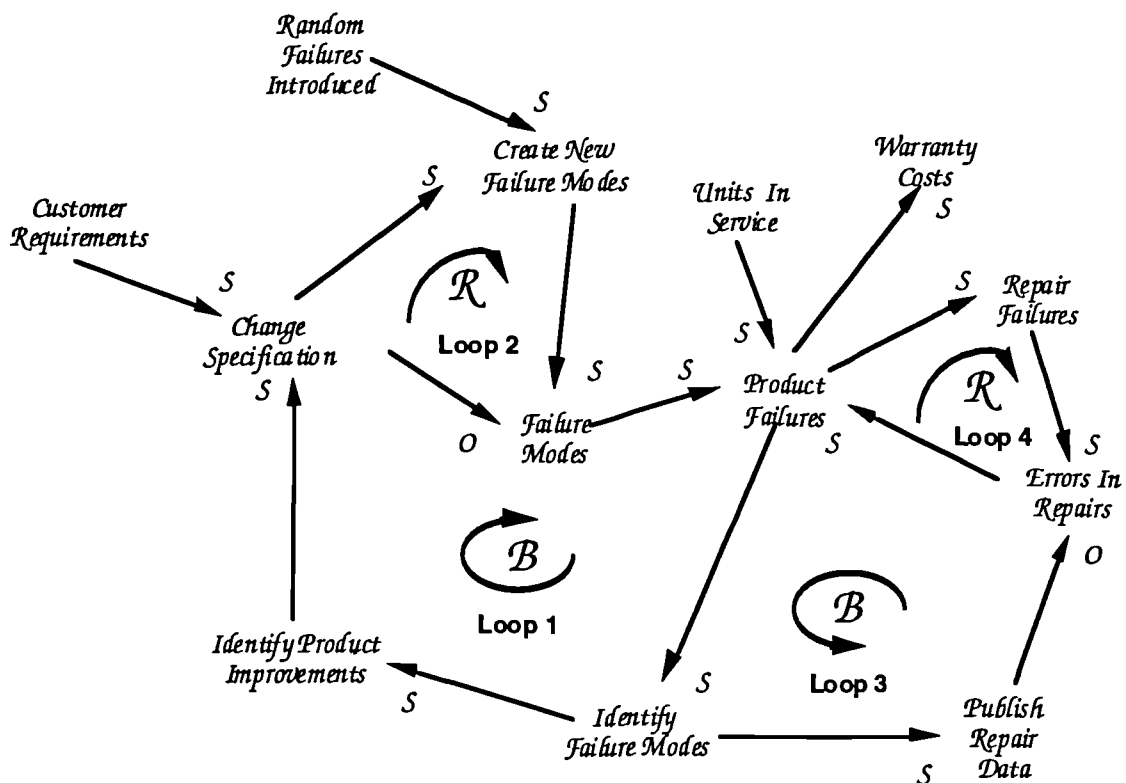


Figure 4.20 Initial causal map of the product improvement model

The main problem with the itthink model was that the fault diagnosis and repair sector was modelled in too much detail and had a time frame that was incompatible with the rest of the model.

The author spent a day producing a working first pass itthink model and a further day, developing this model with the modeller from UKCO. The causal map of the model is shown in Figure 4.21 and the itthink diagram of a simplified version of the model is shown in Figure 4.22.

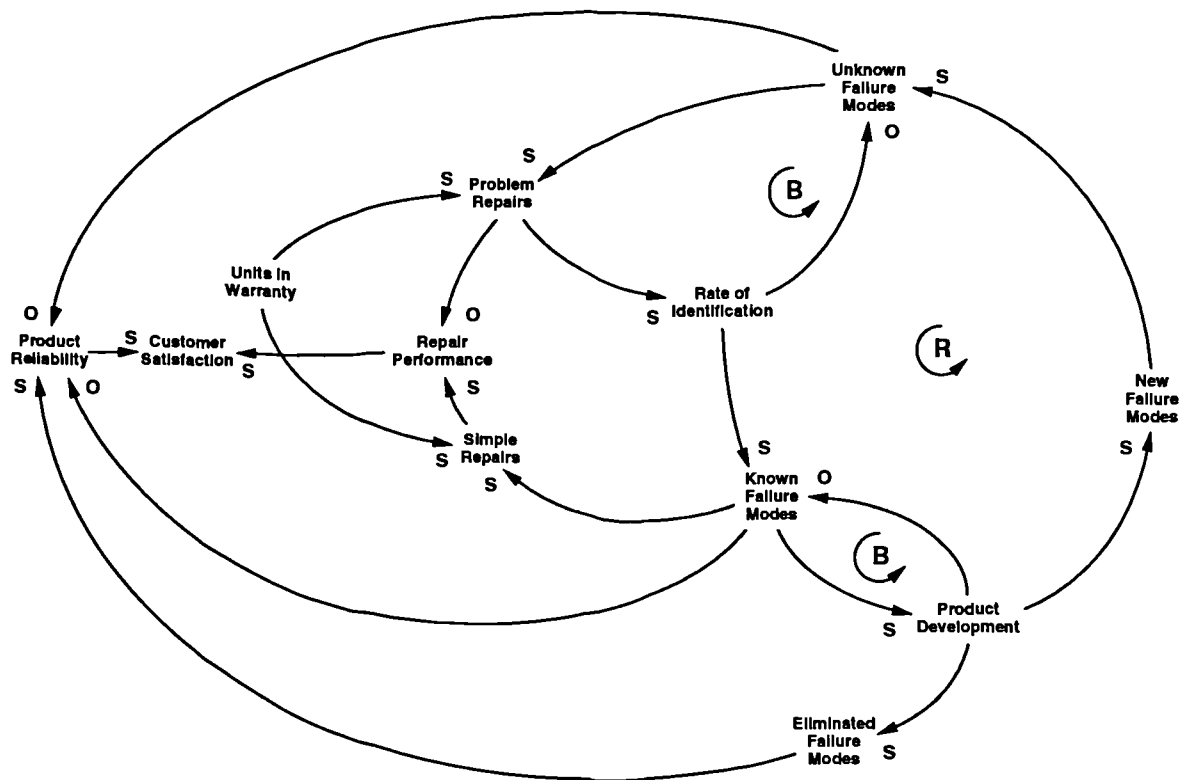


Figure 4.21 Final causal map of the product improvement model

The modeller from UKCO was then able to carry on the modelling project unaided by the author. He took the first pass model back to the group of managers involved in the redesigning of the product improvement system and working closely with them, he successfully implemented a series of incremental developments to the model.

The model was also put to another use by the author. The product improvement process is found in many different situations and it was decided to build a generic model of this activity. This model was then used as the basis of a training case study in process mapping. The itthink map of this version of the model is shown in Figure 4.22. The original model although more complex shares the same basic structure.

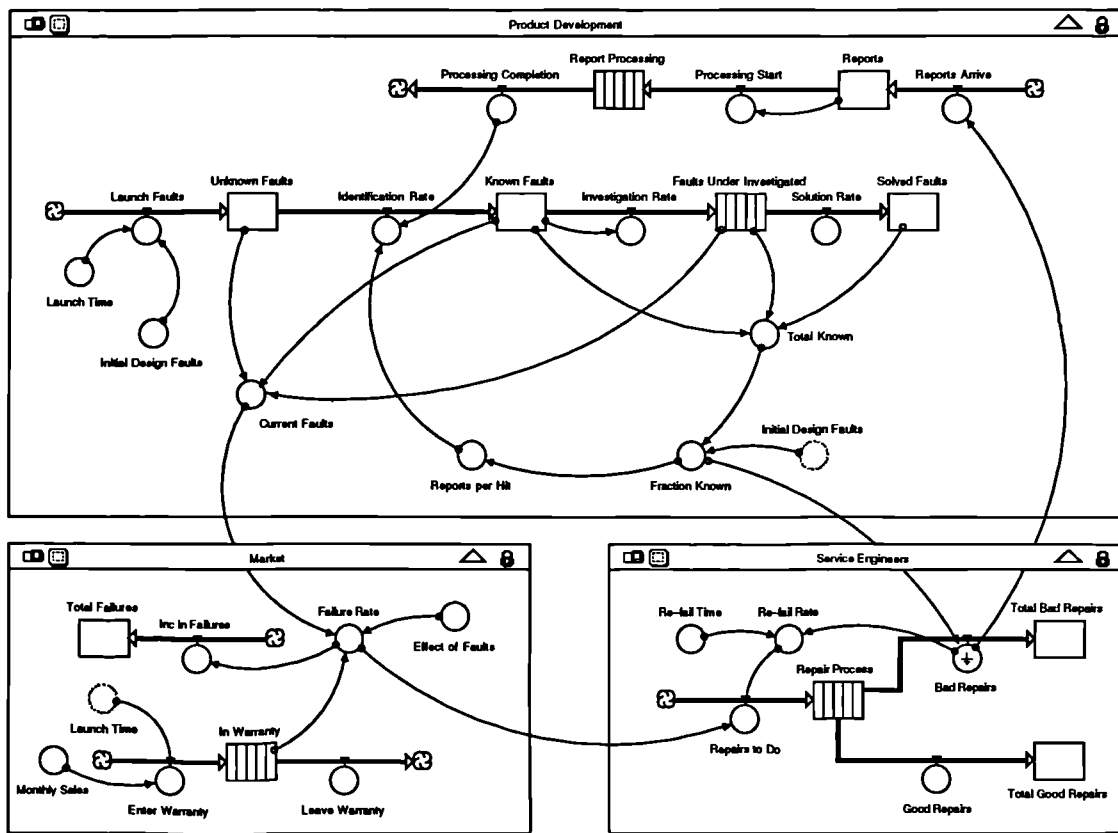


Figure 4.22 Training model derived from the product improvement model

### 4.8.3 The Second In-House Modelling Project

Three months later, two more managers were trained. These managers had attended the supply chain workshop and were part of a team that was involved in re-engineering UKCO's European Distribution System. On return to UKCO, they started to build a model to assist with the re-engineering exercise.

In contrast to the first in-house modelling project, there was no request for external help with this modelling project. The most likely explanation for this lies in the nature of the system being modelled. The European Distribution System Model was another supply chain model and the modellers who built it had already experienced a considerable amount of exposure to this type of model. In contrast, the Product Improvement Model was considerably different from any that the modeller who built it had experience of.

It is also true that the Product Improvement Model is a more difficult model. In building a supply chain model it is very easy to identify the stocks and flows because they are apparent in the real world. The Product Improvement Model is conceptually more difficult; it uses the concept of a stock of design faults to which there is no corresponding observable real world accumulation.

## **4.9 Conclusions**

This chapter has described a wide range of activities and because of this a large amount of material has been presented. In this section, the insights that have been gained during the course of this work will be described and their wider applicability discussed. In order to appreciate the richness of what has been learned, it is necessary to consider the material from a number of different perspectives.

### **4.9.1 Using Ithink for the Modelling of Supply Chains**

During the course of the modelling work described in this chapter, Ithink has proved itself to be a very effective tool for the modelling of supply chain systems at a strategic level.

The stock and flow representation is particularly suitable to modelling this kind of system because the essence of a supply chain is the movement of materials (flows) between inventories (stocks). The addition of the conveyor model element allows the material delays in the system to be clearly represented.

An itthink map of a supply chain is usually very similar to the type of rough sketch that managers draw when explaining the structure of their supply chain. This has two effects; both of which are beneficial. Firstly, it simplifies the task of model conceptualisation and secondly, managers find it easy to understand the itthink representation of their supply chain system.

#### 4.9.2 The Use of Small Models to Disseminate Insights

The supply chain modelling work demonstrates the effectiveness of small simple models as a way of expressing dynamic insights in a form in which they can be easily understood by senior managers. The power of a simple model should never be underestimated. During the course of this research it was found that a very simple one or two stock model is usually capable of gaining and holding a manager's interest.

The use of a simplified or generic model to disseminate the insight of a systems thinking investigation is not new, but the work described in this chapter has shown that this approach can also be used to disseminate the insights of investigations that did not themselves make use of systems thinking. Two ways in which systems thinking can be used to disseminate the insights from a non-systems thinking based investigation are shown in Figure 4.23.

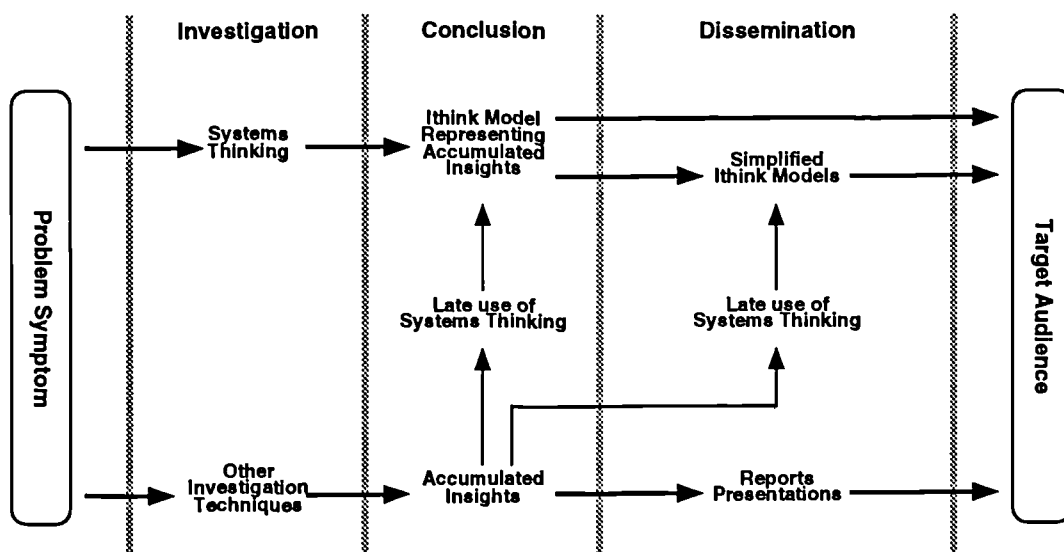


Figure 4.23 The late use of systems thinking



The systems thinking approach to problem-solving is shown across the top of Figure 4.23 and the non-system thinking approach to problem-solving is shown across the bottom. The links between these approaches show two ways in which systems thinking can be used to complement traditional approaches to problem-solving. These two approaches to the late use of systems thinking will now be described.

**Full Modelling Exercise** This approach, treats the work that has already been carried out as a knowledge acquisition stage. A systems thinking modelling exercise is then carried out to build a detailed model which is used to test out the conclusions of the earlier investigative work. This model can then be used, possibly in as simplified form, for knowledge dissemination.

**Modelling the Conclusions** This approach accepts the conclusions that have been reached by the existing work and uses the techniques of systems thinking to develop simple models that can be used to transmit these conclusions.

The first approach requires more effort but has the advantage of explicitly testing out the existing conclusions and open ups the possibility of generating new insights. The second approach requires less effort, but is unlikely to produce new insights.

In both cases, the modelling usually takes the form of a systems thinking modelling expert working in conjunction with a small team of problem domain experts who have already spent a considerable amount of time in studying the system to be modelled. The previous investigative work may have included some detailed modelling, for example discrete event simulation.

The combination of a systems thinking modeller and problem domain experts has proved to be a powerful one that can make rapid progress in model development. The disadvantages of this approach are, firstly that the outcome of the

investigation may have already become fixed and insights that may have been gained if systems thinking had been used earlier in the investigation, may be lost.

There is, of course, more to system thinking than use of *ithink*, but anyone that can see the advantage of using an *ithink* model as a way of communicating their insights is already a long way down the road to becoming a systems thinker.

This use of *ithink* can provide a way of promoting the adoption of systems thinking. The software creates the initial interest. Its application to summarise and communicate the results of an investigation, perhaps supported by causal loop diagrams or archetypes, provides a demonstration of some of the capabilities of systems thinking. If this late application of systems thinking proves useful to the company, then the question is raised as to how much more useful would it have been if systems thinking had been used from the start of the investigation. This issue is explored in more detail in the next section.

### 4.9.3 A Strategy for Gaining Acceptance of Systems Thinking

The sequence of events described in this chapter provide an example of the successful adoption of systems thinking by an organisation. The reason for this will now be discussed.

If managers within an organisation are to adopt systems thinking then they must be both aware of its existence and motivated to spend time acquiring the necessary skills. In the UKCO case, the first use of systems thinking within the company had a very high profile and was credited by senior management with helping the company achieve an important outcome. This high profile use of systems thinking was very fortuitous. It had the effect of creating a great deal of interest in the approach and ensured that backing was available to carry out further work.

The adoption of such a high profile was not without risk. If UKCO had failed to convince OSCO of its case (and OSCO's viewpoint was not without merits) then there would have been a danger that the adoption of systems thinking would have

gone no further. The potential benefits of a high profile first use are so great that the author would certainly recommend that this strategy be tried again, providing there is a high degree of confidence that a good model can be delivered.

Another factor that was important for the successful adoption of systems thinking was that the management within UKCO appreciated the need to carefully manage the initial use of systems thinking. They accepted that it was important that the first few applications should be seen to be successful and so care was taken to select problems which had a good chance of success. It was also appreciated by UKCO that there would be a need for external help and guidance in the early stages and funding was forthcoming to support this. The company was also prepared to fund a certain amount of staff training.

Finally, the supply chain workshop proved to be an effective way of quickly expanding the number of people within the organisation that had some experience of systems thinking. It is true that the workshop did not provide participants with modelling skills, but it did give them sufficient grounding in systems thinking so that they were able to identify new areas of application.

#### 4.9.4 The Supply Chain Workshop

The material upon which the supply chain workshop was based, the Beer game and the generic supply chain model, is now over thirty years old (Forrester 1961; Jarmain 1963). During the design of the workshop, there was some concern as to the relevance of this material; there have of course been a number of changes in supply management practice over this period of time and there was a worry that the participant might find the exercises too easy. There were good reasons for using this material, the simple nature of the models made them easy to grasp and the generic nature of the models allowed the material to be used in a wide range of training situations.

These fears were unfounded; the participants created the usual problematic behaviour when they played the Beer game. It was interesting to observe that although one of the participants had an understanding of how the Beer game functioned and had some fore-knowledge of the type of behaviour to expect, he was unable to influence the overall behaviour of the game; he was as much a prisoner of the system structure as the other players.

The participants did not find the exercises with the supply chain model easy, in particular, they had difficulty in understanding the resonance behaviour of the supply chain. These results show that the Beer game and the generic supply chain model are still useful tools for management training. They also reveal that the logistics managers from a major company were unaware of basic dynamic insights that date back to the early days of system dynamics. This is a worrying observation and it suggests that there must be a large number of managers in other areas who are ignorant of the basic dynamic behaviour of the systems they control.

#### 4.9.5 A Generic Model of the Product Improvement Process

A useful new generic model was identified during the course of the product improvement modelling work. This model is potentially applicable to a wide range of manufacturing companies. It is also of relevance in the context of software engineering. This model has also been used as the basis of a case study<sup>1</sup> for use in training managers in systems thinking.

#### 4.9.6 The Modelling for Learning Framework

Finally the work described in this chapter provides examples of the application of system thinking which are consistent with the modelling for learning framework presented in Chapter 2. This is demonstrated in Figure 4.24 which shows the specific activities carried out with UKCO superimposed upon the generic modelling for learning framework.

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<sup>1</sup>See Chapter 3 for more details.

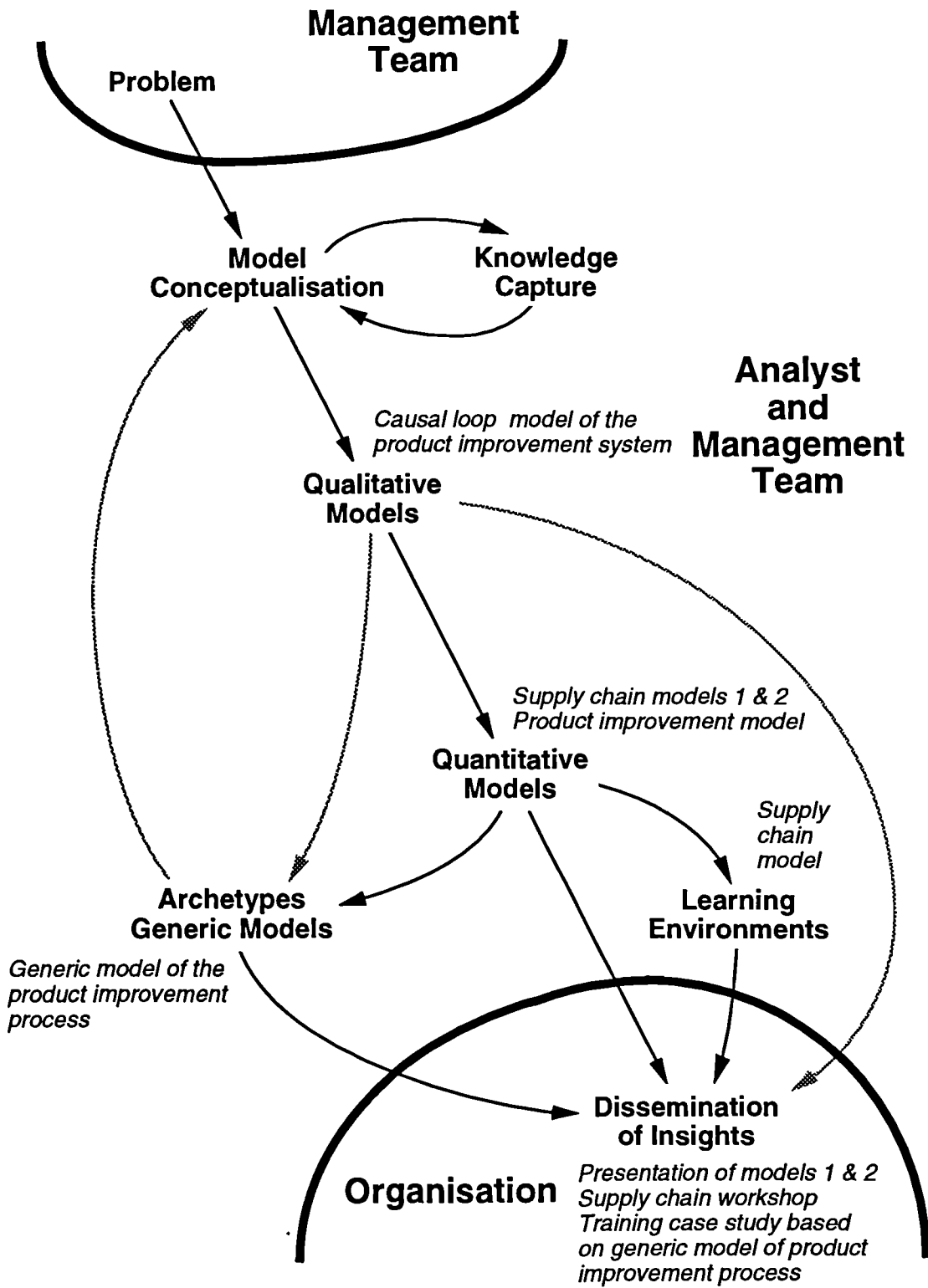


Figure 4.24 Modelling activities in the modelling for learning framework

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# Chapter 5

## *Generic Structures*



## 5.1 Introduction

In this chapter a review of the generic structures found within systems thinking is given. A reduced set of base archetypes is identified and their behaviour is explored. The material presented in this chapter forms the basis of a new framework for model conceptualisation which is described in Chapter 6.

## 5.2 Generic Structures

Generic structures have always been a part of systems thinking; they date back to the earliest days of systems dynamics. The model of the production-distribution system, that is presented in *Industrial Dynamics* was clearly seen by its author, to be a generic structure:

...the system is general in nature and can represent many industrial situations.

Forrester (1961, p. 137)

The existence of generic structures may have been long accepted, but for a long while, little was done to develop the idea.

There is at present, nothing close to an accepted definition of a generic structure: it is unlikely that two system dynamicists discussing the concept will be talking about the same thing.

Paich (1985)

In order to clarify the situation, Paich provided the following definition of a generic structure:

...that there is something “generally applicable” about certain feedback structures to the extent that they deserve the label generic structures.

Paich (1985)

This definition immediately raises the question as to what is meant by the phrase “generally applicable.” Paich realised this problem and identified:

...two broad viewpoints on generic structures which differ primarily in their level of generality.

Paich (1985)

The first kind of generic structure (Type 1) is defined as:

...feedback mechanisms that are transferable to new situations within a particular field.

...structures that might be considered generic to a specific field or area of study.

Paich (1985)

The second kind of generic structure (Type 2) is defined as:

...structures that can be transferred across fields.

Paich (1985)

Finally Paich identified a third kind of generic structure (Type 3) in the work of Richmond (1987); “atoms of structure” and Richardson and Pugh (1981); “commonly recurring rate/level structures”. A summary of these three types of generic structure is given in Table 5.1.

**Table 5.1 Paich’s classification of generic structures**

<b>Structure</b>	<b>Description</b>
Type 1	Structures generic to one problem domain.
Type 2	Structures that are transferable between problem domains.
Type 3	Sub-structures that are found as building blocks in many models.

Before describing these structures in detail it will be useful to apply names to the different types of structure; the following names<sup>1</sup>, which have been chosen to reflect common current usage are suggested, see Table 5.2.

<sup>1</sup>A more formal set of names has been applied to Paich’s categories by Lane and Smart (1994). These are, for Type 1 to Type 3 structures respectively; Canonical Situation Models, Archetypes for Behavioural Insight and Abstract Micro-Structures.

Table 5.2 Applying names to the generic structures.

Structure	Name
Type 1	Generic Models
Type 2	Archetypal Structures
Type 3	Building Blocks

### 5.2.1 Generic Models (Type 1 Structures)

A generic model is a generalisation and simplification of a model that was developed to address a specific problem. A generic model can be used in two different ways; firstly as a starting point to model similar systems and secondly as a means of dissemination insights about the behaviour of a particular class of system. It can be seen from the above that generic models are problem domain specific.

The ideas behind this approach; model reusability and “off the shelf” solutions have their roots in the discipline of Operational Research. The life-cycle of a generic model is shown in Figure 5.1. Two examples of this kind of generic model are the Market Growth and Investment Model (Forrester 1968) and the Research and Development Project Model (Richardson and Pugh 1981).

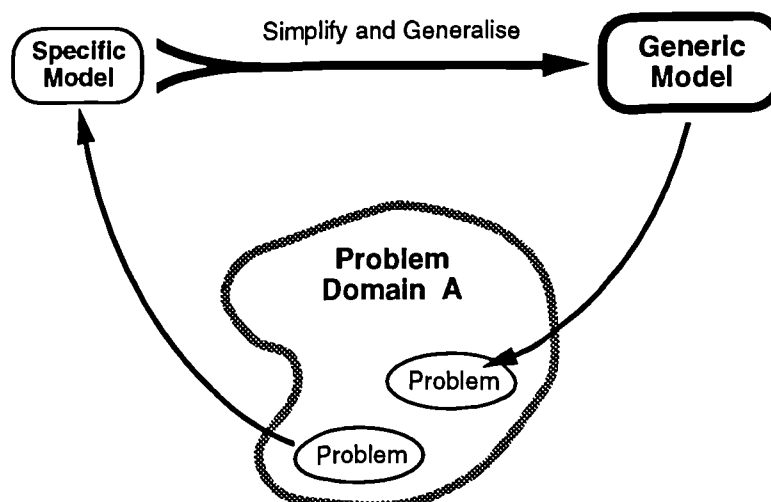


Figure 5.1 The generic model life-cycle

The phrase generic model is often taken to imply a qualitative model. There is however, no reason why a generic model should not be a qualitative model.

### 5.2.2 Archetypal Structures (Type 2 Structures)

The idea of a generic model is found in many disciplines, which although they are concerned with the study of systems do not necessarily themselves adopt a systemic viewpoint. In contrast the idea of an archetypal structure is closely related to the concept of system itself. It is an expression of the idea of universality; that all systems, irrespective of their physical representation have shared properties, structures and behaviours.

Archetypal structures are models of universal system insights. Their purpose is to package the accumulated knowledge of experts about system structure and behaviour in a form that may be easily assimilated by others. In this way the insights that have been gained from the study of a large number of diverse systems can be applied to the study of other systems. The life-cycle of an archetypal structure is shown in Figure 5.2.

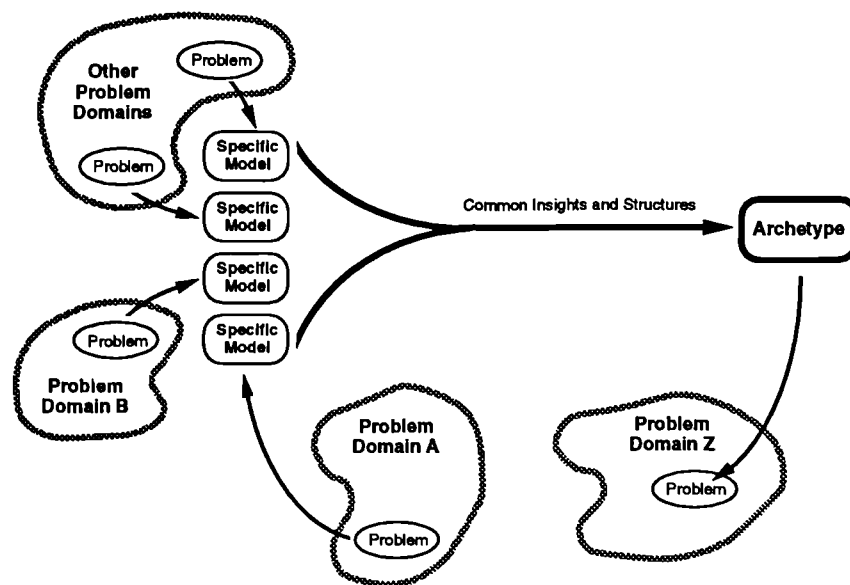


Figure 5.2 The archetypal structure life-cycle

A number of different collections of archetypal structures have been proposed and these will now be described.

### 5.2.2.1 Fundamental Structures

The fundamental structures of systems thinking, balancing and reinforcing feedback loops do satisfy the definition of archetypal structures, but it is more usual to think of them as building blocks.

### 5.2.2.2 A Catalogue of Structures

In systems thinking, the first attempt to produce a set of archetypal structures was by Andersen and Richardson (1980). They proposed a catalogue of structures with which students of systems thinking should become familiar. These structures are quantitative in nature and are defined in terms of abstract modes of behaviour, e.g. overshoot and oscillation. The purpose of these structures is defined as:

The point of having a such a catalogue is to use it to approach understandings of real-world problems. The key to its use is cautious generalisation—the attempt to see general characteristics of structure and behaviour which transfer from one system to another, whatever the surface differences may be.

(Andersen and Richardson 1980)

The emphasis on transferability implies that these structures are not generic models and belong in the category of type 2 generic structures. A full list of the structures is given in Table 5.3.

**Table 5.3 A catalogue of structures**

<b>Structure Name</b>	<b>Loops</b>
First-Order Positive Loop	1
First-Order Negative Loop	1
Sigmoidal Growth Structures	2
Delays	1+
Non-Linear Delays	1+
Overshoot and Oscillation	2
Pure Oscillation	2
Exploding Oscillation	2
Damped Oscillation	2
Non-Linear Oscillators	2

It can be seen from Table 5.3 that these structures are relatively simple containing (with the exception of the delays) at most two loops.

### 5.2.2.3 Computer-Free System Insights

In systems thinking, the first attempt to produce a set of qualitative archetypal structures was by Meadows (1982). Four structures were presented in the form of simple causal loop diagrams, see Table 5.4.

**Table 5.4 Meadow's archetypal structures**

Structure Name	Loops
Policy Resistance	4
Drift to Low Performance	2
Addiction	3
Shifting the Burden to the Intervener	3

The next development built upon the qualitative structures of Meadows (1982) and identified a number of system archetypes.

### 5.2.2.4 The System Archetypes

The development of the system archetypes started was started by Senge (1985) and culminated in the publication of the Fifth Discipline (Senge 1990). This contained the first listing of the systems archetypes.

**Table 5.5 The system archetypes**

Structure Name	Loops	Comments
Accidental Adversaries	4	fifth discipline field book only
Balancing Process with Delay	1	fifth discipline only
Drifting Goals	2	all
Escalation	2	all
Fixes That Fail	2	all
Growth and Under-investment	3	all
Limits to Success	2	all
Shifting the Burden/Addiction	2	all
Success to the Successful	2	all
The Attractiveness Principle	4	fifth discipline field book only
Tragedy of the Commons	3	all

A revised listing which omitted the “balancing process with delay” archetype and made minor changes to the names of some of the others was published in *The System Thinker* (Kim 1992). *The Fifth Discipline Fieldbook* (Senge et al 1994) made some further minor name changes and added two new archetypes to the list; “accidental adversaries” and “the attractiveness principle”. A full listing of all these archetypes is given in Table 5.5.

Archetypes are defined as:

If reinforcing and balancing feedback loops and delays are like the nouns and verbs of system thinking, then the system archetypes are analogous to basic sentences or simple stories that get retold again and again.

(Senge 1990)

...certain common dynamics that seem to recur in many different settings

(Kim 1990)

...eight diagrams that would help catalogue the most commonly seen behaviours

(Senge et al 1994)

There use is seen as:

These “Systems Archetypes” or “Generic Models” embody the key to learning to see structures in our personal and organisational life.

(Senge 1990)

They serve as a starting point from which one can build a clearer articulation of a business story or issue

(Kim 1990)

It can be seen that the system archetypes are not restricted to a single problem domain and are therefore type 2 generic structures. The system archetypes are clearly seen to be a set of qualitative models, although some of them are qualitative representations of quantitative generic models, e.g. “growth and under-investment”.

### 5.2.3 Building Blocks (Type 3 Structures)

The building blocks category contains the most diverse range of structures of any category of generic structure.

#### 5.2.3.1 Modules

Wolstenholme and Coyle (1983) define a set of modular building block as part of a methodology for model building and analysis. There are four different types of modules; the full set is listed in Table 5.6.

**Table 5.6 The modular building blocks**

<b>Module Type</b>	<b>Constituents</b>
Physical flow modules	Undriven flow Simple positive flow Delayed positive flow Bypass flow Transfer flow Delayed (irreversible) transfer flow
Information modules	Direct information Lagged information
Behavioural Modules	Not defined
Control Modules	Not defined

The physical flow modules are a set of simple building blocks, consisting of one or two stocks with associated flows. The information modules are simpler; they represent the normal and averaged (delayed) flow of information. The behavioural and control modules model the interaction between the physical flow modules and the information modules. The difference between the two is that control modules model interactions that are determined by managerial policy whereas behavioural modules represent interactions over which the managers of the system have no direct influence. The nature of these modules depends on context of a particular model and so no generic structures are provided.



### 5.2.3.2 STELLA and Ithink

A number of structures intended for use as model building blocks have accompanied the STELLA and Ithink software and been described in the manuals. The early versions of STELLA (Richmond et al 1987) were provided with structures known as "Generic Processes" and "Generic Sub-Systems", see Table 5.7 and 5.8.

**Table 5.7 The generic processes**

<b>Structure Name</b>	<b>Stocks</b>
External Resource Production Process	2
Compounding Process	1
Draining Process	1
Stock Adjustment Process	1
Implicit Goal-Seeking Process	2
Co-Flow Process	2
Ordering Process	2

**Table 5.8 The generic sub-systems**

<b>Structure Name</b>	<b>Stocks</b>
S-Shaped Growth	2
Overshoot and Collapse	2
Oscillation	2

It can be seen that both types of these structures are relatively simple and consist of one or two stocks. Over time the number of building blocks and their complexity increased considerably. The third version of Ithink (Richmond et al 1993) was accompanied by structures known as "Basic Flow Processes", "Main Chain Infrastructures" and "Support Infrastructures" see Table 5.9, 5.10 and 5.11.

**Table 5.9 The basic flow processes**

<b>Structure Name</b>	<b>Stocks</b>
Compounding Process	1
Draining Process	1
Production Process	2
Co-Flow Process	2
Stock-Adjustment Process	1

**Table 5.10 The main chain infrastructures**

<b>Structure Name</b>	<b>Stocks</b>
Human Resources Main Chain	3
Customer Main Chain	4
Administration Main Chain	5
Manufacturing Main Chain	6
Sequential Work Flow Main Chain	7
Queue/Server Main Chain	7

**Table 5.11 The support infrastructures**

<b>Function</b>	<b>Structure Name</b>	<b>Stocks</b>
Resource	Human Resources: Hiring	1
	Human Resources: Hiring & Training	2
	Human Resources: Attribute Tracking	2
	Human Resources: Productivity	3
	Human Resources: Burnout	1
	Human Resources: Resource Allocation	5
	Physical Capital	1
	Financial Resources	1
	Political Capital	3
Production	Product Production	3
	Service production	4
Score-Keeping	Financial: Cash Flow & Profit	3
	Financial: Debt	3
	Market Share & Relative Attractiveness	4
	Perceived Quality	1
Miscellaneous	Price	2
	Ordering	2
	Shipping	3

## 5.2.4 Issues Arising from the Classification of Generic Structures

A number of issues arise from the classification of the generic structures that is described in the previous section.

### 5.2.4.1 Archetypal Structures

The definition of an archetype rests upon the concept of a universal system insight. The problem is that this raises the question as to what constitutes universality. The most extreme definition would require that for a system insight to be considered universal it should be possible to find examples of it across the whole range of systems; managerial, social, economic, ecological, biological and physical. If this definition is adopted then virtually all the system archetypes are eliminated, with the exception of “limits to success”, because of the lack of examples in physical systems. A case can be made for dropping the requirement for examples from physical systems on the grounds that physical systems are different from all the other systems in the list because they lack purpose.

In fact the system archetypes are essentially a set of universal insights about managerial and socio-economic systems, although examples may be found in other kinds of systems. This is to be expected because they have been developed to aid the understanding of such systems. It is an example of the trade off that exists between universality and usefulness. At one extreme:

...principles that are valid across all systems must be very general.

(Eden and Harris 1975)

At the other extreme there is the generic model that may be very useful for tackling a particular type of problem, but which offers no more widely applicable insights.

If an archetypal structure is to be useful then it must be sufficiently universal so that it can be widely applied yet also specific enough so that its application produces useful insights. The systems archetypes cover this entire range. The most universal of the archetypes, “limit to success”, provides the most obvious insight.

The fact that growth cannot continue for ever without restriction has been well known for a long time. At the other extreme the “growth and under-investment” archetype, is a generic model, that provides insights that are only of use in understanding the management of growth within a company. The rest of the systems archetypes fall between these two extremes.

#### **5.2.4.2 Building Blocks**

Some of the building blocks; in particular the ‘support infrastructures’ and the ‘main chain infrastructures’, are sufficiently complex, in terms of both size and behaviour to be considered as generic models in their own right.

#### **5.2.4.3 Conclusions from Classifying the Generic Structures**

It can be seen that there is some degree of overlap between the categories, in particular between archetypal structures and generic models and also between building blocks and generic models. The lack of a perfect classification is not a problem because the real issue is:

...what is useful, insightful, or significant about generic structures.

Paich (1985)

There is a broad consensus as to the usefulness and applicability of the type 1 structures (generic models) and type 3 structures (building blocks), but none in the case of the archetypes. To some, archetypes are central to systems thinking (Senge 1990), while others see their role as very minor (Forrester 1992). The importance that individuals attach to archetypes is as would be expected related to their view of the importance of qualitative modelling in general.

It is interesting to note that although the main characteristic of systems thinking that distinguishes it from other system approaches to problem solving, is its support of both qualitative and quantitative modelling, there has been little investigation of the interface between these two approaches to modelling. The remainder of this chapter will look at the archetypes in more detail and the issues

involved in moving structures across the interface between qualitative and quantitative modelling.

### 5.3 Problems with the Systems Archetypes

There are two areas of difficulty with the system archetypes. Firstly, the number of system archetypes has changed since their inception; one of the originals has been deleted and two new archetypes have been added. This raises the question as to how comprehensive the current list is and raises the possibility that there may be other systems archetypes waiting to be discovered.

Secondly, the system archetypes are qualitative structures and it has not been demonstrated that these qualitative structures are capable of generating the behaviour that has been claimed. These issues will now be investigated.

#### 5.3.1 Towards a Core Set of Archetypes

It has already been established that some of the archetypes are more archetypal than others. Therefore rather than seeking to add further, possibly less universal archetypes to this list, it would be more useful to identify a subset of the system archetypes that are truly universal and which can be used as building blocks for the other more complex archetypes.

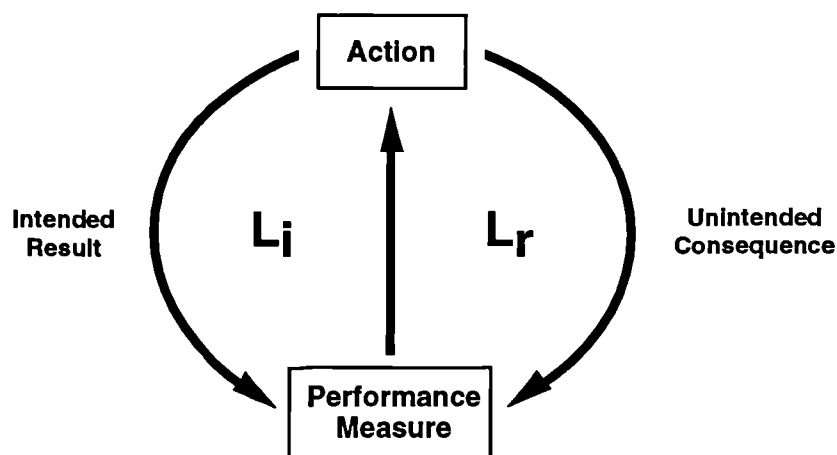


Figure 5.3 The generic management process

Such a subset does exist; it is known as the “Core Archetypes” (Wolstenholme and Corben 1993). The core archetypes arise from consideration of the generic process of management. It is possible to represent any managerial problem in terms of an intended action and a system reaction, see Figure 5.3.

The intended action may be the elimination of some kind of problematic behaviour in which case the intended action loop ( $L_i$ ) will be a balancing loop. Alternatively the intention may be to generate growth in which ( $L_i$ ) will be a reinforcing loop. The system will react in some way to this managerial action. This reaction is represented by the system reaction loop ( $L_r$ ) which may be either balancing or reinforcing. Combining the two possible intended actions with the two possible system reactions gives the set of four core archetypes shown in Figure 5.4. These structures represent the four different ways of ordering a pair of feedback loops.

		Intended Action	
		Control	Growth
System Reaction	Opposition	<b>B/R</b>	<b>R/B</b>
	Competition	<b>B/B</b>	<b>R/R</b>

Figure 5.4 The core archetypes

Some of the core archetypes correspond one to one with system archetypes, for example, the B/R core archetype and the ‘Fixes that Fail’ system archetype. Other of the core archetypes can be mapped onto more than one of the system archetypes. For example, the B/B core archetype has the same loop structures as the ‘Eroding Goals’ and the ‘Escalation’ system archetypes.

### 5.3.2 Behaviour of the Archetypes

The aim of the remainder of this chapter is to identify quantitative structures that correspond to the two loop system archetypes and to explore their relationship to the core archetypes. The main difficulty in attempting to quantify an archetype is that by its very nature, it is possible to build a large number of models which exhibit the particular archetypal behaviour. The aim is therefore to identify the simplest possible quantitative structure that is capable of generating the claimed behaviour for each of the two loop archetypes.

In order to achieve this aim, a three staged program of research was carried out. Firstly, the problems that occur when structures are quantified were investigated and a set of guidelines were formulated to help achieve the unambiguous association of structure with behaviour. Next, the behaviour of abstract generic models of the simplest possible two-looped structures was explored. Finally, the behaviour of these simple structures was compared with that claimed for the two loop archetypes and where possible archetypes were associated with the appropriate generic model.

## 5.4 Issues In Moving From Qualitative To Quantitative Structures

This section discusses the issues involved in moving across the boundary between qualitative and quantitative structures and a set of rules for the quantification of qualitative structures is presented.

### 5.4.1 Problems with Causal Loop Diagrams

In one of the few pieces of work to look at the boundary between qualitative and quantitative modelling, Richardson (1976) identified a number of problems with causal loop diagrams, these will now be discussed.

#### 5.4.1.1 Signing Causal Links

The traditional definition of polarity for a causal link is:

If a change in the variable at the tail of a link causes the variable at the head of the link to move in the same direction then the link is positive (+) or same (S). If the head variable moves in an opposite direction to the tail variable then the link is negative (-) or opposing (O).

There is a problem when this definition is applied to a link between a flow and a stock (Richardson 1976). For example, if an inflow to a stock decreases (but remains positive) the stock will still continue to increase, although more slowly, so the traditional definition breaks down, see Figure 5.5.

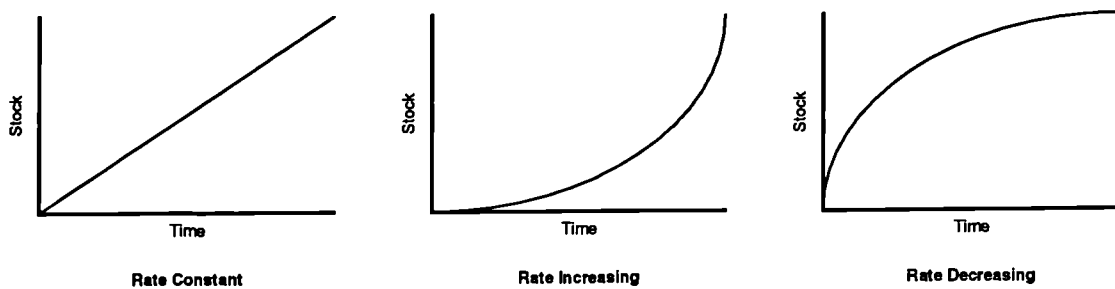


Figure 5.5 The effect of changing rates on a stock after Richardson (1976)

In order to overcome this problem Richardson proposes an improved definition for causal link polarity:

A has a positive influence on B if an increase (decrease) in A results in a value of B which is greater (less) than it would have been had A not changed.

This new definition does solve the problem, but it is possible to keep the original definition if we add the requirement that the test of polarity is made when the loop is in equilibrium, see Figures 5.6a-5.6c.

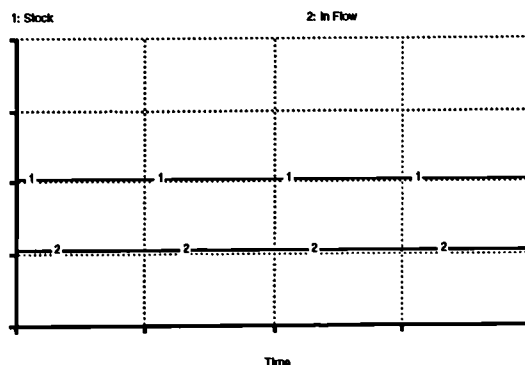
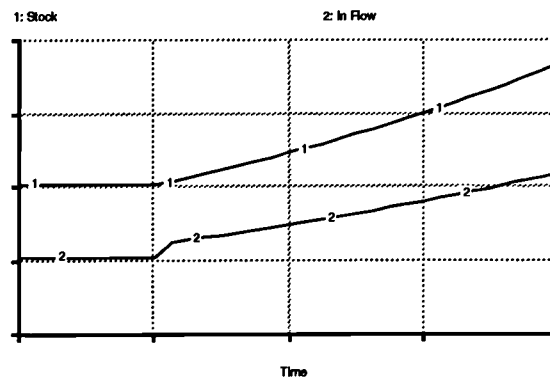
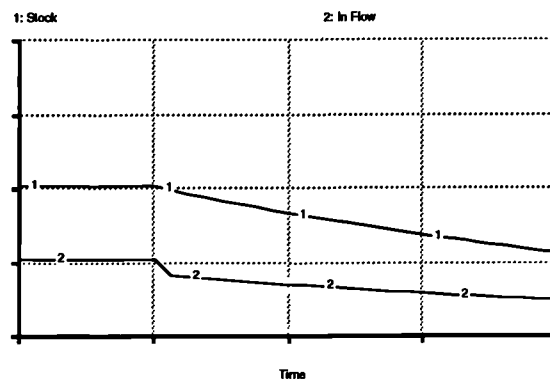


Figure 5.6a The effect of a constant rate on a stock at equilibrium





**Figure 5.6b** The effect of an increasing rate on a stock at equilibrium



**Figure 5.6c** The effect of a decreasing rate on a stock at equilibrium

It can be seen that now the stock and flow move in the same direction, a decrease in the inflow does produce a decrease in the stock and an increase in the inflow produces a corresponding increase in the stock.

#### 5.4.1.2 Hidden Qualitative Loops

The minor stock to flow loops that occur in a model's major feedback loops and the balancing loops that occur within delays and smoothing structures are often omitted from causal loop diagrams (Richardson 1976). This is not a major problem because such loops should become apparent when the structure is quantified.

#### 5.4.1.3 Net Rates

The use of net rates in models can cause ambiguity in the sign of causal links and cause hidden loops. Consider the population model shown in Figure 5.7.

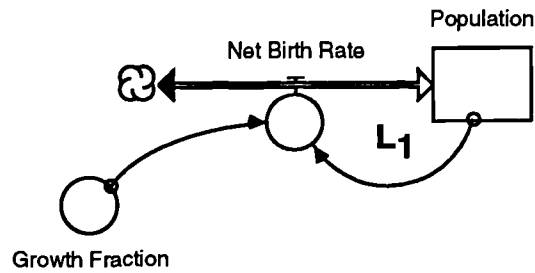


Figure 5.7 Population model with a net birth rate

If the parameter 'growth fraction' is greater than zero then the link between 'net birth rate' and 'population' is positive in nature and the loop  $L_1$  is a reinforcing loop. If on the other hand the parameter 'growth fraction' is less than zero then the link between 'net birth rate' and 'population' is negative and the loop  $L_1$  is a balancing loop with an implied target population of zero. The way to eliminate this uncertainty is to avoid the use of net rates and explicitly represent the pair of reinforcing and balancing loops that are implicit in the net rate. Figure 5.8 shows the population model to which explicit reinforcing ( $L_1$ ) and balancing ( $L_2$ ) loops have been added.

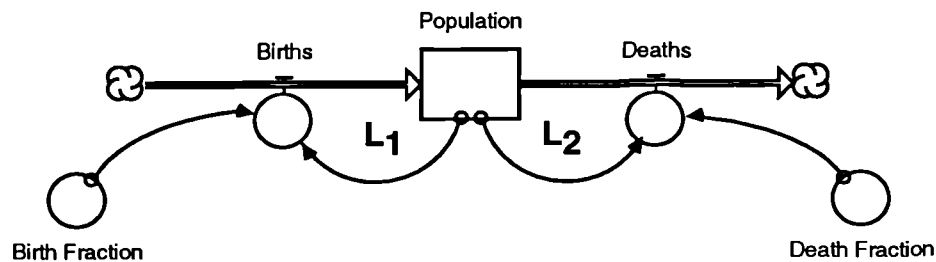


Figure 5.8 Population model with explicit reinforcing and balancing loops

#### 5.4.1.4 Net Rates and Biflows

The *ithink* software supports two different types of material flow; biflows and uniflows, see Figure 5.9. The difference between a uniflow and a biflow is that a uniflow allows material to flow in one direction only. That is, if the rate equation is negative then it is ignored and the flow assumes a value of zero. In contrast, a biflow allows material to flow in both directions. If the rate equation is negative then the material flows in the opposite direction to normal.

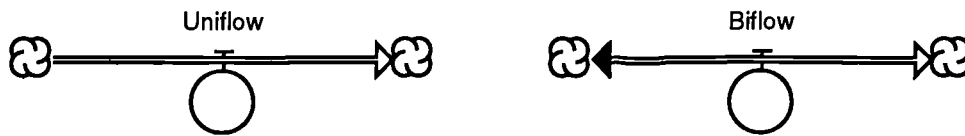
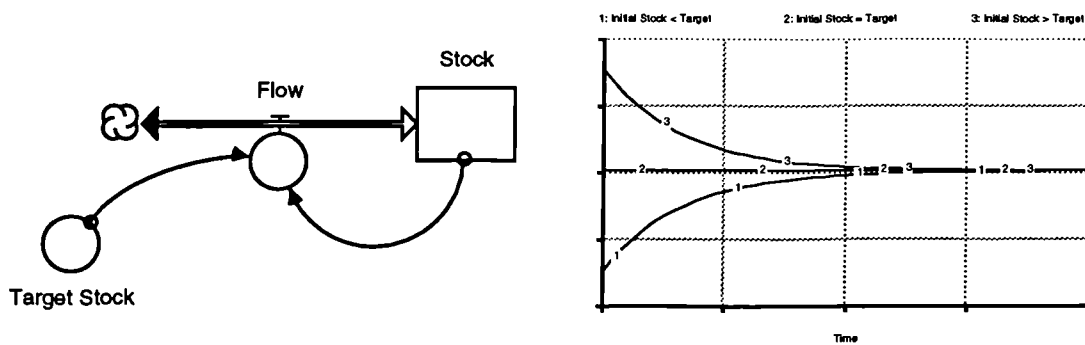


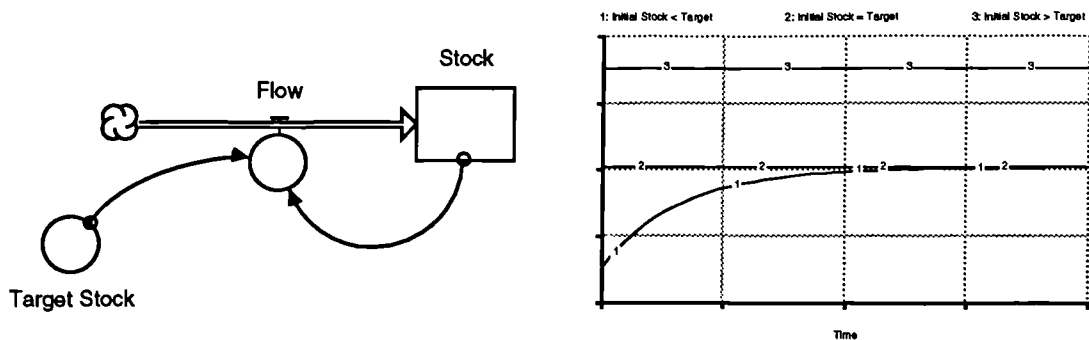
Figure 5.9 Itthink's material flows

It might appear that net rates and a biflows are identical, however this is not the case. It is true that all net rates must be biflows, but not all biflows are net rates. The ambiguity in the structure shown in Figure 5.7 arises because the parameter 'Growth Fraction' is allowed to assume negative values, not because a biflow has been used. The effect that the use of biflows and uniflows have on the behaviour of the reinforcing and balancing loops is shown in Figure 5.10. It can be seen that the use of uniflows artificially restricts the behaviour of these structures.

**Balancing Loop with Biflow**



**Balancing Loop with Uniflow**



**Reinforcing Loop with Biflow**

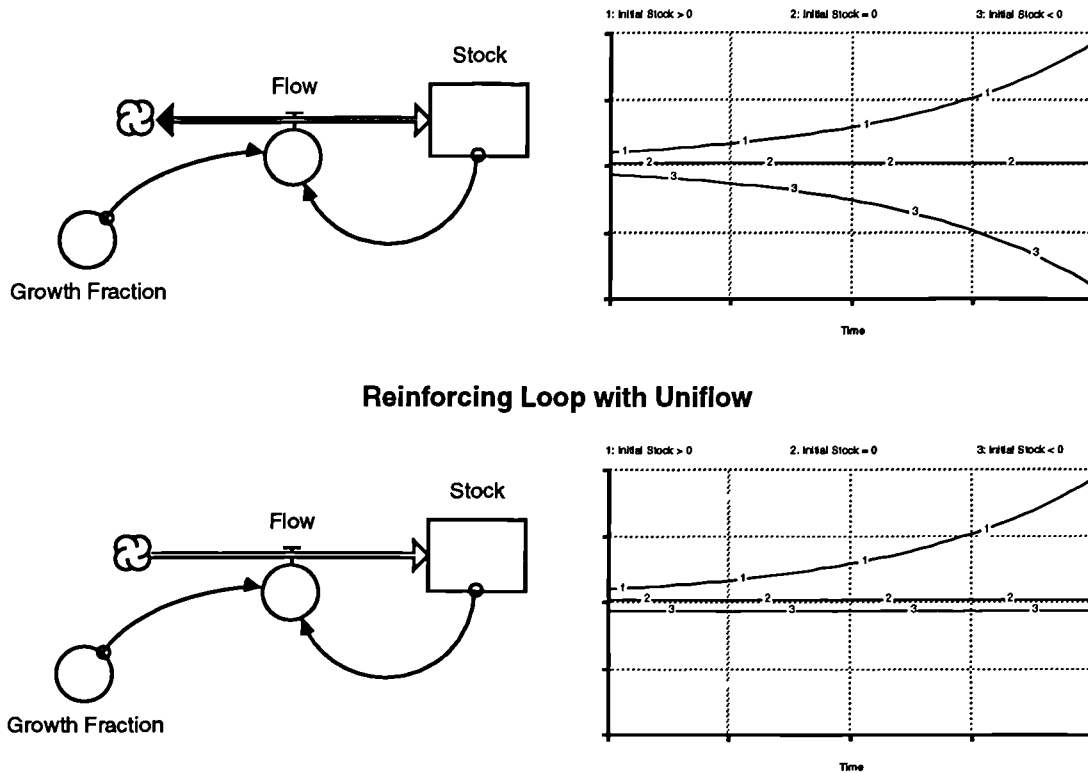


Figure 5.10 The effect of flow type on behaviour

### 5.4.1.5 The Feud Model

To illustrate some of these problems and demonstrate the danger of inferring behaviour from qualitative structures, Richardson presents a model of a feud between two families as an example, see Figure 5.11.

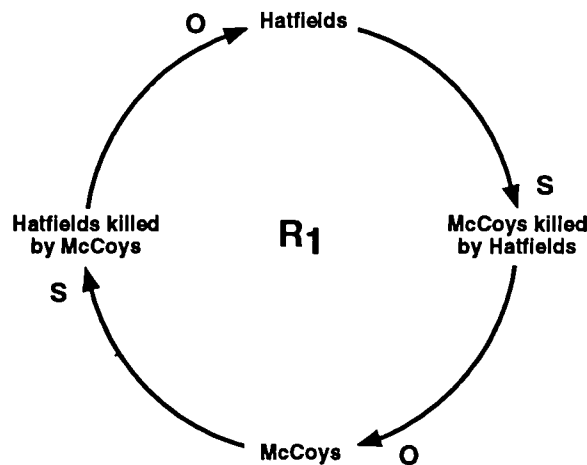


Figure 5.11 The Hatfields and McCoys feud model after Richardson

The model takes the form of a single reinforcing loop. Richardson shows that this structure is capable of producing the target seeking type of behaviour that is more usually associated with a balancing loop. In order to explore the behaviour of this structure, an itthink model was built, see Figure 5.12. This model is capable of reproducing the behaviour claimed by Richardson, see Figures 5.13a-5.13b.

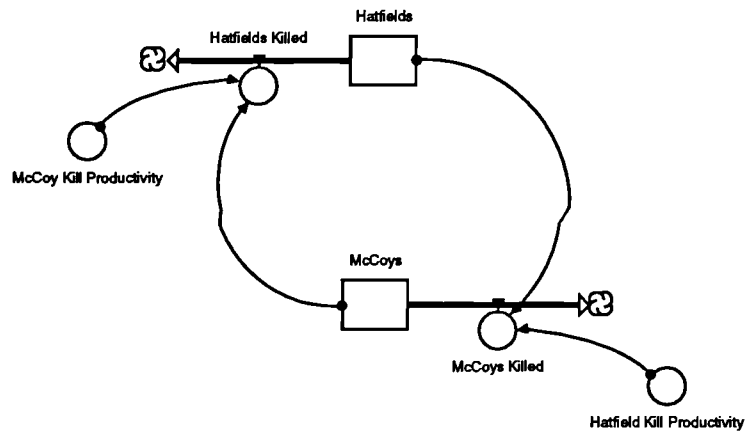
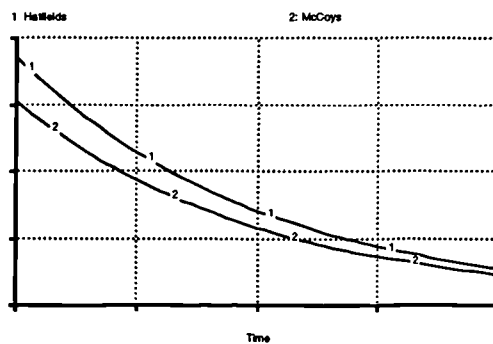
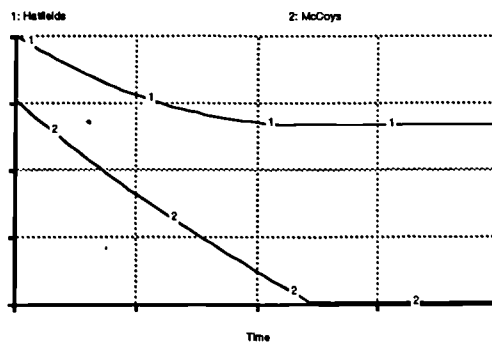


Figure 5.12 Itthink model of the Hatfields and McCoy's feud



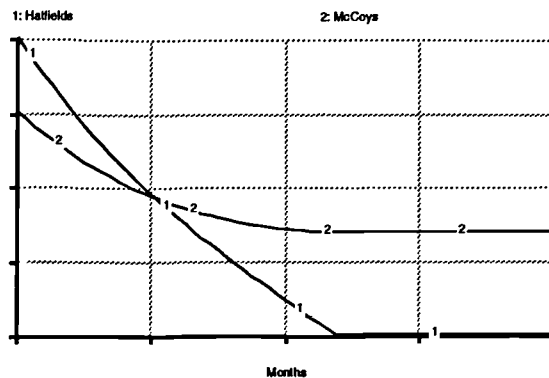
$$INITIAL(\text{Hatfields}) = INITIAL(\text{McCoy's}) * \sqrt{\frac{\text{McCoy Kill Productivity}}{\text{Hatfield Kill Productivity}}}$$

Figure 5.13a Behaviour of the itthink feud model



$$\text{Hatfield Kill Productivity} = \text{McCoy Kill Productivity}$$

Figure 5.13b Behaviour of the itthink feud model



Hatfield Kill Productivity < McCoy Kill Productivity

**Figure 5.13c Behaviour of the ithink feud model**

Figure 5.13a show the target seeking behaviour of the feud model and the initial conditions required to produce this behaviour. Figure 5.13b shows the behaviour that occurs when both sides are equally proficient killers, but one side initially outnumber the other. If one side is more proficient at killing than the other then they may be able to overcome an initial numerical disadvantage, see Figure 5.13c.

Richardson states that the behaviour shown in Figure 5.13a is:

...rather a special case in which numbers and firepower balance out.

and comments on the behaviour shown in the other two graphs:

Without additional negative feedback loops in the model to prevent Hatfields or McCoy becoming negative, the scenarios in [Figures 5.13b and 5.13b] would continue overtime to show McCoy becoming more and more negative and Hatfields growing! The loop indeed has the destabilising character we associate with positive [reinforcing] feedback loops but not over the meaningful time period of the feud and not for some initial conditions.

It is apparent that the structure we are discussing is not a single reinforcing loop, but is in fact a three loop structure consisting of one reinforcing and two balancing loops, see Figure 5.14.

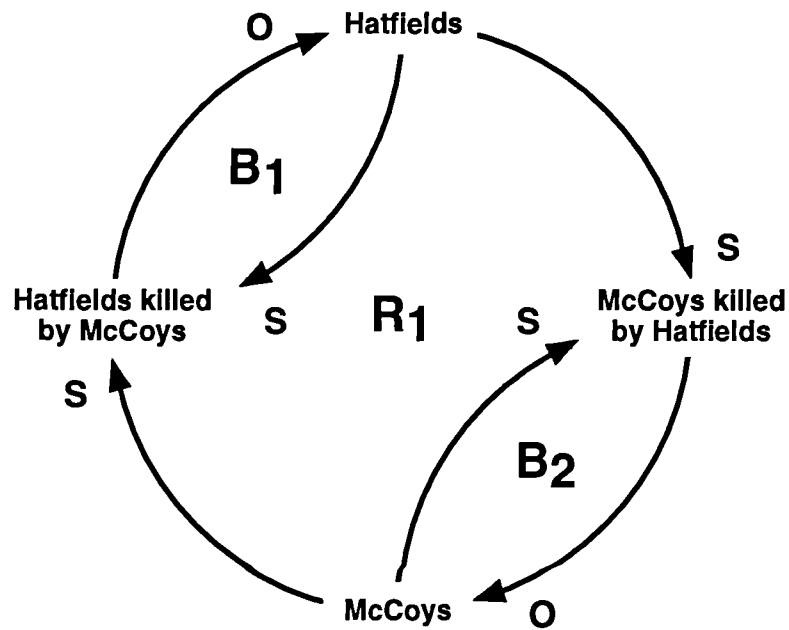


Figure 5.14 The modified Hatfields and McCoys feud model

If these extra balancing loops are removed, by turning the stocks' non-negativity constraints off and the model's behaviour is further unconstrained by replacing the uniflows with biflows, then the behaviour produced is consistent with a reinforcing loop. Figure 5.15, show the modified itthink model and the behaviour of this model is shown in Figure 5.16.

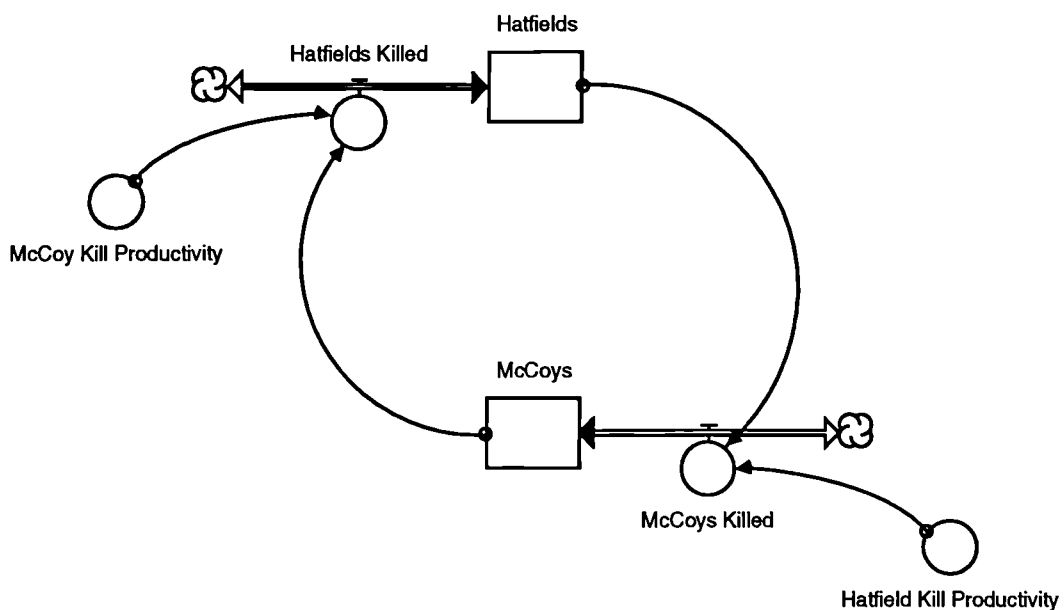


Figure 5.15 Modified itthink model of the Hatfields and McCoys feud

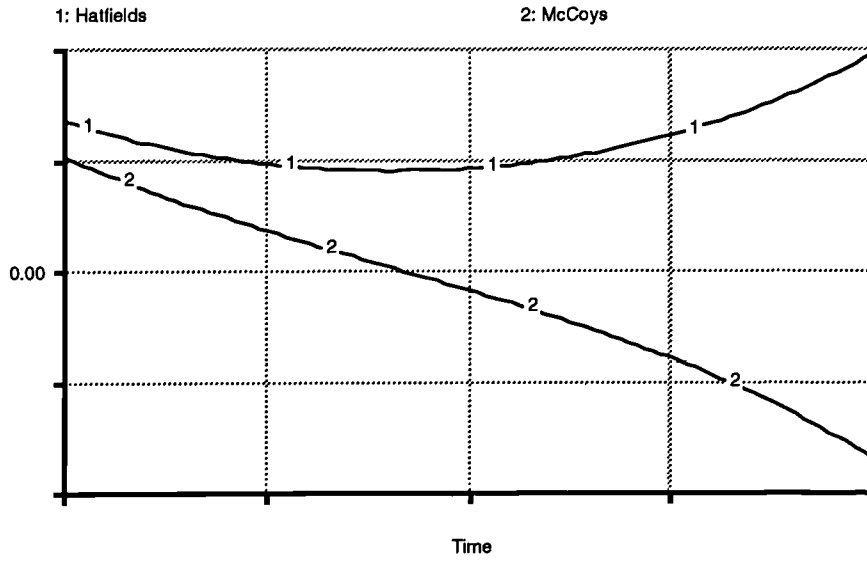


Figure 5.16 Behaviour of the Modified itthink feud model

In all of the simulations presented so far, the model has not been started in equilibrium. If the model is started in equilibrium and then shocked by killing one of the McCoys, then purely reinforcing behaviour is observed; see Figure 5.17. The Hatfield grow exponentially towards plus infinity and the McCoys grow exponentially toward minus infinity.

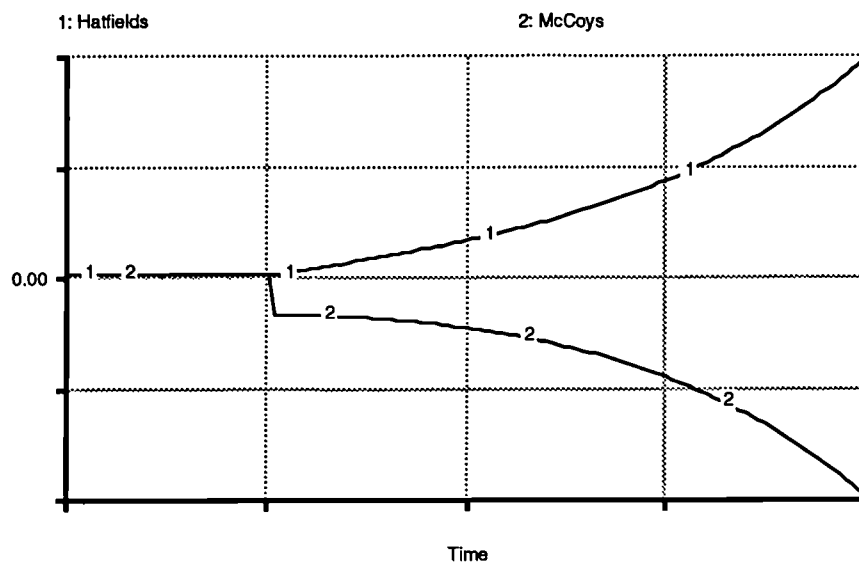


Figure 5.17 Behaviour of the Modified itthink feud model when shocked from equilibrium



This shows that the claimed target seeking behaviour is an artefact caused by running the model with non-equilibrium initial conditions. Richardson claims that the behaviour shown in Figure 5.17 is not meaningful in terms of the feud model. This is undoubtedly true, but this fact should be taken as an indication that the wrong structure has been chosen to model the feud system. It should not be used to argue that the true behaviour of the structure is represented by the false dynamics produced by a model that is run with non-equilibrium starting conditions.

Two valuable lessons emerge from this discussion. The first is the need to ensure that structures are properly initialised when carrying out simulations to determine their behaviour. The second is that it is dangerous to argue about the behaviour of generic structures from the viewpoint of a specific example. It is much better to investigate the behaviour of structures in the abstract and then consider their applicability.

## 5.4.2 Problems with Ithink Maps

It is also possible to identify a number of ways in which an itthink map can obscure loop structure.

### 5.4.2.1 Hidden Quantitative Loops Created by Convertors

The use of convertors (auxiliary variables) may create hidden loops. Consider the structure shown in Figure 5.18, which appears to contain two loops.

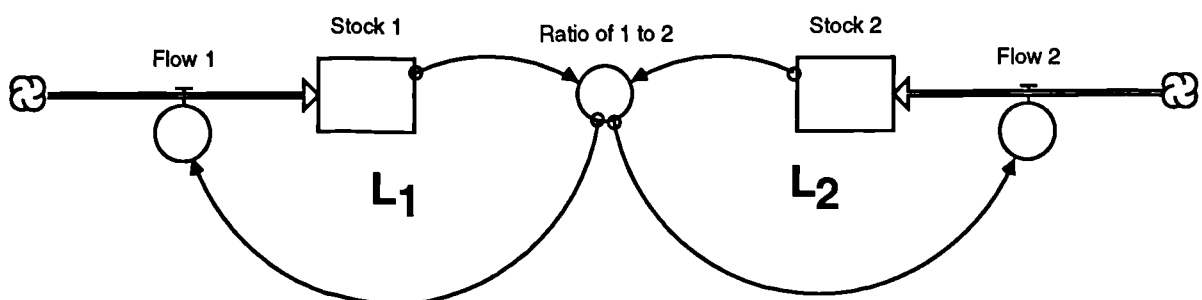


Figure 5.18 An itthink map with a hidden loop

If however the convertor 'Ratio of 1 to 2' is eliminated from the model, so that the map only contains stocks and flows, it can be seen that there are in fact three loops, see Figure 5.19.

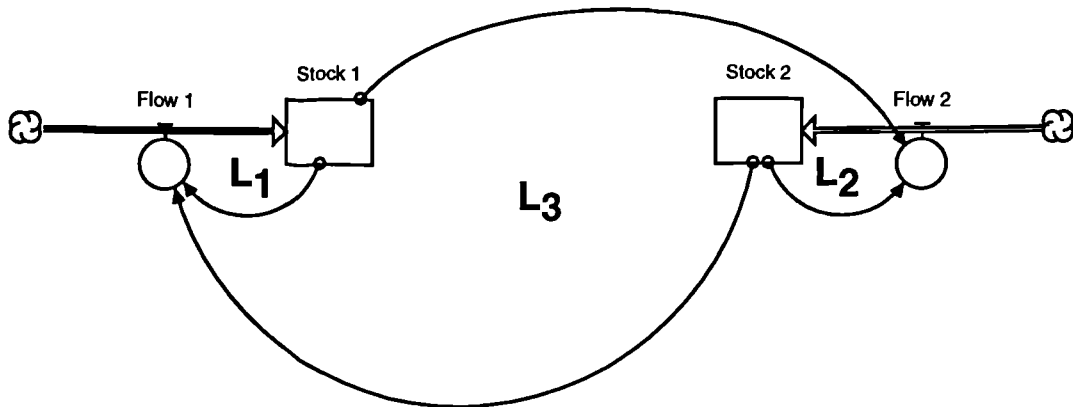


Figure 5.19 The hidden loop revealed

Any itthink map can be simplified so that it consists of only stocks and flows. The relationships defined in the convertors are combined into the flow equations. This is a useful way of clearly demonstrating how many loops a particular structure contains.

#### 5.4.2.2 Hidden Quantitative Loops Created by Built-in Functions

Some of the built-in functions contain implied stocks which create 'hidden' loops. For example, the itthink map of the SMTH1 built-in contains a balancing loop, see Figure 5.20. Other examples of built-ins which contain implicit loops are; DELAY, FORCST, SMTH1, SMTH3, SMTH3 and TREND.

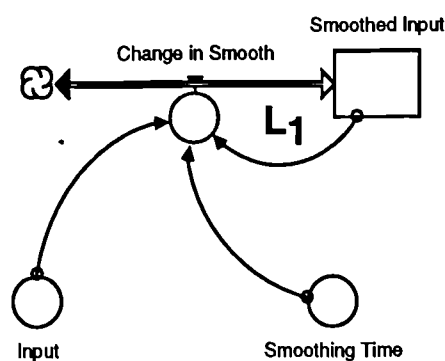


Figure 5.20 The itthink map of the SMTH1 built-in function

These hidden loops may or may not be of significance to a particular structure's behaviour. In order to make all loops explicit in the itthink map of a structure, the built-ins can be replaced with the corresponding explicit stock and flow representation.

### 5.4.2.3 Hidden Quantitative Loops Created by Non-Negativity Constraints

Ithink has the facility to impose a non-negativity constraint on a stock (Peterson and Richmond 1993). Non-negativity is turned on and off using a check box in stock dialog box, see Figure 5.21.

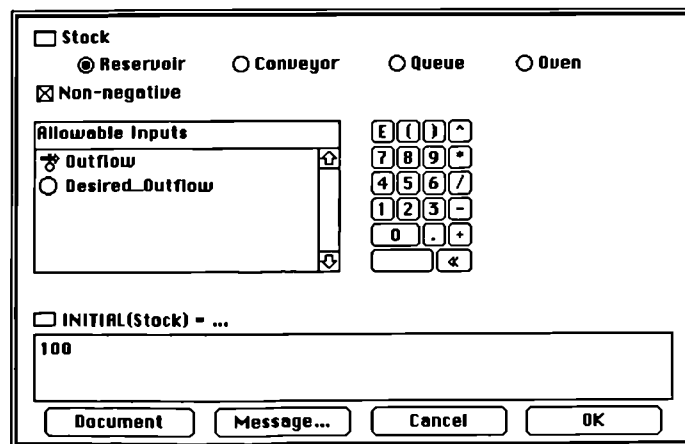


Figure 5.21 The non-negativity constraint

This non-negativity constraint has the effect of creating a hidden balancing loop. Consider the simple stock and flow structure shown in Figure 5.22.

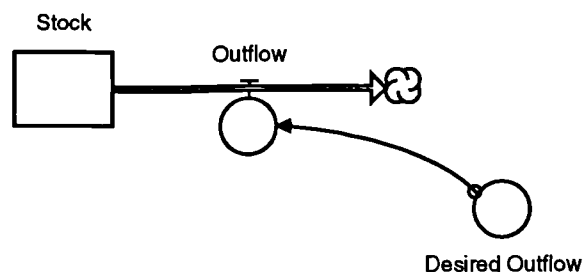


Figure 5.22 Simple stock and flow structure

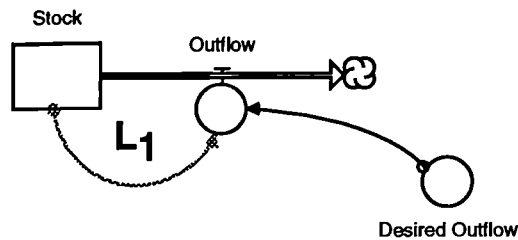
The equation for the outflow is:

$$\text{Out\_Flow} = \text{Desired\_Outflow}$$

If the non-negativity constraint is turned on then this equation effectively becomes:

$$\text{Out\_Flow} = \text{MIN}(\text{Desired\_Outflow} * \text{DT}, \text{Stock}) / \text{DT}$$

It can be seen that the value of the stock is used in this equation. This implies that there is an information link between the stock and flow which in turn implies the existence of a feedback loop, see Figure 5.23.

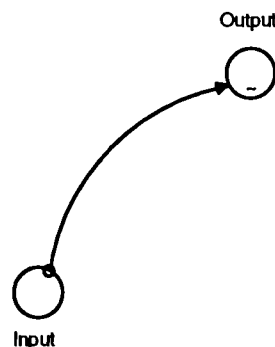


**Figure 5.23** Hidden feedback loop created by non-negativity constraint

In order to avoid hidden loops the non-negativity constraint should not be used. This has an additional benefit of removing an artificial limit on the structure's behaviour.

#### 5.4.2.4 Graphical Functions

The use of graphical relationships can create causal links and hence loops of ambiguous polarity. Consider the structure shown in Figure 5.24.



**Figure 5.24** A causal link defined using a graphical relationship

If the graphical function has, for example, the form shown in Figure 5.25 then it is impossible to determine the sign of this causal relationship. The behaviour of the link is summarised in Table 5.12.

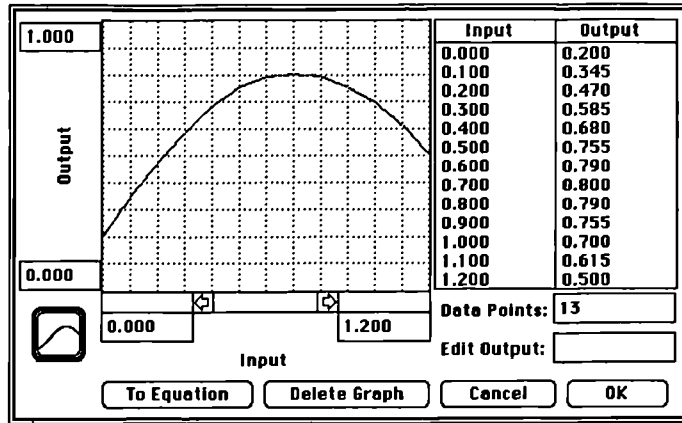


Figure 5.25 A graphical relationship which creates an ambiguous causal link

The problem arises because the graphical function combines two relationships of opposite sign into a single compound relationship. This is analogous to the difficulty with net rates that has already been described.

Table 5.12 The behaviour of the graphically defined causal link

Input Range	Behaviour	Link Type
$0.0 < \text{Input} < 0.7$	Input and output move in the same direction	Same (+)
$0.7 < \text{Input} < 1.2$	Input and output move in the opposite direction	Opposing (-)

The solution is to disaggregate the link into two links, one positive and one negative. This has the effect of creating two feedback loops where previously only one was explicitly represented.

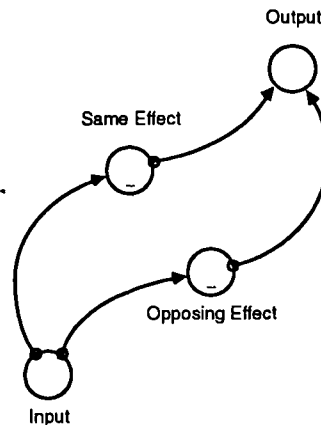


Figure 5.26 Disaggregating the graphical relationship

### 5.4.3 Rules for Quantifying Structures

The material presented in the previous section can be summarised as a set of rules. Following these rules will ensure that a structure is capable of producing the behaviour claimed for it.

These rules were created for the specific purpose of assisting with an investigation of the behaviour of simple abstract loop structures. They are therefore aimed at the experienced modeller who is interested in exploring the behaviour of the fundamental loop structures that are found in many models. They are not intended as general purpose guidelines for the quantification of qualitative structures and are most definitely not aimed at the novice modeller.

#### **General Points**

- The behaviour of structures should be explored in the abstract. Attempting to understand the behaviour of a structure from a specific example can cause confusion. There is a danger of confusing the issue of what is the behaviour of the structure under investigation with the issue of whether this behaviour is applicable to the system being modelled.
- When investigating structures it is better to move from the quantitative to the qualitative because it is not easy to be sure that the simplest representation has been found when starting with qualitative structures and then quantifying them.

#### **Rules Concerning Behaviour**

- A structure's behaviour is defined by the behaviour of its stocks and flows.
- A structure must be capable of being simulated in equilibrium and when shocked produce the behaviour claimed for that structure.

### Rules Concerning Structure

- In order to eliminate hidden loops, all delays and smooths must be explicitly built from stocks and flows.
- Net rates should not be used, they create hidden loops and cause confusion of the polarity of causal links.
- In order to check that a structure's behaviour is not being artificially constrained. It should be established that no change in behaviour occurs when all of the model's unflows are replaced by biflows.
- Graphical functions should not be used, they can cause the same problems as net rates.
- Auxiliary variables or convertors can create hidden loops. In order to overcome this problem, a structure should be condensed down to stocks and flows in order to determine its loop structure.

These rules will now be first applied to the simple single loop structures and then used to discover the behaviour of the more complex two loop structures.

## 5.5 Basic Single Loop Structures

This section describes the development of quantitative models of the basic balancing and reinforcing loops. Additional information on the structures presented in this section; itthink maps, equation listings and graphical output can be found in Appendix 6.

### 5.5.1 Balancing Loops

There are two versions of the balancing loop; that in which there is an explicit target, and that in which there is an implicit target of zero.

#### 5.5.1.1 Balancing Loops with Explicit Target

The causal loop diagram and itthink map of a balancing loop with explicit target are shown in Figure 5.27.

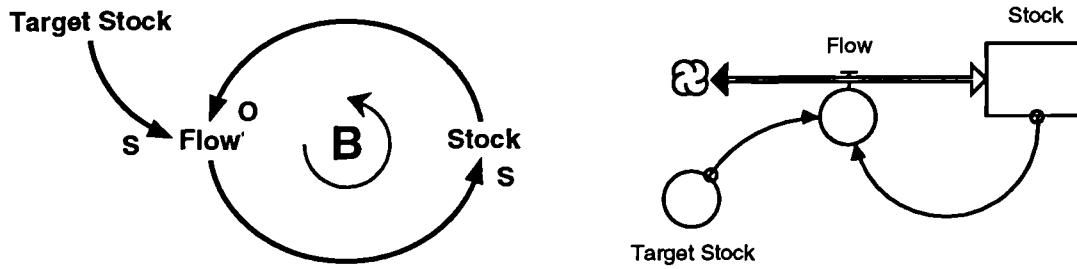


Figure 5.27 Balancing loop with explicit target

The behaviour of this structure is shown in Figure 5.28. The graph shows the effects of applying positive and negative pulses to the system when it is in equilibrium. The response of the system can be seen to be that of opposing the imposed change.

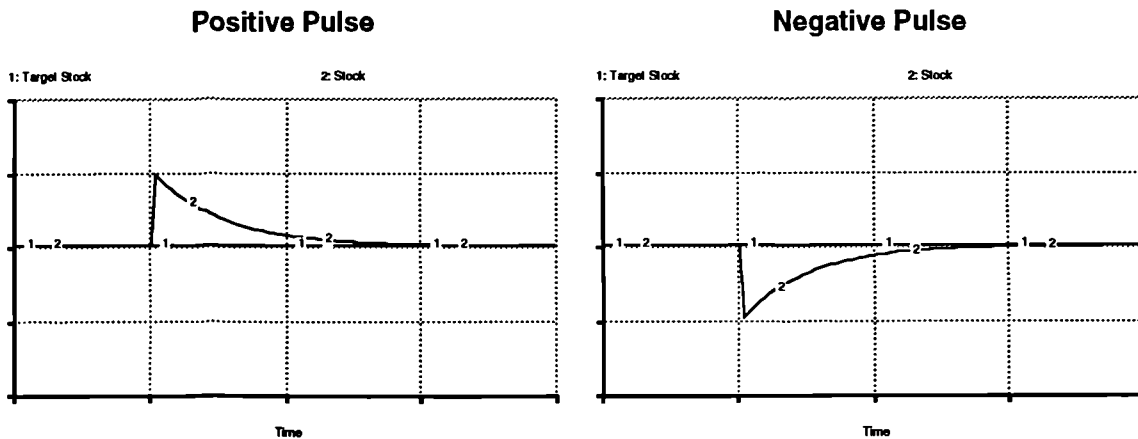


Figure 5.28 Behaviour of the balancing loop with explicit target

### 5.5.1.2 Balancing Loops with Implicit Target

The causal loop diagram and i-think map of a balancing loop with an implicit target are shown in Figure 5.29.

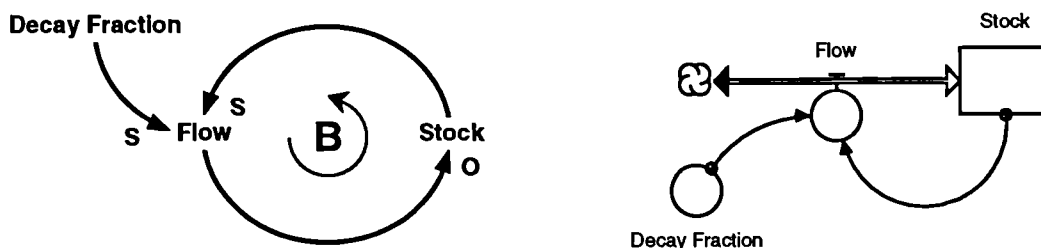


Figure 5.29 Balancing loop with implicit target



The behaviour of this structure is shown in Figure 5.30. The graph shows the effects of applying positive pulse to the system when it is in equilibrium. The response of this system is also that of opposing the imposed change.

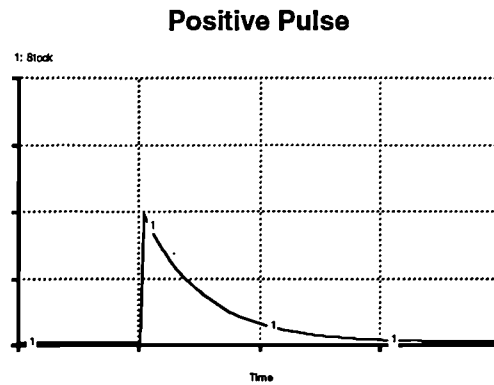


Figure 5.30 Behaviour of the balancing loop with explicit target

### 5.5.2 Reinforcing Loop

Figure 5.31 shows the causal loop diagram and itthink map of a reinforcing loop.

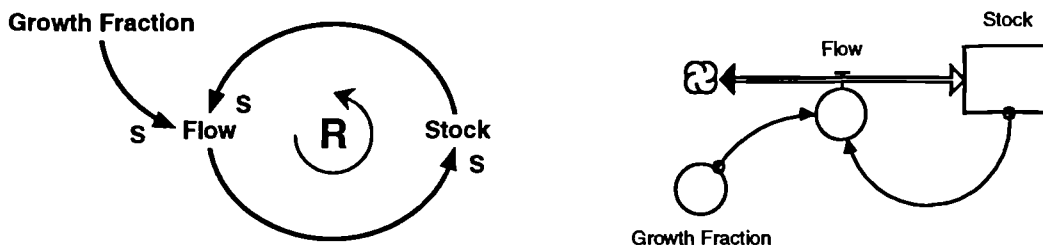


Figure 5.31 Reinforcing loop

The behaviour of this structure is shown in Figure 5.32. The graph shows the effects of applying positive and negative pulses to the system when it is in equilibrium. The response of the system can be seen to be that of reinforcing the imposed change. It should be noted that once a reinforcing loop has started to grow in a particular direction, be that positive or negative, it cannot later begin to grow in the opposite direction. A change in the direction of growth, requires the growth fraction to go negative, which implies that the loop has changed from a reinforcing to a balancing loop.

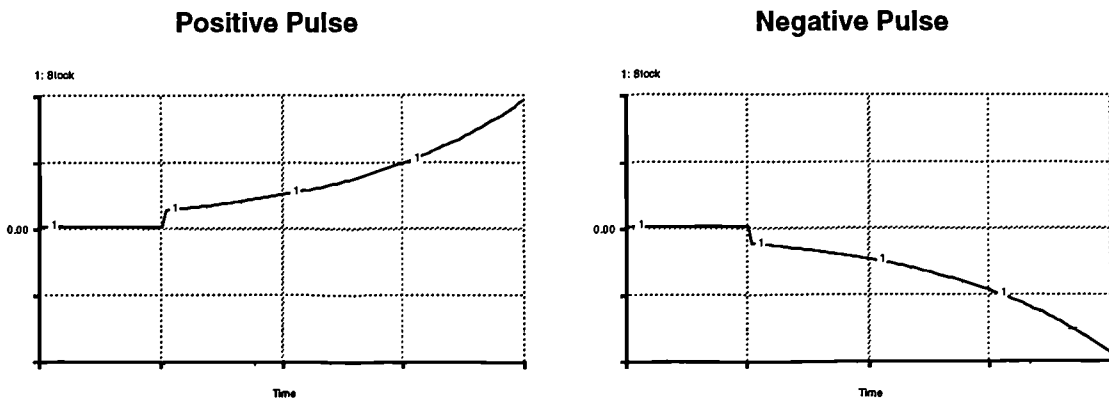


Figure 5.32 Behaviour of the reinforcing loop

There is another version of the reinforcing loops in which there is an even number of opposing links, see Figure 5.33.

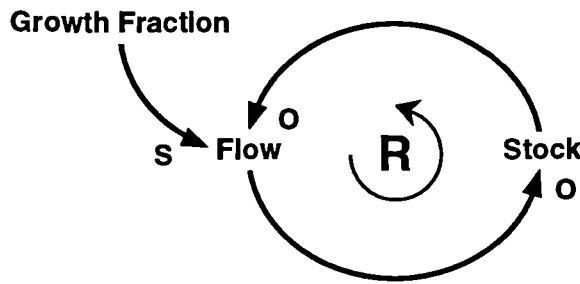


Figure 5.33 Reinforcing loop with two opposing links

The difference in behaviour between the two versions of the reinforcing loop is that in the first case, the stock and the flow grow in the same direction whereas in the second case they grow in opposite directions, see Figure 5.34.

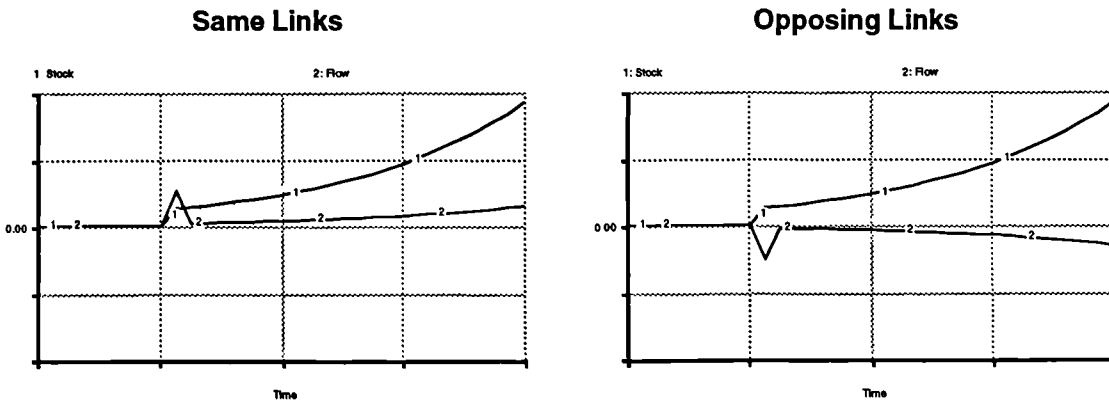


Figure 5.34 Comparison of reinforcing loop behaviour

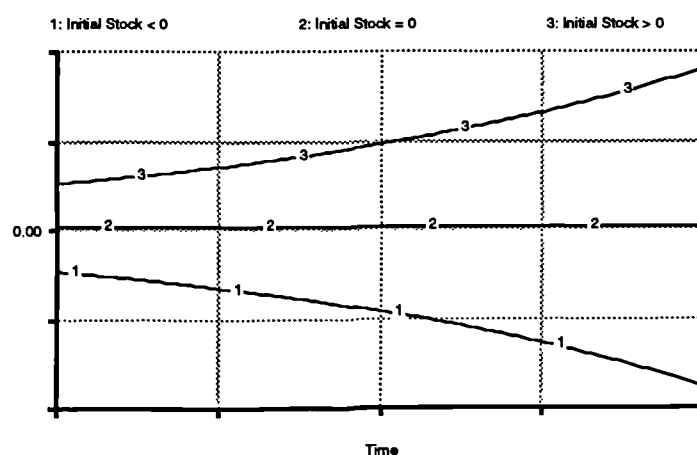
## 5.6 A Comparison of Methods for Achieving Equilibrium

There are two ways of achieving equilibrium for the simple loop structures. Either a value for the stock can be chosen that produces equilibrium or alternatively a parameter value can be selected to achieve the same result. The first approach, which was used in the models presented here, is a much stronger test of equilibrium. An example will demonstrate why this is the case. Consider the simple reinforcing loop that has already been described. The two ways of achieving equilibrium for this structure are listed in Table 5.13.

**Table 5.13 Methods of equilibrium for the reinforcing loop**

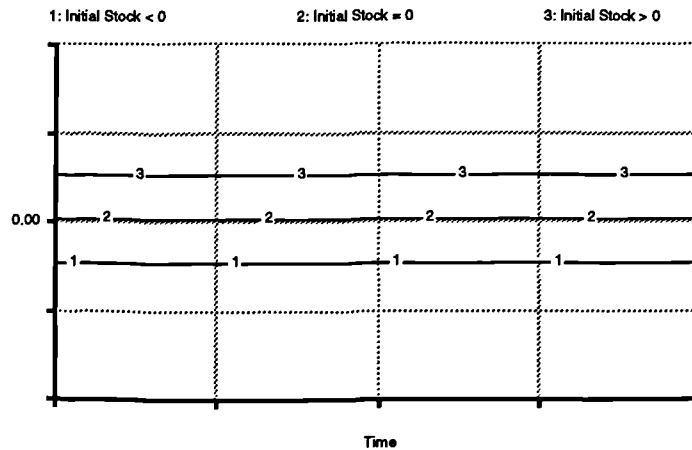
Method	Equilibrium Condition	Method of Perturbation
1	INITIAL(Stock) = 0	Pulse Flow
2	Growth_Fraction = 0	Step Growth Fraction

Method one sets the value of the stock to the only value (zero) that produces equilibrium, see Figure 5.35. Method two, sets the parameter 'Growth\_Fraction' to zero and this produces equilibrium for all values of stock, see Figure 5.36.



**Figure 5.35 Method 1 for obtaining equilibrium**

The problem with the second approach is its artificial nature, by effectively turning the rate off, it forces equilibrium irrespective of the initial values of the stocks.



**Figure 5.36 Method 2 for obtaining equilibrium**

If we consider the feud model again, method 2 would allow the model to produce the false dynamics when shocked from equilibrium. Method 1, which was used in the analysis of the feud model, will only allow the true reinforcing behaviour to be produced when the model is shocked from equilibrium. Therefore method 1 is the only way of achieving equilibrium that should be used when investigating the behaviour of structures.

## 5.7 Multiple Loop Structures

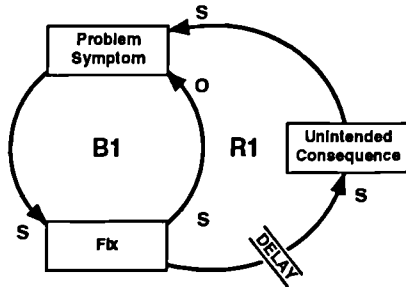
This section describes the development of quantitative representations of the two loop system archetypes. Firstly the two loop archetypes are listed and their claimed behaviour is described. The range of possible quantitative structures with two loops is then developed. Then these two groups of structures are compared and some of the archetypes are associated with quantitative structures. Finally the remaining two loop archetypes are quantified using multiple loop structures. Additional information on the structures presented in this section; itink maps, equation listings and graphical output can be found in Appendix 6.

### 5.7.1 The Two Loop System Archetypes

The five two loop system archetypes; Drifting Goals, Escalation, Fixes that Fail, Limits to Success and Success to the Successful are shown in Figure 5.37. The structures and descriptions are based upon a summary produced by Kim (1992).

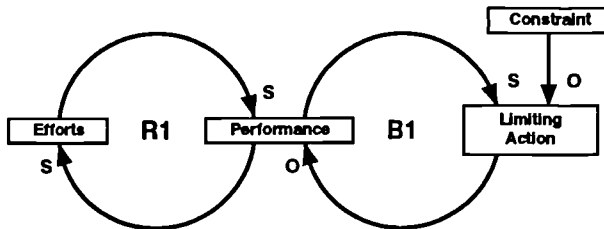
Structure

Description



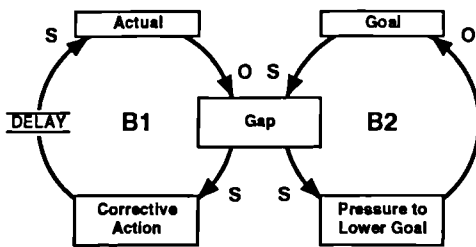
The symptoms of a problem cause a solution to be implemented. This solution creates a short term improvement of the problem's symptoms. In the longer term, the unintended consequences of the solution cause the problem's symptoms to reappear.

Fixes that Fail



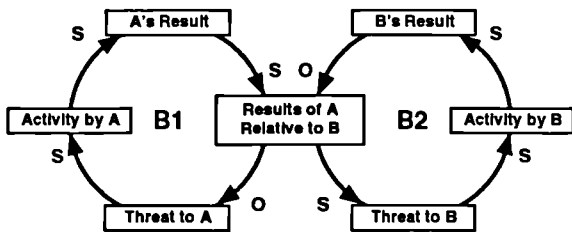
Efforts initially cause performance to improve, until the system hits some kind of constraint. This results in either a reduced rate of growth, no growth or decline.

Limits to Success



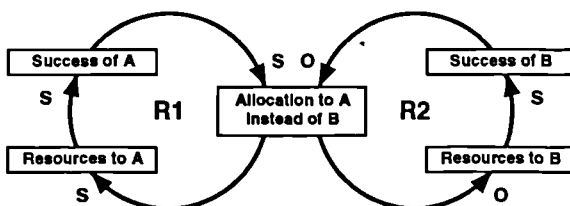
The gap between the desired and actual performance can be eliminated in two ways. Either corrective action can be taken or the goal can be lowered. The first of these takes time to have an effect, whereas the second has an immediate effect.

Drifting Goals



Both sides of the dispute feel threatened by the other. Each side attempts to maintain superiority in response to the perceived threat. The result is escalating growth.

Escalation



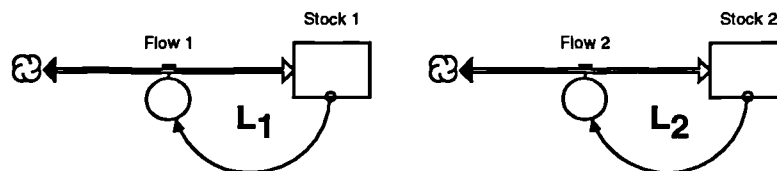
Resources are allocated between two groups on the basis of performance. Initially small discrepancies in performance are amplified into a large performance gap over time by this resource allocation policy

Success to the Successful

Figure 5.37 The two loop system archetypes

### 5.7.2 Simple Two Loop Structures

This section looks at the simple structures that can be built from connecting two single stock feedback loops. The starting point is shown in Figure 5.38. The individual feedback loops may be either balancing or reinforcing.



**Figure 5.38** Two generic single stock feedback loops

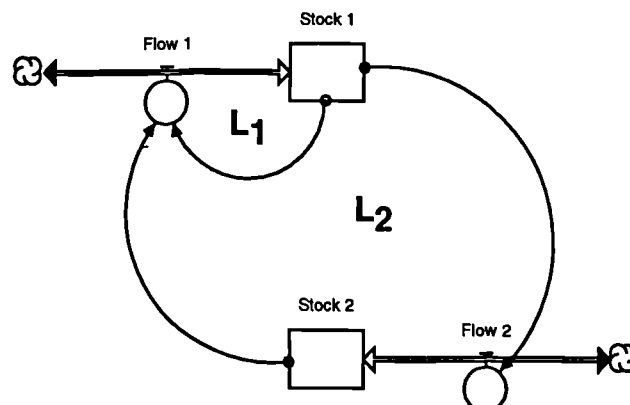
There are three ways in which links between these loop structures can be made:

- Stock to flow information links.
- Common stock.
- Common flow.

The structures that result from applying these methods of linkage to two generic feedback loops will now be described:

#### 5.7.2.1 Stock to Flow Information Link

The result of linking the two generic loops by stock to flow information loops is shown in Figure 5.39. It can be seen from the diagram that one of the loops includes both of the stocks.



**Figure 5.39** Two loops formed by information links

### 5.7.2.2 Common Stock

The result of linking the two generic loops by a common stock is shown in Figure 5.40. It can be seen from the diagram that both of the loops include only one of the stocks.

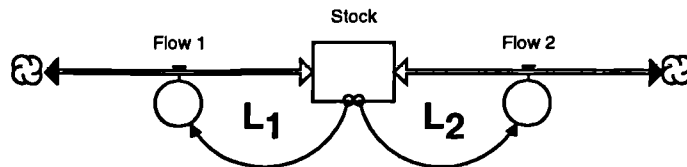


Figure 5.40 Two loops formed by common stock

### 5.7.2.3 Common Flow

The result of linking the two loops by a common flow is shown in Figure 5.41. It can be seen from the diagram that both of the loops include only one of the stocks.

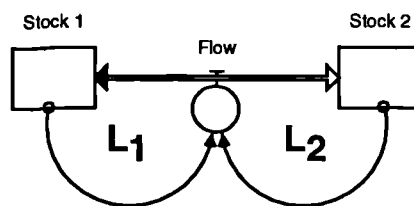


Figure 5.41 Two loops formed by common element: flow

## 5.7.3 Simple Two Loop Structures and the Two Loop Archetypes

The next step is to look at these three simple two loop structures and see how they relate to the five two-looped archetypes.

### 5.7.3.1 'Stock to Flow Information Link' Two Loop Structure

This structure is asymmetric; one of the loops ( $L_1$ ) contains a single stock while the other ( $L_2$ ) contains both the stocks, see Figure 5.39. This asymmetry immediately rules out the structure as a quantification for the 'escalation', and 'success to the successful' archetypes. Initially this structure looks promising as a way of modelling the 'drifting goals' archetype, but the use of the gap in performance to drive the lowering of the goal creates an extra feedback loop ( $L_3$ ), see Figure 5.42.

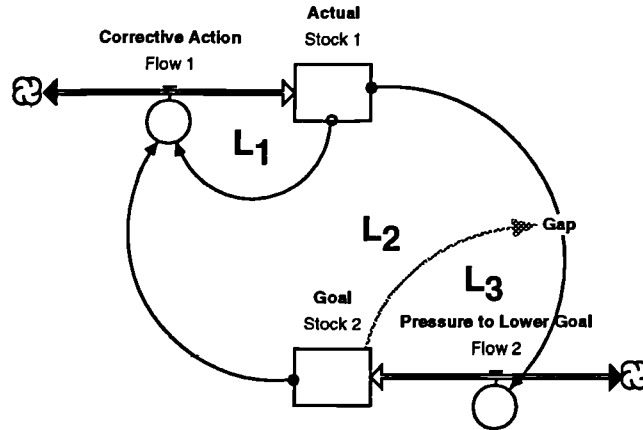


Figure 5.42 The extra loop created by the 'drifting goals' archetype

It is possible to create a 'limits to success' structure when  $L_1$  is a reinforcing loop and  $L_2$  is a balancing loop. The itthink map of this structure is shown in Figure 5.43. Unfortunately this structure produces explosive oscillation, see Figure 5.34.

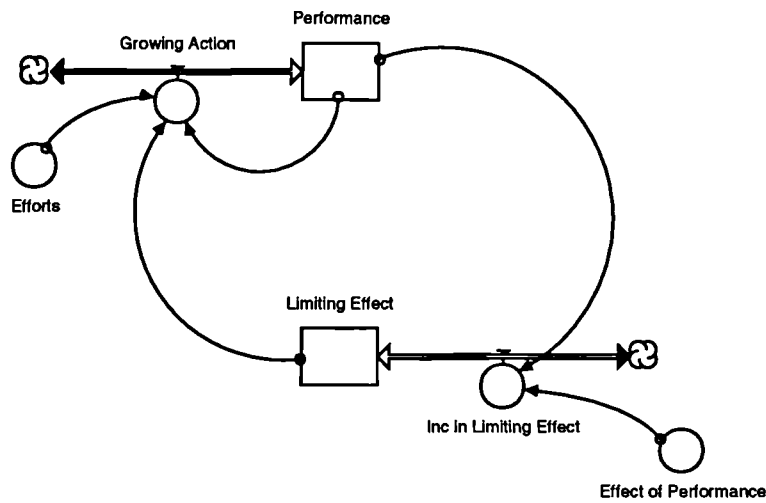


Figure 5.43 Possible structure for the 'limits to success' archetype

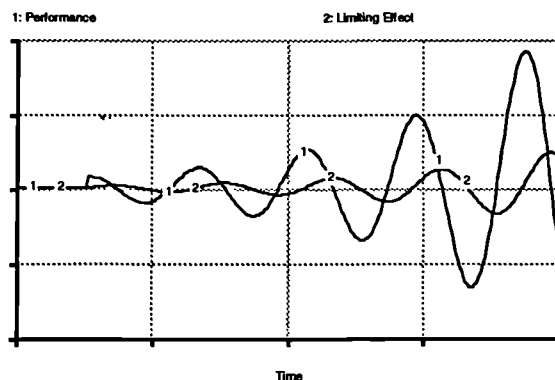


Figure 5.44 Behaviour of possible structure for the 'limits to success' archetype



The loop within a loop that characterises the 'stock to flow information link' two loop structure is reminiscent of the 'fixes that fail' archetypes. The structure corresponds to the 'fixes that fail' archetype when:  $L_1$  is a balancing loop and  $L_2$  is a reinforcing loop, see Figure 5.45.

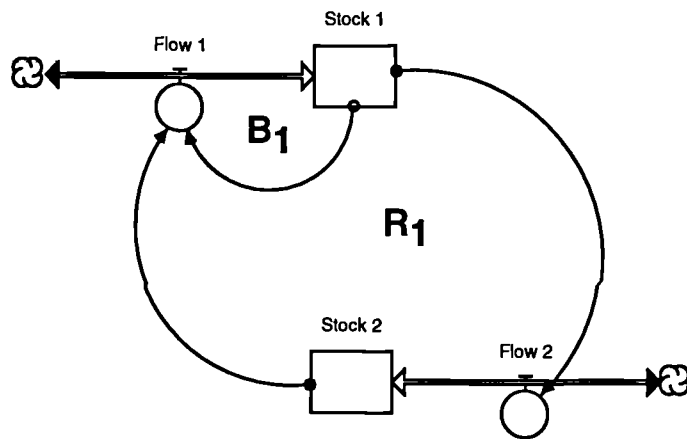


Figure 5.45 The fixes that fail archetype as a basic two loop structure

This correspondence can be made more explicit by naming the model elements and adding a number of convertors, see Figure 5.46.

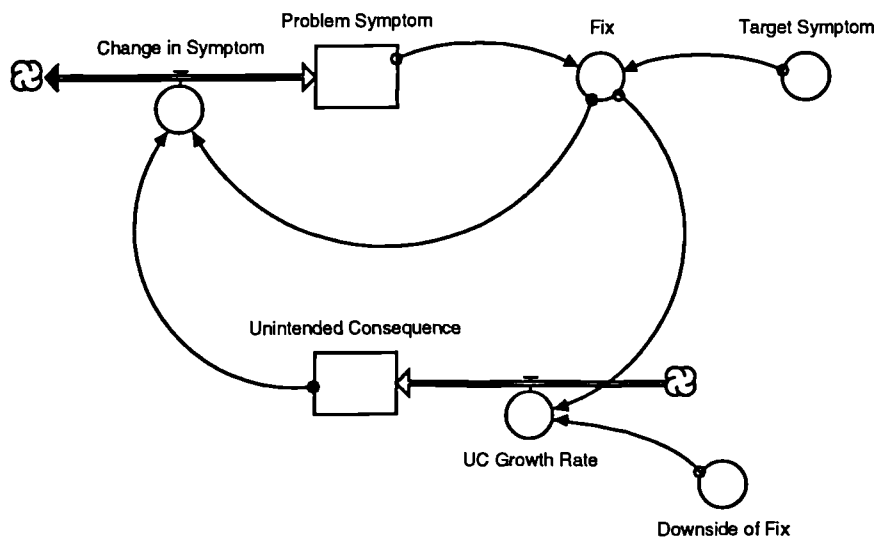


Figure 5.46 The fixes that fail archetype

The behaviour of the 'fixes that fail' archetype is consistent with that claimed for it, see Figure 5.47.

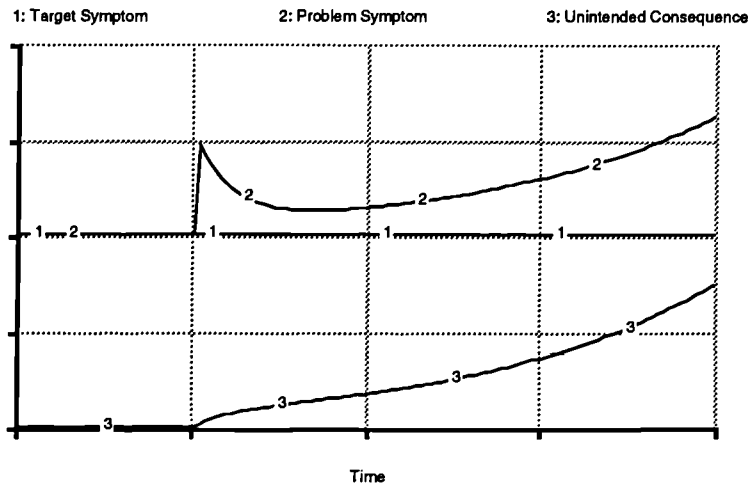


Figure 5.47 Behaviour of the fixes that fail archetype

### 5.7.3.2 'Common Stock' Two Loop Structure

This structure is symmetrical, but the common stock rules out the 'drifting goals', 'escalation' and 'success to the successful' archetypes which clearly must have stocks on each side of the structure. The 'fixes that fail' archetype has already been identified so this leaves the 'limits to success' archetype.

The 'common stock' two loop structure corresponds to the 'limits to success' archetype when:  $L_1$  is a reinforcing loop and  $L_2$  is a balancing loop, see Figure 5.48.

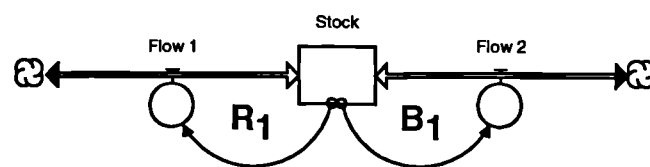


Figure 5.48 The 'limits to success' archetype as a basic two loop structure

This correspondence can be made more explicit by naming the model elements and adding a number of convertors, see Figure 5.49.

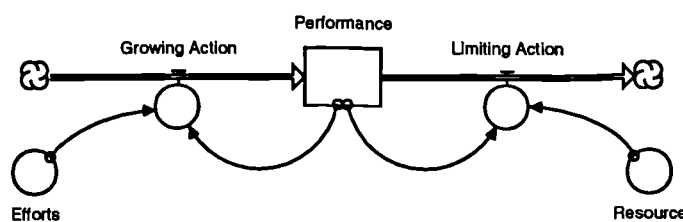


Figure 5.49 The 'limits to success' archetype

The behaviour of the 'limits to success' archetype is consistent with that claimed for the structure, see Figure 5.50.

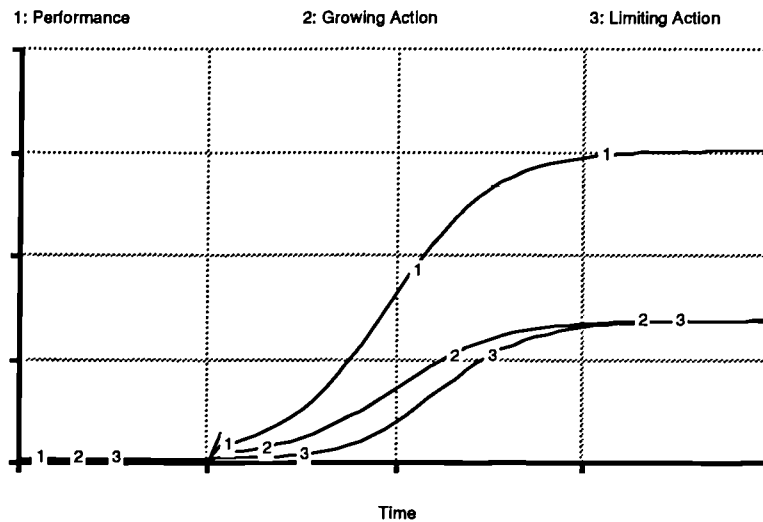


Figure 5.50 Behaviour of the 'limits to success' archetype

### 5.7.3.3 'Common Flow' Two Loop Structure

This structure is also symmetrical, but again the common element, this time a flow, causes problems. The common flow results in a main chain structure which models the process of transporting or converting some kind of resource between two different states. The only archetype to which this kind of process is applicable is 'limits to success.' This archetype has already been quantified using the 'common flow' two loop structure, there is therefore more than one way in which the 'limits to success' archetype can arise from the basic two loop structures.

The 'common flow' two loop structure also corresponds to the 'limits to success' archetype when:  $L_1$  is a balancing loop and  $L_2$  is a reinforcing loop, see Figure 5.51.

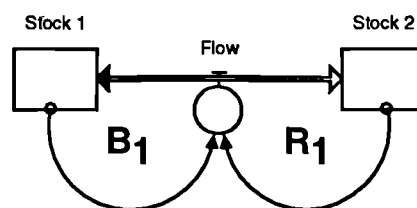
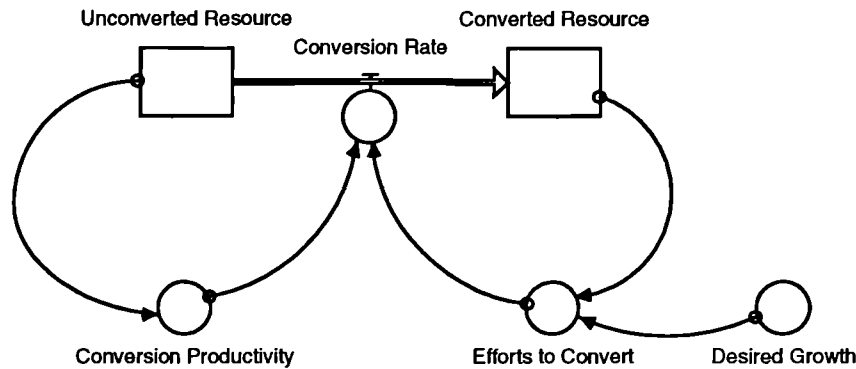


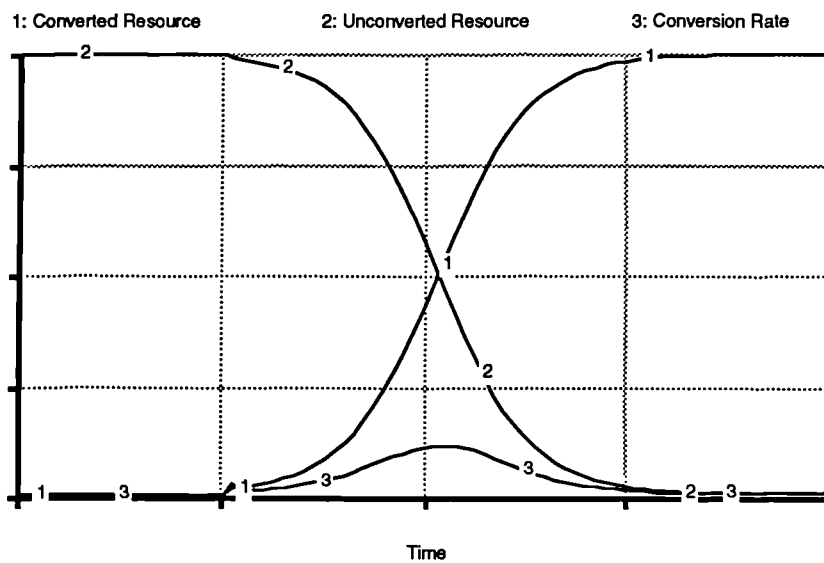
Figure 5.51 The 'limits to success' archetype as an alternative basic two loop structure

This correspondence can be made more explicit by naming the model elements and adding a number of convertors, see Figure 5.52.



**Figure 5.52** An alternative realisation of the 'limits to success' archetype

The behaviour of this version of the fixes that fail archetype is also consistent with that claimed for the structure, see Figure 5.53.



**Figure 5.53** Behaviour of the alternative 'limits to success' archetype

The fact that two of the basic two loop structures correspond to the 'limits to success' archetype shows that there are two physically different implementations for this qualitative structure. The two versions of the structure have an important difference. The first version of the structure applies to sustaining processes and the second version of the structure applies to conversion processes.

### Limits to Success for Sustaining Processes

In this type of system, the resource is continually consumed to maintain the level of success. The resource represents the carrying capacity of the system; the maximum level of performance that the system can sustain. Examples of this type of system are; populations of living organisms and the use of a sales force to provide customer support.

### Limits to Success for Conversion Processes

In this type of system, the resource represents the capacity of the system to convert material from one state to another. The resource is not needed to support material that has already been converted. Examples of this type of system are mineral extraction and debugging software.

The difference between the two types of the 'limits to success' structure can be demonstrated by simulating the two structures and switching off the growth generating loop a quarter of the way through the simulation. The results of doing this are shown in Figures 5.54 and 5.55.

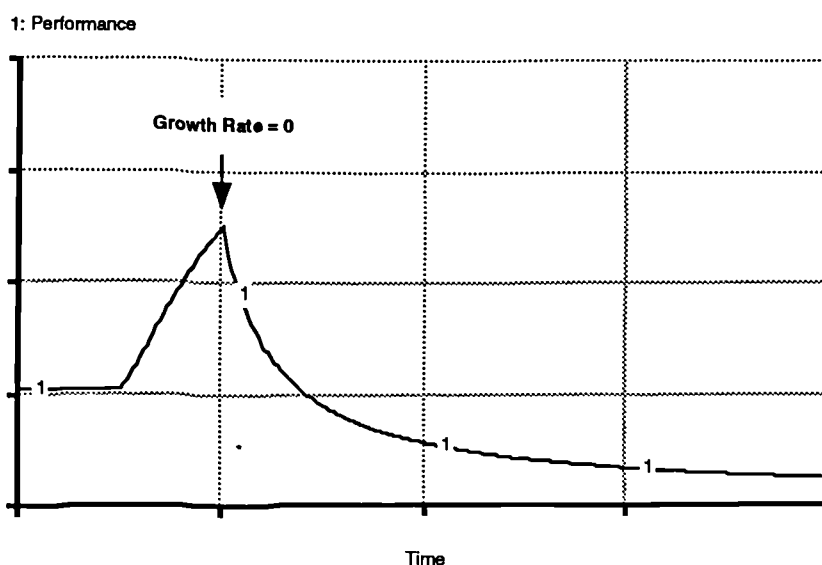
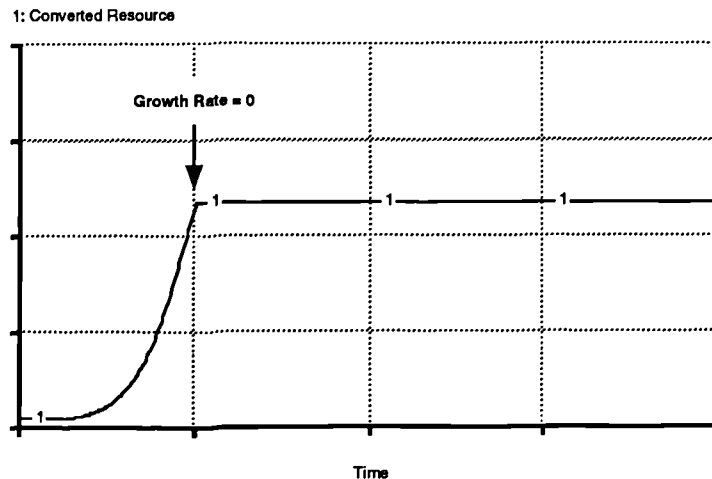


Figure 5.54 Behaviour of the 'limits to success' archetype for sustaining processes



**Figure 5.55 Behaviour of the 'limits to success' archetype for conversion processes**

It can be seen that for the case of the sustaining process; the disabling of the growth loop causes the performance of the system to decay. In the case of conversion process; the disabling of the growth loop causes conversion to stop, but the amount of material converted remains constant.

#### 5.7.3.4 Summary

This section has shown that only two of the two loop archetypes can be associated with the basic two loop quantitative structures. The other two loop archetypes must therefore be related to other more complicated quantitative structures. Therefore there must be a hierarchy of structure within the systems archetypes. This result has confirmed the viewpoint, reached by the author from qualitative considerations, that the 'limits to success' and 'fixes that fail' archetypes are in some way more archetypal than the other archetypes.

In order to discover how the other system archetypes fit into the hierarchy of structure the next section will describe the quantification of the remaining two loop archetypes.

#### 5.7.4 Multiple Loop Structures

In order to quantify the remaining two loop archetypes, it is necessary to investigate multiple loop. In the previous section some characteristics of the

required structures were identified; it should be symmetrical and contain independent stocks and flows for each half of the archetypes. The simplest structure that meets these requirements has three loops and is shown in Figure 5.56.

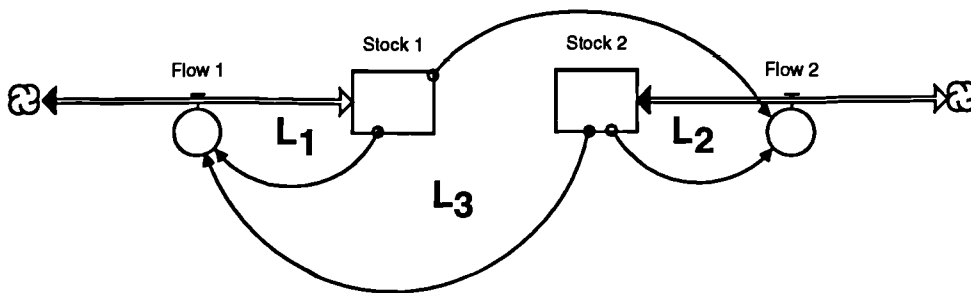


Figure 5.56 The three loop structure

In the structure each half of the archetype has its own independent loop which consists of a single stock and flow. These two loops (L<sub>1</sub> and L<sub>2</sub>) are linked by a third loop (L<sub>3</sub>) which includes both of the stocks. This structure can be used as the basis for quantification of the 'drifting goals' and 'escalation' archetypes.

#### 5.7.4.1 Drifting Goals

The itthink map of the 'drifting goals' archetype is shown in Figure 5.57.

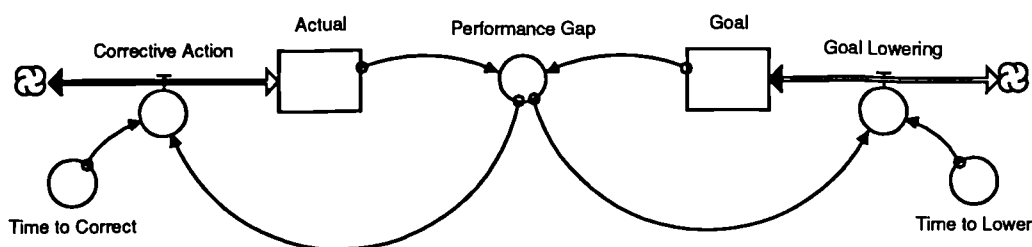


Figure 5.57 The 'drifting goals' archetype

It might appear at first sight that the 'drifting goals' archetype is a two loop structure. This is because the convertor 'Performance\_Gap' is creating a hidden loop. If the convertors are eliminated from the itthink map then the three loop structure shown in Figure 5.58 is obtained.

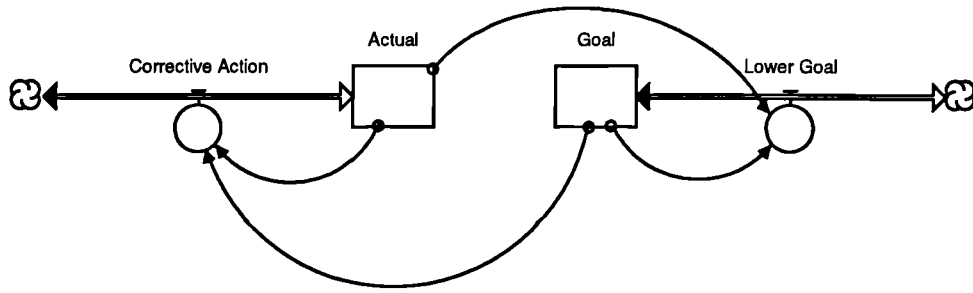


Figure 5.58 Basic loop structure of the 'drifting goals' archetype

The behaviour of the 'drifting goals' archetype is consistent with that claimed for the structure, see Figure 5.59. This should be compared to the behaviour that is obtained with a fixed goal which is shown in Figure 5.60.

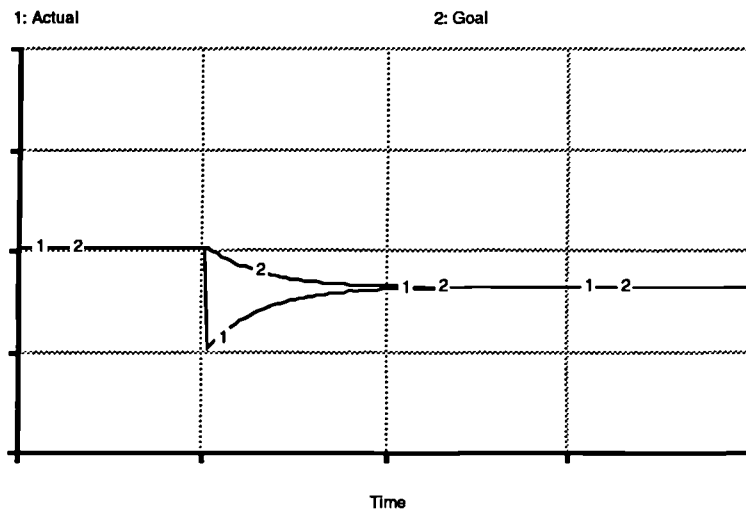


Figure 5.59 Behaviour of the 'drifting goals' archetype

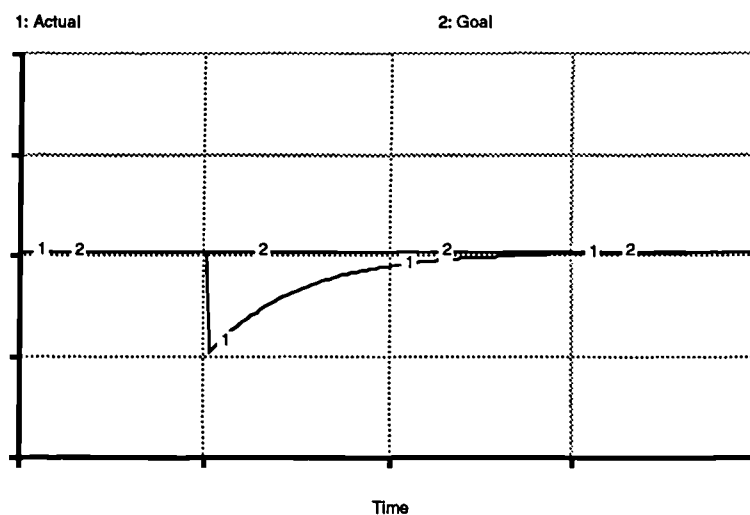


Figure 5.60 Behaviour of the 'drifting goals' archetype with fixed goals



The use of biflows in this structure allows one other mode of behaviour. This occurs when a one off improvement in "actual" causes the "goal" to rise, although not as far as the initial improvement in performance, see Figure 5.61. This suggests that there is a twin archetype to 'eroding goals' where improvements in performance cause the expected level of performance to rise. It is suggested that 'increasing expectations' is a suitable name for this version of the archetype.

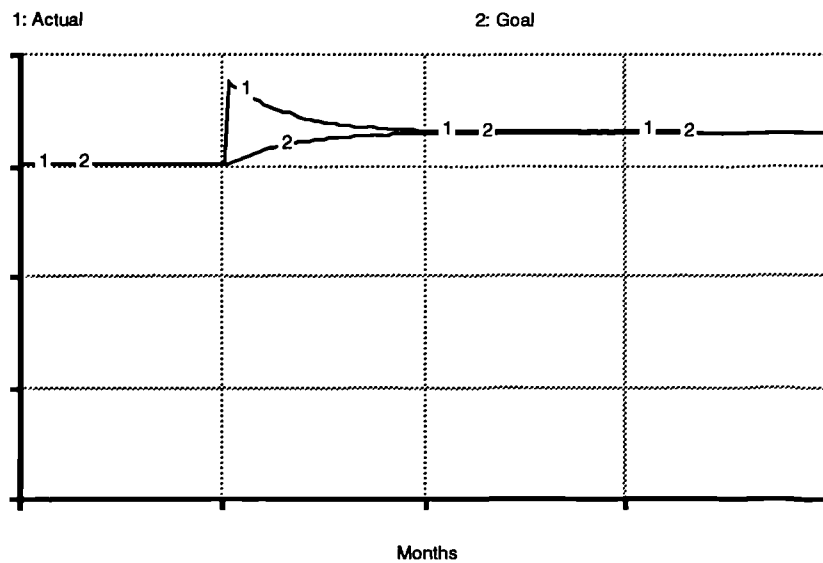


Figure 5.61 The 'increasing expectations' behaviour.

### 5.7.4.2 Escalation

The itthink map of the 'escalation' archetype is shown in Figure 5.62.

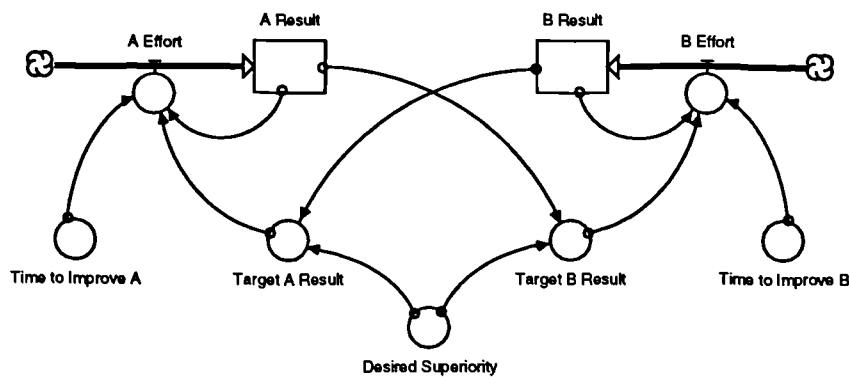


Figure 5.62 The 'escalation' archetype

The convertors also obscure the loops in this structure. The true loop structure is shown in Figure 5.63.

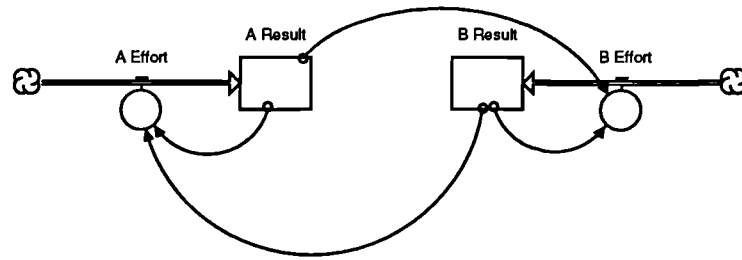


Figure 5.63 Basic loop structure of the 'escalation' archetype

The behaviour of the 'escalation' archetype is consistent with that claimed for the structure, see Figure 5.64.

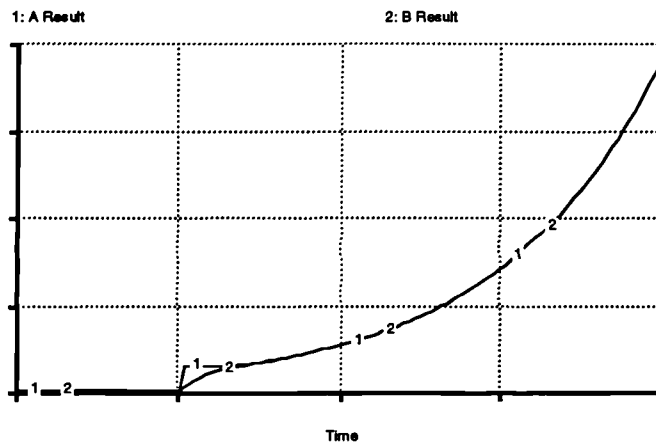


Figure 5.64 Behaviour of the 'escalation' archetype

The use of biflows in this structure allows one other behaviour mode to occur. This is the case where the growth occurs in a negative as opposed to a positive direction, see Figure 5.65. It is not felt that this behaviour is applicable to the real world and so there is no need to use biflows in the 'escalation' structure.

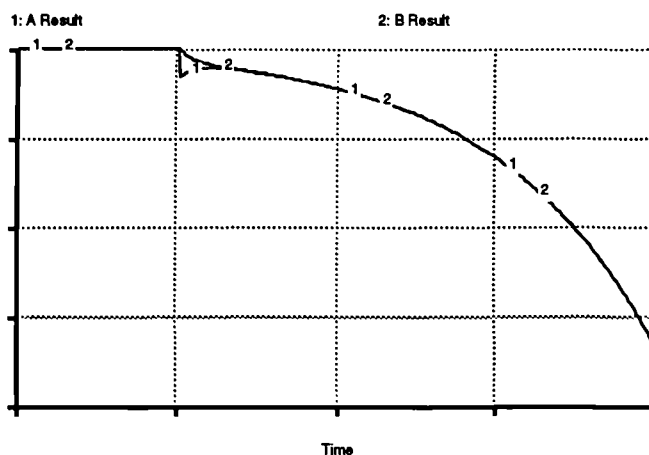


Figure 5.65 Alternative behaviour of the 'escalation' archetype

### 5.7.4.3 Success to the Successful

The 'success to the successful' archetype cannot be modelled using the same structure as the 'drifting goals' and 'escalation' archetypes. The itthink map of the 'success to the successful' archetype is shown in Figure 5.66.

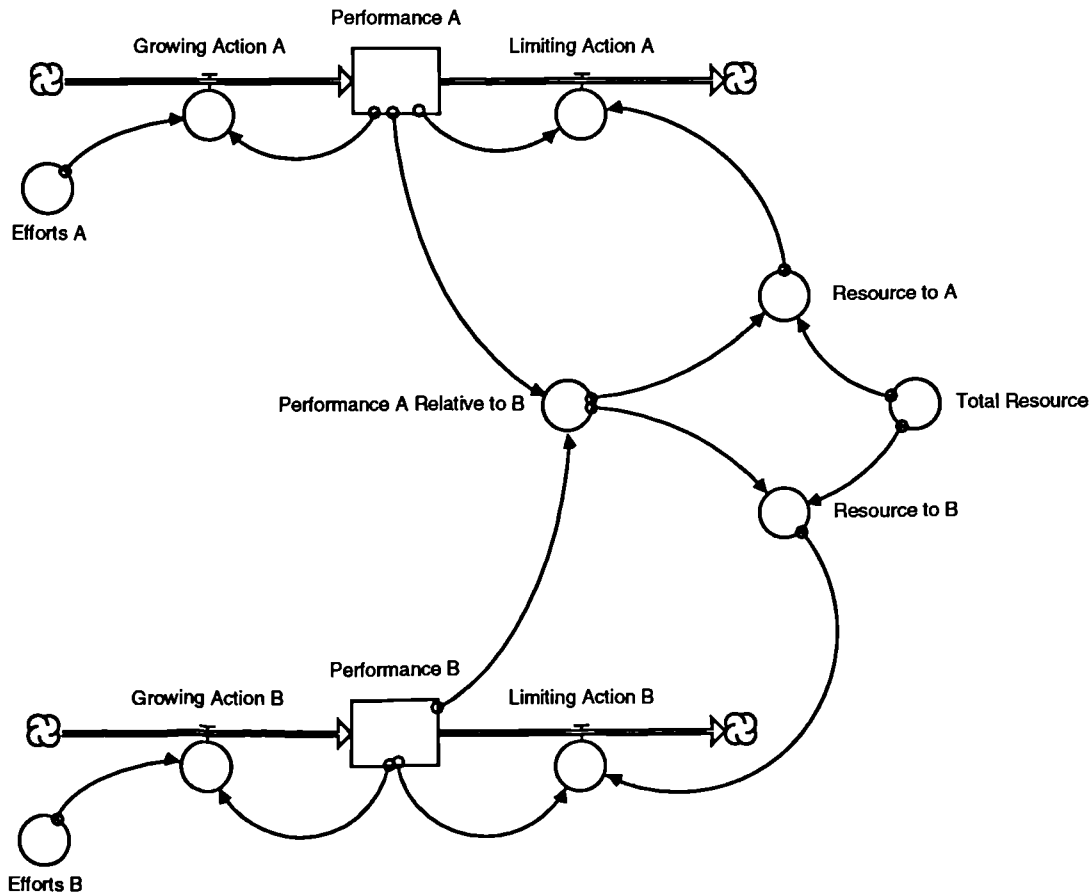


Figure 5.66 The 'success to the successful' archetype

This is a five loop structure as can be seen from the simplified itthink map shown in Figure 5.67. This structure is similar to the three loop structure; the only difference is that each of the stocks has an additional flow associated with it. If net rates were introduced then the structure would appear to have only three loops. If the simplified map of 'success to the successful' archetype is compared to 'limits to success' archetype (Figure 5.49) then it can be seen that it consists of two 'limits to success' archetypes linked by one other loop.

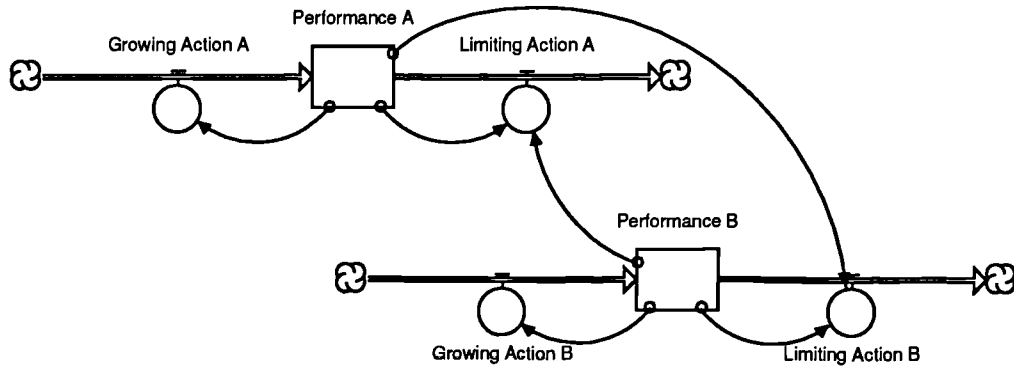


Figure 5.67 Basic loop structure of the 'success to the successful' archetype

The behaviour of the 'success to the successful' archetype is consistent with that claimed for the structure, see Figure 5.68. It can be seen that "A" makes a minor one off gain in performance, which is amplified by the resource allocation policy so that "A" experiences accelerating growth in performance at the expense "B", who's performance declines.

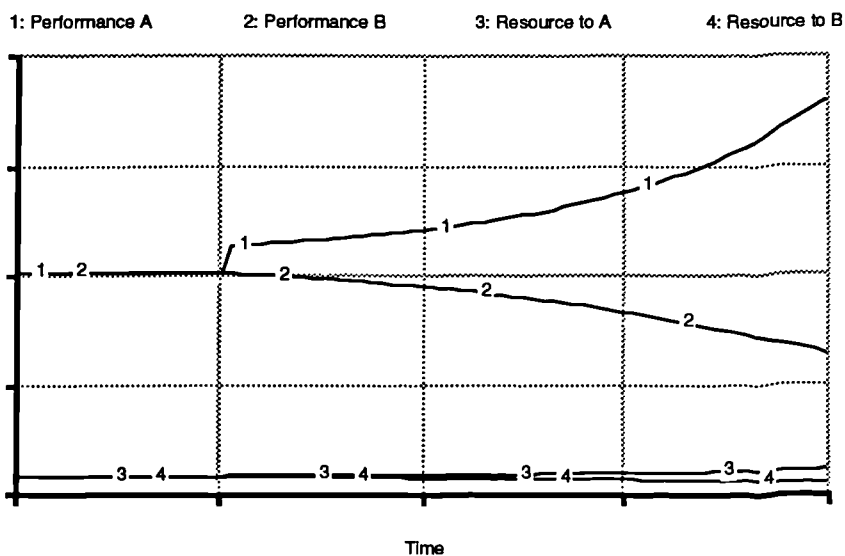


Figure 5.68 Behaviour of the 'success to the successful' archetype

The use of biflows in this structure allows another mode of behaviour to occur. A one off deterioration in the performance of "A" is amplified by the resource allocation policy so that "B" grows a the expense of "A", see Figure 5.69. It should also be noted that the 'success to the successful' structure is symmetrical and therefore if the same shocks are applied to "B" as were applied to "A" then identical behaviour will result.

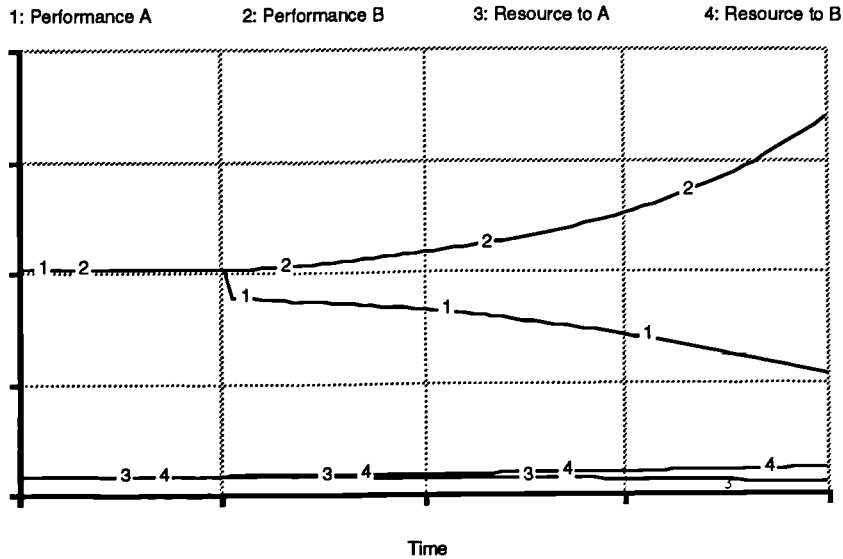


Figure 5.69 Alternative behaviour of the 'success to the successful' archetype

#### 5.7.4.4 Summary

This section has shown that two of the two loop archetypes; 'drifting goals' and 'escalation' are actually three loop structures. It has also been shown that the other two loop structure; 'success to the successful' is in fact a five loop structure.

## 5.8 Conclusions

In this chapter, five of the system archetypes; 'fixes that fail', 'limits to success', 'drifting goals', 'escalation' and 'success to the successful' have been mapped onto quantitative models and a twin archetype to 'drifting goals'; 'increasing expectations' has been identified. It has been shown that the two loop systems archetypes represent a hierarchy of structure; they map onto quantitative structures that range in complexity from two to five loops, see Figure 5.70.

The fact that some of the systems archetypes are more complex than their qualitative representation suggests, is not a serious problem. The purpose of the system archetypes is the transmission of system insights. In this context, it is sensible to use the simplest possible structures. It has always been considered acceptable to simplify the loop structure of a model when using causal loop diagrams to summarise a quantitative model.

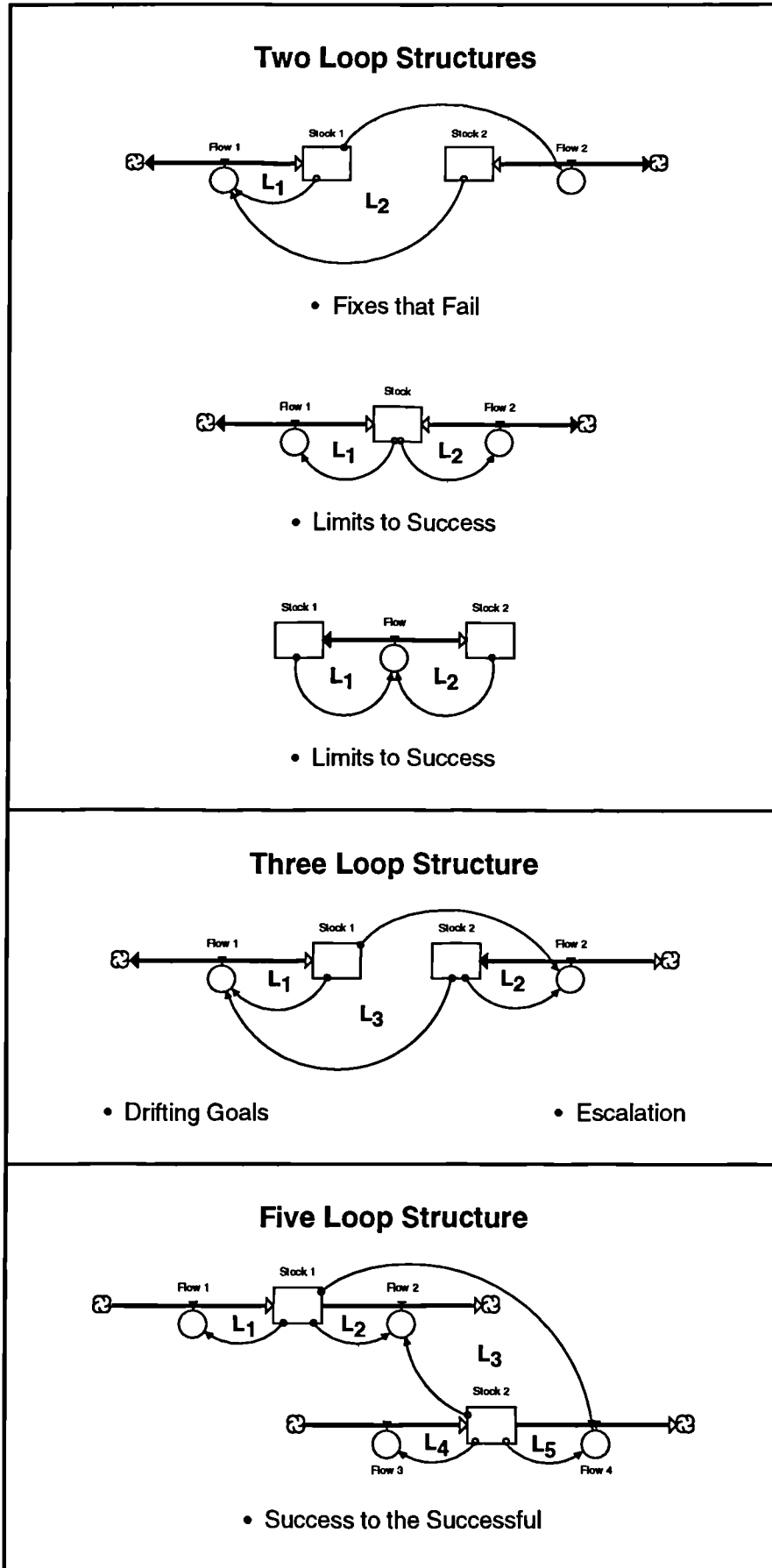


Figure 5.70 The hierarchy of structure for the 'two' loop archetypes

This hierarchy of structures is potentially more of a problem for the core archetypes, because these are based on the concept of a two looped structure which represents intended action and system reaction. However the symmetrical nature of the multiple loop structures and the fact that they contain an odd number of loops allows this view of the system to be sustained.

In the case of the 'drifting goals' and 'escalation' structures, there are the usual two intended action and system reaction loops, the third loop models the interaction between these two loops, see Figures 5.71 and 5.72.

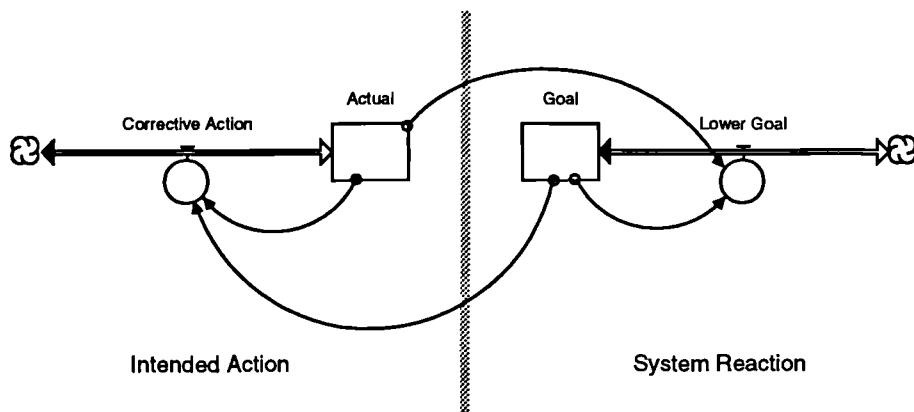


Figure 5.71 The 'drifting goals' archetype with boundary

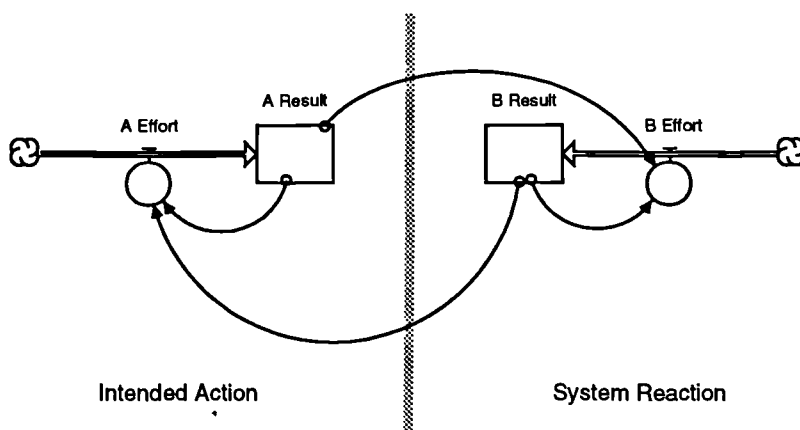
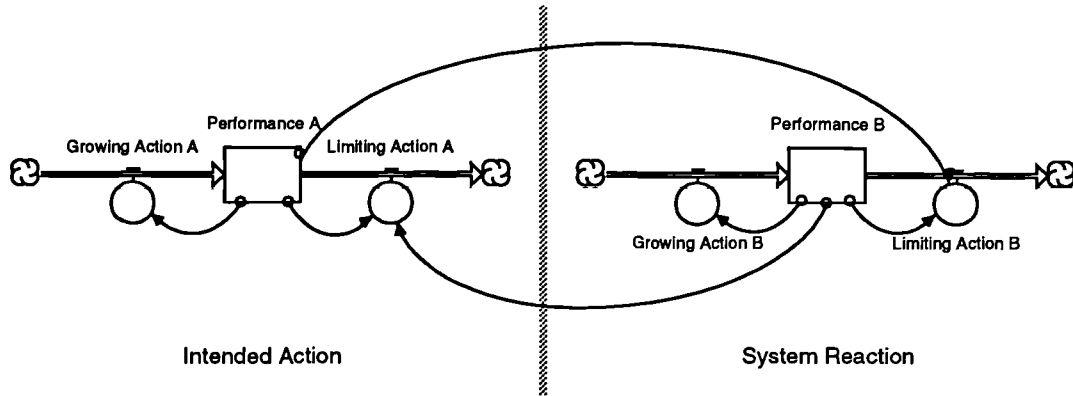


Figure 5.72 The 'escalation' archetype with boundary

The case of the 'success to the successful' archetype can be treated in a similar manner. The intended action and system reaction are now themselves two loop

archetypes ('limits to success') and the fifth loop models the interaction between these two archetypes, see Figure 5.73.



**Figure 5.73** The 'success to the successful' archetype with boundary

The nature of this structure is such that although each side of the archetype contains two loops, only one loop on each side will actually be active. If the structure is shocked from equilibrium by increasing A's performance then the reinforcing loop will become dominant on A's side of the archetype. The consequence of this will be that the balancing loop will become dominant on B's side of the archetype. It is therefore still possible to capture the essence of the behaviour of this five looped system with a two looped core archetype.

There is one occasion where the discrepancy between the loop structure of the systems archetypes and the underlying quantitative structures has the potential to cause problems; when a structure is being moved across the qualitative to quantitative boundary. The material presented in this chapter has eliminated this problem by providing a set of quantitative structures on to which the systems archetypes can be mapped. The moving of archetypes across the boundary between qualitative and quantitative modelling will be further discussed in the next chapter, which describes the development of an archetype based method of model conceptualisation.



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## **Chapter 6**

### *The Development of a New Framework for Model Conceptualisation*

## 6.1 Introduction

This chapter describes the development of a new framework to assist model conceptualisation. The framework has been specifically designed to help the novice system thinker through the difficulties of their early model conceptualisations, so that through this experience they may develop their own system thinking skills.

### 6.1.1 The Problem

In chapter three, model conceptualisation was identified as the major area of difficulty for the novice modeller. In particular it was found that:

- Participants find conceptualisation easier if it is carried out within some kind of framework. A good example of this can be found in the case study that is used in the second day of the training course. The task of incorporating the qualitative solution into the base case quantitative model, is usually carried out very successfully, with little need for facilitator intervention. In contrast the less transparent of the overnight modelling exercises and the freeform modelling on day three, are found to be much more difficult.
- Participants confronted with a blank sheet of paper, find it difficult to begin the modelling process. If however, they can be facilitated to build a working first pass model (this can be a very simple model), then they usually have the confidence to incrementally develop this model, with only occasional need for facilitator assistance.

Model conceptualisation is a difficult skill to master. It usually takes the novice several years of experience to become a competent modeller. In many ways model conceptualisation is more of an art than a science, therefore it is difficult to codify the experienced modellers skills in a way that they can be easily transmitted to the novice modeller.

The aim of the research described in this chapter was to find a way of overcoming the blockages in the modelling process identified above. In particular to provide participants with a framework that would give them the confidence to begin their first real modelling project and in so doing, start off the learning process.

### 6.1.2 Existing Modelling Frameworks

A number of techniques for the building of system dynamics models have been proposed (Forrester 1961, Randers 1980, Richardson & Pugh 1981, Morecroft 1982, Wolstenholme & Coyle 1983, Wolstenholme 1985; 1990; 1992, Mass 1986, Richmond et al. 1987; 1993). These approaches typically break the modelling process down into a series of steps (one of which is conceptualisation) and provide guidelines and suggest techniques for each step.

### 6.1.3 Current Techniques for Model Conceptualisation

A number of conceptualisation techniques will be described and their suitability as a vehicle for developing the novice modeller's conceptualisation skills discussed.

#### 6.1.3.1 Use of an Experienced Facilitator/Consultant

The easiest way for a manager or a group of managers to conceptualise a model is to work with an experienced modeller. This approach should ensure that a useful model is conceptualised, but because the expert is carrying out the conceptualisation, it will do little to develop the individual manager's conceptualisation skills.

#### 6.1.3.2 Starting with Loops

This approach to model conceptualisation aims to identify the systems key feedback loops by studying the systems observed reference mode of behaviour. The nature of non-linear feedback systems makes it very difficult to infer structure from behaviour. Therefore this will not be an easy skill for the novice modeller to acquire. A further disadvantage of this approach is that the resulting causal loop model must be converted into a simulation model. The development of the

“product improvement” model described in chapter 4, provides an example where a novice modeller had created a good causal loop model but was unable to build a corresponding simulation model.

### **6.1.3.3 Starting with Stocks**

This approach to conceptualisation, starts by identifying the key stocks of the system to be modelled. Having identified the stocks; the next stage is to identify the associated material flows. The information flows can then be superimposed. This approach can work well when the stocks are obvious; it is particularly suitable for conceptualising the “main chain” type of model. It is relatively easy to convert the resulting model into a simulation model because the stocks are known. The problem with this approach arises when the stocks are not obvious due to their highly aggregated or ‘soft’ nature.

### **6.1.3.4 Using Building Blocks**

This approach to model conceptualisation, make use of generic structures or modular building blocks (Wolstenholme & Coyle 1983; Richmond et al. 1987, 1993). The modeller is provided with a set of model sub-assemblies that can be connected to build a model.

There are a number of advantages to this approach. Firstly, the modeller is provided with something to work with. The building blocks are an order of magnitude more complicated than the basic model elements, therefore the modeller starts at one step closer to a first pass model. Secondly, the behaviour of the individual modular building blocks will be known to the modeller and this information can be used to aid the selection of the correct structure<sup>1</sup>. Finally, The internal structure of the modular building blocks is known to be technically correct. The modeller knows therefore that a considerable part of their model is also technically correct.

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<sup>1</sup>This assumes that the building blocks are quantitative in nature or alternatively that they are qualitative versions of quantitative structures with known modes of behaviour.

The main disadvantage is that the modeller needs to be familiar with the set of structures. To effectively apply a set of modular building blocks the modeller will need to understand the structure and behaviour of those building blocks. It is also the case that if the modular building blocks are simple (basic flow structures) then turning them into a working model may still be a difficult task for the inexperienced. Finally there is the danger that if the modular building blocks are larger and more complex (generic infrastructures or generic subsystems) then the modeller may force the problem to fit one of the available structures.

#### 6.1.4 Conceptualisation Methods for the Novice Modeller

The 'starting with loops' and 'starting with stocks' approaches to model conceptualisation provide very little in the way of support for the novice modeller. In particular they do not provide guidance as to the type of structure to use in the model.

The use of some form of building block based approach seems to be a more promising way of supporting the novice modeller. The building blocks will at least provide the novice modeller with some structures to work with. The observation of the participants' performance during the training courses shows that this is an important factor in promoting successful conceptualisation.

It was therefore decided to develop a framework that consisted of a sequence of operations to be carried out using a set of pre-defined generic structures or modular building blocks that will allow the modeller to move easily to a simple working model as early as possible in the model conceptualisation process.

## 6.2 Issues in Designing a Framework for Conceptualisation

This section investigates the issues involved in the development of a new method of model conceptualisation. First the nature of the framework is discussed and then the ability of the different types of generic structures to support this framework is assessed.

### 6.2.1 Philosophy Behind the Modelling Framework

In designing the framework, careful thought has been given to striking an appropriate balance between, providing sufficient structure to help a manager build a model and the danger of enforcing an over prescriptive set of rules that will constrain a manager's thinking. There is a real danger of this, in the specific case of model development and in the more general development of an individual's system thinking skills. In the case of model development, the availability of generic structures may encourage the forcing of the problem to fit the available model.

In the wider context of an *individual's modelling skills, system thinking is more* than just a simulation technique, it is a distinctly different way of looking at the world. This ability can only be acquired by thinking hard about real problems and therefore there can be no formal proscriptive method for practising systems thinking. This fact has been recognised from the earliest days of system dynamics and has been restated many times over the intervening years. (Forrester 1961; Saeed 1986; Senge 1990; Richmond 1990).

### 6.2.2 Purpose of the Modelling Framework

The purpose of the conceptualisation framework is therefore seen by the author as a tool to help the novice system thinker through the difficulties of their early model conceptualisations, so that through this experience they may develop their own system thinking skills. Experienced systems thinkers may not need to use the framework to aid to their own thinking, but it can be used to good effect as a facilitation technique, to aid the thinking of others, when model building with a group of managers for example.

### 6.2.3 Using Generic Structures to Support a Modelling Framework

The suitability of the generic structures for aiding the model conceptualisation process will now be discussed.

### **6.2.3.1 Generic Models**

The use of an appropriate generic model can greatly simplify or even eliminate the conceptualisation process. If such a model can be found then it is possible to move straight to a first pass model. Generic models can therefore be very effective tools for model conceptualisation.

There are however a number of problems with this approach. Firstly, there needs to be a suitable generic model available for the problem domain under investigation. Secondly, there is a danger that an inexperienced modeller will select an inappropriate model. Finally, the existence of a generic model may give the modeller a preconceived view of the problem. There is a real danger of the problem being fitted to the model rather than the other way round.

### **6.2.3.2 Building Blocks**

The lower level building blocks are more suited to the model development than model conceptualisation. It has already been established that some of the more complex building blocks are in effect generic models and so can be used in the conceptualisation process.

The same danger of bending the problem to fit the model exists. In fact even more care is required with the building blocks than with the generic models. It is seductively easy to keep on adding in another infrastructure simply because it is available 'off the shelf'. This can result in unfocused system mapping.

### **6.2.3.3 Archetypal Structures**

Archetypes are universal insights and so potentially they are powerful tools for model conceptualisation. The main problem is that there is a big jump to make in moving from identifying an archetype in a problem situation to reaching first pass quantitative model. There is also a danger that the problem may be fitted to an inappropriate archetype.



### 6.2.4 The Choice of Generic Structure

If the framework is to have the capability of tackling a wide range of problems, then the supporting structures also need to be widely applicable. This immediately suggests some kind of archetypal structure. Also, the work described in the previous chapter has shown that it is possible to quantify the archetypes; in effect build generic models of the archetypes. The capability to relate an archetype to a simulation model provides a simple way of moving across the qualitative/quantitative boundary.

Having decided to use archetypal structures to underpin the modelling framework; the next step was to choose between the core archetypes and the system archetypes. It was decided to use the core archetypes for a number of reasons, which will now be listed:

- There are fewer core archetypes than systems archetypes, therefore less needs to be learned in order to use the framework.
- The ability of the core archetypes to represent a problem in terms of two loops provides a simple and effective start to the conceptualisation process.
- The core archetypes are more abstract structures than the system archetypes so there is less danger of fitting the problem to the structure.
- The core archetypes are compatible with the systems archetypes, it is possible to move from a core archetype to one or more of the systems archetypes.

In conclusion, the selection of a base archetype is merely a starting point for investigation, not a final definitive statement about the problem. The initial identification of a loop pair, can lead to a model that is equivalent to one of the system archetypes or indeed no specific system archetype at all.

The framework could have been built around the full set of system archetypes, but it was felt that this would have been too restrictive. In using the system archetypes for conceptualisation, there is a real danger that the selection of an archetype will be both a starting point and an ending point; the modeller will miss out on the challenging but rewarding task of structuring their own view of the system. The flexibility of this approach can be demonstrated in two ways.

Firstly, starting with one of the base archetype it is possible to incrementally develop this structure into more than one of the more complex system archetypes. This is the property of divergence, see Figures 6.1. An example is shown in Figure 6.2. Here, the intended action has been identified as growth and the system reaction as control. This gives the reinforcing/balancing core archetype. This archetype can be developed into any one of three system archetypes; ‘limits to success’, ‘growth and under-investment’ and ‘tragedy of the commons’.

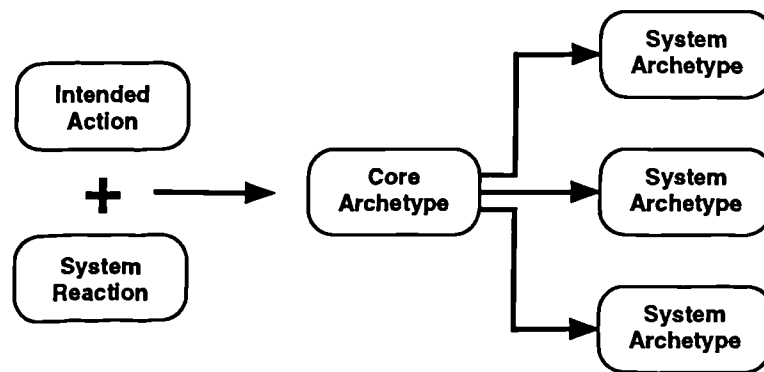


Figure 6.1 Divergent model development

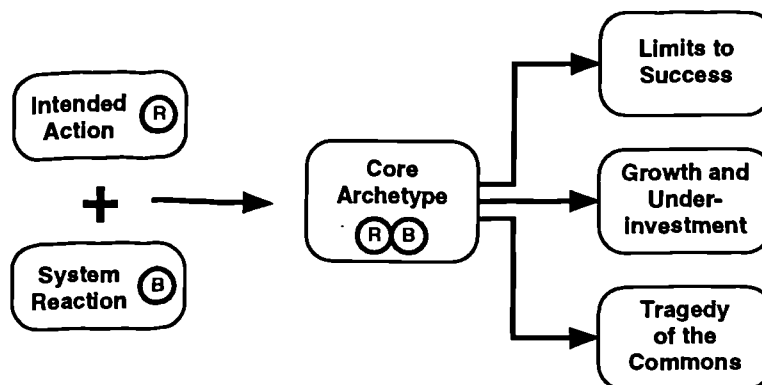


Figure 6.2 An example of divergent model development

Secondly, it is possible, starting from two different base archetypes to incrementally develop these structures into the same system archetype; this is the property of convergence, see Figures 6.3. An example is shown in Figure 6.4. This shows how it is possible to arrive at the 'growth and under-investment' system archetype, from two separate starting points.

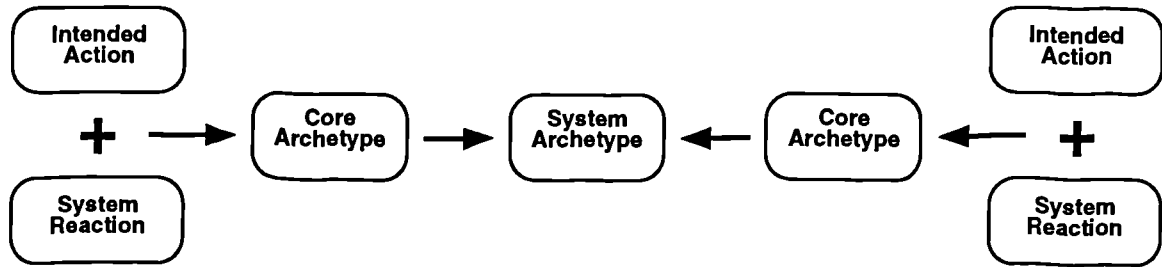


Figure 6.3 Convergent model development

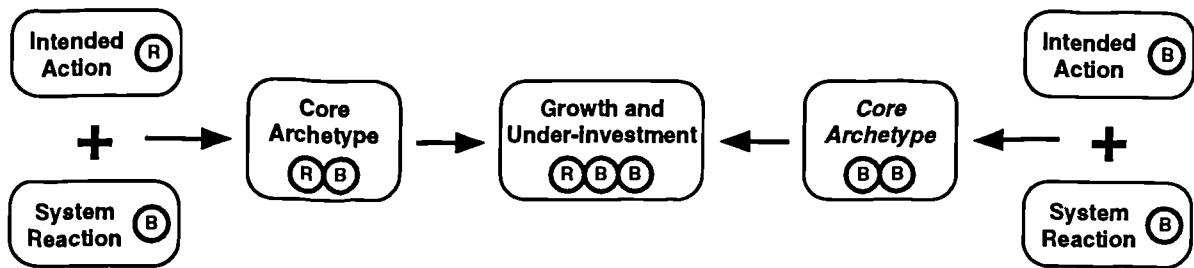


Figure 6.4 An example of convergent model development

One starting point focuses on the intention action of promoting growth and the system reaction which limits this growth; this gives the reinforcing/balancing core archetype. The other starting point focuses on the intended action of controlling lead-time by adjusting manufacturing capacity and the system reaction which also controls lead-time through the action of the sales rate; this gives the balancing/balancing core archetype. These two core archetypes can both be incrementally developed into the 'growth and under-investment' system archetype.

### 6.3 A Framework for Model Conceptualisation

This section describes the model conceptualisation framework and its associated support materials. Once this has been done, an example that demonstrates the application of the method will be presented.

#### 6.3.1 Overview of the Framework

The method uses the core archetypes and generic models of those archetypes to ease the transition to a simple working model. The identification of an intended managerial action and a system reaction allows a core archetype and its corresponding generic model to be selected. The modeller therefore only needs to identify two loops before they can begin experimenting with a working model, that can be used as an aid to clarify their thinking by exploring the chosen structure's dynamic behaviour. The selected generic model is next customised to produce a first pass model that can then be iteratively developed. The steps of the method are described in Table 6.1 and an overview is given in Figure 6.5.

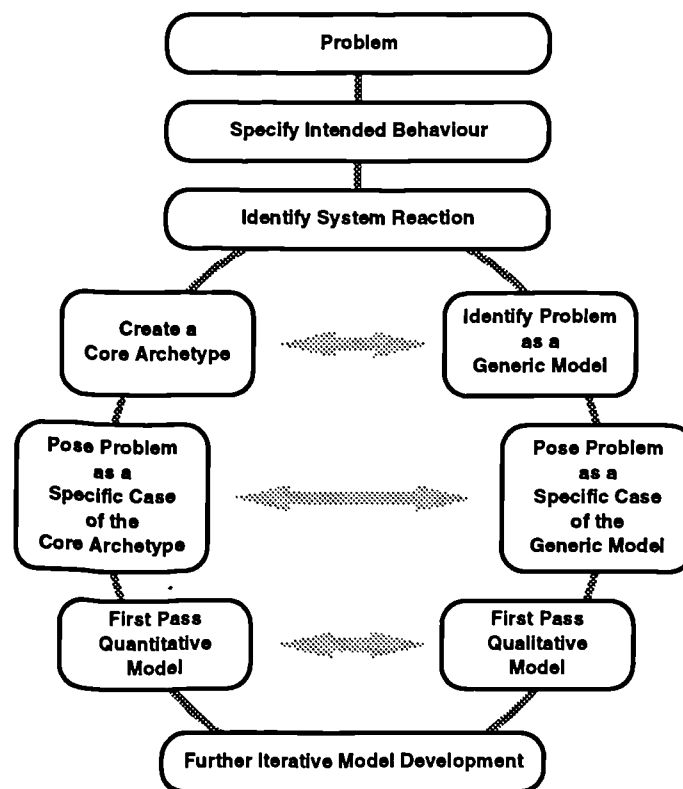


Figure 6.5 Overview of the conceptualisation method

Table 6.1 The steps of the conceptualisation method

Step	Description
1	<b>Specify the Intended Behaviour</b> Is the aim growth or control. Draw the intended behaviour loop.
2	<b>Identify the System Reaction</b> Will the system respond with growth or control. Draw the system reaction loop.
3	<b>Create a Core Archetype</b> Link the loops identified in steps 1 & 2 to create a core archetype.
4	<b>Specify the Problem as a Generic Model</b> Take the generic itink model corresponding to the core archetype and by renaming the model elements, customise it to represent the problem. It can now be verified that the chosen generic structure is capable of producing appropriate behaviour.
5a	<b>Qualitative First Pass Model</b> Flesh out the loops, by adding intermediate variables and the organisational boundaries.
5b	<b>Quantitative First Pass Model</b> Add extra detail to the itink model to keep it consistent with the qualitative model. Incorporate "order of magnitude" data into the model and experiment with the model.
6	<b>Iterative Model Development</b> From here onwards the model(s) can be developed in an iterative fashion.

The model conceptualisation framework makes use of a number of different types of supporting material:

- Fact file on the core archetypes
- Archetype templates
- Generic model(s)
- Conceptualisation example

This material will now be described, using 'fixes that fail' as an example.

### 6.3.2 Fact Files on the Core Archetypes

These provide a reference work on each of the core archetypes, that users can refer to during the conceptualisation process. Information is given on both the structure and behaviour of the core archetypes.

The 'fixes that fail' archetype consists of two loops; the intended action loop and the system reaction loop, see Figure 6.6. The intended action loop is a balancing

loop, that seeks to reduce a problem symptom through the implementing a fix. The system reaction loop is a reinforcing loop, implementing the fix causes an “unintended consequence” to occur which makes the original problem symptom worse. What has just been described is the generic behaviour of the ‘fixes that fail’ archetype. There are a number of possible variants, three cases will be described.

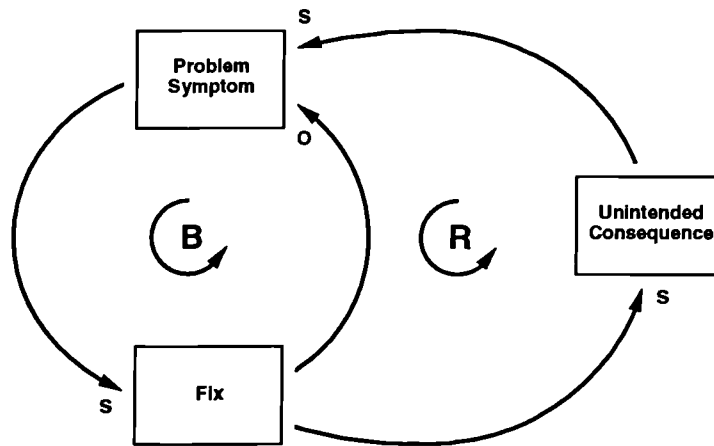


Figure 6.6 Structure of the ‘fixes that fail’ archetype

### 6.3.2.1 Type 1 Behaviour

In this case the implementation of the fix provides some short term improvement in system behaviour, but this benefit is eroded over time and the problem symptom return to its original level, see Figure 6.7.

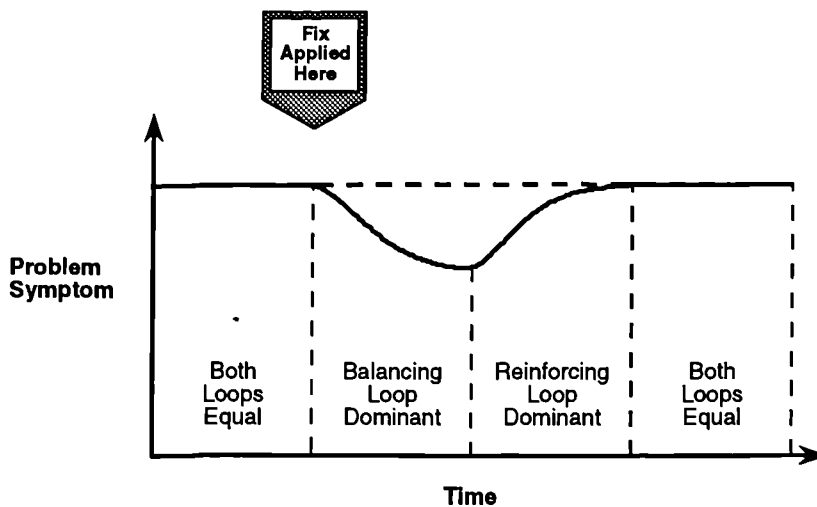


Figure 6.7 Type 1 behaviour of the ‘fixes that fail’ archetype

### 6.3.2.2 Type 2 Behaviour

In this case the fix again provides a short term solution, but over the longer term it causes the problem symptom to escalate out of control, see Figure 6.8.

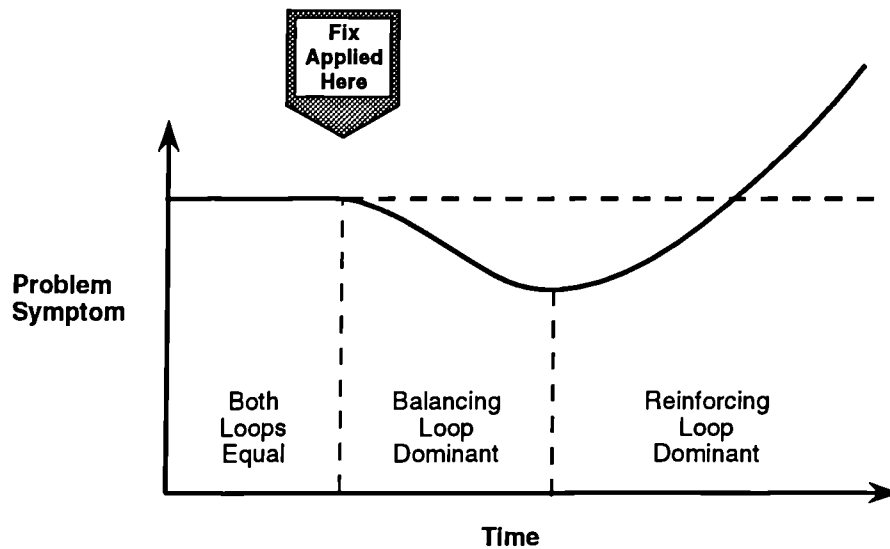


Figure 6.8 Type 2 behaviour of the 'fixes that fail' archetype

### 6.3.2.3 Type 3 Behaviour

Type 1 and Type 2 behaviour results from the implementation of a single fix. In response to the Type 2 behaviour, the fix may be applied more than once. This gives Type 3 behaviour, see Figure 6.9.

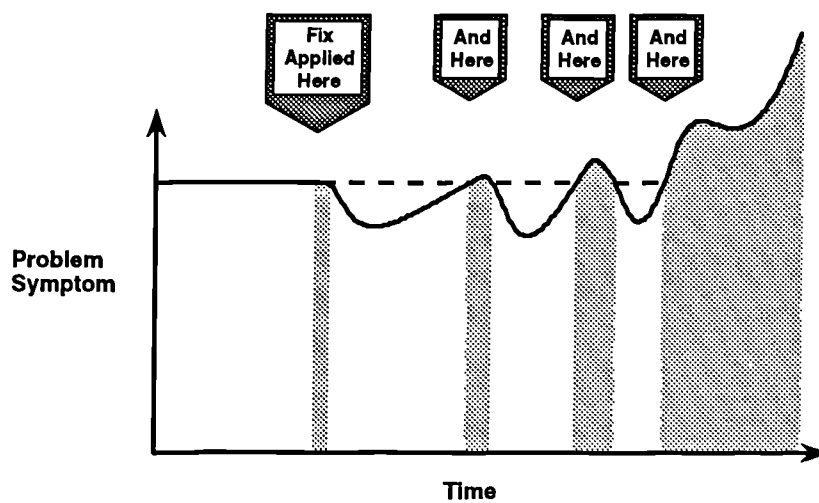


Figure 6.9 Type 3 behaviour of the 'fixes that fail' archetype

In this case, the fix is applied each time the problem symptoms reappear. This strategy may prove satisfactory over the short term, but as time passes, the fix will

need to be applied for longer and longer to regain control and eventually a point will be reached where the fix is ineffective in controlling the problem symptom.

### 6.3.3 Archetype Templates

To promote familiarity with the archetypes blank templates are provided, allowing users to create their own specific examples of the archetypes, see Figure 6.10.

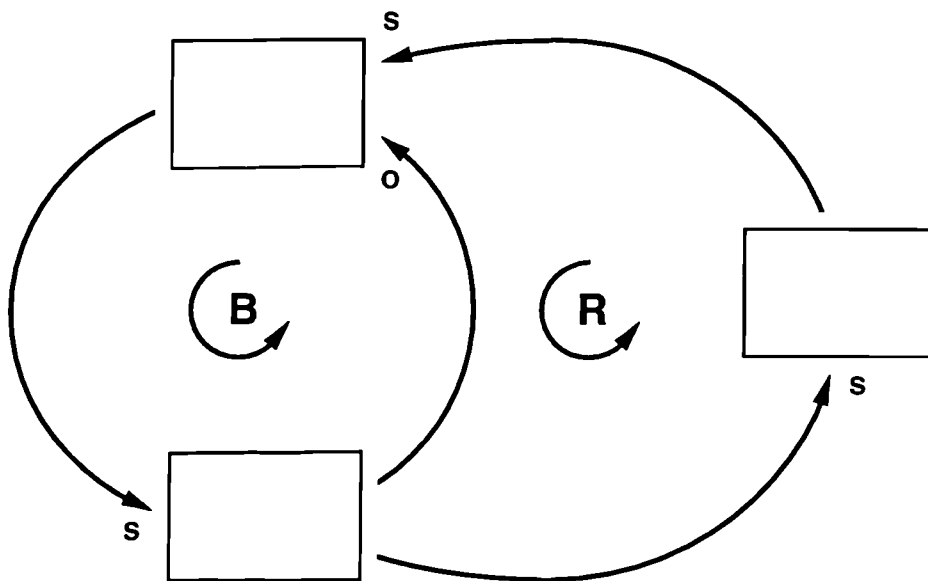


Figure 6.10 Blank template of the 'fixes that fail' archetype

### 6.3.4 Generic Models

The provision of generic models of the core archetypes allows the users to perform "what if" simulations and so gain an understanding of the dynamic behaviour of the core archetype. This allows system behaviour as well as structure to be taken into account when choosing an archetype. There may be more than one generic model associated with a particular core archetype, in this case simulation can help the user choose between the alternative structures. Two generic models of the 'fixes that fail' archetype are described here. These models are more complex than the model of the 'fixes that fail' structure that was presented in Chapter 5. This extra detail was included to make it easier for users of the framework to customise these structures to represent their own problem situation.



### 6.3.4.1 Fixes That Fail Generic Model: Single Fix

The itthink map of this generic model is shown in Figure 6.11. The typical behaviour of the model is shown in Figure 6.12. The behaviour of the single fix version is determined by the five parameters listed below.

- Trigger Level
- Benefit of Fix
- Action Time
- Down-Side of Fix
- Reaction Time

The first parameter controls the point at which the corrective action will be implemented. The next two parameters determine the magnitude of the beneficial effect of the fix and the time it takes for this effect to occur. The third and fourth parameter control the detrimental side of the fix in a similar manner. Experimenting with these parameter will give the modeller an insight to the different modes of behaviour that this structure is capable of generating.

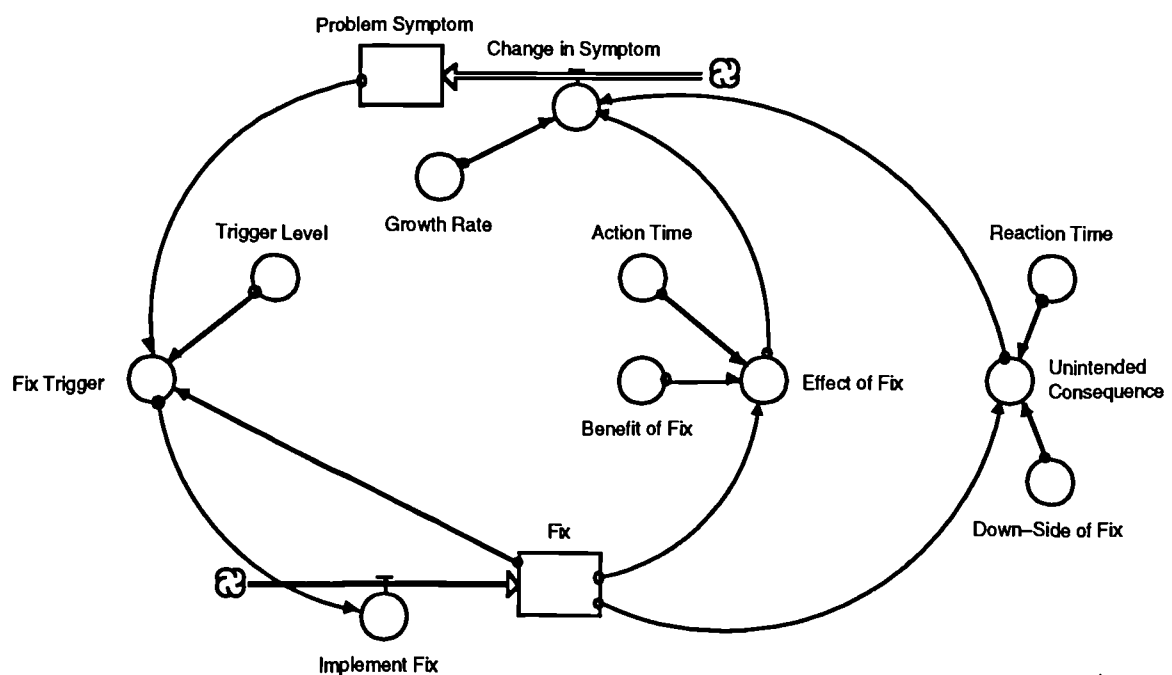


Figure 6.11 Itthink map of the generic single fix 'fixes that fail' model

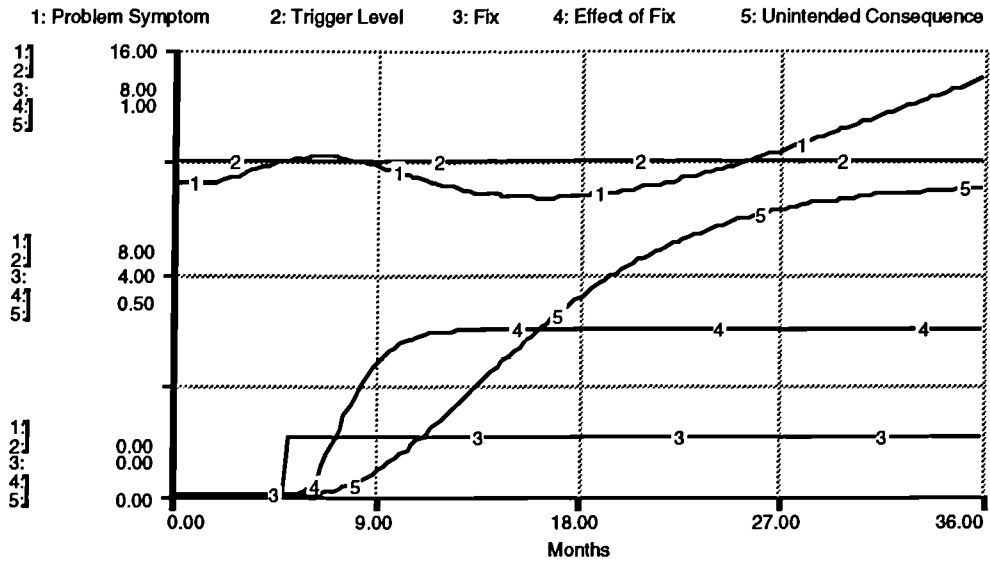


Figure 6.12 Behaviour of the generic single fix ‘fixes that fail’ model

### 6.3.4.2 Fixes That Fail Generic Model: Multiple Fixes

The multiple fix generic model is very similar to the single fix model. The itthink map of this generic model is shown in Figure 6.13. The typical behaviour of the model is shown in Figure 6.14.

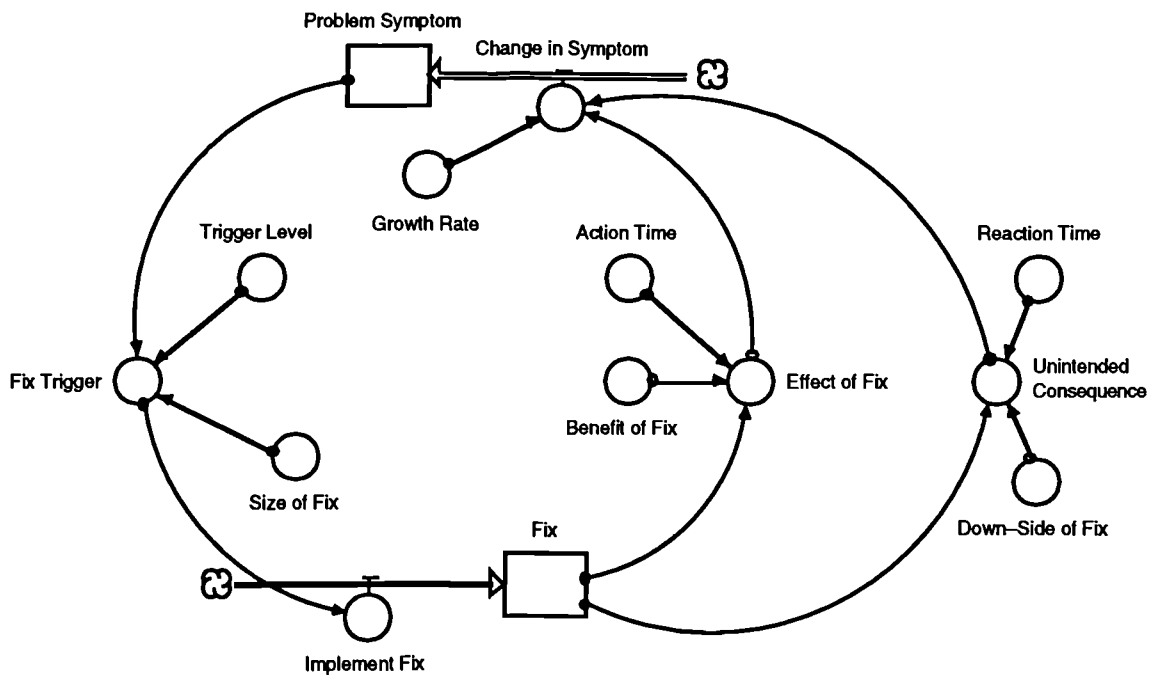
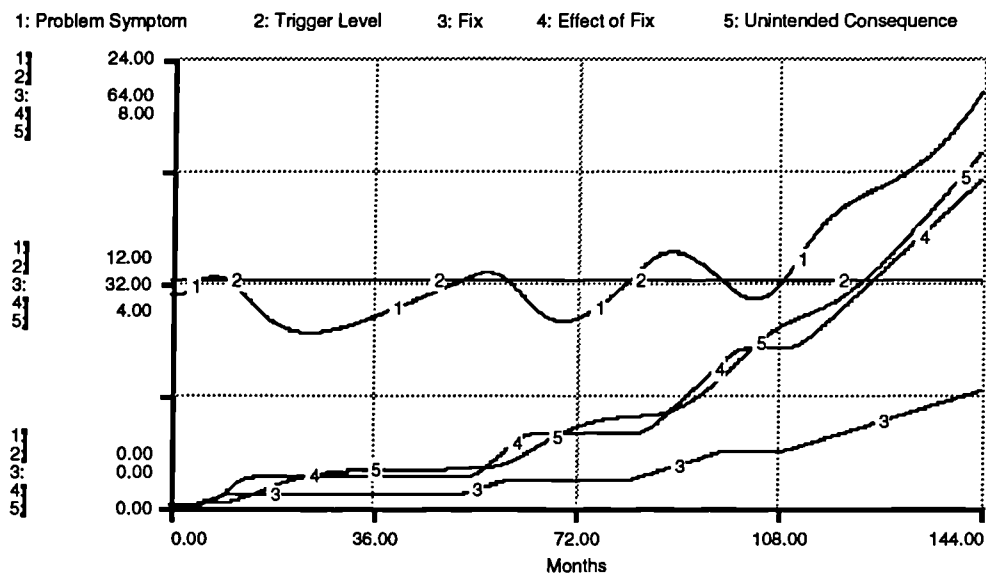


Figure 6.13 Itthink map of the generic multiple fixes ‘fixes that fail’ model

The behaviour of the multiple fix version is determined by the six parameters listed below.

- Trigger Level
- Benefit of Fix
- Action Time
- Down-Side of Fix
- Reaction Time
- Size of Fix

In addition to the five parameters of the single fix model, there is one extra parameter; size of fix. This parameter control the amount of corrective action is taken while the problem symptom exceeds the trigger level.



**Figure 6.14** Behaviour of the generic multiple fixes 'fixes that fail' model

### 6.3.5 Conceptualisation Example

A step by step conceptualisation of a model based on a real problem is provided to demonstrate the application of the method and to provide inspiration for the users own modelling. The 'fixes that fail' conceptualisation example is presented in the next section.

## 6.4 An Example: Conceptualising the Housing Association Model

In this section an application of the method, to aid the conceptualisation of a model of Government funding of housing associations is described. This example is also used in the training courses to introduce the conceptualisation method and the material presented here is derived from the course documentation.

### 6.4.1 Problem Description

The government is seeking to control its spending by imposing cash limits on the individual government departments. In this particular case we are focusing on the Department of the Environment and the grant aid that it gives to support social housing. Low cost housing is provided by independent non-profit making bodies called housing associations.

The amount of grant aid given to Housing associations by the Department of the Environment has fallen from 90% five years ago to around 55% today. This reduction in grant aid has required the housing associations to borrow more money in the open market the extra cost of which has caused rent levels to rise. The majority of the people housed by housing associations have low incomes and many cannot afford the higher rents. Therefore they claim housing benefit from the Department of Social Security to help pay their rent. (Philips 1993; Page 1993)

### 6.4.2 Step 1: Specify Intended Behaviour

The intention is control. The Government Executive reacts to increases in total Government spending by cutting the spending of individual government departments. This policy creates a balancing loop, that seeks to reduce total Government spending, see Figures 6.15 and 6.16.

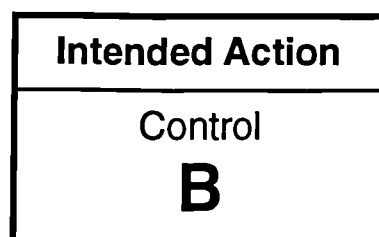


Figure 6.15 The intended action

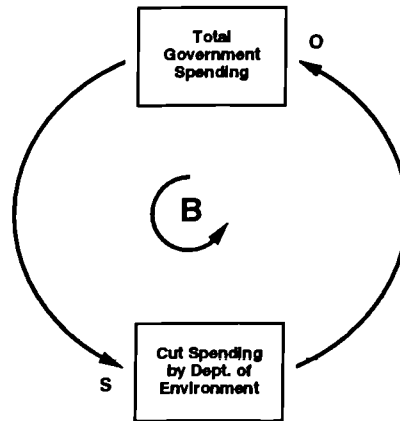


Figure 6.16 Causal map of the intended action

### 6.4.3 Step 2: Identify System Reaction

The system reaction is growth, cuts in spending by the one Government Department, cause additional costs to be incurred by other Departments. In this particular case we are looking at how the spending cuts implemented by the Department of the Environment, cause spending by the Department of Social Security to rise, see Figure 6.17 and 6.18.

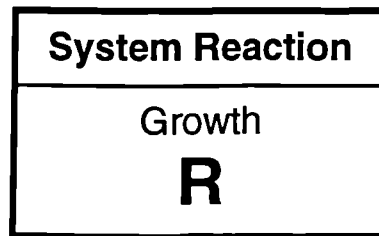


Figure 6.17 The intended action

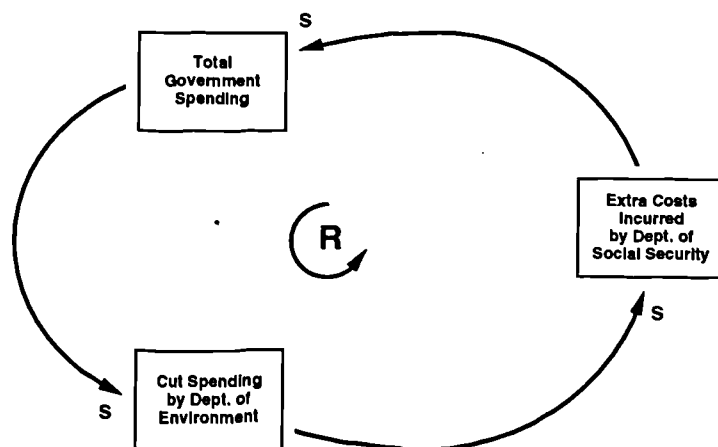


Figure 6.18 Causal map of the system reaction

### 6.4.4 Step 3: Create a Core Archetype

Combining the intended policy loop with the system reaction loop creates a core archetype; 'fixes that fail', see Figure 6.19 and 6.20.

Intended Action	System Reaction
Control <b>B</b>	Growth <b>R</b>

Figure 6.19 The core archetype: 'fixes that fail'

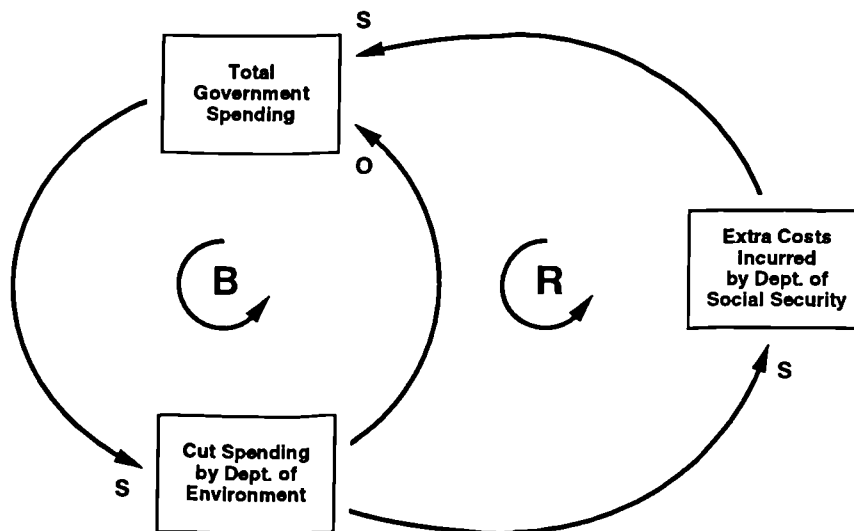


Figure 6.20 Causal map of the core archetype

### 6.4.5 Step 4: Identify Problem as an Generic Model

There is only one generic model onto which the 'fixes that fail' core archetype can be mapped. If another core archetype had been arrived at, a pair of balancing loops for example, then it would have been necessary to choose between a number of possible generic models. These alternative models correspond to the 'escalation', 'eroding goals' and 'shifting the burden' systems archetypes. The choice of model can be helped by experimentation with the various generic ithink models under consideration. This ability to simulate allows system behaviour as well as structure to be taken into account when choosing an appropriate archetype.

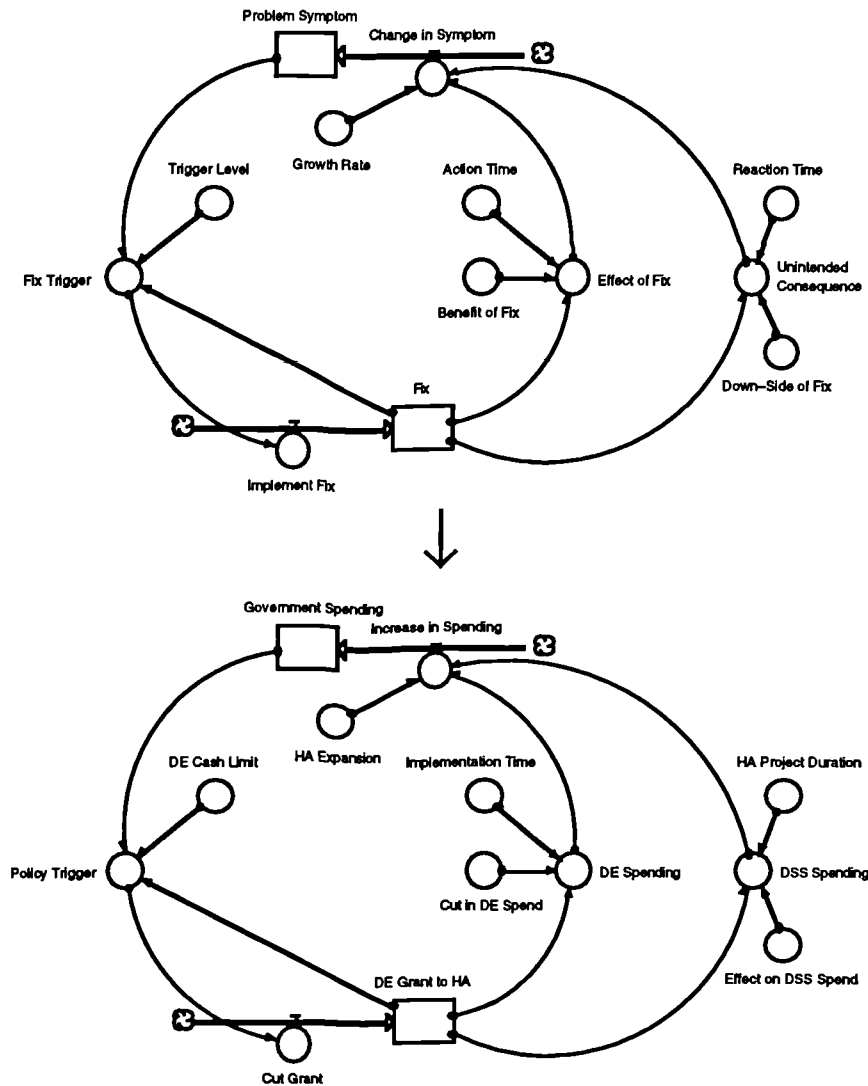


Figure 6.21 Customising the 'fixes that fail' generic model

Having selected an appropriate generic model; the next step is to customise it. This is achieved by changing the names of the model elements so as to represent the system under investigation. In customising the generic model, the problem symptom has been defined as the size of Government spending and the fix has been identified as the reduction of Department of the Environment grant to housing associations.

At this point the user should be happy that they have a structure that is capable of producing behaviour relevant to the system under investigation. Qualitative and quantitative model development can now proceed in parallel.

### 6.4.6 Step 5a: Qualitative First Pass Model

The qualitative model is developed by “fleshing out” the feedback loops identified in the core archetype, that is adding intermediate variable to the existing causal links, see Figure 6.22.

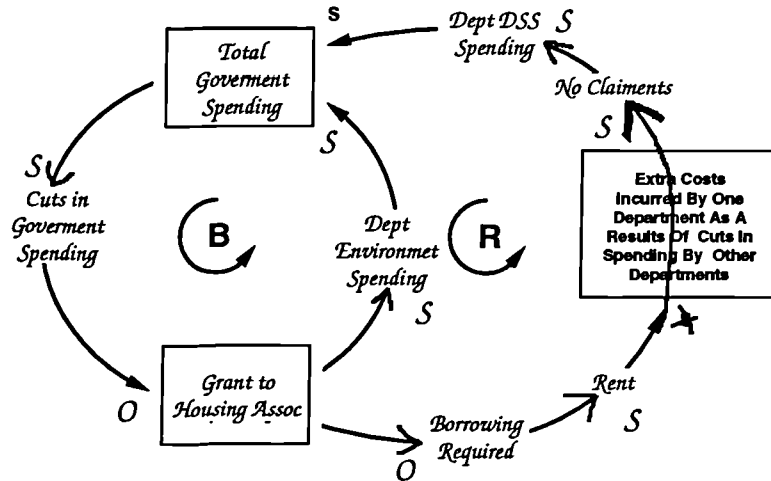


Figure 6.22 Developing the core archetype causal map

Adding the organisational boundaries to the map and identifying the delays within the system completes the first pass qualitative model, see Figure 6.23.

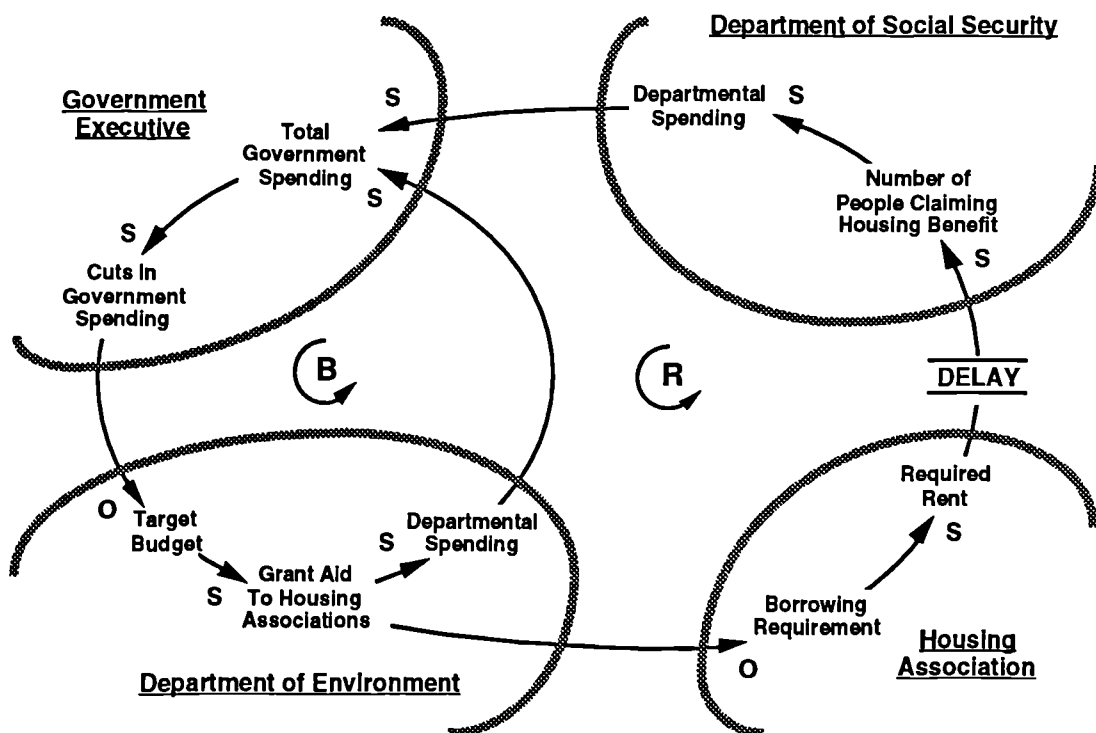


Figure 6.23 Qualitative first pass model



### 6.4.7 Step 5a: Quantitative First Pass Model

A number of changes need to be made to the generic model to produce a first pass qualitative model. The direction of the “Fix” flow has been reversed (the fix is a reduction in grant fraction). An outflow has been added to the Government spending stock so as to model annual budgeting. Two graphical functions have been created to quantify departmental spending, see Figure 6.24.

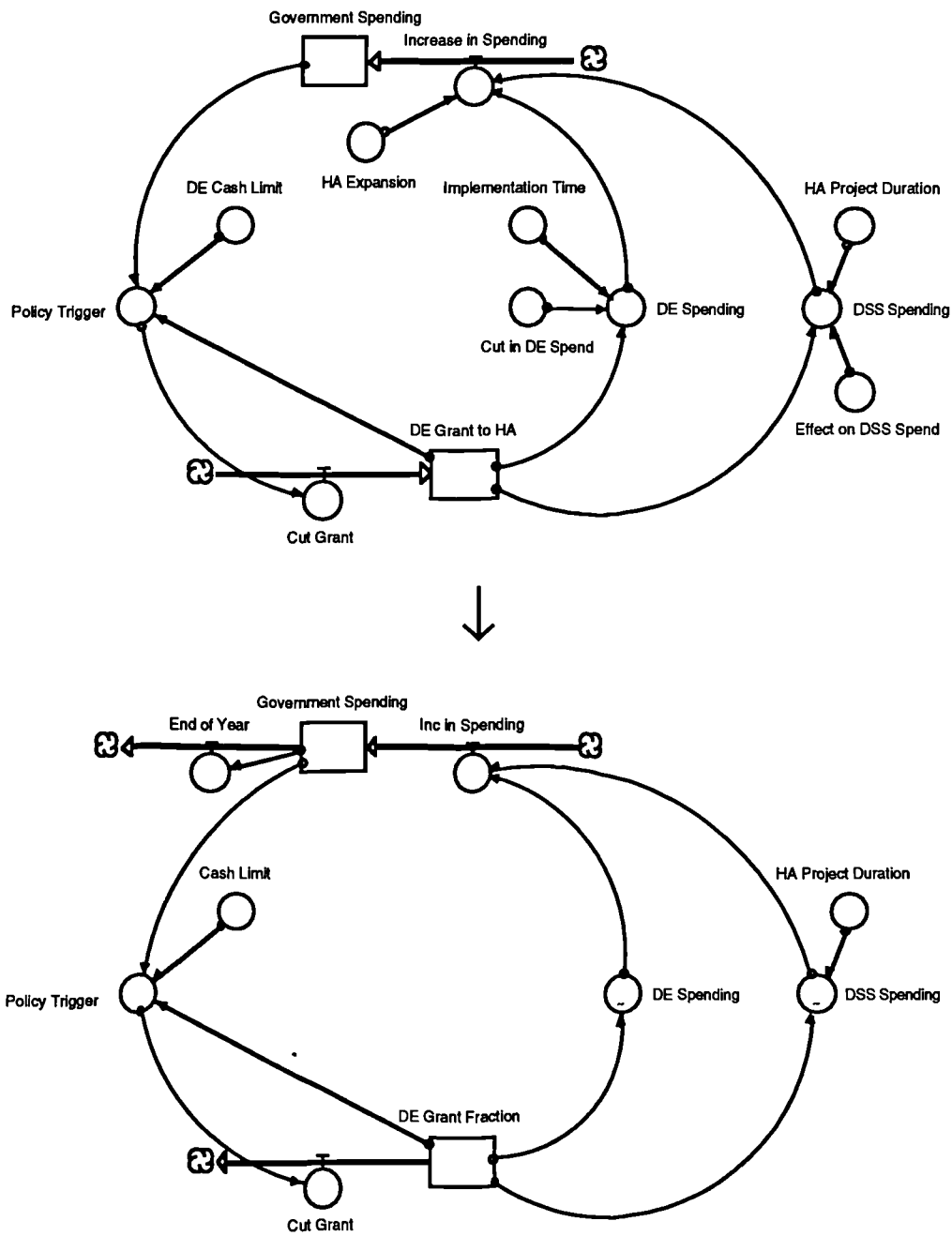


Figure 6.24 Customising the ‘fixes that fail’ generic model

The model also incorporates the order of magnitude data. This model is capable of running in equilibrium, see Figure 6.25 and producing a convincing reference mode of behaviour, see Figure 6.26.

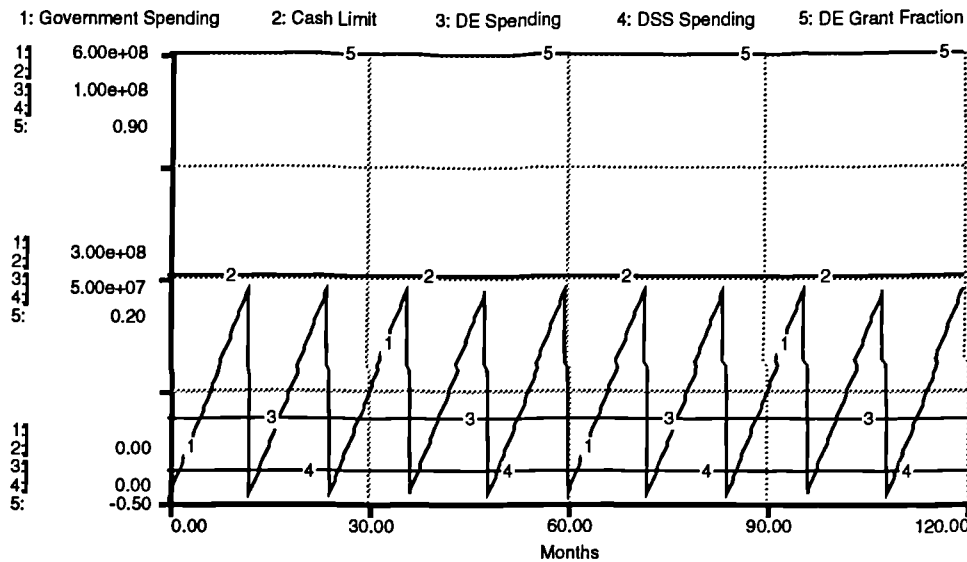


Figure 6.25 Equilibrium behaviour of the first pass model

The cash limit (target for Government spending) is set to be higher than the current level of government spending, so no action is taken to reduce spending and the system is in equilibrium.

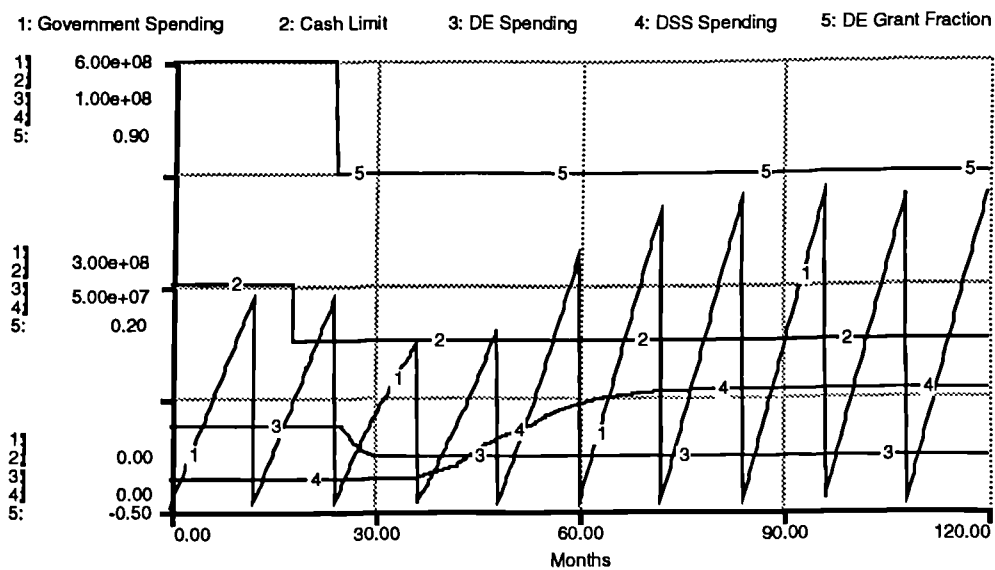


Figure 6.26 Base run behaviour of the first pass model

The base run of the model produces the required reference mode of behaviour. After the first year, a cash limit for total government spending is introduced, with the aim of reducing total Government expenditure. Towards the end of year two, the limit is exceeded and in response to this the grant fraction paid by the Department of the Environment to the housing association is cut from ninety to fifty-five per cent. The immediate effect of this cut is to reduce spending by the Department of the Environment and therefore total Government spending is brought under control; the target spending level for year three is achieved. During year four, Department of Social Security spending slowly start to rise as a result of the increasing cost of housing benefit claims, but total Government spending is only slightly above target so there appears to be no real cause for concern. In year five the increased spending on housing benefit, by the Department of social Security causes total Government spending to increase rapidly, exceeding the target value by over thirty per cent.

The system has settled to an equilibrium position by year seven with total Government spending not only well above its target level but also nearly fifty per cent greater than the Government expenditure in year one. It should be remembered that this starting value was considered to be too high and it was the reason for that Government policy was changed. The model clearly shows the dangers of implementing the chosen policy.

#### 6.4.8 Step 6: Iterative Model Development

The user is now in a position to further develop either or both of the models as required. In this particular case, the qualitative model has been further developed to eliminate a number of limitations in the first pass model.

There are two main areas where the first pass model needs improvement. Firstly, departmental spending is currently generated by graphical functions driven from the grant fraction. It would be better to show this relationship in more detail so that costs arise from the effects of grant fraction on rent levels and benefit claims.

Secondly, at present it is assumed that a cut in grant effects rent levels for all houses where in practise it will only effect the rents of new houses.

Modelling the internal interaction within the Housing Associations and the Department of Social Security will allow these improvements to be incorporated. The resultant model is shown in Figure 6.27. In addition to the previously mention changes, organisational boundaries (sectors) have also been added to this model.

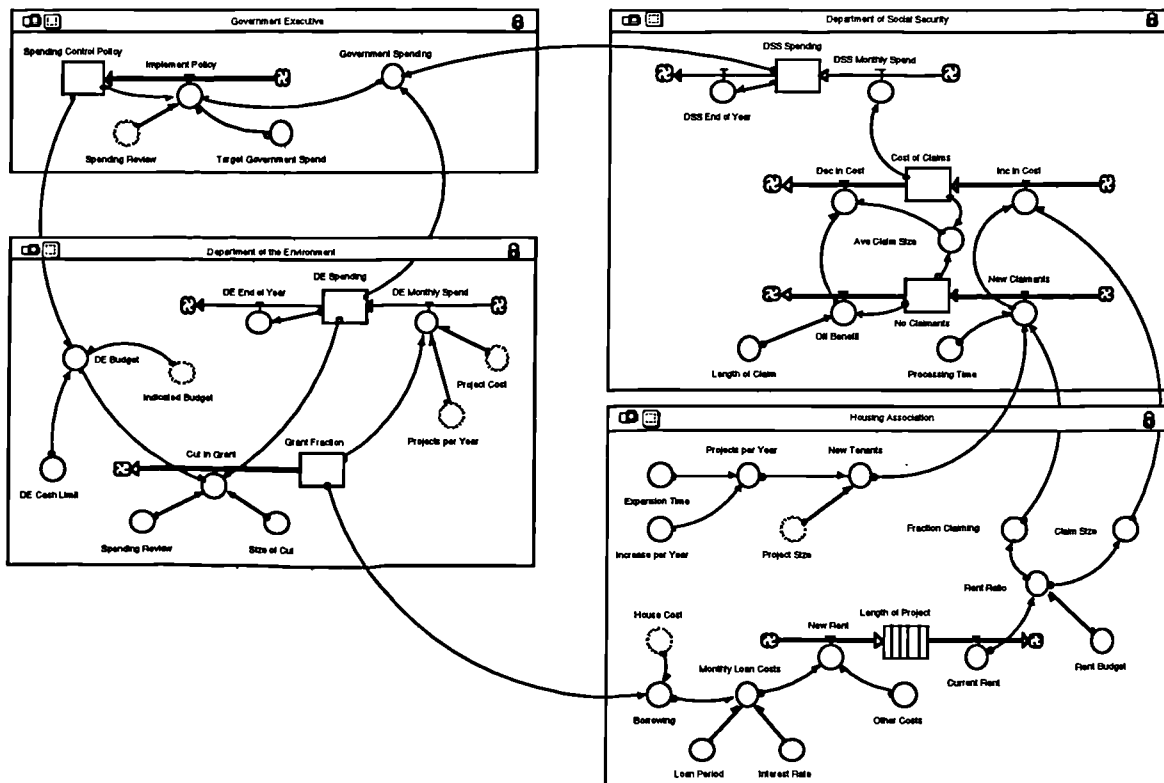


Figure 6.27 Final version of the housing association model

The final version of the model is considerably more complex than the first pass mode, it has over four times the number of model elements, but the basic feedback structure has not changed, indeed the final model has the same main loops as the initial core archetype, see Figure 6.28.

The behaviour of the final model is shown in Figures 6.29-6.35. The graphs show the system as seen from the particular viewpoint of each of the organisations that make up the system.

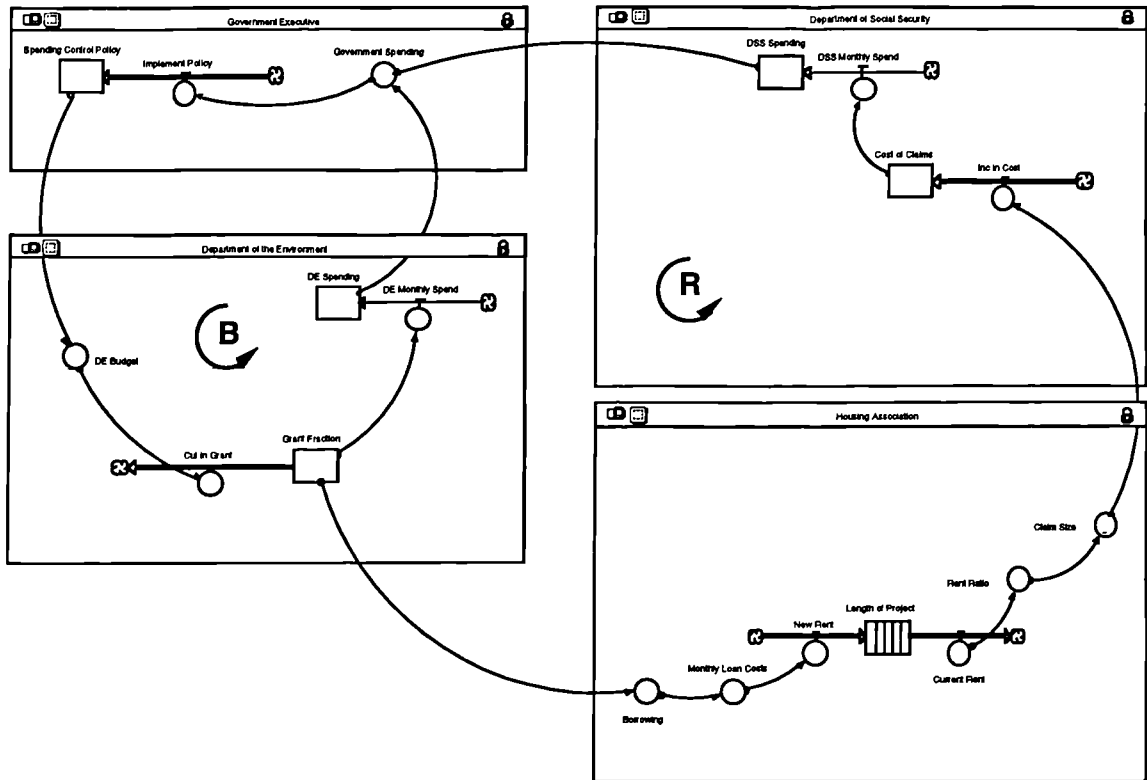


Figure 6.28 Simplified feedback structure of the housing association model

The housing associations are currently running ten housing development projects per year. An expansion program is planned which will expand this to fifteen projects per year over a four year period, an increase of fifty per cent. This expansion is due to start at the beginning of year three of the simulation.

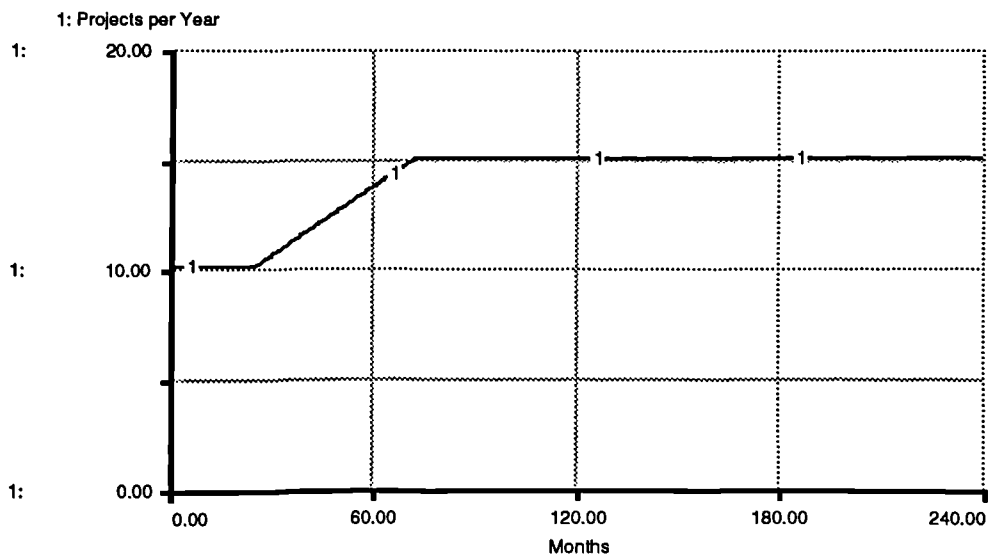


Figure 6.29 The housing association plan

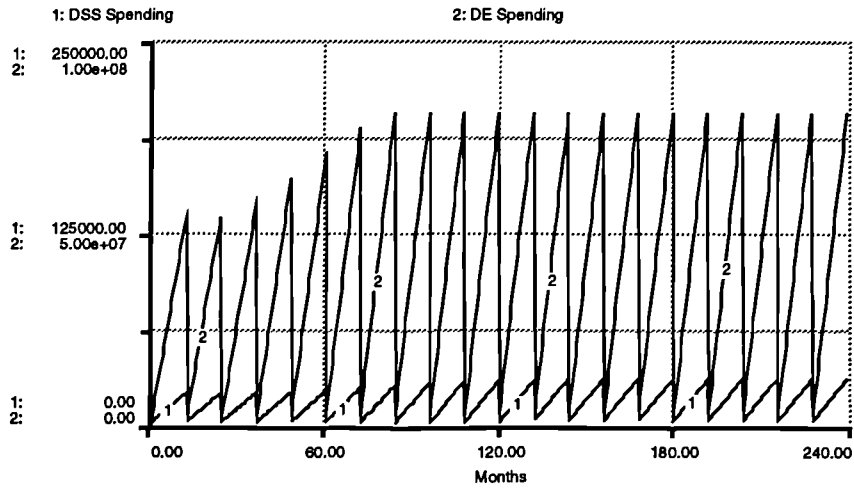


Figure 6.30 Expected effect on government spending

The expansion of the housing association building program is expected to result in a corresponding increase in spending by the Department of the Environment. The spending of other Government departments will be unaffected. This forecast assumes that there will be no change in Government policy to the housing associations. In fact the introduction of departmental cash limits, as part of a strategy to reduce Government spending will result in a rather different outcome.

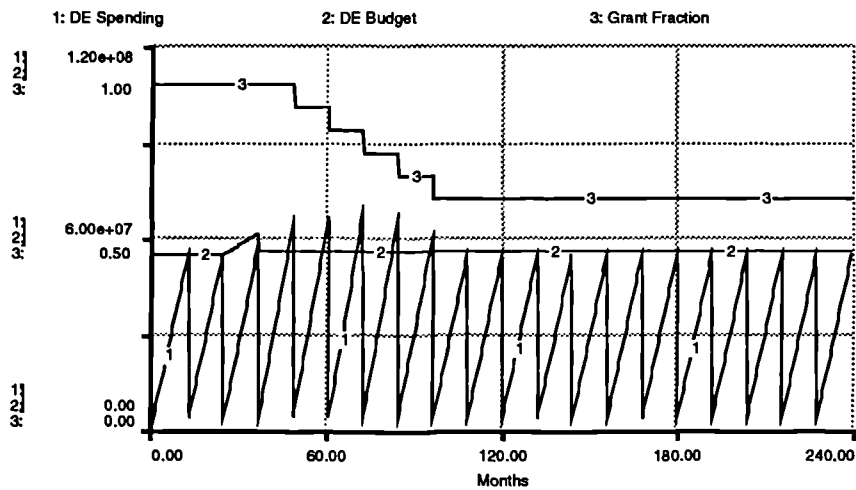


Figure 6.31 Department of the environment view: success

As the housing association expansion starts to take place, spending by the Department of the Environment start to rise above budget. In response to this overspend the Department of the Environment makes progressive cuts in the amount of grant that is paid to the housing associations, which brings spending

back within budget. From the view point of the Department of the Environment, the Governments strategy for controlling expenditure has been a success.

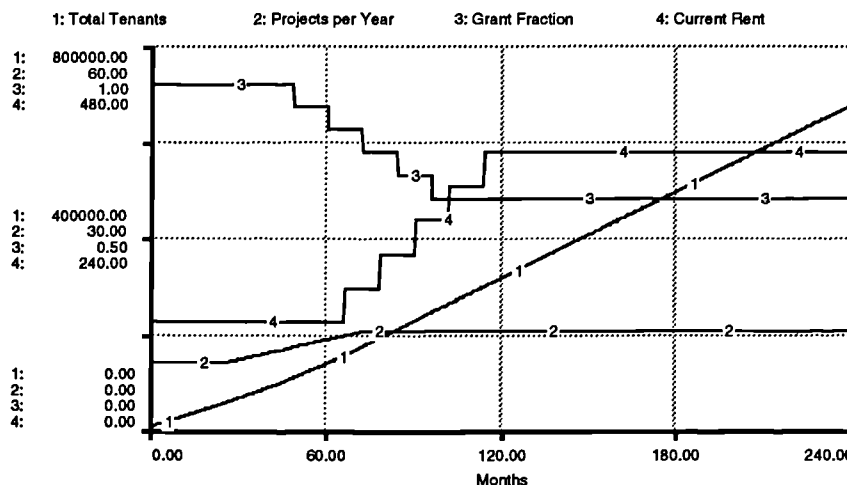


Figure 6.32 Housing association view: concern over rents

The housing associations have fulfilled their planned expansion program despite the reduced level of grant that they are receiving from the Department of the Environment. The reduction of grant levels has caused rents to rise and this is a cause of concern to the housing associations.

The higher rents have caused an increase in both the numbers of people claiming housing benefit and the average size of payment. This has resulted in increased spending by the Department of Social Security.

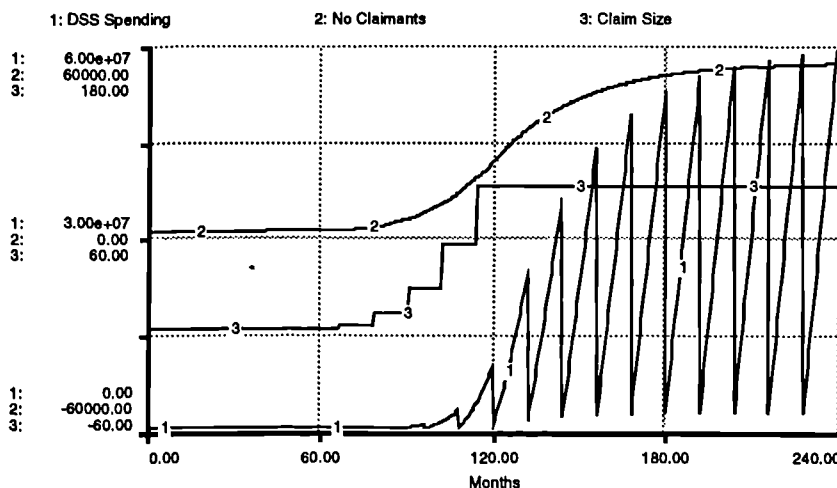
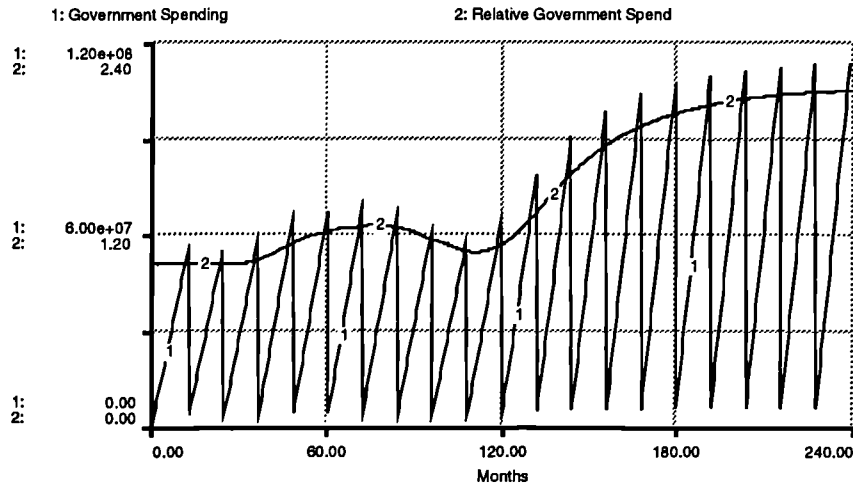


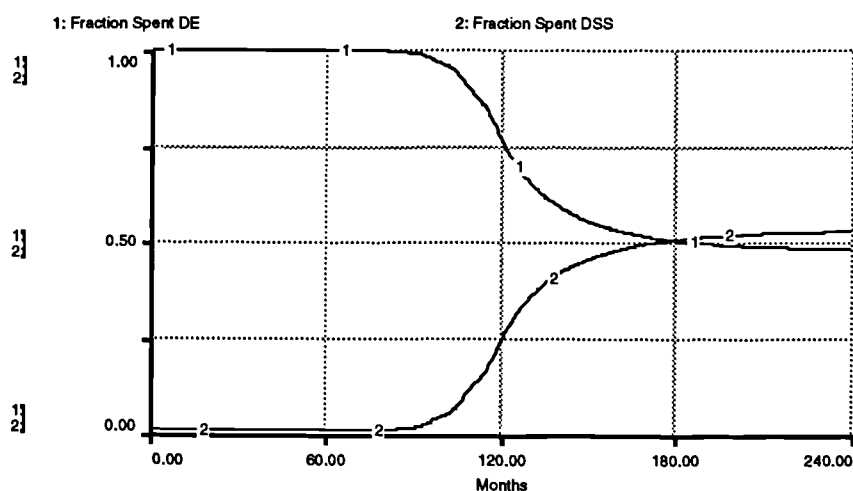
Figure 6.33 Department of social security view: disaster



**Figure 6.34 Government executive view: success then disappointment**

From the perspective of the Government Executive, the policy has produced mixed results. In the short term, the policy has halted the increase in Government spending indeed for a short while it even caused Government spending to fall. But in the long run the policy has caused a large increase in Government spending.

This behaviour is typical of the ‘fixes that fail’ archetype; a short term improvement in the problem symptom followed by a longer term deterioration in performance due to the effect of the unintended consequence.



**Figure 6.35 Breakdown of spending**

The final graph shows how the cost of providing social housing has been shifted from the Department of the Environment to the Department of Social Security.



## 6.5 Conclusions

A conceptualisation framework, that quickly takes managers from a problem to a working model has been developed. The framework has been applied to the conceptualisation of a model of public housing provision.

Currently the framework supports the 'fixes that fail' and the 'limits to success' core archetypes. This limits the application of the framework to the conceptualisation of problems based upon these two core archetypes. Further development work will extend the method to cover the rest of the core archetypes. and so allow the enhanced framework to be applied to any type of problem.

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## **Chapter 7**

### *A Delphi Based Knowledge Acquisition Tool for Group Model Building*

## 7.1 Introduction

This chapter describes the development of a computerised knowledge acquisition tool for system dynamics model building. In particular, it addresses the problem of how is it possible to involve a large group of geographically dispersed people in the model development process. Logistical considerations make meetings difficult or impossible, but it is widely accepted that much of the benefit of a system dynamics modelling exercise comes about because of personal management involvement in the actual process of model development (Richardson et al. 1989, De Geus 1990).

The need to conduct the project described arose out of the development of a system dynamics based method of information system design and evaluation, known as the Bradford Information System Evaluation Methodology; BISEM (Gavine & Wolstenholme 1990, Henderson & Wolstenholme 1990, Watts & Wolstenholme 1990, Wolstenholme et al. 1990, Wolstenholme et al. 1992, Wolstenholme et al. 1993). This methodology is specifically aimed at the development of large scale information systems, where the host organisation is correspondingly large and complex and the system actors numerous and geographically dispersed.

Part of the work described in this chapter has been published elsewhere in a shortened form (Corben and Wolstenholme 1992, Wolstenholme and Corben 1994).

## 7.2 Bradford Information System Evaluation Methodology

This section gives an overview of the Bradford Information System Evaluation Methodology (BISEM), full details of the method, it's development and applications can be found in Wolstenholme, Henderson & Gavine (1993).

### 7.2.1 Description

BISEM applies system dynamics modelling to the task of information system design and assessment. It has three stages:

**Stage 1**

The development and interpretation of a strategic model, representing the operations of the essential activities of the organisation, in terms of global performance measures under defined scenarios, prior to the proposed installation or modification of the information system.

**Stage 2**

The modification of the stage 1 model to incorporate the expected changes in its information flow attributes resulting from the installation or modification of the information system and an assessment of the behaviour of the model under the same performance measures and scenarios as in stage 1

**Stage 3a**

The identification of the opportunities presented by the installation of the information system for improved organisational performance and an assessment, using the stage 2 model as a test bed, of the structural and/or policy changes required to implement them.

**Stage 3b**

The identification of likely detrimental effects arising from the installation of the information system and an assessment, using the stage 2 model as a test bed, of the structural and policy changes required to avoid them.

## 7.2.2 Applications

BISEM has, during the course of its development, been successfully applied to two systems:

- A logistics information system (Watts and Wolstenholme 1990)
- A battlefield command, control, communication and information system (Henderson and Wolstenholme 1990).

### 7.3 A Method for Group Model Building

This section firstly describes the standard Delphi method for group knowledge capture, next an application of the Delphi method to system dynamics modelling is described, the characteristics of the system dynamics Delphi are identified and method is evaluated. Finally the logistics of undertaking a Delphi-based exercises are described and the desirability of producing a computerised tool to support the system dynamics Delphi method is established.

#### 7.3.1 The Delphi Method

The traditional Delphi method was developed by researchers at the Rand Corporation in the late 1960's (Dalkey 1969). Initially it was used as a method of consulting a group of experts for the purpose of predicting long term technological change. The method has been widely applied in the years since its development.

The major way that the Delphi method differs from more conventional questionnaires, is in its use of iteration and feedback. The individual experts being consulted are given a summary of the results of the preceding iteration and the questions asked of the experts is also influenced by this information. The stages of the Delphi method are shown in Figure 7.1.

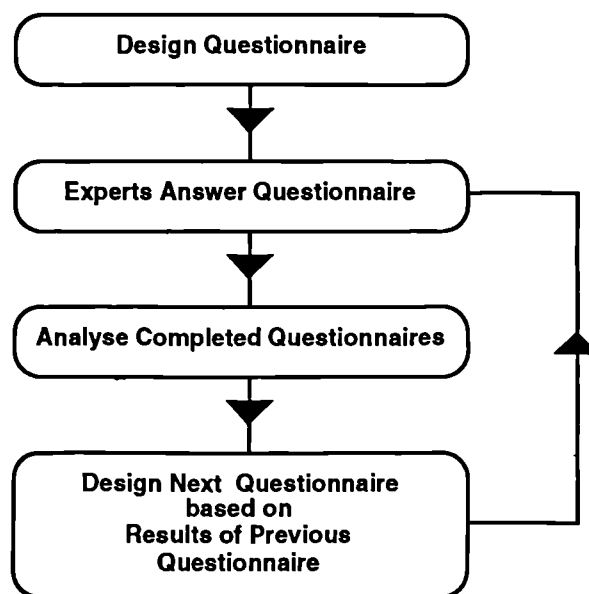


Figure 7.1 The stages of the delphi method

The Delphi thus allows an exchange of ideas to occur and promotes the emergence of a consensus. The characteristics of the Delphi method are listed in Table 7.1.

A successfully performed Delphi will allow the same discussion to occur as if the group had actually met face to face. The anonymous and remote nature of the interaction between differing points of view prevents any unfavourable group dynamics that might occur in an actual meeting.

**Table 7.1 The characteristics of the delphi method**

<b>Summary of the Delphi method</b>
<p><b>Anonymous response</b> The opinions of the group of experts are obtained through the use of questionnaires.</p>
<p><b>Iteration and controlled feedback</b> The experts are exposed to the opinions generated in the previous iterations.</p>
<p><b>Statistical group response</b> The experts collective opinion is some aggregate of the individuals opinions as expressed in the responses to the final questionnaire.</p>

The traditional Delphi method has recently been applied to assist model building in the field of health care (Vennix et al. 1988). In this study a group of over sixty health care professionals were involved in the development of a system dynamics model of the Dutch health care system. This work is described in the next section.

### 7.3.2 The Delphi Method Applied to System Dynamics Modelling

Jac Vennix describes the use of Delphi based method of knowledge acquisition for model building (Vennix et al. 1988, Vennix et al. 1990a; 1990b, Vennix 1992, Vennix & Gubbels 1992, Richardson et al. 1989). This is part of a nine stage method for group model building. The sequence of activities is shown in Figure 7.2. The knowledge acquisition using a Delphi takes place during stages 2 to 4 and it is these that will be described here.

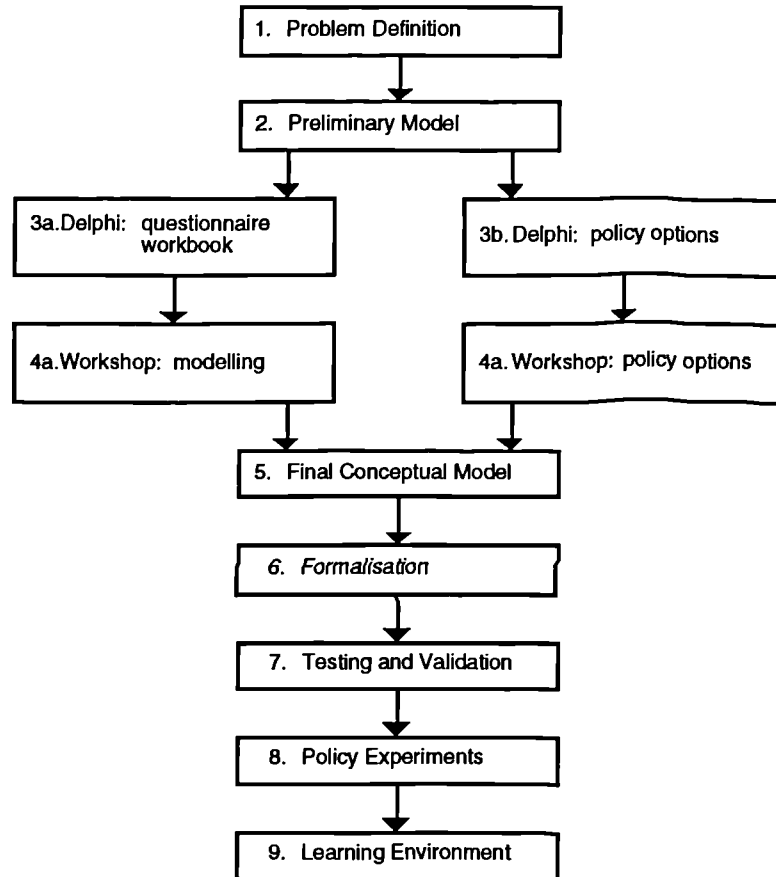


Figure 7.2 The stages of the group model building method

### 7.3.2.1 Stage 2: Preliminary Model

In this stage, the facilitator initiates contact with the clients, and after consulting key experts from within the organisation produces a preliminary model. This model aims to capture an overview of the organisation.

### 7.3.2.2 Stage 3: Delphi

A two step Delphi is performed in this stage. The first iteration is a questionnaire based on the preliminary model. A statement describing the relationship between two model variables is presented to the experts, who indicate their opinion by means of a multiple choice answer. In addition the experts are asked to justify each of their answers, by giving reasons for their replies. The aim of this procedure is to help the facilitator obtain an understanding of the mental models of the organisation which the experts have.



The second iteration is in the form of a workbook based on the results of the previous iteration. In addition to answering specific questions, the experts have the opportunity to modify the model that is presented to them in diagrammatic form.

#### **7.3.2.3 Stage 4: Workshop**

The workshop consists of two parts; firstly the experts work in small sub-groups, each group being given a particular sector of the model to develop. The members of the group discuss the modifications each proposed during the previous workbook stage. The aim of these discussions is to produce an agreed final version of the *sector of the model with which the group has been working*.

In the second stage the full group meets to combine the sectors into one overall model. Each sub-group presents the final version of its part of the model to the full groups and the changes made are fully discussed and modified if necessary. When all the sectors have been reviewed, the group moves on to discuss the relationship between the individual sectors. The final task of the workshop is to link the sectors to create a final consensus model.

#### **7.3.2.4 Summary**

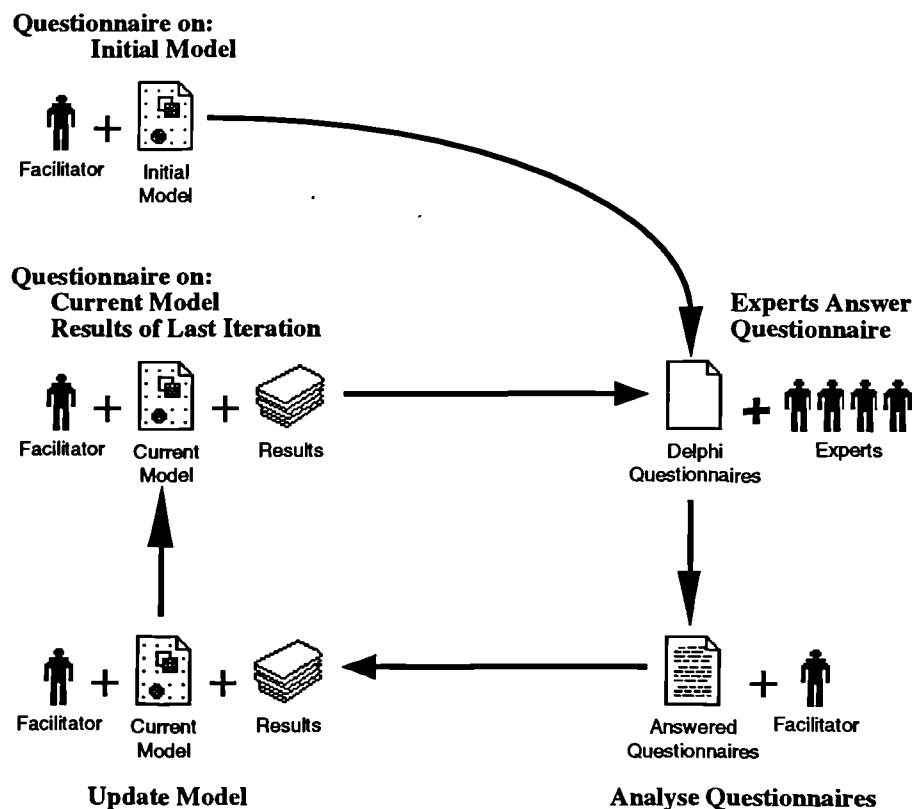
This method allows the participation of a much larger group of people than would be feasible if face to face meeting had to take place. Logistic problems are minimised because there is only one step (the workshop) where the experts are required to meet as a group. The preceding Delphi ensures that those attending the workshop are already versed in the modelling methodology, have had experience of formulating models and are familiar with the range of views that others have expressed about the model. This prior knowledge ensures that the maximum benefit is gained from the one required workshop session.

### **7.3.3 The System Dynamics Delphi**

The preceding section described a specific application of the Delphi method to system dynamics modelling. This section describes the generality of the approach.

In the Delphi approach to system dynamics model building (system dynamics Delphi), the model, initially in the form of a qualitative diagram, assumes the role of a transitional object by which individual perspectives and the group consensus is expressed. The stages of the system dynamics Delphi are shown in Figure 7.3

To allow members of the group to inspect and modify the model, diagrams must be incorporated into the Delphi questionnaires.



**Figure 7.3** The stages of the systems dynamics delphi

To start the process off an initial model of a perceived issue or cause for concern is required. This model is a high level overview model developed by the facilitator in consultation with key experts. The facilitator uses this initial model as the basis for a questionnaire that is put to a group of people who are expert in the domain in question. The answered questionnaires are then analysed by the facilitator as a basis on which to design the questions to be answered in the next iteration of the application. The characteristics of the method are summarised in Table 7.2.

If a comparison is made between Table 7.1 and Table 7.2 it can be seen that the main difference between the traditional Delphi and the System dynamics Delphi is the method used to represent group opinion. The traditional approach relies on statistical analysis whereas the System dynamics approach uses a model.

**Table 7.2 The characteristics of the system dynamics delphi method**

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**Summary of the System Dynamics Delphi method**

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**Anonymous response**

The opinions of the experts are obtained through questionnaires, which include the use of diagrams.

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**Iteration and controlled feedback**

The experts are exposed to the opinions generated in the previous iterations and to the state of the group consensus as expressed in the current state of the evolving System dynamics model.

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**Group response represented by the model**

The experts collective opinion is some aggregate of the individuals' opinions as expressed in the final System dynamics model.

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### 7.3.4 Evaluation of the System Dynamics Delphi Method

The conventional Delphi based method is highly suitable for consulting large, geographically dispersed groups of experts, while still allowing the exchange of ideas that occur in face to face meetings. It has also been shown that the method can with slight modification; the inclusion of diagrams in the questionnaire, be successfully applied to system dynamics modelling, thereby allowing the sharing of mental models, that is the key to a successful system dynamics modelling exercise, to occur, without the need for group meetings.

### 7.3.5 The Logistics of a Delphi Exercise

The tasks that need to be carried out to support one iteration of the Delphi method are listed in Table 7.3.

**Table 7.3 The tasks required by the questionnaire life-cycle**

<b>Tasks</b>
Questionnaire design
Questionnaire production
Questionnaire distribution
Questionnaire collection
Questionnaire analysis

#### **7.3.5.1 Questionnaire design**

This will only be a major task in the first iteration, after that the analysis of the previous iteration should provide the information required for the new questionnaire.

#### **7.3.5.2 Questionnaire production**

This is a relatively simple task and standard word processing software may be used to carry this out.

#### **7.3.5.3 Questionnaire distribution and collection**

The organisation of the distribution and collection of the questionnaires will depend on the circumstances of the particular investigation and so will not be further discussed.

#### **7.3.5.4 Questionnaire analysis**

The analysis of the questionnaires is the biggest workload of all the stages of the Delphi method. Software does exist to aid the analysis of questionnaire, but this is unsuitable to support the systems dynamic Delphi for two main reasons.

Firstly this kind of software is designed to process ordinary questionnaires, so the emphasis is on the statistical analysis of coded responses. In contrast, the aim in analysing Delphi questionnaire is to identify facts, ideas and arguments that can be fed back to the group of experts in the next iteration.

Secondly such software is invariably text based, without the facility for storing the diagrams that are a crucial element of the system dynamics Delphi.

### 7.3.6 Need for a Computerised Delphi Tool

It has been shown that the processing of the completed system dynamics Delphi questionnaires creates a considerable work load for which there is no suitable computerised support available. It was therefore decided to investigate the practicality of computerising the whole process, including the actual questionnaires themselves. The rest of this chapter describes the design, production, testing and evaluation of a computerised system dynamics Delphi tool.

## 7.4 Design and Development of the Tool

In this section the requirements of a computerised Delphi tool are identified and the choice of the hardware and software that was used to build the tool is discussed.

### 7.4.1 Requirement of a Computerised Delphi Tool

If the production and analysis of the Delphi questionnaires were to be computerised, it seemed logical to computerise the actual questionnaires themselves. If the questionnaires were not computerised, then most of the potential for savings would be lost in the data entry effort required to code up the questionnaires. The manual processing of diagrams would be particularly difficult and time consuming in this respect.

The following requirements were drawn up for a tool that would fully support the system dynamics Delphi method:

- 1 The tool should enable the creation and editing of a computerised Delphi questionnaire, with support to be provided for both text and diagram based questions.

- 2 The Delphi Questionnaire should be easy to use, and it should be assumed that users had no previous experience with computers. Context dependent help should be available to the user at all times.
- 3 The Delphi Questionnaire should have a facility allowing the users to explain and give reasons for their answers. The users should be encouraged to use this facility as much as possible.
- 4 The tool should automate the process of collating and analysing the completed questionnaires.
- 5 The tool should create an archive, containing the results of all the iterations. The facilitator should be provided with the means to browse this archive and to add text and diagrams, summarising the opinions of the experts.

#### 7.4.2 Implementation of the Computerised Delphi Tool

The main requirement of the software used to build the computer based Delphi tool, was the ability to store and manipulate both text and graphics. This immediately suggested the use of a Hypermedia-based solution; these systems are specifically designed to allow the creation, mixing and linking of text, graphics and sound. The use of a commercially available Hypermedia program would therefore eliminate the need for a large amount of programming.

#### 7.4.3 Hypermedia

The forerunners of hypermedia were simple text-based systems, known as hypertext. The term hypertext was first used by Theodore Nelson (Nelson 1967), but the idea dates from earlier (Bush 1945). The key idea of hypertext is the interconnection of all knowledge. A hypertext application uses computer technology to create documents in which ideas are linked; the user can roam at will following a chain of discovery through the information contained within the document.

Hypermedia takes the idea of hypertext a stage further and allows the creation of interactive documents that contain graphics, sound, animation and text. The graphical and animation capabilities vary from the basic; simple computer graphics to the sophisticated; high resolution colour images and video. Applications providing these advanced facilities are often called multimedia. The distinction between hypermedia and multimedia is somewhat blurred and these terms are often used interchangeably.

A comparison of the list requirements for the tool, with the capabilities of hypertext, hypermedia and multimedia systems, suggested that a basic hypermedia program would be adequate for the task of building the tool.

#### 7.4.4 Choice of Hardware

The Apple Macintosh was selected because of its user friendly graphical interface, the availability of a wide range of hypermedia software<sup>1</sup> and for its compatibility with the STELLA/ithink software<sup>2</sup> for system dynamics model building.

#### 7.4.5 Software Selection

There is a wide range of hypertext, hypermedia and multimedia software available for the Apple Macintosh. Many of these are designed to produce multimedia documents and lack the scripting language necessary to build applications. This requirement narrowed down the decision to the choice between HyperCard and SuperCard, both of which the author had previous experience of using. The next two sections give a brief overview of HyperCard and SuperCard.

##### 7.4.5.1 HyperCard

HyperCard (Apple Computer 1990) was the original hypermedia system for the Apple Macintosh; it was launched in August 1987. HyperCard uses the metaphor of a card index. The user creates an application by building up a collection of cards,

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<sup>1</sup> This decision was made in the autumn of 1990 before the use of Windows 3 became widespread . There was consequently, a lack of simple low cost multimedia applications for the PC.

<sup>2</sup>Windows versions of STELLA and ithink became available in March 1994.

known as a stack. The cards are of a fixed size, equal to the dimensions of the original Macintosh screen.

Functionality is added to a stack by placing objects onto the cards; text fields, buttons and paint graphics may all be added to the cards, sounds can also be incorporated. Colour is not supported, so the objects on the cards are limited to being shown in black and white. In addition to creating these objects, the user can program them to respond to events, such as mouse clicks. Programming in HyperCard is carried out using a scripting language called HyperTalk. This is an object oriented programming language that has an English like syntax. HyperTalk has wide range of commands and functions; text manipulation is a particularly well supported as is the ability to sort and search the cards within a stack.

A number of ready built stacks comes with HyperCard, one of these, the Home stack, is an essential part of the software. The Home stack is used as a control panel to access other stacks, customise and configure HyperCard and act as a place to store resources.

It is easy to create simple applications using HyperCard and more advanced stacks that include animation are possible with a corresponding increase in programming effort. The capabilities of HyperCard can be enhanced by the creation of external commands and external functions. These are user defined routines written in C or Pascal, that perform tasks not usually possible in HyperCard.

#### **7.4.5.2 SuperCard**

SuperCard (Silicon Beach Software 1989) provides the same basic features as HyperCard and a number of additional enhancements, as shown in Table 7.4. There are a few changes in nomenclature, applications are called projects rather than stacks and the scripting language is known as SuperTalk (a super-set of HyperTalk). The other major difference is the lack of a Home stack; SuperCard has a "runtime editor" to provide the user with runtime control. The Home stack's other function; resource storage, is performed by the "shared-file" in SuperCard.



**Table 7.4 The extra features of SuperCard compared with HyperCard****SuperCard Additional Features**


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Multiple window applications  
 Window styles, including floating palettes  
 Variable card size  
 Draw graphics  
 Colour graphics  
 Animation  
 List and scrolling list fields  
 Menus, pull-down and pop-up  
 Standalone applications  
 Editing environment  
 Debugging facilities

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So what is the relationship between SuperCard and HyperCard, is it simply a clone? Not according to C. Jackson, president of Silicon Beach Software, the company that produces SuperCard, he does not see SuperCard as a HyperCard clone, but argues that its additional features in particular the draw-based graphics, entitles SuperCard to the status of a second generation product (Himes & Ragland 1990).

This claim is obviously not being made from a neutral view point, but as has already been shown, SuperCard does offer greatly enhanced functionality compared to HyperCard. From the perspective of the user, SuperCard does feel a significantly more powerful product. The user of HyperCard, feels that they are working within an application, even though they may be authoring their own applications. SuperCard has the feeling of a programming language.

**7.4.5.3 Choice of Software**

SuperCard was chosen in preference to HyperCard because of its many extra features. The most important of which was, the ability to produce standalone applications, thus enabling the questionnaire to be run on any Apple Macintosh

computer without the need for any specific software to be present. The superior development facilities; the separate editing environment and the ability to debug script using the trace facility, were also important factors in the choice of SuperCard. This decision does not imply that HyperCard would have been inadequate to the task of building the tool, simply that SuperCard would allow a better tool to be developed<sup>1</sup>.

#### 7.4.6 Construction of the Tool

The tool-set was built using SuperCard on an Apple Macintosh computer and became known as the SuperDelphi. To ensure that the software was easy to use and conformed to user's expectations of a Macintosh program, the appropriate guidelines for human interface design (Apple Computer 1987; 1991) and stack design (Apple Computer 1989) were followed. The development of the tool-set took place over the period of six months.

### 7.5 Description of the SuperDelphi Tool-Set

The SuperDelphi tool-set consists of six parts:

- 1 SuperDelphi Creator
- 2 SuperDelphi Builder
- 3 Standalone Delphi Questionnaire
- 4 SuperDelphi Analyser
- 5 SuperDelphi Archiver
- 6 SuperDelphi Archive

The use of the individual tools to support the system dynamics Delphi is shown in Figure 7.4, which depicts the performance of one iteration.

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<sup>1</sup> At the time this decision was made; autumn 1990, the choice was between HyperCard 1.2 and SuperCard 1.5. At the end of 1990 HyperCard 2.0 was launched, providing many enhancements. Since then SuperCard 1.6 and HyperCard 2.2 have appeared, neither of which represents a radical development over their predecessors.

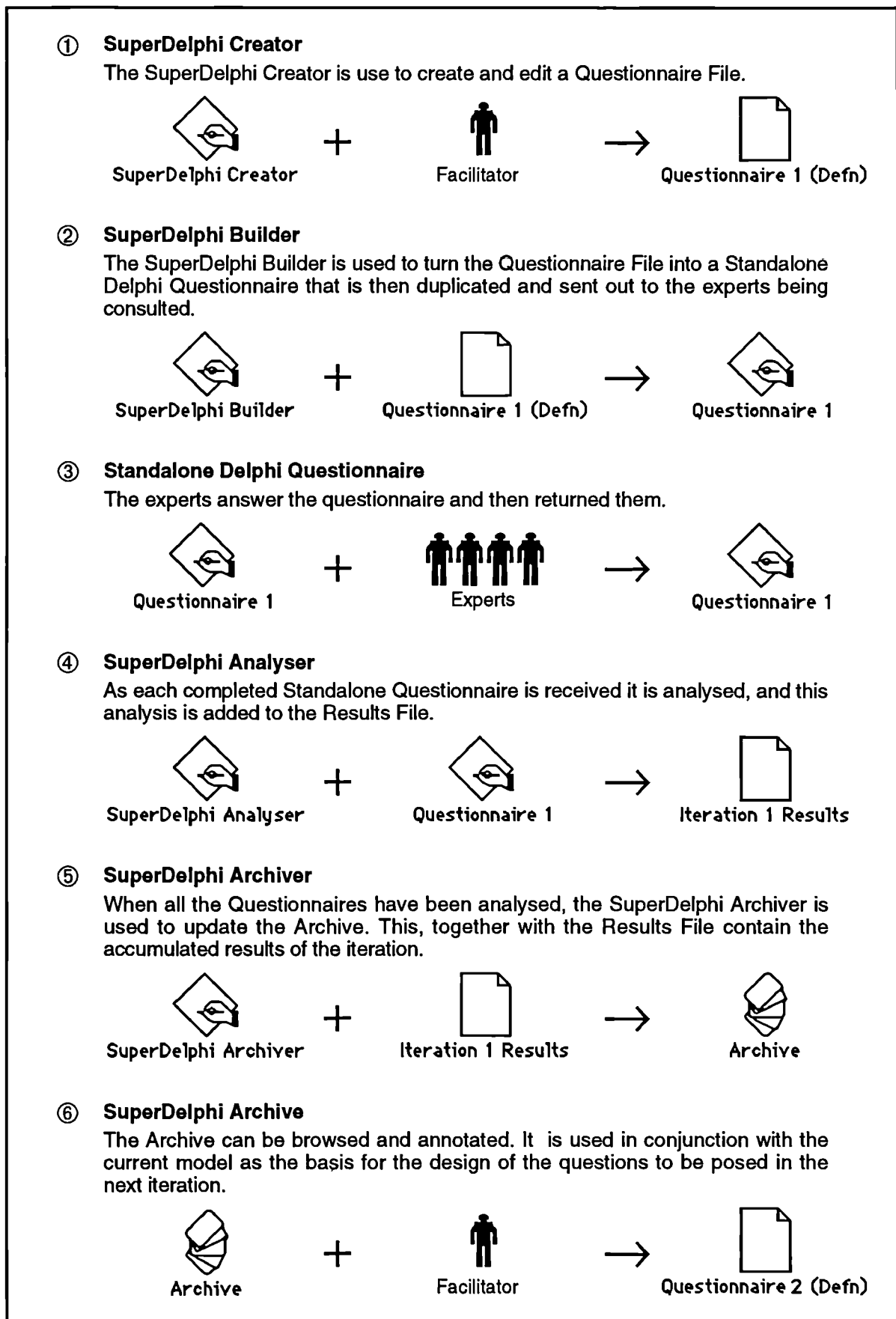


Figure 7.4 One iteration of the system dynamics delphi method.

The most important parts of the SuperDelphi system from the modelling point of view are the SuperDelphi Questionnaire and the SuperDelphi Archive. These are described in the next sections. The other parts of the tool-set perform a mechanical, supporting role and are not further described.

### 7.5.1 The SuperDelphi Questionnaire

The Standalone Delphi Questionnaire is the only part of the SuperDelphi tool set that is used by the experts being consulted. The Delphi Questionnaire consists of a window in which the question cards are displayed and two floating palettes, the Standard Palette and the Drawing Palette. See Figure 7.5.

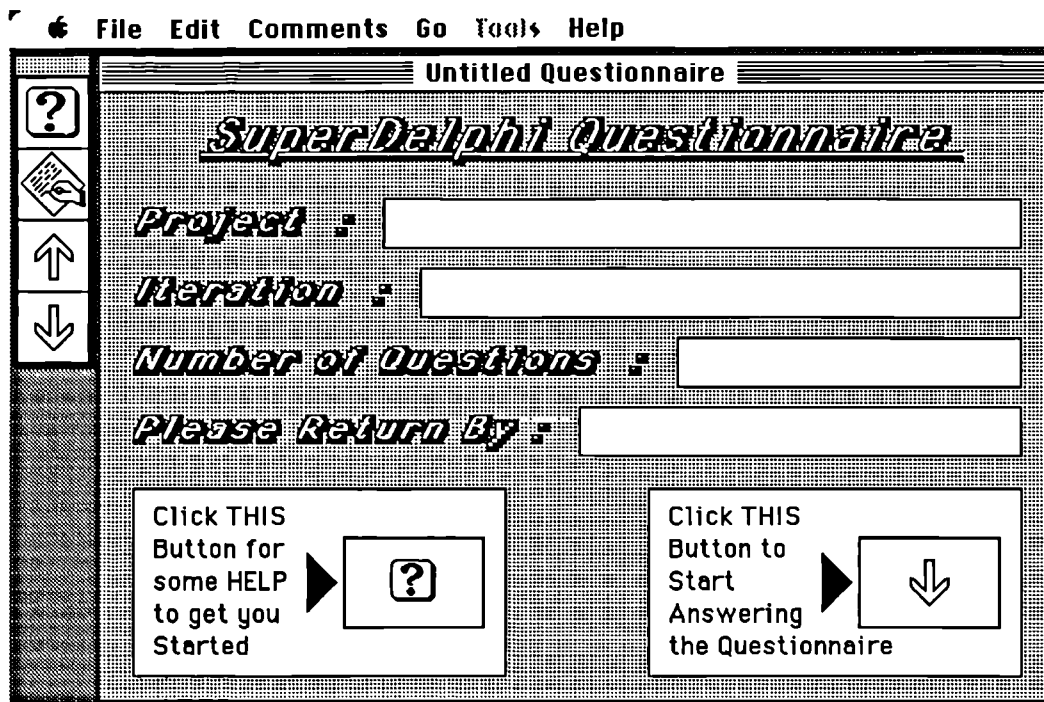


Figure 7.5 The questionnaire window and standard user tool palette

#### 7.5.1.1 The Standard Palette

This palette is permanently displayed and contains four buttons that enable the user, to perform the following operations: request help, add a comment, go to the previous question and go to the next question, see Figure 7.6.

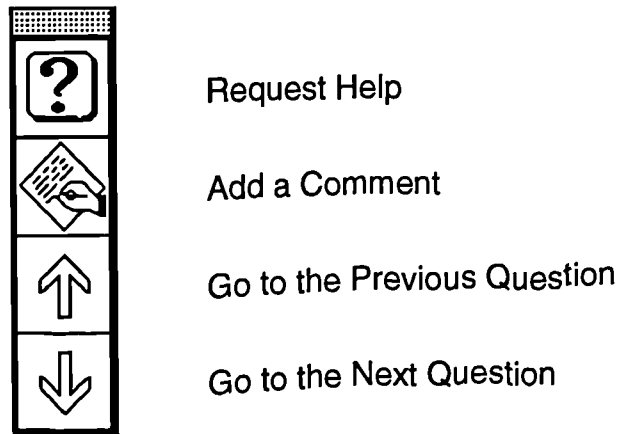


Figure 7.6 The standard user tool palette

Help is available in two forms, general and specific.

### General help

This gives help on how to move around the questionnaire; add a comment; quit the questionnaire and work with text.

### Specific help

This gives help on how to answer the current question.

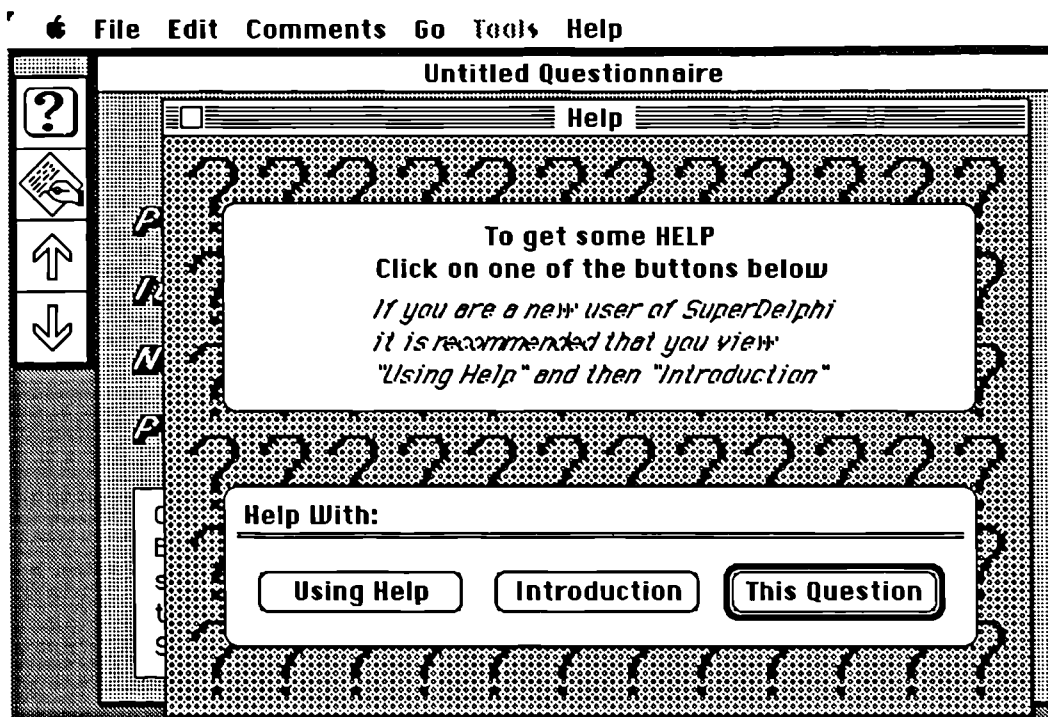


Figure 7.7 The help window

### 7.5.1.2 The Drawing Palette

This palette is displayed when the user is asked to draw or modify a diagram, it contains four buttons that allows the user to select one of the following tools:

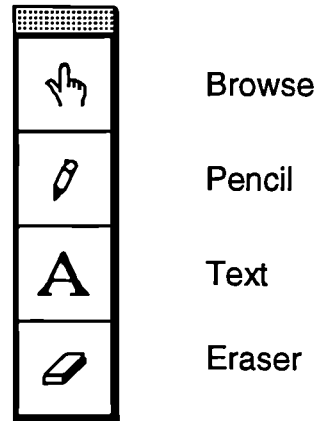


Figure 7.8 The user drawing palette

### 7.5.1.3 Encouraging Answers and Comments

When the user asks to quit the questionnaire the response rate is calculated. If the user has left some of the questions unanswered then a dialogue appears, warning that there are some unanswered questions and offering the opportunity to go to the first of these unanswered questions.

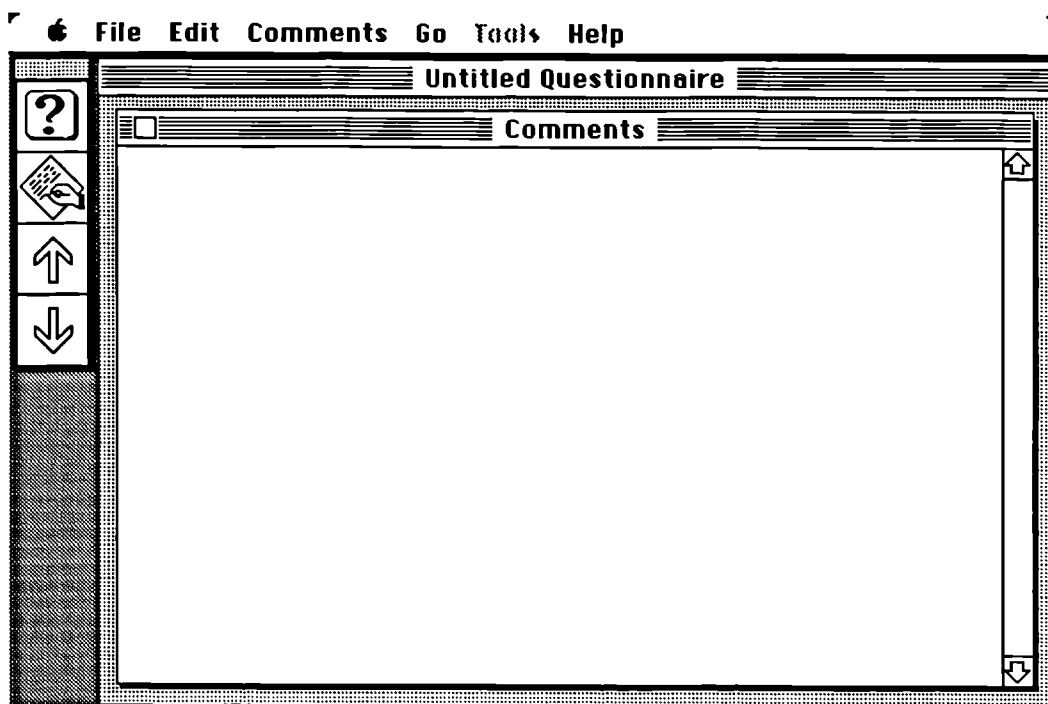


Figure 7.9 The comments window

To encourage the experts to make as many comments as possible, the use of the comment facility is monitored. If the expert appears to be making little use of the comment facility, then they are prompted to do so. This is implemented in the following manner; if the expert leaves more than two consecutive questions without comments, then it is increasingly likely that as the expert tries to move on to the next question, a dialog box will appear reminding the expert about the comment facility and stating how useful it would be if it were used. Three slightly different dialog box messages are used to provide variety.

### 7.5.2 Questions Available for the SuperDelphi Questionnaire

There are four types of questions available for use in the questionnaire; text, factors, diagram and graph. Each type of question is implemented in a number of different formats. This range of formats allows the facilitator to choose how the user will answer a particular question. A hierarchical menu is used to select a specific question, that is a question of a certain type and format. The full range of questions is shown, as it appears on the hierarchical menu, in Figure 7.10. In the following sections, an overview of each type of question is given.

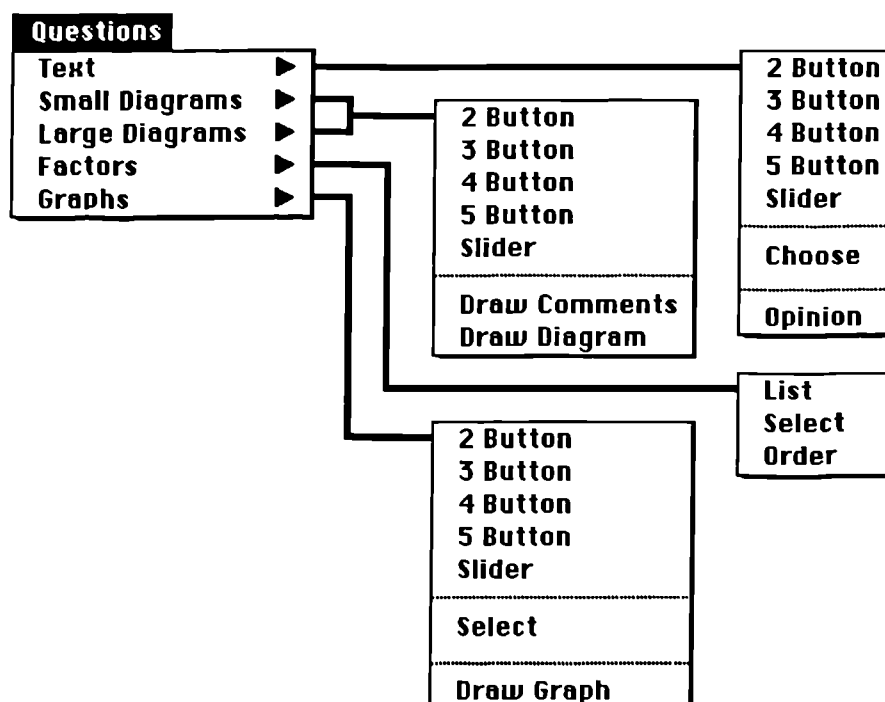


Figure 7.10 The full range of questions provided for use in the SuperDelphi

### 7.5.2.1 Text Based Questions

These types of questions use only text to ask questions. In the second and subsequent iterations, the text will usually contain some feedback, summarising the replies to the previous iteration. Three different types of text based questions were developed.

#### Multiple-choice questions

The user selects one of the displayed options, with a mouse-click, to indicate their opinion of the text statement.

#### Choose

The user chooses between two alternative statements, using the mouse.

#### Opinion

This question allows the user to provide a written reply.

Please read the following statement and indicate your opinion by clicking on the appropriate button.

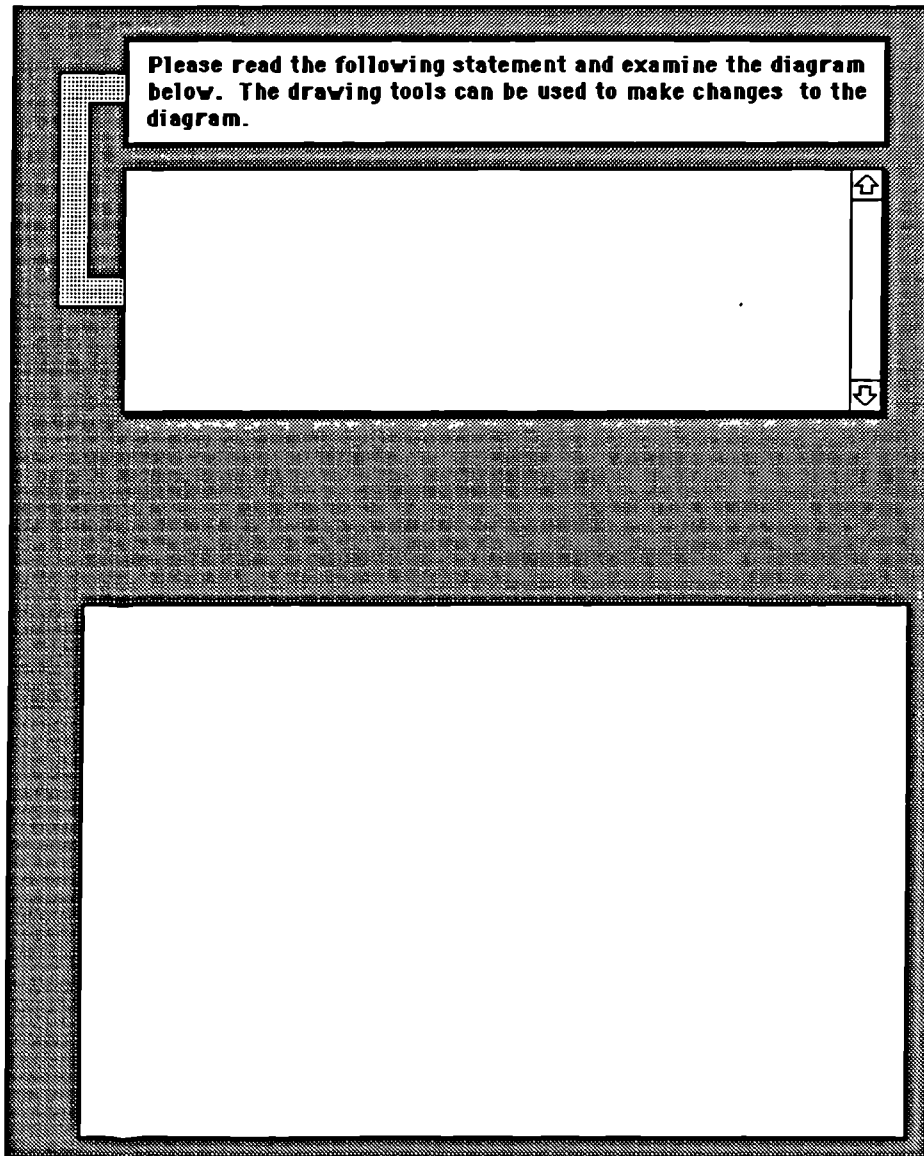
AGREE      UNCERTAIN      DISAGREE

Figure 7.11 An example of a text based question



### 7.5.2.2 Diagram Based Questions

Diagrams are an essential feature of the system dynamics methodology. It is therefore important to allow the experts being consulted to view, modify and create diagrams. The tool provides the facilities to draw both causal loop diagrams and system dynamics flow diagrams.



**Figure 7.12** An example of a diagram based question

The diagram based questions are available in two sizes, small and large, the large diagram being four times the area of the small. In all other aspects the questions are similar.

### **Multiple-Choice Questions**

These are the same as the text based questions, except that the user is asked for their opinion about some aspect of a given diagram.

### **Draw Comments**

These questions allow the users to add comments and make changes to a given diagram. The diagram provided can be a complete diagram, in which case the question will ask the experts to annotate or modify it. Alternatively, a partial diagram can be given which the experts are requested to expand by creating links and adding new model elements.

### **Draw Diagram Questions**

The user draws their own diagram in reply to the question.

## **7.5.2.3 Factor Based Questions**

These questions are designed to investigate the factors that influence a particular aspect of the system being modelled and so identify causal relationships.

### **List Factors**

The users are asked to make a list of factors in response to a text question. This question is used early on in the modelling process, to identify causal relationships.

### **Select Factors**

The users are given a list of factors and are then asked to indicate their opinion of the importance of these factors. The expert answers the question by clicking on a "Tick" or a "Cross" next to the description of each factor.

### **Order Factors**

This question asks the users to consider a list of factors and to place them in order of importance. The expert answers the question by selecting a factor and then clicking a numbered button.

The following factors have been identified as having an important influence on

Click on the Tick or Cross to indicate your opinion of the relevance of the factor. Please suggest any other factors that should be included.

Missing Factors

Figure 7.13 An example of a factor based question

#### 7.5.2.4 Graph Based Question

There are three situations in which is important for the experts to be able to view, modify, comment on and select graphs. The first is the identification of reference models of behaviour for key system variables. The second is the design of the graphical relationships. The third is to present simulation output for comment in the later iterations. It is therefore important to allow the experts being consulted to view, select and create graphs.

### Multiple choice

These questions ask for the users' opinion of a graph

### Select

This question asks the user to choose a curve, from a selection of twelve, that best describes a given non-linear relationship or mode of behaviour.

### Draw Graph

This user is asked to draw a graph in response to a question.

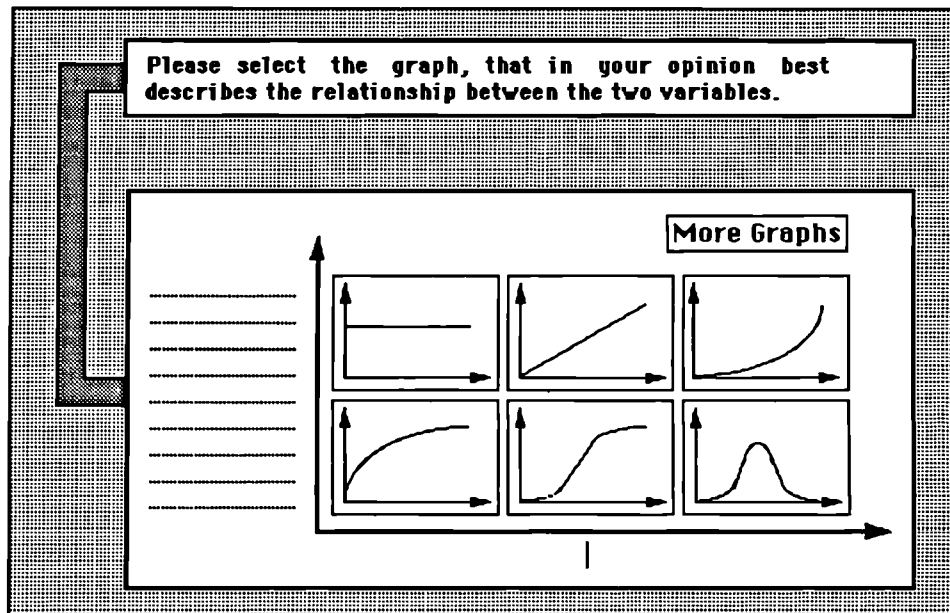


Figure 7.14 An example of a graph based question

### 7.5.3 The SuperDelphi Analyser

The SuperDelphi Analyser is used to analyse the Standalone Delphi Questionnaires to produce a Results File. The questionnaires do not have to be analysed simultaneously. The results file can be updated each time additional questionnaires become available.

The first task the analyser performs when given a questionnaire from a new iteration to analyse is to create a Results File. Then the analyser scans the Standalone Delphi and for each question a result card is added to the Results File.

The Analyser now works its way through the questionnaire, taking the information from the question card and adding it to the corresponding Result Card. The analyser transfers the response, diagrams, comments and where appropriate produces histograms of responses and some simple summary statistics.

Finally the Analyser “tags” the Standalone Delphi so that it cannot be analysed twice by mistake and adds the details of the Standalone Delphi that has been analysed to the Analysis History of the Results File

Subsequent questionnaires from the same iteration are processed in an identical manner except that now there is no need to create a new Results File, as the existing one can be updated.

#### 7.5.4 The SuperDelphi Archive

The SuperDelphi Archive holds the results and collected comments of an iteration. The Archive can be browsed and annotated to produce a summary of the experts’ opinions, that can be used as the basis for the design of the questions in the next iteration.

The SuperDelphi Archive consists of four windows, Results, Comments, Summary and Diagrams. For every card in the original questionnaire, there is a corresponding card in each of these four windows.

##### **Results Window**

The first card of this window contains details of the identity of the iteration and the name of the modelling project. A list of the questionnaires whose analysis is contained in the Archive is also available at the click of a button.

The other cards in the window contain the results. The type of information that is displayed by each result card is dependant on the nature of the original question. All result cards give details of the response rate for each question and the number of comments made. The result cards for the

multiple choice questions provide a histogram and some simple statistics to give an indication of the group view. For questions that ask the expert to draw or modify a diagram, the result cards always display the resulting diagrams. These diagrams can be viewed either singly or they can be superimposed, to show at a glance, all the changes that have been made.

### **Comments Window**

This window contains a card with a scrolling text field, in which all the comments made by the experts about a particular question are collected together. The facilitator can browse through these comments, search them for a particular text string and copy the text as required.

### **Summary Window and Diagrams Window**

These windows are used by the facilitator to summarise the replies and comments to each question. The facilitator can use text or diagrams to record thoughts.

## **7.6 Testing the Delphi Tool**

A small scale test of the system dynamics Delphi tool was performed on a project concerned with the development of automated tools to support the Jackson System Development (JSD) methodology (Jackson 1983).

The object of the test was to acquire knowledge from a widely dispersed team of software engineers on what tools were being used and in what way to support JSD applications. The idea was to collect and structure knowledge by creating a quantitative model of the software engineering process and the way in which existing and proposed tools for automating it impinged on the process.

To start the knowledge acquisition process off, an initial qualitative causal loop model of the software development life cycle was conceptualised. This model which has a high level of aggregation is shown in Figure. 7.15. It incorporates organisational sectors and was created by the facilitator in discussion with the key

domain expert. The first iteration of the computer based system dynamics Delphi tool was based upon this model. The results of the first iteration were analysed and a second iteration produced

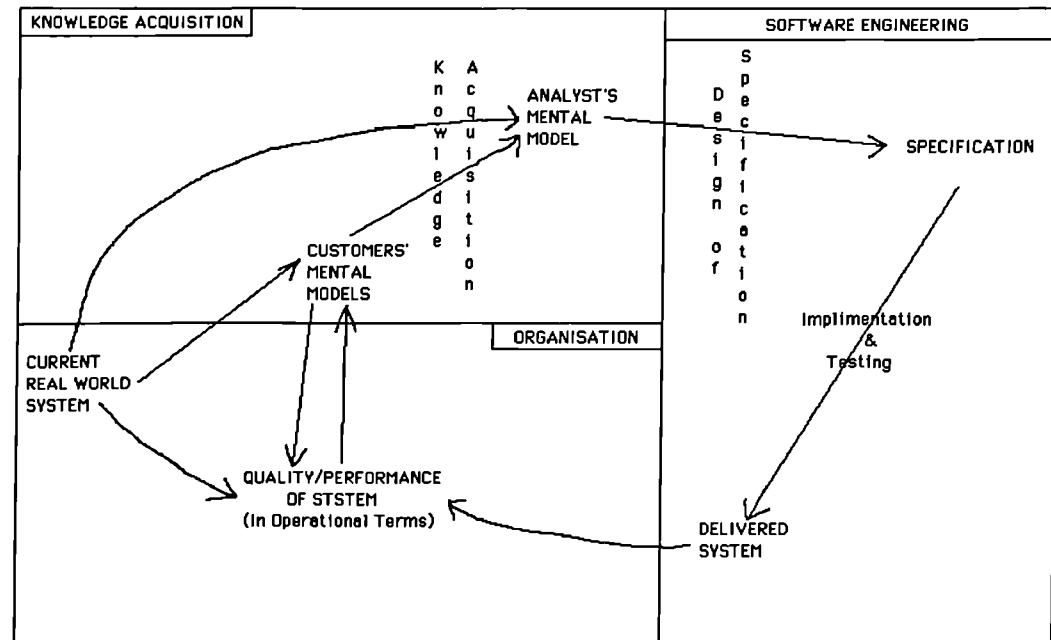


Figure 7.15 Initial model of the information system design process

## 7.7 Results

The results of the application of the computer based system dynamics Delphi tool will be described in two parts. Firstly, the contribution of the tool to the knowledge acquisition process will be outlined and secondly comments will be made on the technical performance of the tool.

### 7.7.1 The Knowledge Acquisition Process

The emphasis in this section is on the use of the approach to capture knowledge in the context of the software engineering process. In particular, discussion is focused on the diagram based questions, since this is where the uniqueness of the approach lies. The diagram based questions were designed to obtain information in two areas. Namely, the overall nature of the software engineering process and the form of the relationships between its stages. Some responses of the experts to diagram

based questions taken from the first iteration of the application are presented to provide an indication of the approach to model development.

### 7.7.1.1 Examples of Causal Map Developments

The experts were given the opportunity of modifying the initial model as a whole or doing changes by sector. The majority modified the diagrams by creating additional links between the model elements; a minority added new model elements and linked them to the rest of the model. Figure 7.16 and Figure 7.17 show individual responses that proposed structural changes to the initial model.

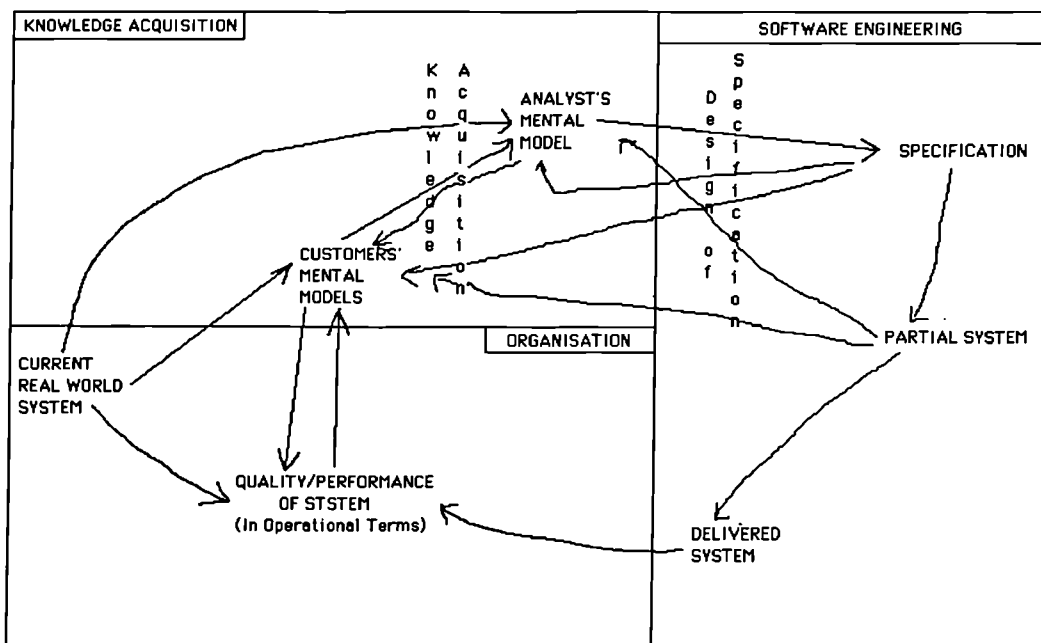


Figure 7.16 A suggested structural change to the initial model

In Figure 7.16, the expert has introduced a new stage to the information system development process. This is referred to as a 'Partial system' that comes between 'Specification' and 'Delivered System' and it is suggested in Figure 7.16 that this intermediate product will modify the mental models of both the customers and analysts. Additionally, the modifications suggested in Figure 7.16 indicate that the 'Specification' itself will change the mental models of the software engineers and customers and that the mental models of one group of actors will impinge on those of others. The comment facility was used to describe the advantages to be gained



from an ability to simulate an information system specification to produce a partial information system that could be demonstrated to the customer.

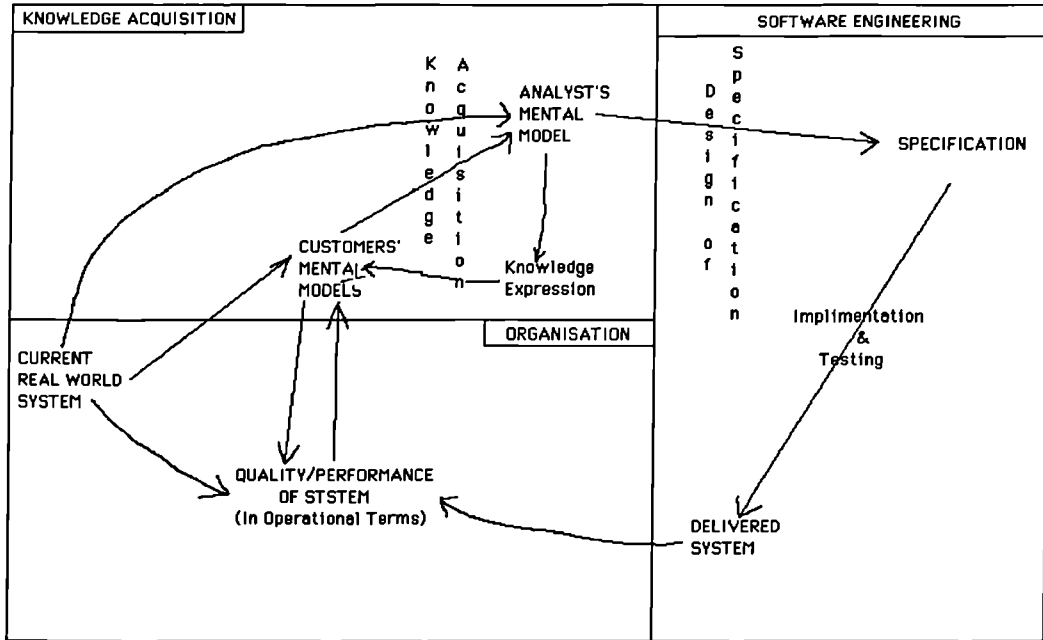


Figure 7.17 Another suggested structural change to the initial model

In Figure 7.17, the expert has introduced a shorter feedback path between the 'Analyst' and the 'Customer', by way of a 'Knowledge Expression' model element.

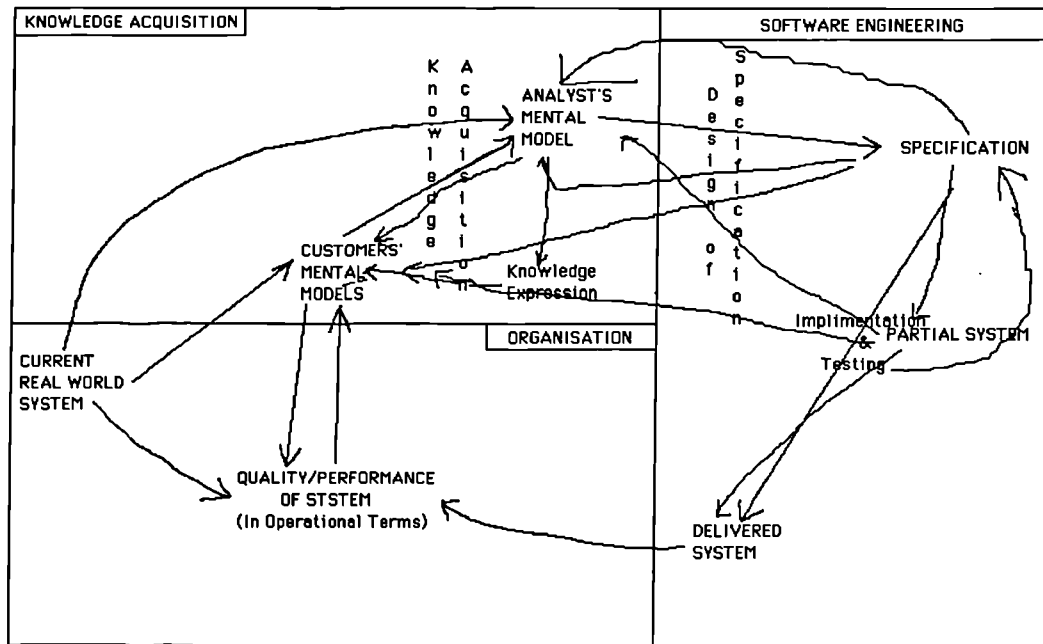
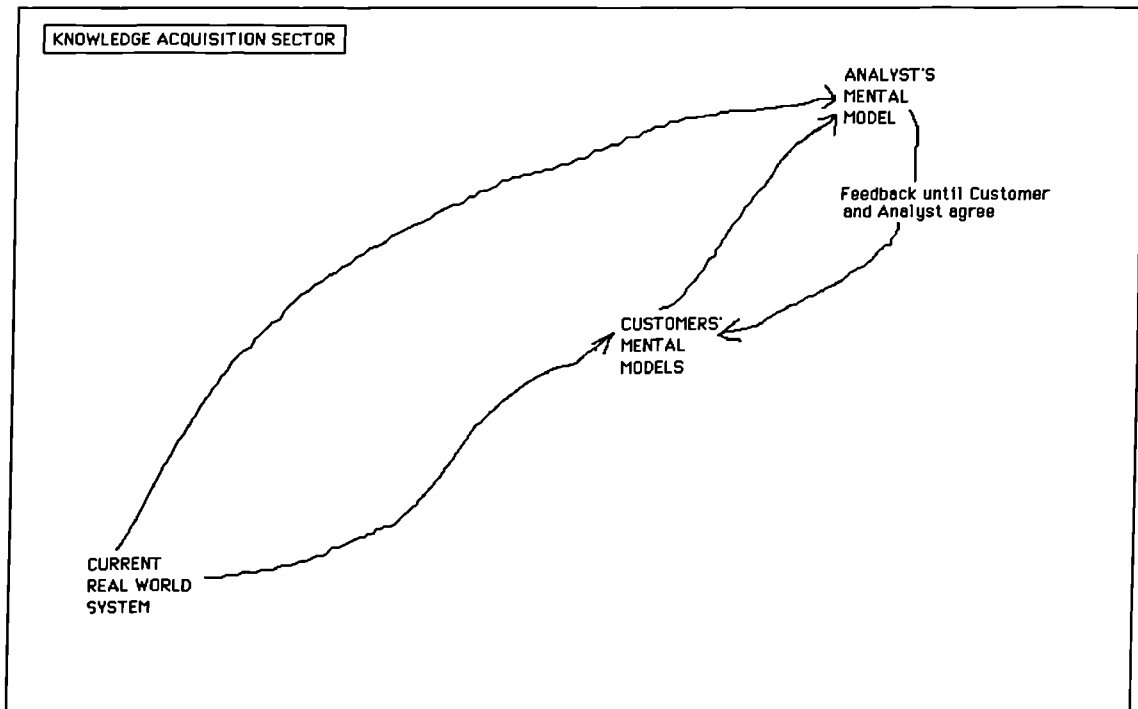


Figure 7.18 Superimposed modifications to the initial model

In addition to viewing individual changes to diagrams, the SuperDelphi Tool allows all the proposed changes to be viewed superimposed as shown in Figure 7.18. The collected modifications show that a large number of additional links were proposed which transcended the organisational boundaries of the model.

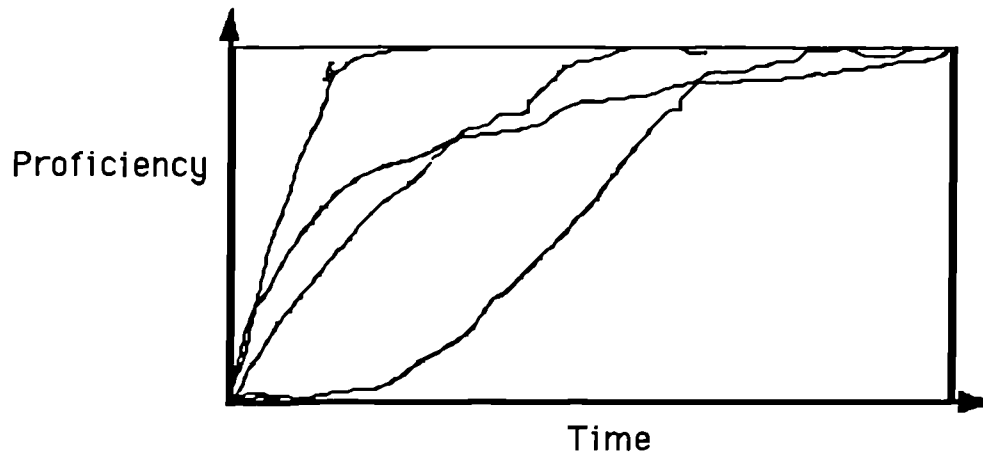


**Figure 7.19** Modifications to the knowledge acquisition sector

Further, the experts were asked to modify individual organisational sectors of the model and an example of one such reply is shown in Figure 7.19.

### 7.7.1.2 Examples of Developing Graphical Relationships

In addition to the questions asking the experts to suggest modifications to the model, some questions gave the experts an opportunity to draw graphical relationships. For example the experts were asked to draw the shape of their learning curve over a defined time horizon for the CASE Tool that they currently use most frequently and the results of this are shown in Figure 7.20.



**Figure 7.20** Response to a graphical relationship question

### 7.7.2 Outcome of the Trial

The influence diagram of the final model is shown in Figure 7.21. It can be seen that this has developed significantly from the initial model (Figure 7.15). In particular, the links between sectors were consolidated, the loops have been fleshed out by the creation of intermediate variable and new loops modelling prototyping have been added.

### 7.7.3 The Participants Perspective

One of the questions asked the participants to give their opinion on the method of knowledge acquisition. Most of the participants were positive in their assessment of this approach to knowledge acquisition. Some identified benefits over conventional meetings. In particular, the extra time available for assimilation was considered to be an advantage. The anonymity of the process also appealed to some respondents, who found the face to face confrontation of a meeting an inhibition to their making a full contribution.

On the downside it was commented on by some users that, as with most questionnaires, it is always easy to put off finding the time to complete it. This shows the importance of the facilitator motivating the selected group of experts, by stressing the importance of hearing each individual opinion.

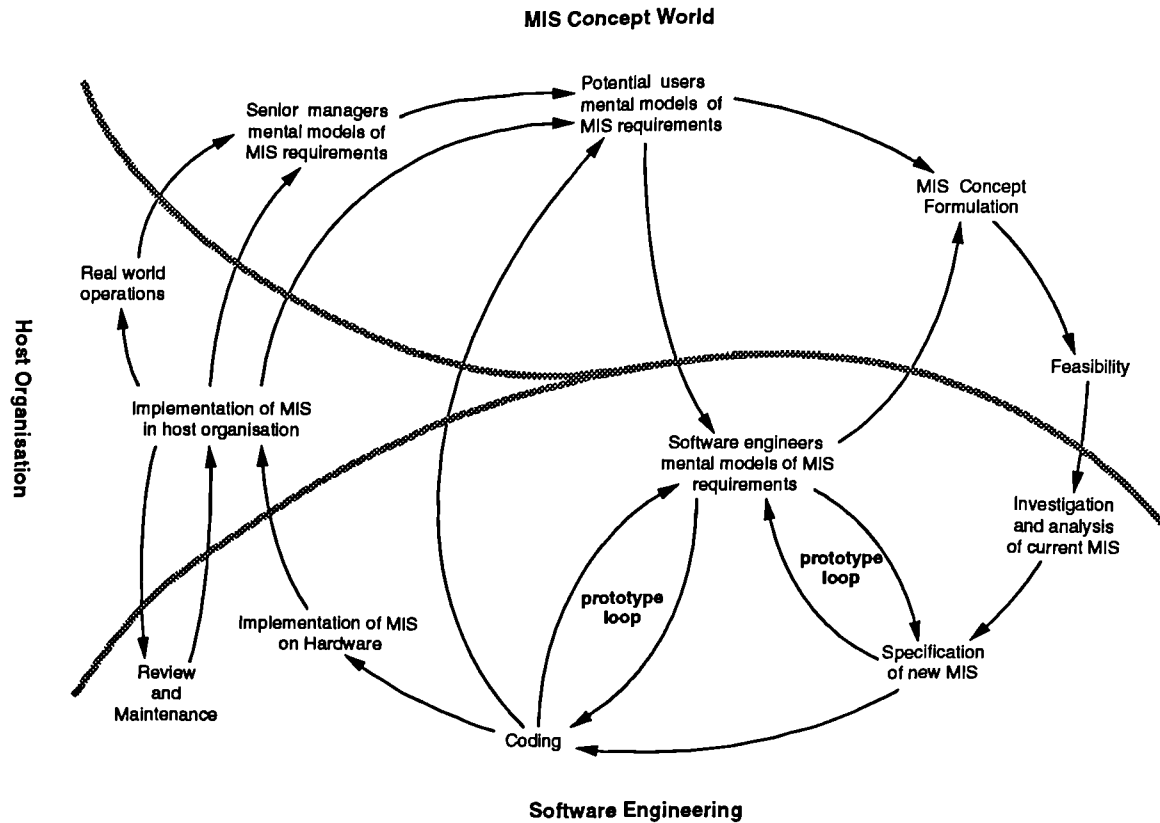


Figure 7.21 The final diagram

#### 7.7.4 Technical Performance of the Tool

The tool-set successfully performed all the technical tasks necessary to conduct a computerised system Dynamic Delphi application. The test highlighted several areas where the software could be improved which are discussed below. Participants were also asked to comment on the performance of the tool.

##### 7.7.4.1 Modifying Diagrams

The users are currently provide with a simple set of Paint based tools with which to annotate and modify diagrams. Whilst these proved serviceable, it was felt by the users (all Macintosh power-users), that a more elegant method of modifying diagrams was required, and Draw based tools were their preferred option. Draw tools are superior to Paint tools, but are initially more difficult to master, it was felt that the more typical inexperienced user, would find Draw tools too much to cope with.

#### **7.7.4.2 Report Generation**

From the Facilitator's point of view, the Archive would be improved by the addition of a report generation facility.

#### **7.7.4.3 Ideas for New Types of Questions**

The current questions are general in nature and it was felt that some question cards, that were more specifically adapted to the system dynamics methodology should be produced. To encourage the development of systems thinking by the users it is considered that cards asking no specific question, but giving help and information on the concepts of systems modelling, would be a useful addition

### **7.8 Conclusions**

The SuperDelphi tool-set has demonstrated that the Delphi method can be successfully computerised and used for knowledge acquisition. Although this approach is at an early stage, it has been shown possible for the approach to assist dispersed experts in contributing, directly and actively, their own perspectives of the domain in which they work to a joint modelling effort; in this case the software engineering process. In particular, the value of diagrams for the structuring of these perceptions has been reinforced. Additionally, much valuable information was obtained on the variety of approaches and tools available for the design and evaluation of information systems. Further, a number of refinements to the tool-set were identified and are under development.

Finally, it should be emphasised that, although the tools described were developed in the context of the development of system dynamics models, it is felt that the approach used has considerable potential across the whole field of model building and structuring of complex problem situations.

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# Chapter 8

## *Conclusions*



The research described in this thesis has taken a wide-ranging look at the whole of the modelling process and its relevance to managerial learning and performance. This has resulted in a thesis that consists of a number of pieces of essentially free-standing, but related work. The aim of this chapter is to summarise the research presented in the individual chapters and show how they all inter-connect.

The research described in this thesis makes a multi-level contribution to the development of techniques to aid development of managerial skills in systems thinking. In particular, the following has been achieved.

- A number of systems thinking training case studies have been developed and tested, including one built round a new model; the rocket powered flight case study.
- A supply chain management training workshop, based upon the use of a generic supply chain model, has been developed and tested.
- The performance of a large number of managers in both acquiring and applying modelling skills during a systems thinking training course has been observed. A number of blockages to the use of systems thinking have been identified. In particular, model conceptualisation was identified as a major area of difficulty for novice modellers.
- A case study of the adoption of systems thinking by a large manufacturing company has been carried out.
- System thinking has been successfully used as a method of summarising and disseminating the insights of investigations that did not themselves make use of systems thinking. The use of small simple model has proved to be particularly powerful in this context.

- The relationship between qualitative and quantitative structures has been investigated. Simulation models of a number of systems archetypes have been created and a set of guidelines for the quantification of structures has been developed. It has been shown that the two loop systems archetypes represent a hierarchy of structure; they map onto quantitative structures that range in complexity from two to five loops.
- A new approach to model conceptualisation has been developed that combines the use of archetypes and generic models of those archetypes to ease the transition to a simple working model.
- A computerised Delphi-based knowledge acquisition tool has developed and tested. This tool was developed to allow a large group of geographically dispersed people to become directly involved in the modelling process.

The common theme that emerges from this research is that of accessibility. There is a real need to make systems thinking more accessible to *managers*.

System dynamics modelling has built up a huge body of accumulated knowledge over the last thirty-seven years. This knowledge is of two types. The general; insights into the nature of non-linear feedback systems and the specific; case studies and models that cover a wide and diverse range of problem domains. Yet the vast majority of managers are unaware of the existence of this body of knowledge.

The research described in this thesis has made a contribution to increasing the accessibility of systems thinking in four areas.

- The accessibility of system thinking as a managerial modelling technique has been increased by the development of the framework for model conceptualisation.

- The accumulated body of knowledge concerning the dynamics of supply chain systems has been made more accessible to practising managers by the development of the supply chain workshop.
- The knowledge acquisition tool has allowed large and geographically dispersed groups of people to participate in group model building.
- The biggest barrier to a more widespread use of system thinking is that of ignorance. The use of systems thinking to disseminate the insight of non-systems thinking based investigations has been identified as a successful strategy for promoting the adoption of systems thinking.

The work described above has only scratched the surface, much more needs to be done to open up this accumulated knowledge base to all managers. The outgrowth of systems thinking from system dynamics indicates the way forward. The development of the archetypes has shown that it possible to increase accessibility of system insights by packaging them in an easily consumable form that is attractive to managers. The willingness of systems thinking to become part of the discipline of organisational learning, has vastly increased its exposure.

The accessibility of systems thinking would be further increased by the following developments.

- There is a need to package quantitative models in a way that makes them accessible to managers. There is much potential for developing themed workshops and microworlds based upon existing generic models.
- There is a need to identify other disciplines into which systems thinking can integrate itself.

In addition to identifying the need for further efforts to increase awareness of systems thinking, the research in the thesis has also highlighted two areas within systems thinking itself that would benefit from further research.

- Effort needs to be devoted to investigating the interface between qualitative and quantitative modelling. The relative neglect of this area of research is surprising when it is considered that it is this support of both qualitative and quantitative modelling that distinguishes systems thinking from other system approaches.
- The area of model conceptualisation also warrants further investigation. Novice modellers need as much support as possible in this area.

Finally, the observation of the training course participants has confirmed the value of training practising managers in modelling. The great enthusiasm shown by many of the managers on being able to model for the first time has made a lasting impression on the author. This confirms the assertion in the title of this thesis that managers should become modellers.

# **Appendix 1**

## *An Introduction to Systems Thinking*

## Introduction





This appendix describes the qualitative and quantitative modelling techniques of systems thinking. It also contains a bibliography and a glossary of systems thinking terms.

## Qualitative Modelling

In systems thinking, diagrams known as causal maps are used to qualitatively represent system structure. These maps consist of variables that are linked by arrows. The arrows indicate that a causal link exists between a pair of variables. These links are signed to indicate the nature of the causal link. There are two kinds of causal link; same and opposite.

If a change in the value of the variable at the tail of the arrow causes a change to occur in the same direction in the variable at the head of the arrow then the link is said to be of the same sense. If a change in the value of the variable at the tail of the arrow causes a change to occur in the opposite direction in the variable at the head of the arrow then the link is said to be of the opposite sense. Same and opposite causal links are shown in Table 1.

**Table 1 Causal map model elements**

Model Element	Description
<b>S</b> 	Same Sense Link
<b>O</b> 	Opposite Sense Link
	Reinforcing Loop
	Balancing Loop

The purpose of creating a causal map is to identify a systems feedback loop structure. The key idea of systems thinking is that a systems behaviour is generated by its feedback loop structure.

There are two types of feedback loop; reinforcing and balancing. Reinforcing loops magnify change and are used to model growth processes. An example of a reinforcing loop is shown in Figure 1. Balancing loops are goal seeking and model control processes. An example of a balancing loop is shown in Figure 2.

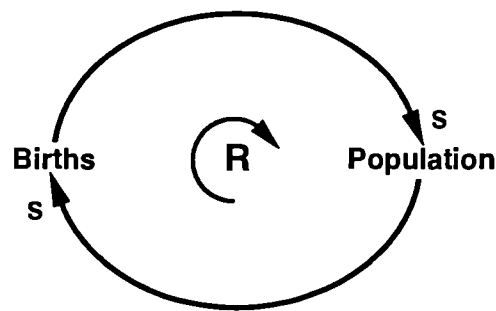


Figure 1 Causal map of a reinforcing loop

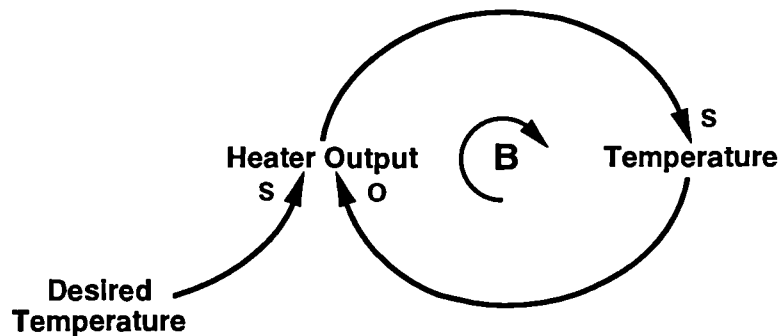


Figure 2 Causal map of a balancing loop


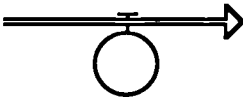




## Quantitative Modelling

DYNAMO (Pugh-Roberts Associates 1986) was the original system dynamics' simulation tool. In DYNAMO, the model is represented as a set of time-scripted equations, which need to be compiled before a simulation run can be performed. DYSMAP (Dangerfield and Vapenikova 1987) also uses this method of model representation. These simulation packages are essentially customised programming languages. The method of model representation and the need to

compile models inhibits interactive use and limits the accessibility of these tools to those with a technical orientation.

STELLA (Richmond et al. 1988) introduced a graphical method of model representation which was also adopted by Ithink (Peterson and Richmond 1993) and Powersim (Myrtveit 1994). The model is represented by a diagram made up of the elements shown in Table 2.

**Table 2 STELLA and Ithink model elements**

<b>Model Element</b>	<b>Description</b>
	Stock
	Flow
	Convertor
	Graphical Relationship
	Information link
	Source or Sink

The model's equations are created by defining numerical relationships for each of the individual model elements. This is done using the mouse. The user 'double-clicks' a model element and a 'dialog box' appears which is used to enter an equation for that model element. Figures 3 and 4 show the STELLA/Ithink representation of the balancing and reinforcing loops that were modelled qualitatively in the previous section.



There are two main differences between a causal map and an Ithink map. The first is that the Ithink map distinguishes between flows of material and flows of information. The second is that the Ithink map identifies the nature of the model element; in particular it highlights the accumulations of material (the stocks) in a system.

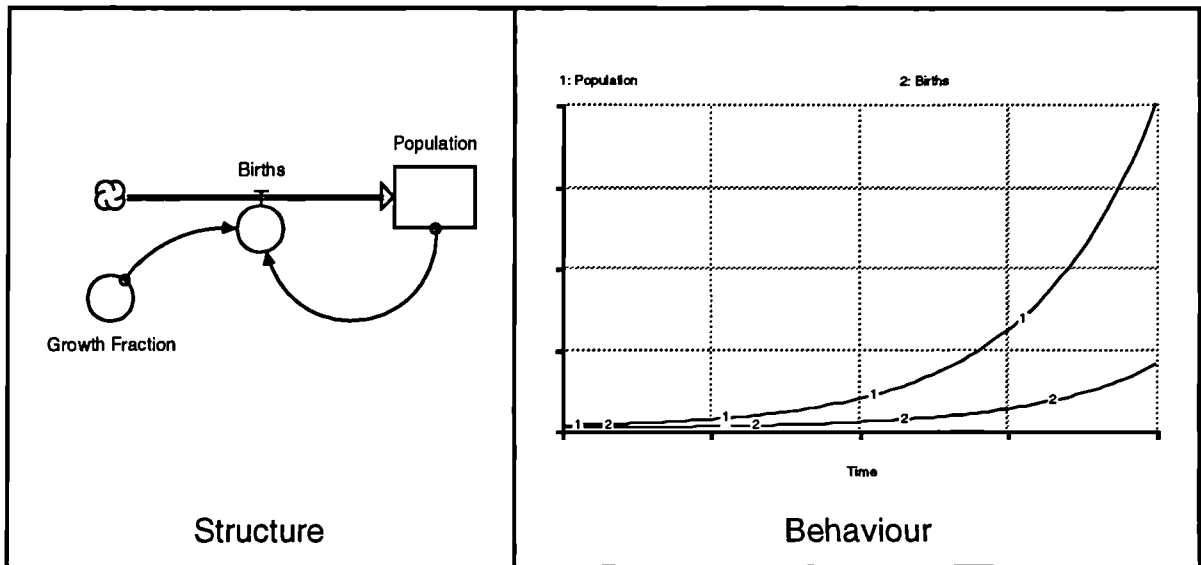


Figure 3 Reinforcing loop

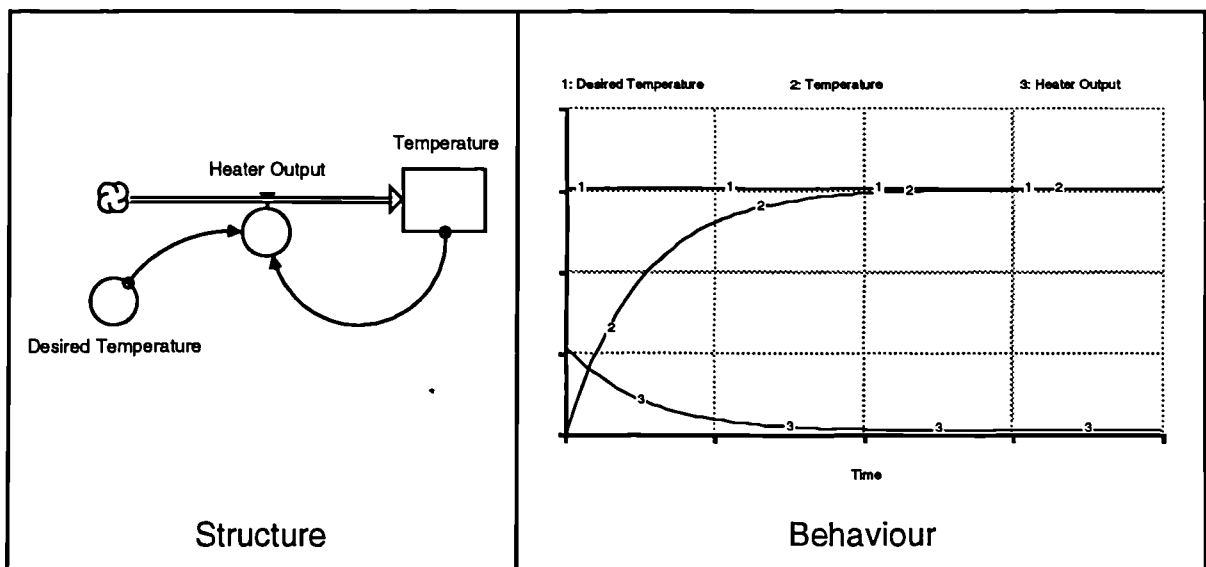


Figure 4 Balancing loop

## Glossary

Systems thinking lacks a clearly defined set of technical terms. In many cases, two and sometimes three different names are applied to the same thing. Table 3 lists commonly used alternatives for the technical terms that have been used in this thesis and Table 4 lists alternative causal map symbols.

**Table 3 Technical terms**

<b>Adopted</b>	<b>Alternative(s)</b>
Balancing Loop	Negative Loop
Reinforcing Loop	Positive Loop
Causal Map	Causal Loop Diagram Influence Diagram <sup>1</sup>
Ithink Map	Ithink Diagram Plumbing Diagram
Ithink	STELLA <sup>2</sup>
Stock	Level
Flow	Rate
Convertor	Auxiliary

**Table 4 Causal map symbols**

<b>Adopted</b>	<b>Alternative</b>	<b>Description</b>
R	+	Reinforcing Loop
B	-	Balancing Loop
S	+	Same Sense Causal Link
O	-	Opposite Sense Causal Link

<sup>1</sup>The term Influence Diagram is potentially confusing because it is also used in the field of decision analysis.

<sup>2</sup>STELLA is the educational version of the software.

## Bibliography

There is no single book which provides a complete introduction to all aspects of systems thinking. The following list aims to provide a good introduction to the subject in a minimum number of books. A comprehensive annotated bibliography can be found in Morecroft and Sterman 1994.

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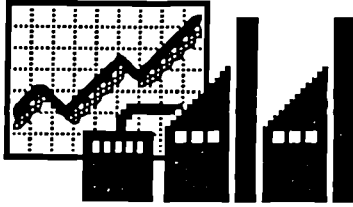
Peterson, S. & Richmond, B. (1993). *Technical Reference* Lyme, NH: High Performance Systems.

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## **Appendix 2**

### *The MGI Case Study*



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***Market Growth & Investment***

**Part 1: Mapping Exercise**

## Introduction

In this exercise we will produce a qualitative influence diagram model of a company that is experiencing problems with maintaining its market share in a growing market.

### Aim of the Exercise

To provide an opportunity to apply the qualitative modelling techniques; influence diagramming, identification of feedback loops and the analysis of system behaviour in terms of feedback loop structures.

## The Problem

Five years ago MGI emerged as a major operator in a rapidly expanding market and had expectations of a smooth growth pattern in sales and market share. However, instead the company has experienced sales which grow for periods but then regularly go through dips and troughs. During the troughs the company has been losing market share. Figure 1 shows the type of growth pattern being experienced.

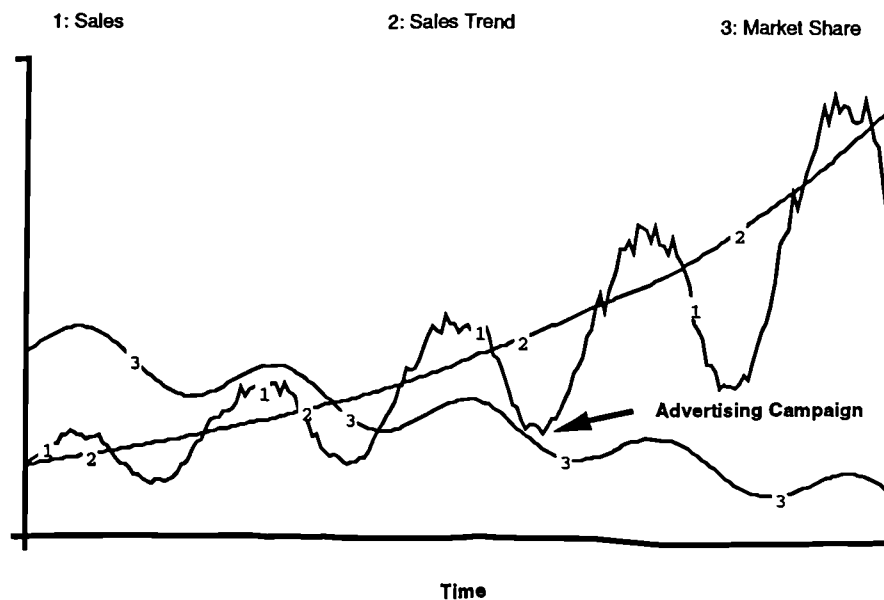


Figure 1 MGI Growth Pattern

MGI's problems were initially blamed on external factors, centred on a belief that customers lacked awareness of the product due to MGI's relatively poor marketing efforts. However, recent attempts to boost sales by increasing expenditure on advertising has not seemed to disturb the existing trends.

Currently, the company MD is under further pressure from the Marketing Department to undertake more advertising on the assumption that the last round was insufficient to kick the company out of its problems.

he MD has a gut feeling that this action will not really affect things and having recently attended a course on Systems Thinking, wishes to see if a more systemic approach might improve his understanding of the situation. In particular he feels that the problem could be of MGI's own making.

## Instructions

Create an influence diagram of MGI based on the description of the problem and the additional information given in the next section. Identify and sign all of the feedback loops. Use the model to answer the following questions. Your answers should aim to explain how the problematic behaviour is caused in terms of the systems feedback structure.

- 1 How do the firm's operating policies contribute to its problems?
- 2 Does a renewed advertising campaign makes sense?
- 3 What should MGI do to improve sales growth and regain market share?

## Some Information on MGI's Operating Policies

MGI ploughs back a proportion of its sales revenues into hiring new sales force. Because the market is expanding rapidly, new sales people almost immediately generate new orders.

MGI manufactures to fill its orders with a competitive lead-time as long as it has sufficient manufacturing capacity to do so. As orders build up in a backlog, lead-time rises and as the manufacturing rate increases, lead-times fall.

Longer lead-times make it harder for sales staff to win orders. Sales staff have to spend more time with each potential customer so sales force productivity falls.

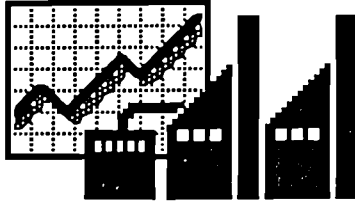
Rising lead-time is the company's signal to add manufacturing capacity. The size of the financial outlays involved implies that there is a significant delay in the approval and acquisition of manufacturing capacity.

## Some Help To Get You Started

Start by identifying the levels and associated rates of each resource within the company. The following should be modelled as levels; Sales Force, Order Backlog, and Manufacturing Capacity.

Link these model elements together, creating other intermediate model elements as required to form feedback loops. It may help you to focus on one loop at a time. Try to identify the growth producing loop (a positive loop) and then add the growth limiting loop (a negative loop). You should be able to identify at least one other loop.

When using the influence diagram to explain the system behaviour, you may find it helpful to draw in the organisational boundaries and also to identify the delays that are present in the flows of material and information within the model.



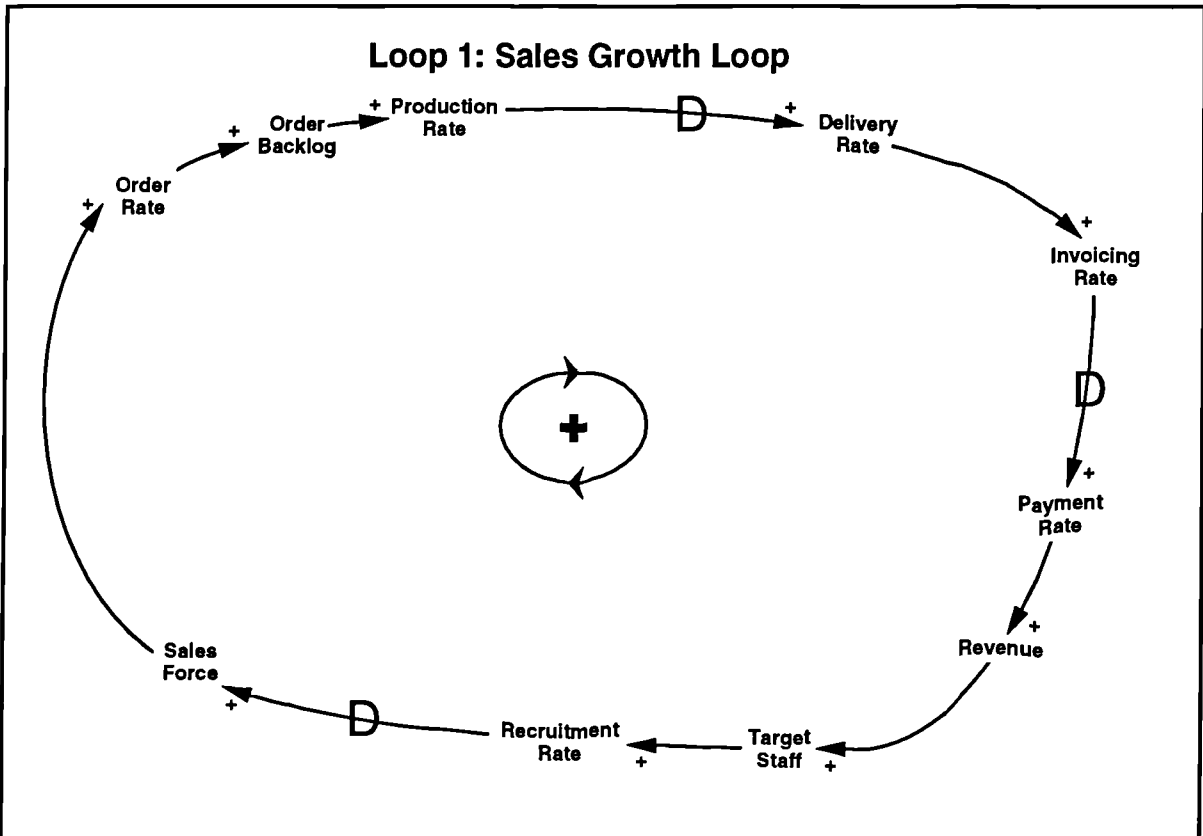
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**Part 1: Solution**







This is a **Positive Loop** and will, in isolation, create exponential growth. Increases in orders generate additional revenue which allows the sales force to be enlarged. A larger sales force will (since this is a growth market) increase the number of orders obtained, which will in turn increase revenue, which...

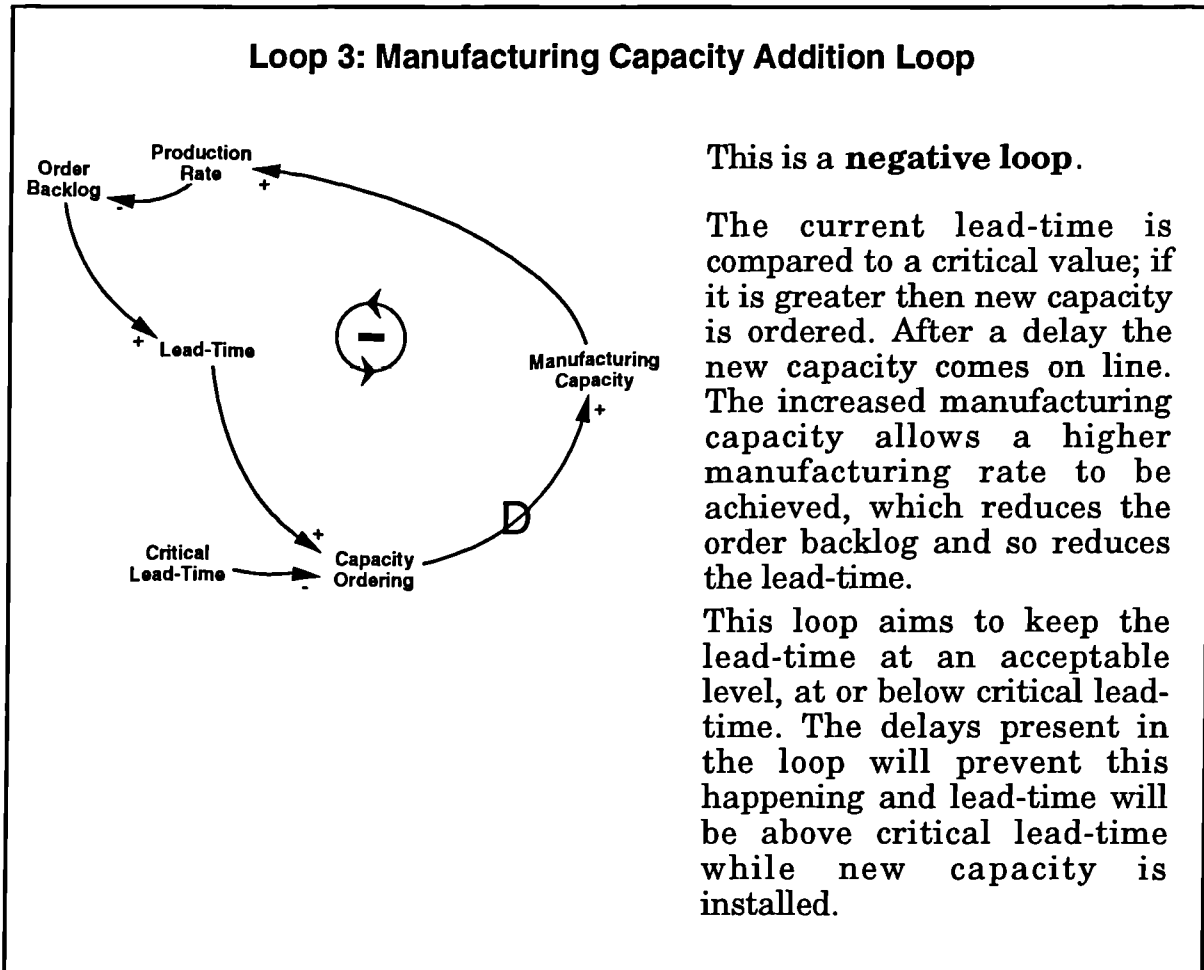
### Loop 2: Effect of Lead-Time on Sales Loop

This is a **negative loop**.

An increase in the order rate causes the order backlog to increase. This in turn causes the lead-time to increase. Longer lead-times discourage customers, so the order rate will fall.

This loop in isolation would seek to limit the order rate to a point at which the implied order backlog gives an acceptable lead-time.

There is a delay between lead-time and order rate. This delay represents the time it takes customers to perceive changes in lead-time. For example, customers who have recently experienced an unacceptably long lead-time, may be discouraged from placing orders even though the current lead-time is much shorter.



## System Behaviour

The overall system behaviour is caused by the interaction of the three feedback loops. This system is typical of many in that it contains the potential for growth; the positive loop and a growth inhibiting mechanism; the two negative loops. It is the relative strength of these loops that will determine the mode of behaviour of the system. The strength of the loops is not fixed, but will vary over time, causing the behaviour of system to change over time.

Initially the "growth loop" predominates. MGI has sufficient spare manufacturing capacity and so lead-time is short and the sales force can easily obtain orders. The revenue so generated allows the sales force to expand which in turn generates more orders. At some point MGI will run out of spare manufacturing capacity and lead-time will start to rise.

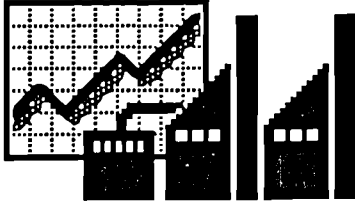
The rising lead-time will have two effects; customer orders will fall and additional manufacturing capacity will be ordered. In other words the negative feedback loops will start to exert an influence. The relative strength of these two loops will determine whether growth is sustained or decline occurs.

To fully investigate the system's behaviour it is necessary to build a quantitative simulation model, but we can still learn more from the qualitative approach by considering the "reference mode of behaviour".

We know that dips are occurring in the sales curve. Therefore the "effect of lead-time on sales loop" must come to dominate "capacity addition loop" at some point







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**Part 2: Simulation Exercise**

## Introduction

In this exercise we will produce a quantitative Ithink model of MGI.

### Aim of the Exercise

To test the prediction of system behaviour made by the qualitative model and allow the relative strength and importance of the feedback loops to be investigated.

To give hands on experience using Ithink to create a model from a given Ithink map and written information, including the use of graphical relationships. Not all the relationships will be given explicitly, so introducing the topic of equations formulation.

To allow interactive experimentation with a Ithink model, including sensitivity analysis.

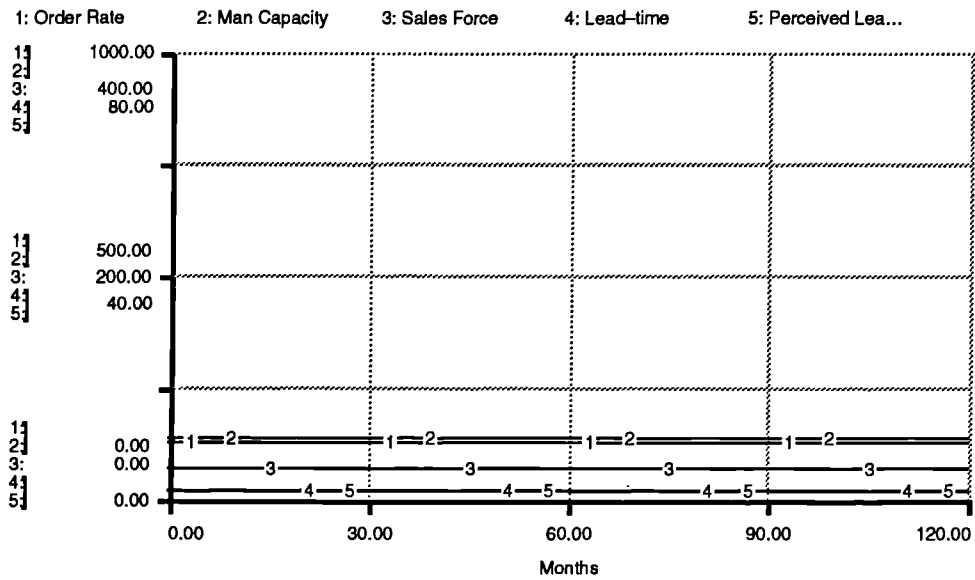
To provide the opportunity to structurally modify an existing Ithink model to investigate the effects of a proposed change. The exact details of the required modifications will not be given, but sufficient understanding of the model should have been gained by this stage, to allow the participants to successfully undertake this task.

## Instructions

- 1 Build the MGI model using the Ithink Map and the other information contained in the second part of this document. The best way to tackle this exercise is to construct the Ithink Map and then, define the relationships.
- 2 Use the following "Simulation Specs..." values.

TIME SPECS	
<b>Length of simulation:</b>	<b>Unit of time:</b>
From: <input type="text" value="0.000"/>	<input type="radio"/> Hours
To: <input type="text" value="120.00"/>	<input type="radio"/> Days
DT: <input type="text" value="0.25"/>	<input type="radio"/> Weeks
Pause interval: <input type="text" value="∞"/>	<input checked="" type="radio"/> Months
	<input type="radio"/> Quarters
	<input type="radio"/> Years
	<input type="radio"/> Other
<b>Integration Method:</b>	<b>Movie synchronization:</b>
<input checked="" type="radio"/> Euler's Method	<input type="text" value="1"/> movie secs = 1 unit time
<input type="radio"/> Runge-Kutta 2	Movie length: 120 secs
<input type="radio"/> Runge-Kutta 4	
	<input type="button" value="Cancel"/> <input type="button" value="OK"/>

- 3 Run the simulation. The initial conditions for the model have been chosen to give equilibrium. Reproduce the following graph. Remember to scale the graph!

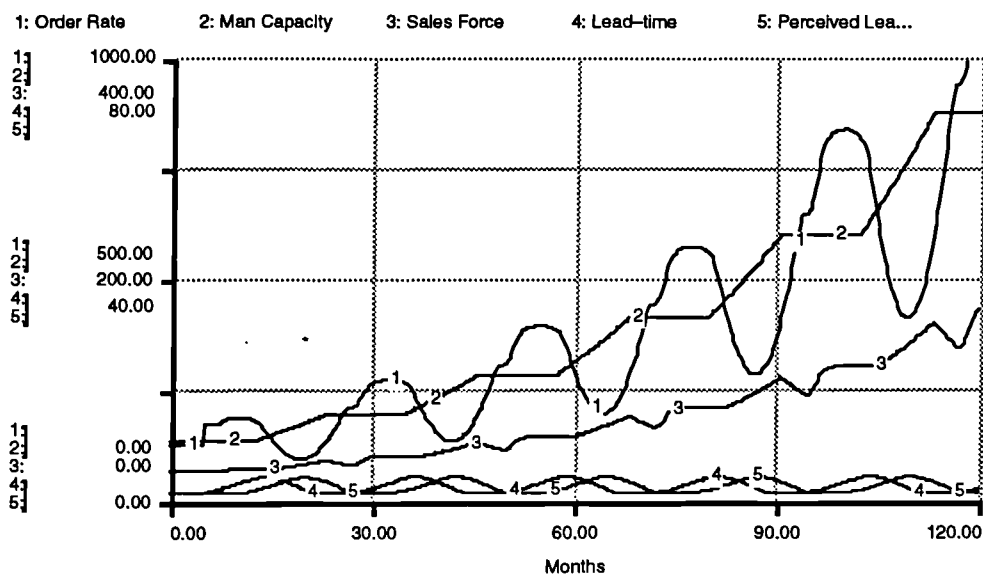


Equilibrium Run Graph

- 4 Introduce a step change of 2 to sales productivity at month 5.

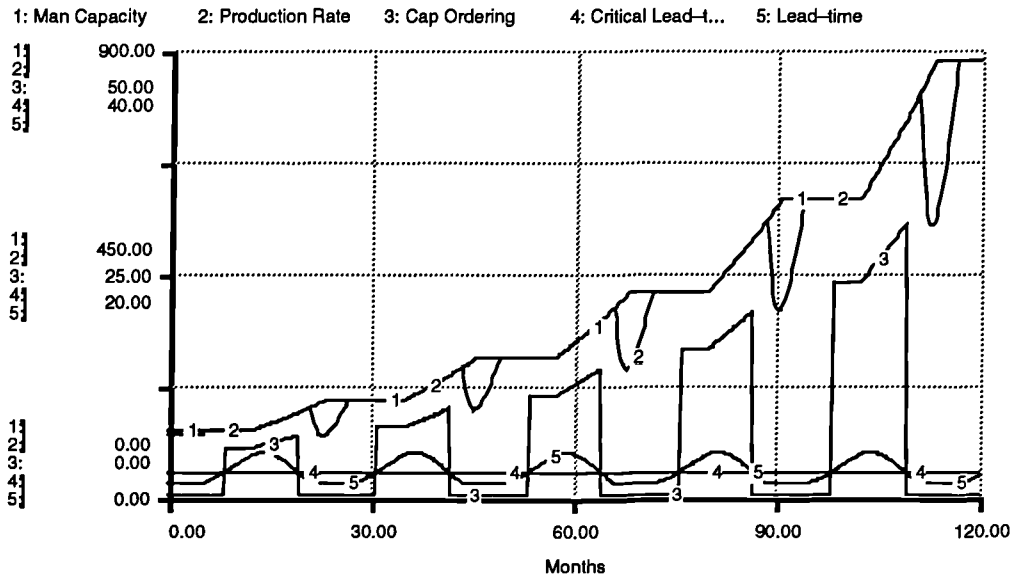
$$\text{Productivity} = 5 + \text{STEP}(2,5)$$

Now run the simulation. The model will respond to the step test, because the model was started in equilibrium, we can be sure that the dynamic behaviour that occurs is due solely to the step test. Reproduce the following graphs.

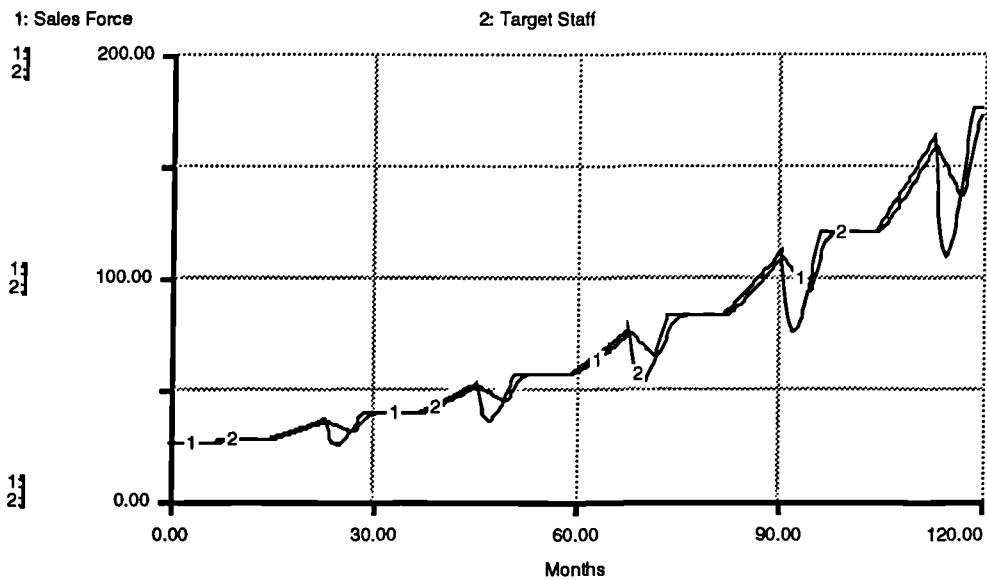


Overview Graph





**Manufacturing Capacity Addition Graph**



**Sales Force Graph**

- 5 Examine the graphs, try to relate the behaviour to the feedback loop structure identified in the qualitative exercise. It may help to trace out these loops in the Ithink map, remembering that a Ithink map shows outflows from a level in the opposite direction to that on to a Causal Loop diagram.
- 6 Investigate the effect of varying Critical\_Lead-time on sales growth, by performing the following sensitivity analysis.

- Critical\_Lead-time = 1.5 (months)
- Critical\_Lead-time = 2.0 (months)
- Critical\_Lead-time = 3.0 (months)
- Critical\_Lead-time = 4.5 (months)

Use the "Ad Hoc" sensitivity option, you will also need to create a comparative graph of Order\_Rate, scaled 0 - 2000.

- 7 Modify the model to incorporate the solution obtained from the qualitative modelling exercise.

Before you do this, save your current model, then save it again under another name such as “MGI Model Modified” for instance.

Use **Save As...** from **File** menu to do this.

#### **Some Help to get you going**

Set a target for manufacturing capacity. The **FORCST()** built-in may be of use in doing this.

Use the target for manufacturing capacity and the actual manufacturing capacity to control capacity ordering. Ideally you should also take capacity being installed into account.

It should be possible to achieve sustained growth.

- 8 Investigate the effect of market saturation on the modified model.

#### **Some Help to get you going**

The simplest way to do this is to create another convertor called **Market\_Limit** (with a value of say 750 units/month) and link this to **Order\_Rate**. The **MIN()** built-in can then be used to limit orders to the maximum market size.

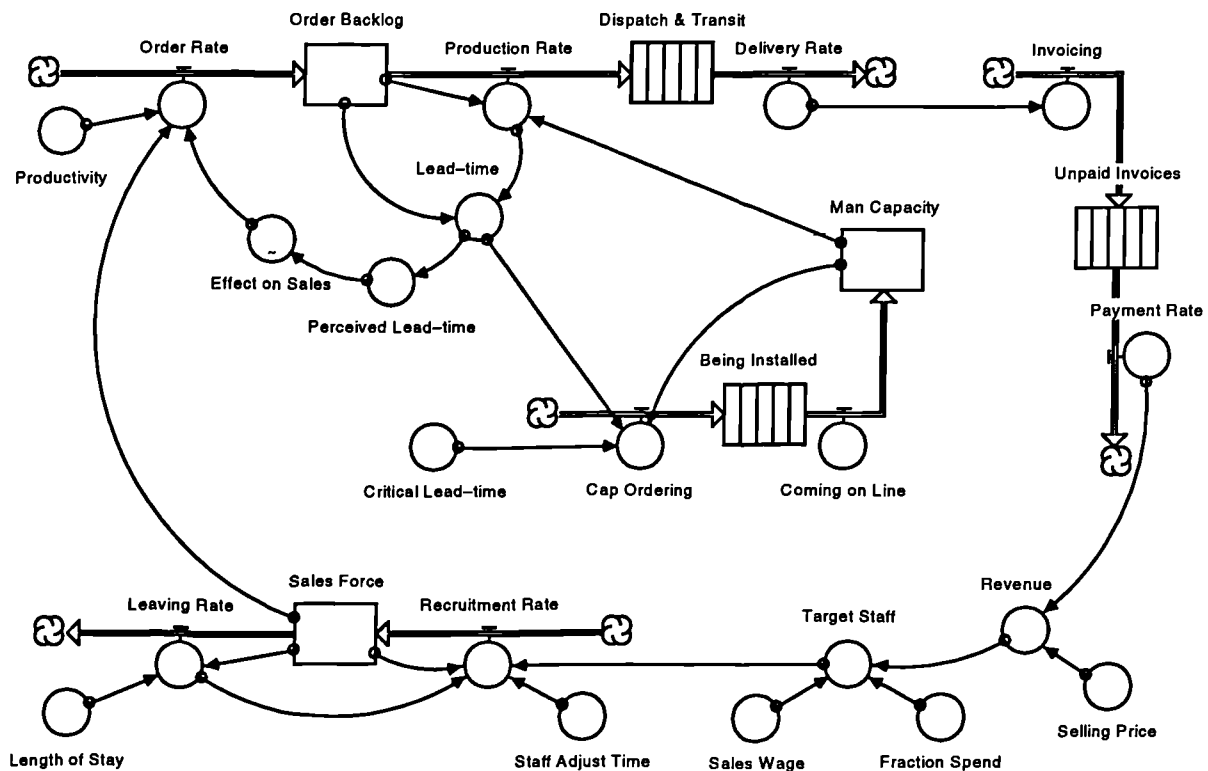
## **Further Work**

Here are a few suggestion for further exercises with the MGI model.

- 1 Model market saturation in a more realistic way, most markets exhibit s-shaped growth.
- 2 Manufacturing capacity will eventually become obsolete and require replacement. Add an outflow to manufacturing capacity and modify the ordering policy to take this into account.
- 3 Investigate the effect of an “advertising blitz”. The effect of advertising can be modelled as a multiplier to productivity. There will be a delay between the decision being taken to have an advertising campaign and customers becoming aware of the campaign. The campaigns should be triggered by drops in sales, you will need to keep a record of maximum sales achieved so far to implement this policy.

## Model Data

## ithink Map of the MGI Model



## Model Relationships

### Initial Values

The stocks and conveyors in the model need to be given initial values. Use the following values.

INIT Being_Installed = 0	(units/month)
INIT Dispatch_&_Transit = 120	(units)
INIT Man_Capacity = 130	(units/month)
INIT Order_Backlog = 120	(units)
INIT Sales_Force = 24	(people)
INIT Unpaid_Invoices = 120	(invoices)

### Points to Note

- 1 There is sufficient manufacturing capacity to meet the initial order backlog.
- 2 There is no new capacity in the pipeline.

### Parameter Values

The following parameter values should be used.

Critical_Lead-time = 2	(months)
Fraction_Spend = 0.25	(none)
Length_of_Stay = 24	(months)
Productivity = 5	(sales/person/month)
Sales_Wage = 1000	(£/month)
Selling_Price = 800	(£)
Staff_Adjust_Time = 1	(months)

### Material Delays

There are a number of material delays in the model, these are represented by conveyors. The length of the various delays are given below.

Activity	Time (Months)
Install new manufacturing capacity	4
Process, dispatch and deliver an order	1
Waiting for an invoice to be paid	1

### Relationships

The following relationships need to be defined. The list of “required inputs” in model element definition dialog box will show which variables need to be included in the relationship. Units are also a useful guide to the required form of a relationship.

#### Cap\_Ordering (units/month/month)

The decision to add manufacturing capacity depends on the current lead time. If lead-time is greater than the critical lead-time then capacity is ordered. The amount of capacity ordered is a constant proportion (4%) of current capacity .

Hint: Use the IF THEN ELSE built-in.

#### Production\_Rate (units/month)

Production will match the order backlog, up to the limit of manufacturing capacity.

Hint: Use the MIN() built-in.

#### Order\_Rate (units/month)

The order rate depends on the number of sales staff and the productivity of the sales staff. The effect of lead-time on sales force productivity is modelled using a multiplier (Effect\_on\_Sales).

**Recruitment\_Rate (people/month)**

Staff are recruited to maintain the sales force at the target level and to cover the current average quarterly leaving rate.

Hint: Use the **SMTH3()** built-in to “average” the leaving rate.

**Leaving\_Rate (people/month)**

The rate at which staff leave depends on the number of staff and the average length of stay.

**Invoicing (invoices/month)**

Invoices are delivered at the same time as the goods.

**Lead-time (months)**

The lead-time depends on the size of the backlog and the current manufacturing capacity

**Perceived\_Lead-time (months)**

It takes customers six months to perceive any change in lead-time.

Hint: Use the **DELAY()** built-in.

**Revenue (£)**

Revenue generation depends on the rate of payment and the selling price.

**Target\_Staff (people)**

MGI has a policy of spending a fixed proportion of revenue on sales staff. The target number of sales is staff therefore dependent on the revenue available for sales staff and the sales staff salary.

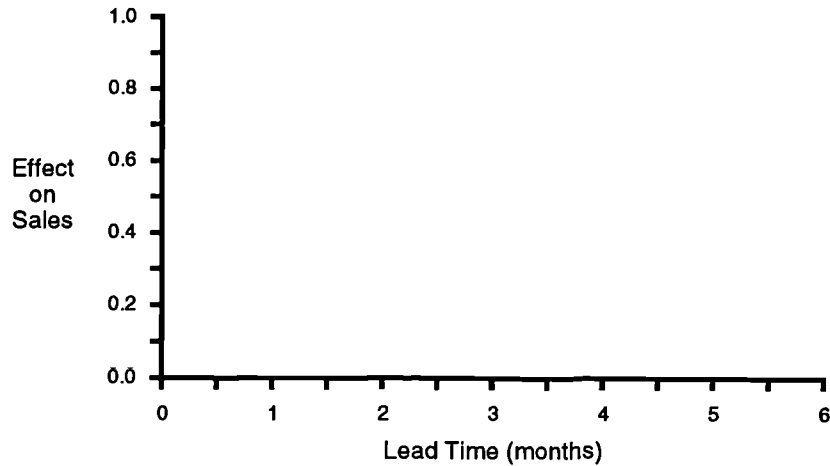
**Graphical Relationship**

The relationship between two model elements can be represented in think as a graph. The MGI model contains one such graphical relationship “Effect on Sales”. This section describes how such graphical relationships are created and then gives the actual values to use for the MGI model.

**Creating the scales**

Experience at MGI suggested that lead-time never exceeds six months. Therefore the X-Axis can be set as 0 - 6. The Y-Axis needs to capture the effect of lead-time on sales. We know that as lead-time increases, it becomes more difficult for the sales force to obtain orders. Sales personnel are required to spend more time winning over each customer, so productivity falls, but how can this be quantified.

The best way to model the effect of lead-time on sales is to create a normalised (0 - 1) scale.



The sales rate is then calculated as follows:

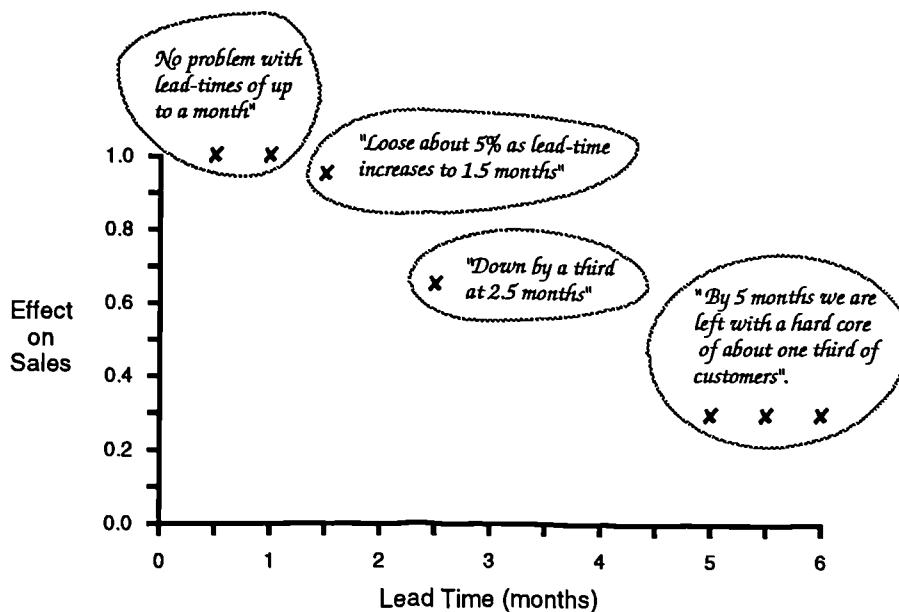
$$\text{Sales} = \text{Sales Staff} * \text{Standard Productivity} * \text{Effect of Lead-Time on Sales}$$

If lead-time is acceptable to the customer then "Effect of Lead-Time on Sales" will be 1 and the sales force will generate a normal number of orders. As lead-time increases, "Effect of Lead-Time on Sales" will become less than 1 and so sales will decline.

**Putting in the known points**

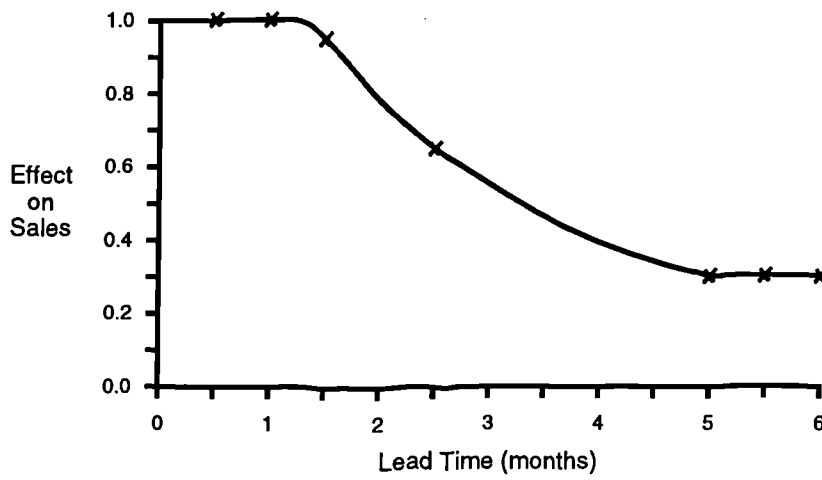
Having created suitable scales, the next task is to draw in the curve. It may be possible to estimate the shape of the curve from historical data. Unfortunately it is highly unlikely that such data will be easily available. This need not be a problem, usually all that is required is that the general shape of the relationship be correct.

Our definition of the "Effect of Lead-Time on Sales" gives us a value of 1 for a lead-time of 0. The following data points are based on an interview with the sales manager.



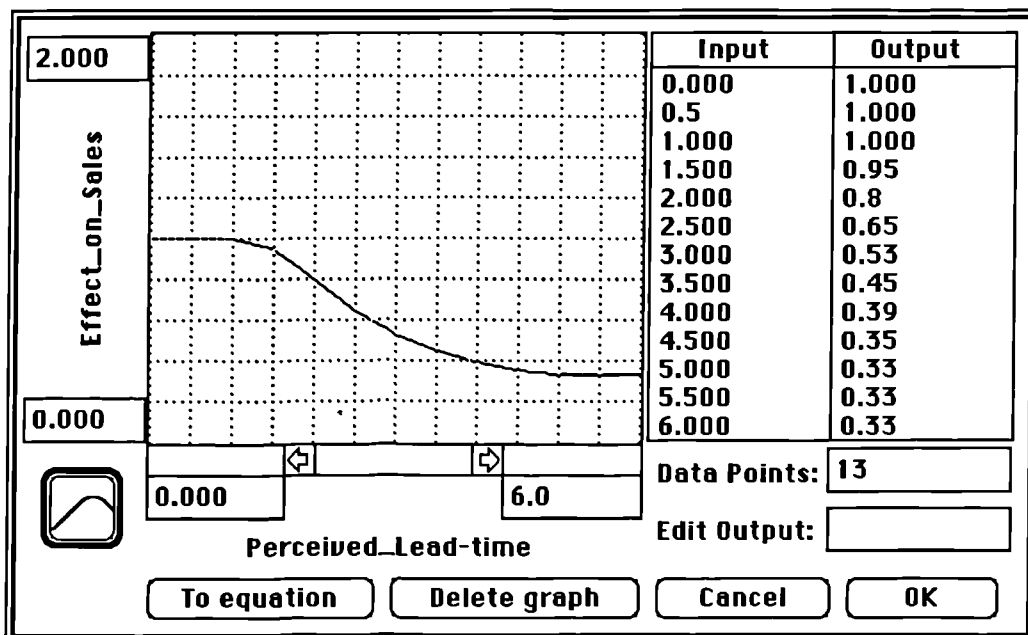
### Creating the curve

All that remains to do is to draw a smooth curve through the known points. The resulting curve can be "verified" by considering whether it "tell a convincing story". The curve we have created suggests that the majority of MGI's customers are insensitive to a slight increase in lead-time, however as lead-time increases further sales drop rapidly, eventually leaving a hard core of customer who seem unconcerned by long lead-times. This seems to be a plausible pattern of behaviour. It is possible to test out other likely scenarios by conducting a series of "what if" simulation runs using a number of differently shaped curves.

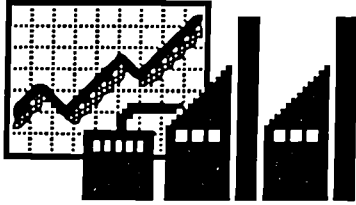


### Entering the curve into itthink

The curve can now be put into itthink.







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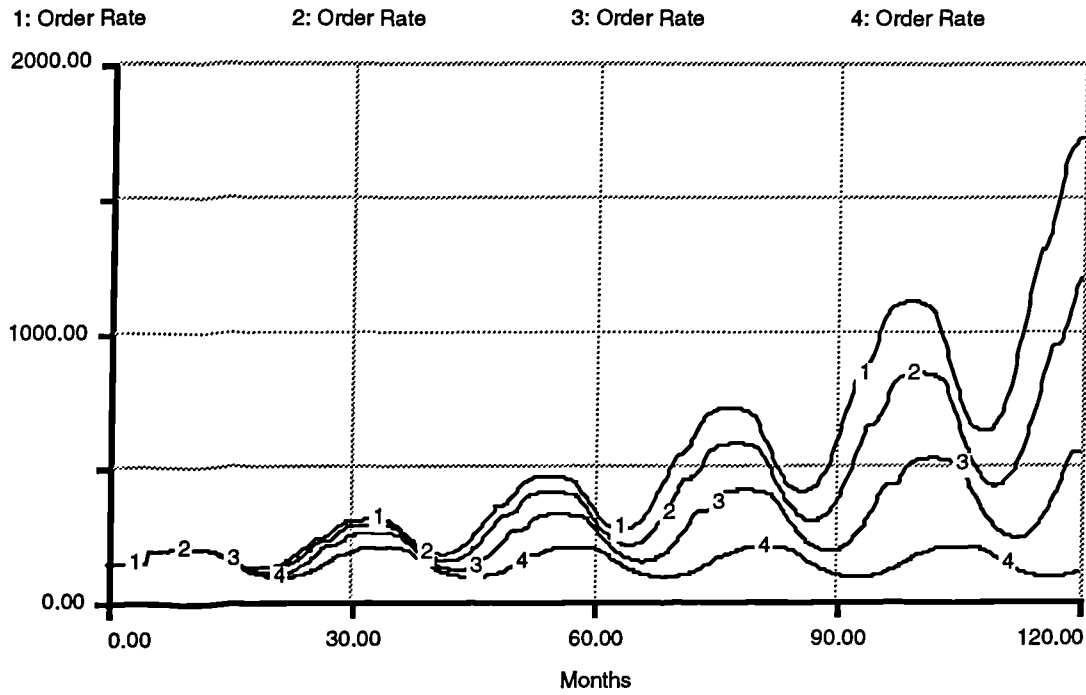
***Market Growth & Investment***

**Part 2: Solution**

## Equation Listing for MGI Base Model

- $Being\_Installed(t) = Being\_Installed(t - dt) + (Cap\_Ordering - Coming\_on\_Line) * dt$   
 INIT  $Being\_Installed = 0$   
 TRANSIT TIME = 4  
 INFLOW LIMIT =  $\infty$   
 CAPACITY =  $\infty$   
 INFLOWS:  
      $Cap\_Ordering = IF\ Lead-time \geq Critical\_Lead-time\ THEN\ 0.04 * Man\_Capacity\ ELSE\ 0$   
 OUTFLOWS:  
      $Coming\_on\_Line = CONVEYOR\ OUTFLOW$
- $Dispatch\_ \& \_Transit(t) = Dispatch\_ \& \_Transit(t - dt) + (Production\_Rate - Delivery\_Rate) * dt$   
 INIT  $Dispatch\_ \& \_Transit = 120$   
 TRANSIT TIME = 1  
 INFLOW LIMIT =  $\infty$   
 CAPACITY =  $\infty$   
 INFLOWS:  
      $Production\_Rate = MIN(Man\_Capacity, Order\_Backlog)$   
 OUTFLOWS:  
      $Delivery\_Rate = CONVEYOR\ OUTFLOW$
- $Man\_Capacity(t) = Man\_Capacity(t - dt) + (Coming\_on\_Line) * dt$   
 INIT  $Man\_Capacity = 130$   
 INFLOWS:  
      $Coming\_on\_Line = CONVEYOR\ OUTFLOW$
- $Order\_Backlog(t) = Order\_Backlog(t - dt) + (Order\_Rate - Production\_Rate) * dt$   
 INIT  $Order\_Backlog = 120$   
 INFLOWS:  
      $Order\_Rate = Sales\_Force * Productivity * Effect\_on\_Sales$   
 OUTFLOWS:  
      $Production\_Rate = MIN(Man\_Capacity, Order\_Backlog)$
- $Sales\_Force(t) = Sales\_Force(t - dt) + (Recruitment\_Rate - Leaving\_Rate) * dt$   
 INIT  $Sales\_Force = 24$   
 INFLOWS:  
      $Recruitment\_Rate = (Target\_Staff - Sales\_Force) / Staff\_Adjust\_Time + SMTH3(Leaving\_Rate, 3)$   
 OUTFLOWS:  
      $Leaving\_Rate = Sales\_Force / Length\_of\_Stay$
- $Unpaid\_Invoices(t) = Unpaid\_Invoices(t - dt) + (Invoicing - Payment\_Rate) * dt$   
 INIT  $Unpaid\_Invoices = 120$   
 TRANSIT TIME = 1  
 INFLOW LIMIT =  $\infty$   
 CAPACITY =  $\infty$   
 INFLOWS:  
      $Invoicing = Delivery\_Rate$   
 OUTFLOWS:  
      $Payment\_Rate = CONVEYOR\ OUTFLOW$
- $Critical\_Lead-time = 2$
- $Fraction\_Spend = .25$
- $Lead-time = Order\_Backlog / Production\_Rate$
- $Length\_of\_Stay = 24$
- $Perceived\_Lead-time = DELAY(Lead-time, 6)$
- $Productivity = 5 + STEP(2, 5)$
- $Revenue = Payment\_Rate * Selling\_Price$

## Results of Sensitivity Analysis



Run No	Critical Lead-time (months)
1	1.5
2	2.0
3	3.0
4	4.5

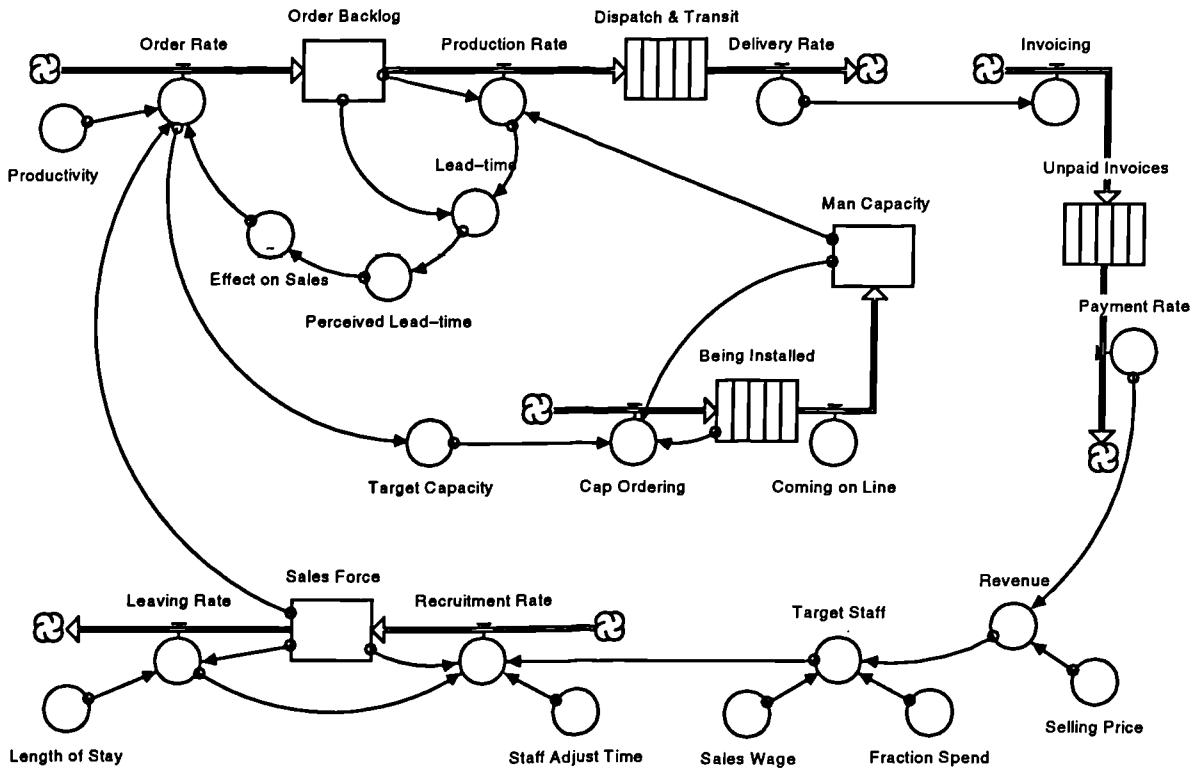
The result of the sensitivity analysis is shown below. It can clearly be seen that the problematic behaviour cannot be eliminated by adjusting the current manufacturing capacity ordering policy. A shorter "Critical\_Lead-Time" produces greater growth, but the dips in the sales rate still occur and their amplitude is increased.

To improve system behaviour it is necessary to design a new manufacturing capacity ordering policy.

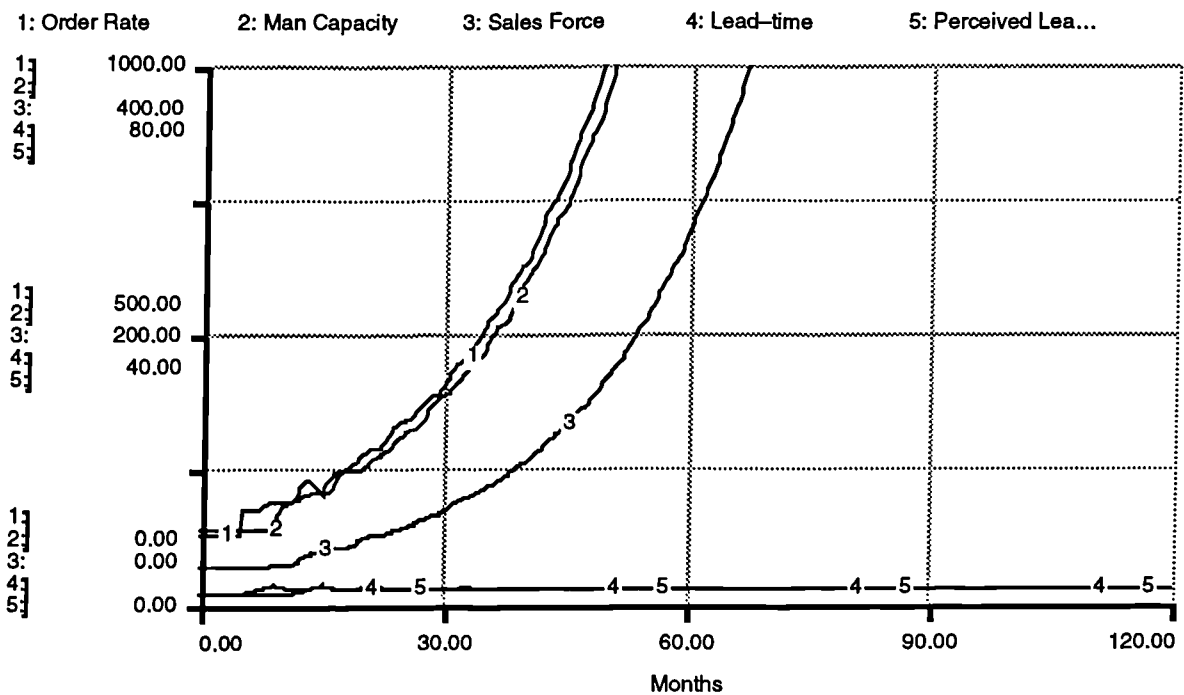
## Equations Listing for MGI Solution Model

- Being\_Installed(t) = Being\_Installed(t - dt) + (Cap\_Ordering - Coming\_on\_Line) \* dt  
 INIT Being\_Installed = 0  
 TRANSIT TIME = 4  
 INFLOW LIMIT = ∞  
 CAPACITY = ∞  
 INFLOWS:  
     ☞ Cap\_Ordering = Target\_Capacity - (Man\_Capacity + Being\_Installed)  
 OUTFLOWS:  
     ☞ Coming\_on\_Line = CONVEYOR OUTFLOW
- Dispatch\_&\_Transit(t) = Dispatch\_&\_Transit(t - dt) + (Production\_Rate - Delivery\_Rate) \* dt  
 INIT Dispatch\_&\_Transit = 120  
 TRANSIT TIME = 1  
 INFLOW LIMIT = ∞  
 CAPACITY = ∞  
 INFLOWS:  
     ☞ Production\_Rate = MIN(Man\_Capacity, Order\_Backlog)  
 OUTFLOWS:  
     ☞ Delivery\_Rate = CONVEYOR OUTFLOW
- Man\_Capacity(t) = Man\_Capacity(t - dt) + (Coming\_on\_Line) \* dt  
 INIT Man\_Capacity = 130  
 INFLOWS:  
     ☞ Coming\_on\_Line = CONVEYOR OUTFLOW
- Order\_Backlog(t) = Order\_Backlog(t - dt) + (Order\_Rate - Production\_Rate) \* dt  
 INIT Order\_Backlog = 120  
 INFLOWS:  
     ☞ Order\_Rate = Sales\_Force \* Productivity \* Effect\_on\_Sales  
 OUTFLOWS:  
     ☞ Production\_Rate = MIN(Man\_Capacity, Order\_Backlog)
- Sales\_Force(t) = Sales\_Force(t - dt) + (Recruitment\_Rate - Leaving\_Rate) \* dt  
 INIT Sales\_Force = 24  
 INFLOWS:  
     ☞ Recruitment\_Rate = (Target\_Staff - Sales\_Force) / Staff\_Adjust\_Time + Leaving\_Rate  
 OUTFLOWS:  
     ☞ Leaving\_Rate = Sales\_Force / Length\_of\_Stay
- Unpaid\_Invoices(t) = Unpaid\_Invoices(t - dt) + (Invoicing - Payment\_Rate) \* dt  
 INIT Unpaid\_Invoices = 120  
 TRANSIT TIME = 1  
 INFLOW LIMIT = ∞  
 CAPACITY = ∞  
 INFLOWS:  
     ☞ Invoicing = Delivery\_Rate  
 OUTFLOWS:  
     ☞ Payment\_Rate = CONVEYOR OUTFLOW
- Fraction\_Spend = .25
- Lead-time = Order\_Backlog / Production\_Rate
- Length\_of\_Stay = 24
- Perceived\_Lead-time = DELAY(Lead-time, 6)
- Productivity = 5 + STEP(2, 5)
- Revenue = Payment\_Rate \* Selling\_Price
- Sales\_Wage = 1000
- Selling\_Price = 800

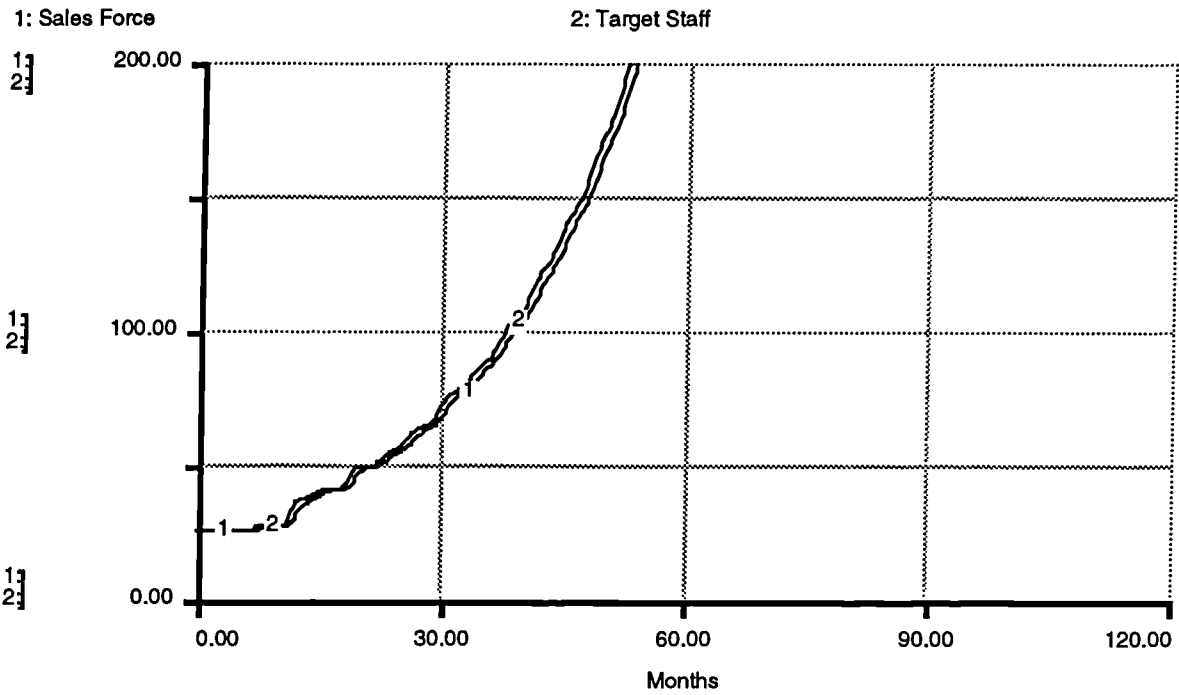
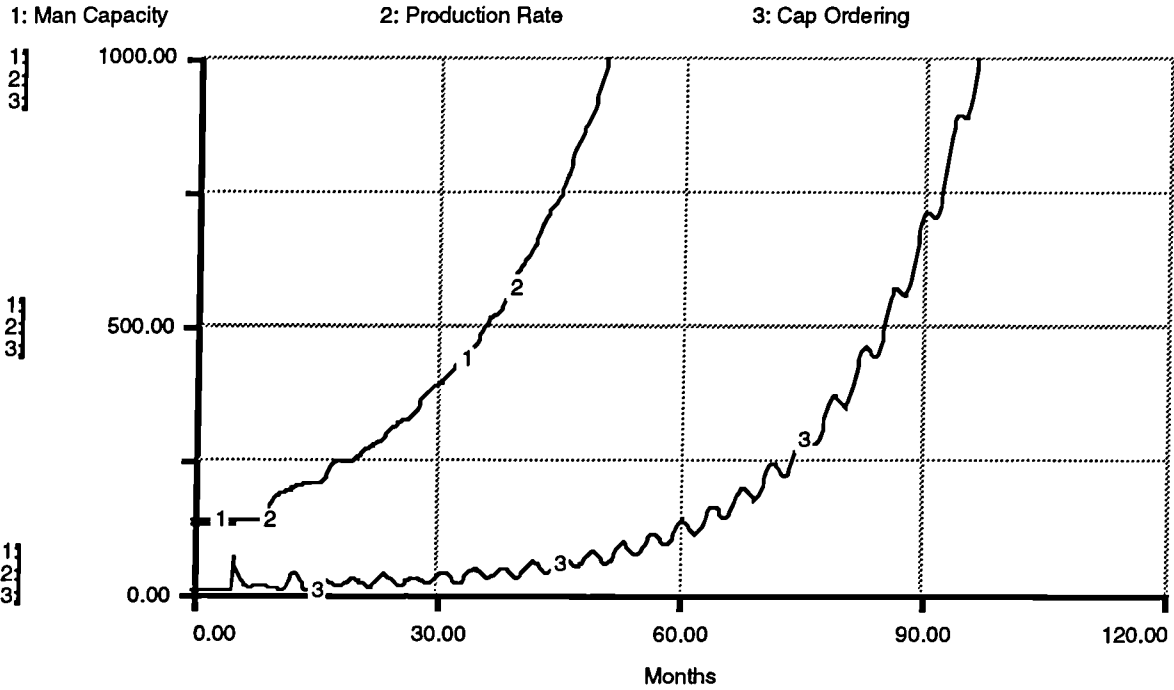
### Ithink Map of MGI Solution Model



### MGI Solution Model Output



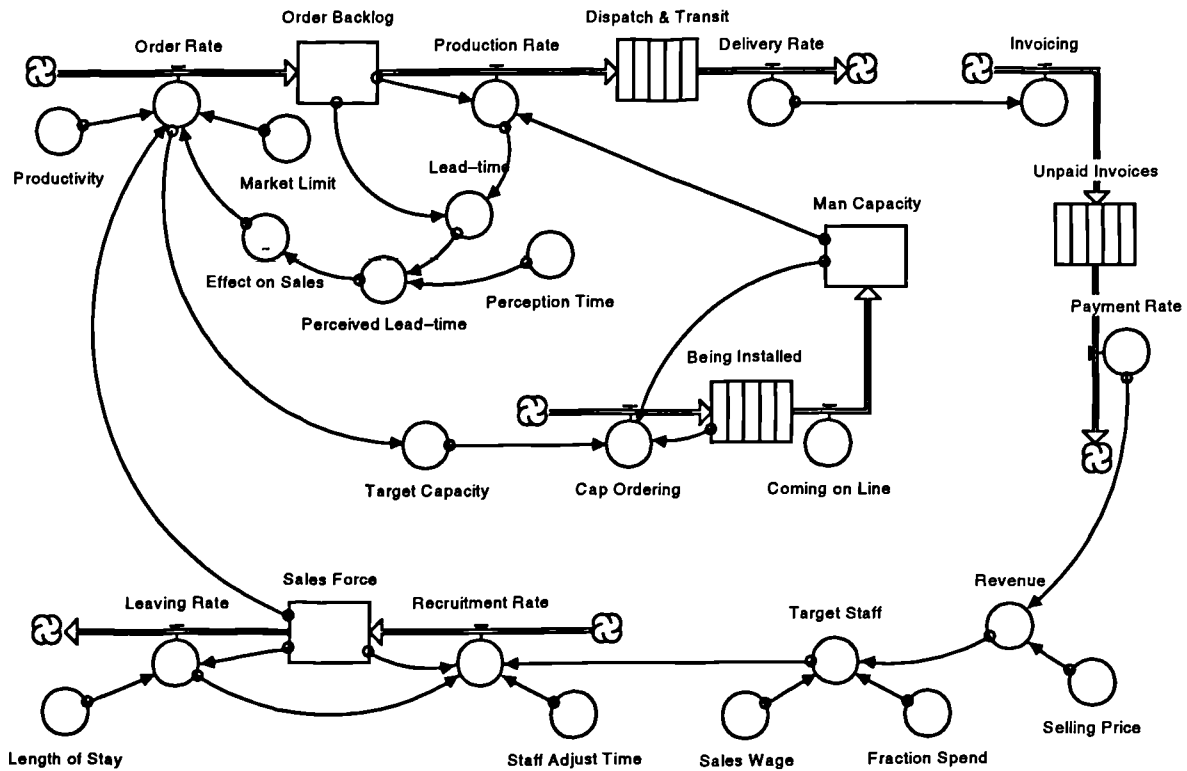
### MGI Solution Model Output



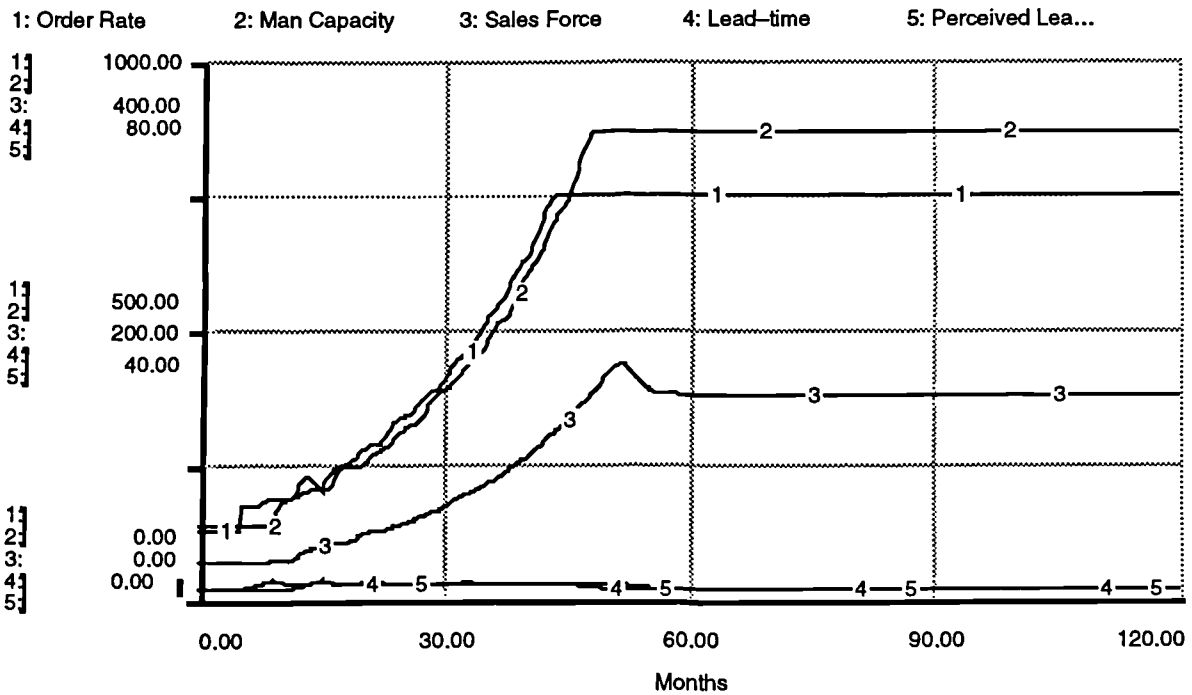
## Equations Listing for MGI Market Limit Model

- Being\_Installed(t) = Being\_Installed(t - dt) + (Cap\_Ordering - Coming\_on\_Line) \* dt  
 INIT Being\_Installed = 0  
 TRANSIT TIME = 4  
 INFLOW LIMIT = ∞  
 CAPACITY = ∞  
 INFLOWS:  
     ☞ Cap\_Ordering = Target\_Capacity - (Man\_Capacity + Being\_Installed)  
 OUTFLOWS:  
     ☞ Coming\_on\_Line = CONVEYOR OUTFLOW
- Dispatch\_&\_Transit(t) = Dispatch\_&\_Transit(t - dt) + (Production\_Rate - Delivery\_Rate) \* dt  
 INIT Dispatch\_&\_Transit = 120  
 TRANSIT TIME = 1  
 INFLOW LIMIT = ∞  
 CAPACITY = ∞  
 INFLOWS:  
     ☞ Production\_Rate = MIN(Man\_Capacity, Order\_Backlog)  
 OUTFLOWS:  
     ☞ Delivery\_Rate = CONVEYOR OUTFLOW
- Man\_Capacity(t) = Man\_Capacity(t - dt) + (Coming\_on\_Line) \* dt  
 INIT Man\_Capacity = 130  
 INFLOWS:  
     ☞ Coming\_on\_Line = CONVEYOR OUTFLOW
- Order\_Backlog(t) = Order\_Backlog(t - dt) + (Order\_Rate - Production\_Rate) \* dt  
 INIT Order\_Backlog = 120  
 INFLOWS:  
     ☞ Order\_Rate = MIN((Sales\_Force \* Productivity \* Effect\_on\_Sales), Market\_Limit)  
 OUTFLOWS:  
     ☞ Production\_Rate = MIN(Man\_Capacity, Order\_Backlog)
- Sales\_Force(t) = Sales\_Force(t - dt) + (Recruitment\_Rate - Leaving\_Rate) \* dt  
 INIT Sales\_Force = 24  
 INFLOWS:  
     ☞ Recruitment\_Rate = (Target\_Staff - Sales\_Force) / Staff\_Adjust\_Time + Leaving\_Rate  
 OUTFLOWS:  
     ☞ Leaving\_Rate = Sales\_Force / Length\_of\_Stay
- Unpaid\_Invoices(t) = Unpaid\_Invoices(t - dt) + (Invoicing - Payment\_Rate) \* dt  
 INIT Unpaid\_Invoices = 120  
 TRANSIT TIME = 1  
 INFLOW LIMIT = ∞  
 CAPACITY = ∞  
 INFLOWS:  
     ☞ Invoicing = Delivery\_Rate  
 OUTFLOWS:  
     ☞ Payment\_Rate = CONVEYOR OUTFLOW
- Fraction\_Spend = .25
- Lead-time = Order\_Backlog / Production\_Rate
- Length\_of\_Stay = 24
- Market\_Limit = 750
- Perceived\_Lead-time = DELAY(Lead-time, Perception\_Time)
- Perception\_Time = 6
- Productivity = 5 + STEP(2, 5)
- Revenue = Payment\_Rate \* Selling\_Price

### Ithink Map of MGI Market Limit Model

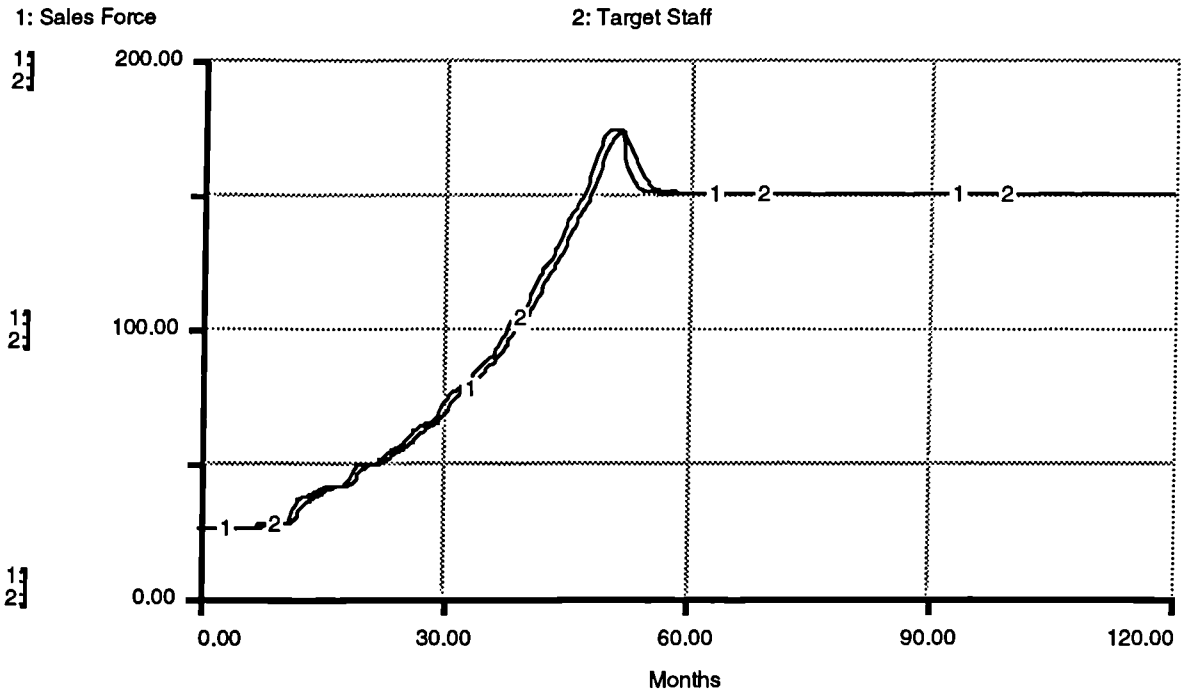
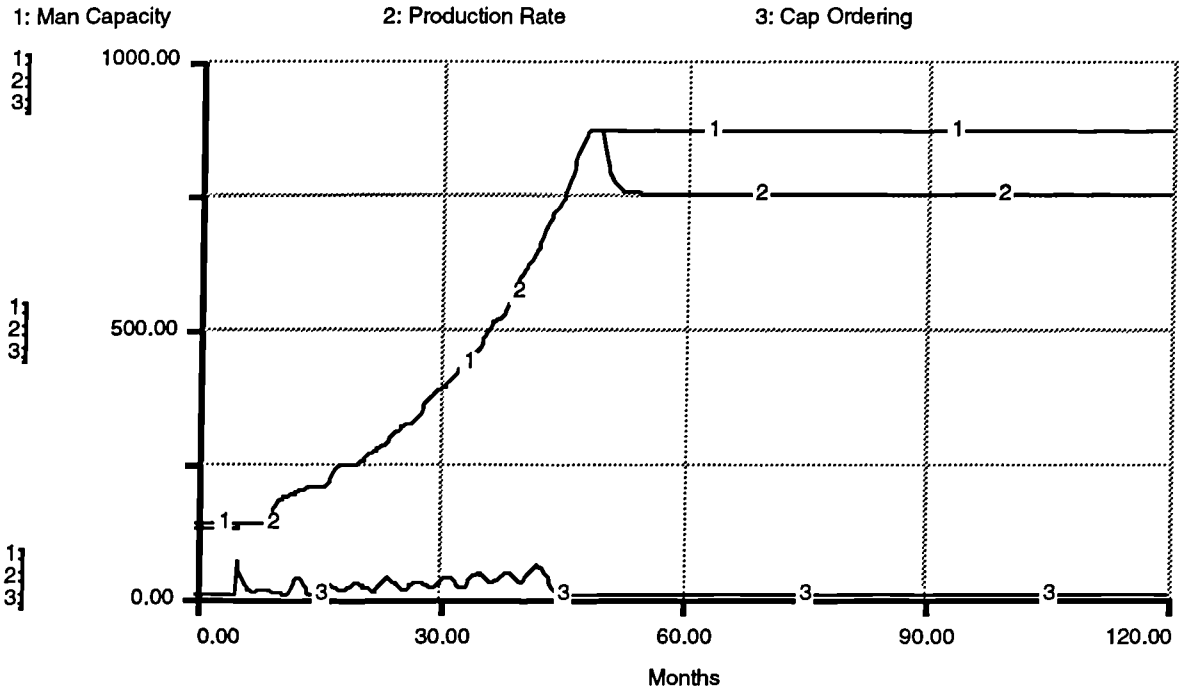


### MGI Market Limit Model Output



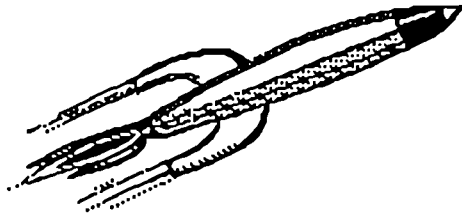


### MGI Market Limit Model Output



## **Appendix 3**

### *The Rocket Case Study*



A Systems Thinking Case Study in

## ***Rocket Powered Flight***

**Part 1: Mapping Exercise**

## Introduction

In this exercise we will produce a qualitative influence diagram model of a rocket.

### Aim of the Exercise

To provide an opportunity of applying the techniques of qualitative modelling; influence diagramming, identification of feedback loops and the analysis of system behaviour in terms of feedback loop structures.

## Instructions

Create an influence diagram of a rocket, identifying and signing all feedback loops. Predict the behaviour of the system in terms of its feedback structure.

## Some Information on Rocket Propulsion

A rocket burns fuel which creates exhaust gases that are ejected from the back of the rocket, decreasing the mass of the rocket. These exhaust gases have a momentum and the rocket receives a compensating momentum in the opposite direction (Law of Conservation of Momentum), therefore the rocket is propelled by the reactive force of the exhaust gases.

The acceleration force on a rocket is equal to the thrust of the engine, this is proportional to the fuel burn rate and the exhaust gas velocity.

## Some Additional Information

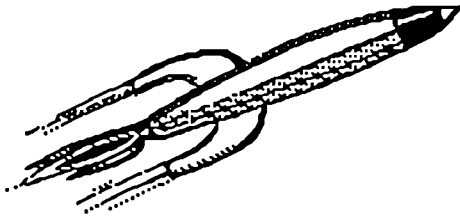
The drag force on a body moving through the air is proportional to the shape of the body, the density of the air and velocity of the body.

The force of gravity between two bodies is inversely proportional to the square of the distance between them. (Newton's Law of Gravitation)

The density of the atmosphere decreases with altitude.

## Some Help To Get You Started

Start by considering three model elements, the Mass of the Rocket, the Engine Burn Rate and the Rocket Acceleration. The section on rocket propulsion contains information which will allow you to link these. The additional information section describes some feedback mechanisms. Your influence diagram should contain at least one positive and one negative feedback loop.



A Systems Thinking Case Study in

***Rocket Powered Flight***

**Part 1: Solution**

### Qualitative Model

An influence diagram describing rocket powered flight is shown in Figure 1. The influence diagram that you have created may well be slightly different; the important thing is that it should contain the same basic loop structure.

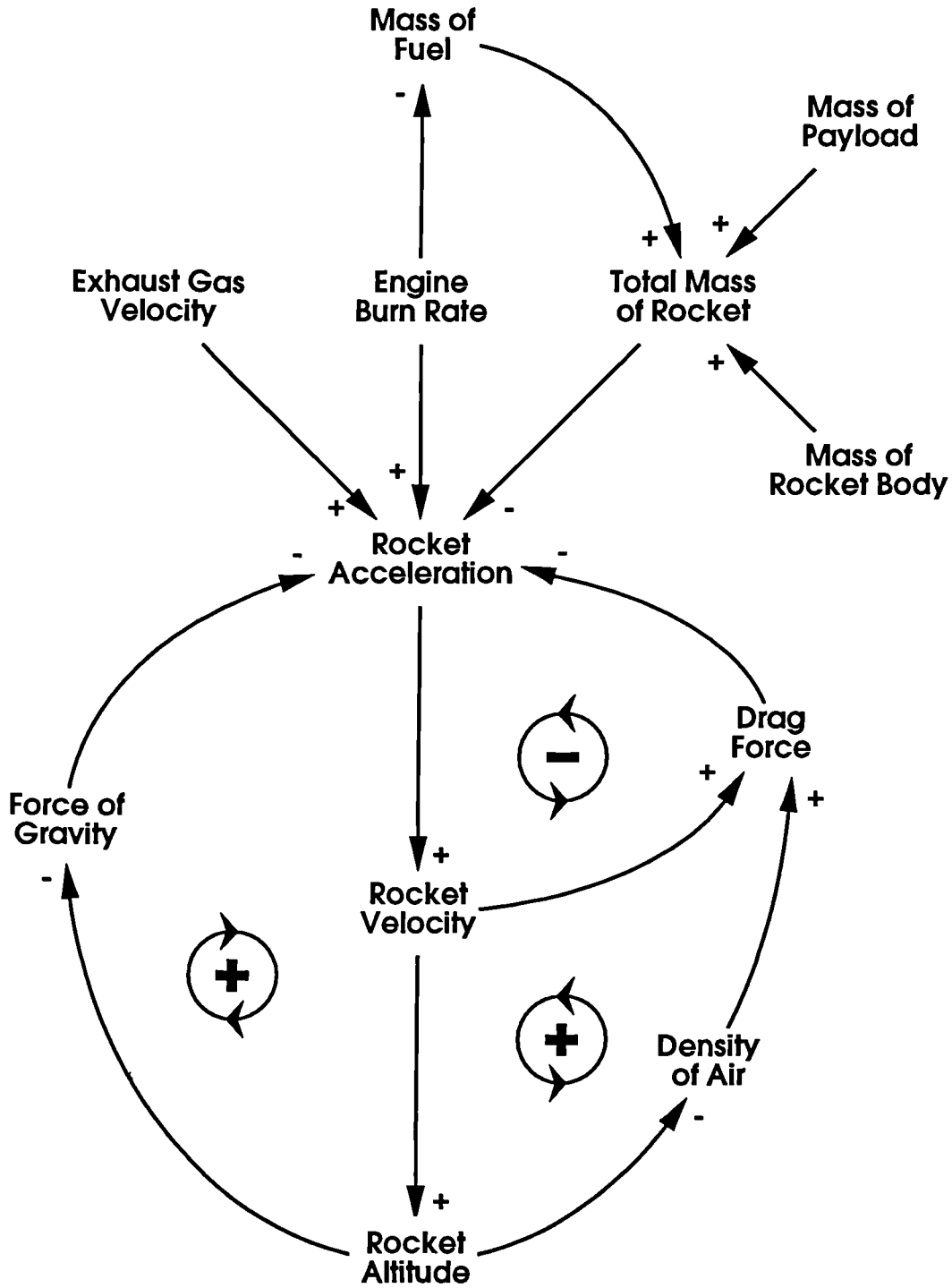
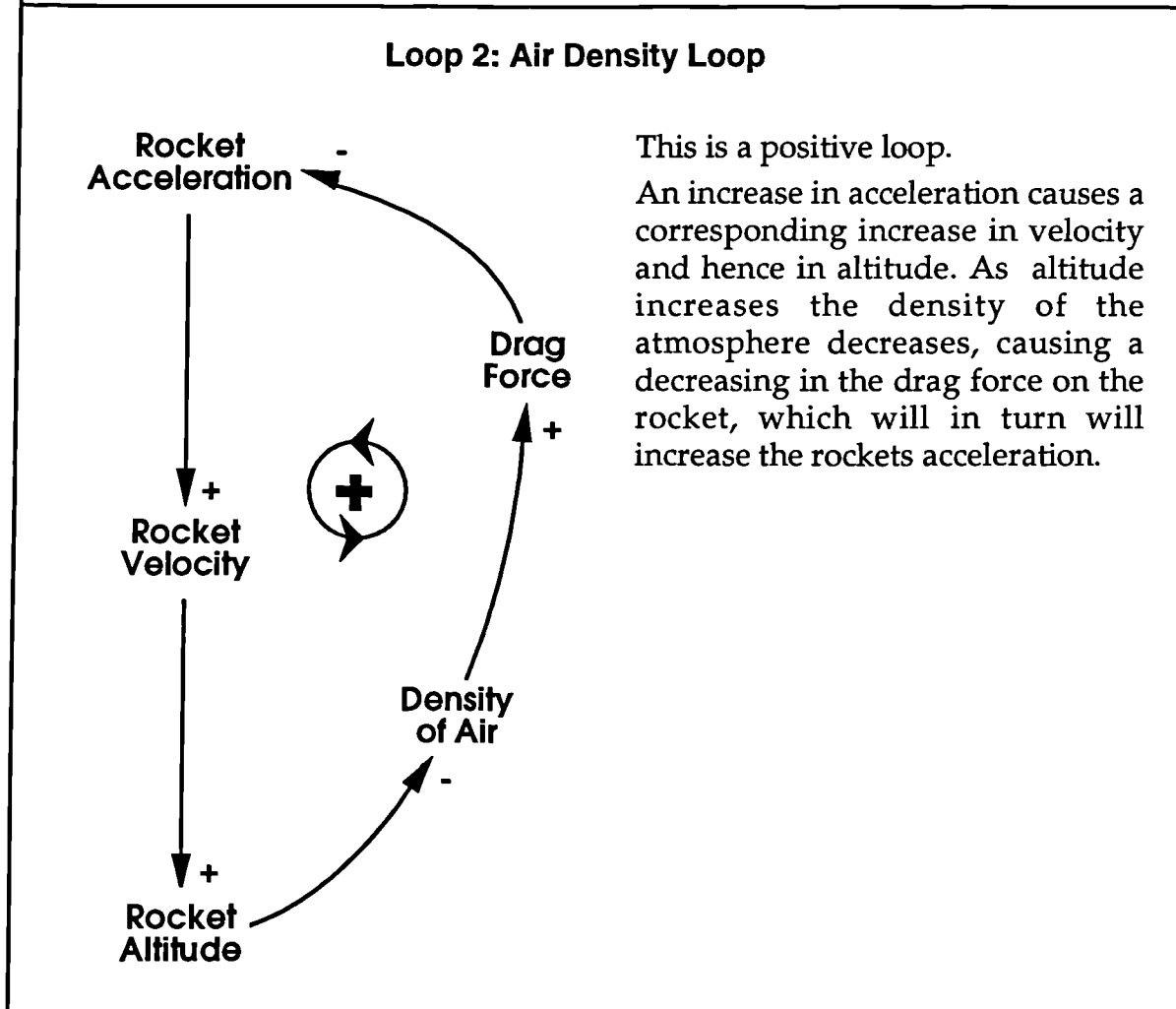
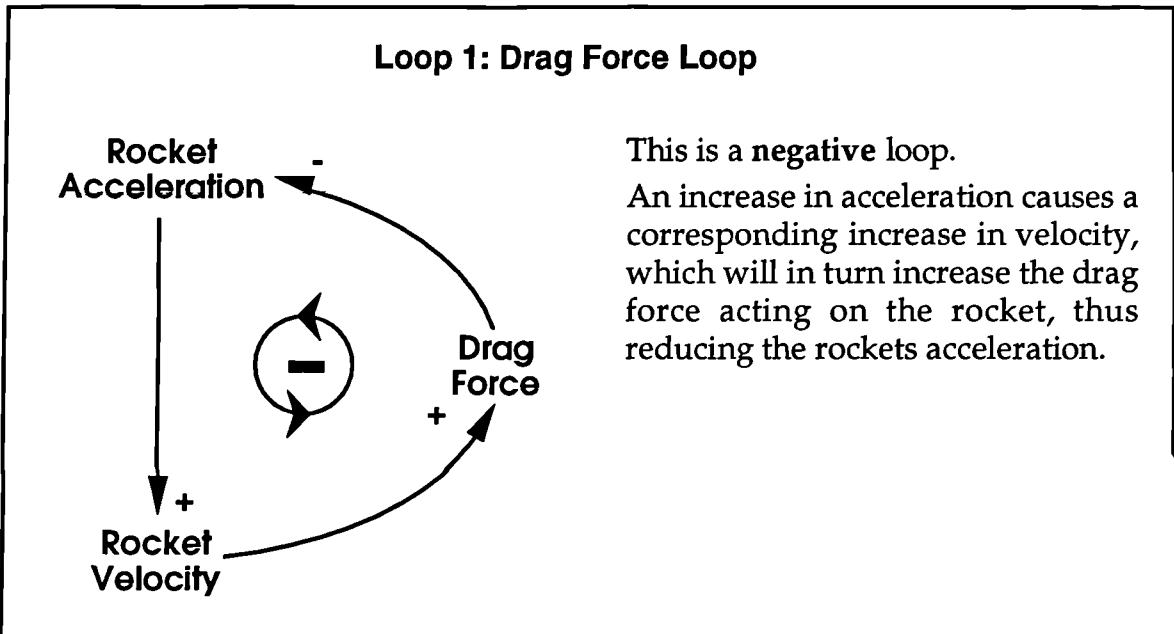
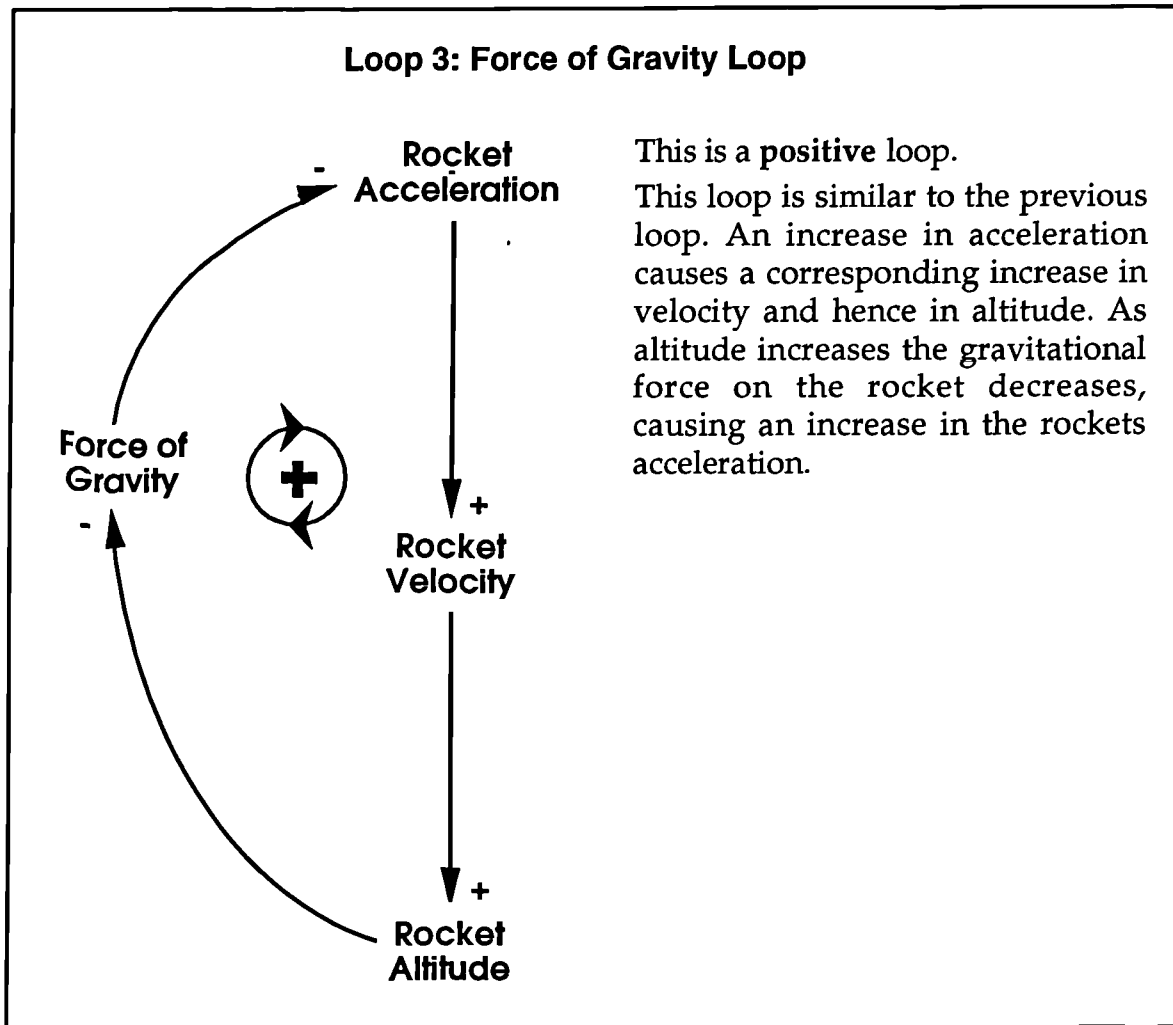


Figure 1 Influence Diagram of Rocket Powered Flight

### Feedback Loops

The qualitative model contains three main feedback loops, one positive and two negative. Each loop will now be described in turn.





## System Behaviour

The overall system behaviour is caused by the interaction of the three feedback loops. This system is typical of many in that it contains the potential for growth; the two positive loops and a growth inhibiting mechanism; the negative loop. It is the relative strength of these loops that will determine the mode of behaviour of the system. The strength of the loops is not fixed, but will vary over time, causing the behaviour of system to change over time.

Initially none of the loops will have much effect, but as the velocity of the rocket increases, the negative influence of the drag force loop will increase and the acceleration of the rocket will be limited or even perhaps reduced. As the altitude increase, the influence of the two positive loops will increase and both the drag and the gravitational forces retarding the rocket will decrease and the acceleration of the rocket will increase.

To fully investigate the systems behaviour it is necessary to build a qualitative simulation model, but we can get a little bit further with the qualitative approach by considering some quantitative data.

The density of the Earth's atmosphere is negligible above an altitude of about 50 kilometres.

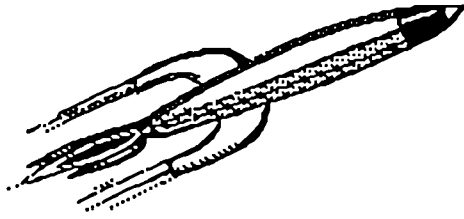


The force of gravity at the same height is only reduced by about 5%, but by an altitude of 3000 km it will have halved and at 50000 km it will be down below 2% of its sea level value.

Using this data in conjunction with our loop analysis allows use to make the following prediction of system behaviour.

The rocket will accelerate and then its acceleration will be checked by the drag force, the drag force will increase as the velocity increases and then it will start to decrease due to the effect of air density decreasing with altitude. By the time an altitude of 50 km has been reached the drag force will have died away to nothing, therefore the point of maximum drag must occur somewhere between sea level and 50 km.

The effect of the reduction of gravitation force with altitude will be unimportant until altitudes of the order of 1000s of km have been reached. At very high altitudes, the restraining force on the rocket will be very small and if the velocity is high enough the rocket may well be unstoppable.



A Systems Thinking Case Study in

***Rocket Powered Flight***

**Part 2: Simulation Exercise**

## Introduction

In this exercise we will produce a ithink model of a rocket.

### Aims of the Exercise

To test the prediction of system behaviour made by the qualitative model and allow the relative strength and importance of the feedback loops to be investigated.

To give hands on experience using ithink to create a model from a given Ithink map and written information, including the use of graphical relationships. Not all the relationships will be given explicitly, so introducing the topic of equations formulation.

To allow interactive experimentation with a ithink model, including sensitivity analysis.

To provide the opportunity to structurally modify an existing Ithink model to investigate the effects of a proposed change. The exact details of the required modifications will not be given, but sufficient understanding of the model should have been gained by this stage, to allow the participants to successfully undertake this task.

## Instructions

- 1 Build the Rocket Propulsion Model using the Ithink diagram and the other information contained in the second part of this document.
- 2 Use the following parameter values:

### Experimental Parameters

Design\_Burn\_Rate = 125 Kg/s

Fuel\_Capacity = 10,000 Kg

### Simulation Parameters

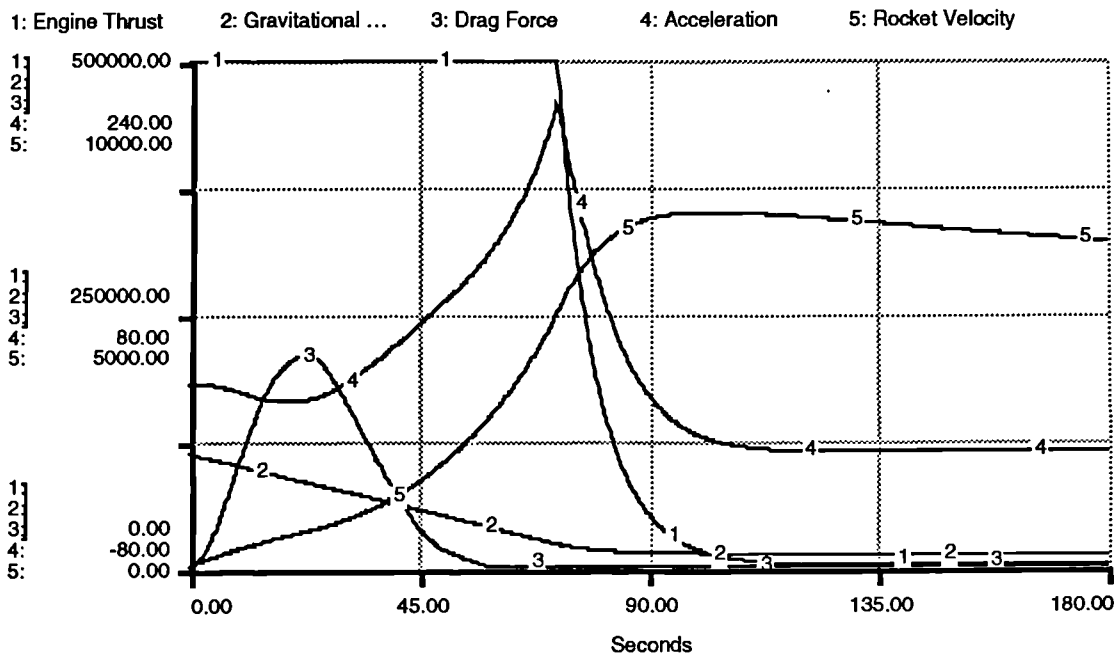
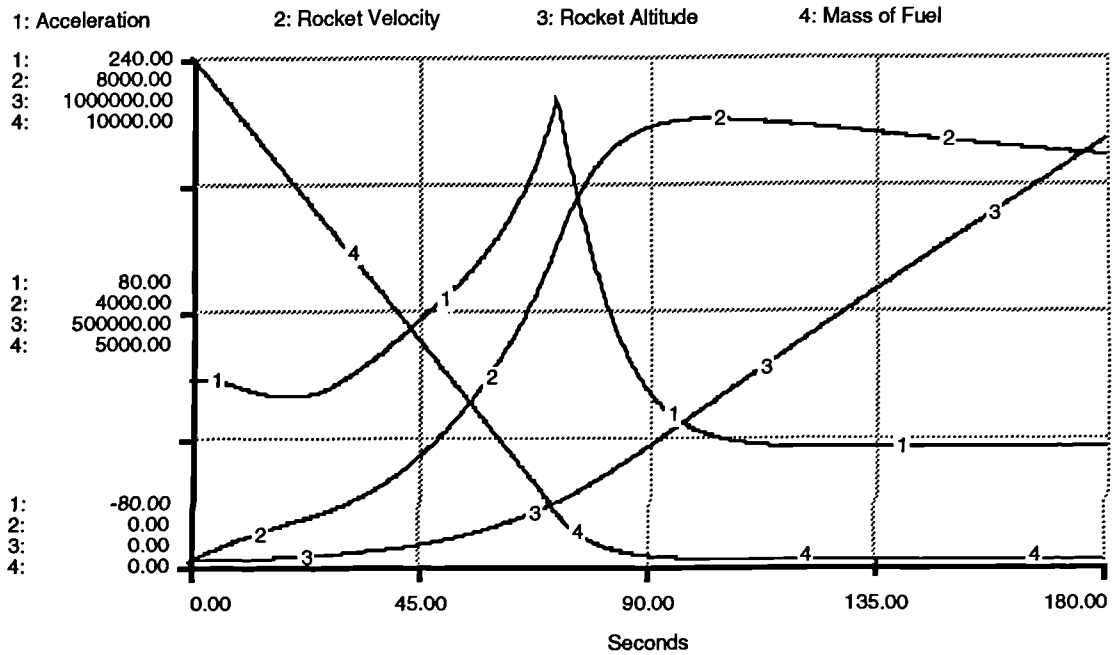
Simulation Start Time = 0

Simulation Stop Time = 180

DT = 0.125

Units of Time = Seconds

Run the simulation and reproduce the following graphs. Remember to scale the graphs!



- 3 Examine the graphs. Explain the behaviour be in terms of the feedback structures identified in the qualitative model.
- 4 Trace out these loops in the ithink diagram, remembering that a ithink diagram shows outflows from a level in the opposite direction to that on a causal loop diagram.

- 5 Investigate the effect of varying the size of the rocket, by performing the following sensitivity analysis.

**Sensitivity Parameters**

Fuel\_Capacity = 12,000 Kg

Fuel\_Capacity = 24,000 Kg

Fuel\_Capacity = 36,000 Kg

Fuel\_Capacity = 48,000 Kg

**Simulation Parameters**

Start Time = 0

Stop Time = 4000

DT = 1

Units of Time = Seconds

What is the maximum altitude achieved and for what value of Fuel capacity was it achieved?

Explain why increasing the amount of Fuel does not necessarily increase the maximum altitude reached.

What parameter changes would increase the maximum height reached?

Are there any structural changes that would increase the maximum height reached?

- 6 One possible way of increasing the maximum height reached is to use a multi-staged rocket. Modify the existing model to simulate a two staged rocket with a fuel capacity equal to that found optimum in the sensitivity analysis.

Before you do this, save your current model, then save it again under another name such as "Rocket Model Modified" for instance.

Use **Save As...** from **File** menu to do this.

**Some Help to get you going**

Keep the engine performance the same for both stages and assume all the other parameter remain unchanged. Make the fuel capacity of the 1st stage 3 times that of the 2nd stage. The Copy, Paste and Ghosting facilities can be used to good effect here!

**Further Work**

- 1 Perform a sensitivity analysis to determine the optimum ratio of size between the two stages of the rocket.
- 2 Investigate the effect of adding a third and fourth stage to the rocket. Is there any limit to the number of stages it is worthwhile to add?
- 3 The current model has no control policy for the engine burn rate, this results in some rather high accelerations being achieved, this may cause damage to the rocket or payload, particularly if the payload is human! (The human body can withstand accelerations up to about 10 - 20 g for a short duration) Introduce an engine control policy to limit the maximum acceleration to a reasonable level.

## Rocket Model Data



## Parameter Values

The parameter values for the model are given in the question or in the following pages.

Body\_to\_Fuel\_Ratio  
Design\_Burn\_Rate  
Drag\_Coefficient  
Exhaust\_Gas\_Velocity  
Fuel\_Capacity  
Mass\_of\_Payload  
X\_Section\_Area

## Given Relationships

The following relationships are given to you.

$\text{Burn\_Rate} = \text{Design\_Burn\_Rate} * \text{Burn\_Rate\_Multiplier}$   
 $\text{Drag\_Direction} = \text{IF Rocket\_Velocity} < 0 \text{ THEN } -1 \text{ ELSE } 1$   
 $\text{Gravitational\_Force} = \text{Total\_Mass} * \text{Strength\_of\_Gravity}$

## Graphical Relationships

There are two graphical relationships in the model, information about them can be found in the “Variation of Atmospheric Density with Altitude” and the “Graphical Functions” sections. The burn rate multiplier model the fall off in performance of the engines that occurs as the fuel level gets low.

Atmospheric\_Density  
Burn\_Rate\_Multiplier

## Required Relationships

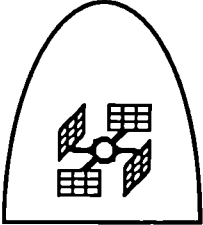
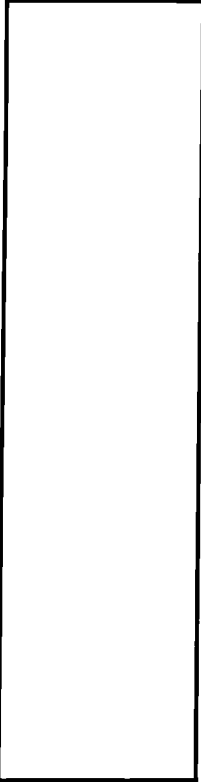
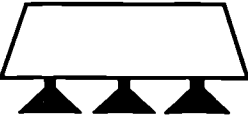
You will need to formulate the following relationships. Some of them are given in the information on the following pages, others you will need to create for yourself.

Hint: Units are a useful guide to the required form of a relationship.

Acceleration  
Drag\_Force  
Engine\_Thrust  
Mass\_of\_Body  
Strength\_of\_Gravity  
Total\_Force  
Total\_Mass



## Rocket Blue Print

	<p style="text-align: center;"><b>Rocket Nose Cone Data</b></p> <p>Mass of payload.....500 kg</p>
	<p style="text-align: center;"><b>Rocket Body Data</b></p> <p>Drag coefficient .....0.15</p> <p>Cross sectional area .....12 m<sup>2</sup></p> <p>Mass of body* = 7.5 % fuel capacity</p> <p>* including the mass of the engine</p>
	<p style="text-align: center;"><b>Engine Data</b></p> <p>Exhaust gas velocity.....4000 m/s</p>

## Gravitational Force and Drag Force

### Variation of Gravitational Force with Altitude

The acceleration due to gravity  $g'$  at altitude  $h$  above the Earth's surface is given by

$$g' = \frac{GM_e}{(R_e + h)^2}$$

where

$G$  = Universal Gravitational Constant

$M_e$  = Mass of the Earth

$R_e$  = Radius of the Earth

**Table of Values**

$G$	$6.67 \times 10^{-11}$	$\text{N.m}^2/\text{kg}^2$
$M_e$	$5.98 \times 10^{24}$	kg
$R_e$	$6.38 \times 10^6$	m

### Calculation of Drag Forces

The drag force  $R$  on a body moving through the atmosphere with velocity  $v$  is given by

$$R = \frac{1}{2} C_p A v^2$$

where

$C$  = Drag Coefficient

$\rho$  = Density of Air

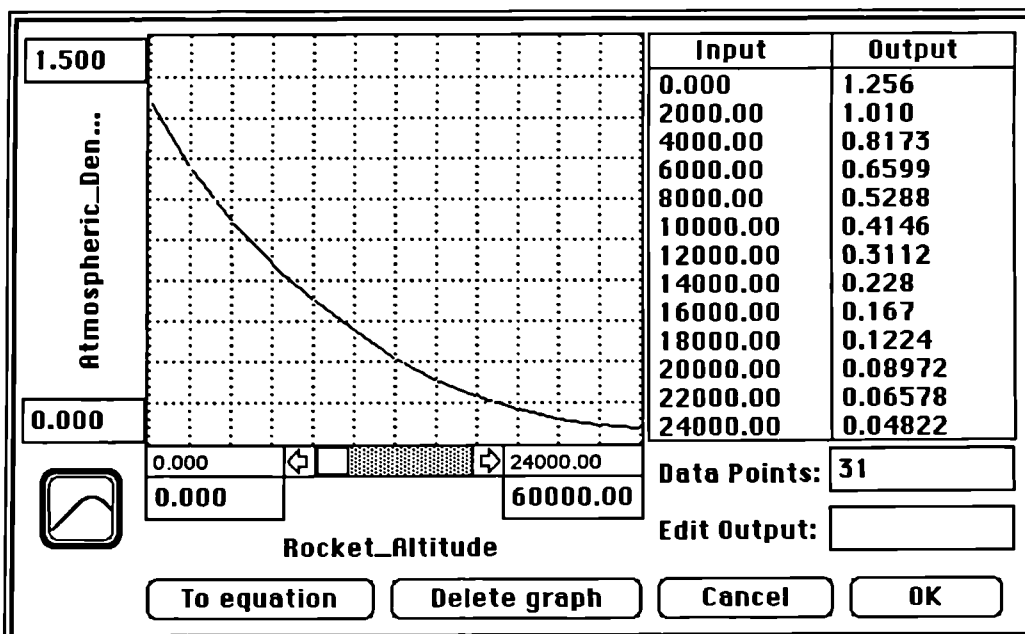
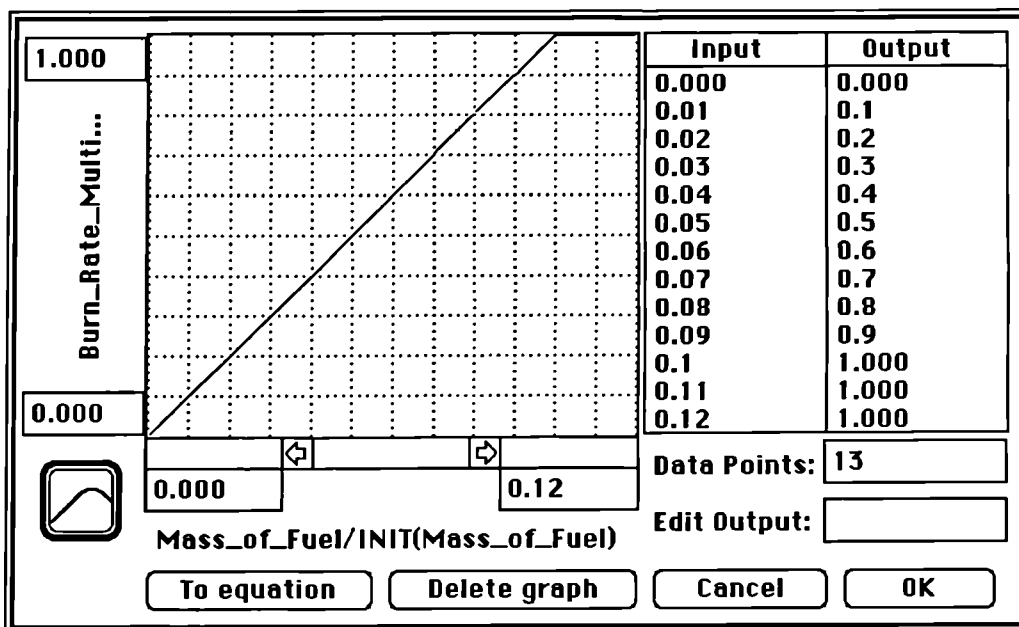
$A$  = Cross-Sectional Area of Body

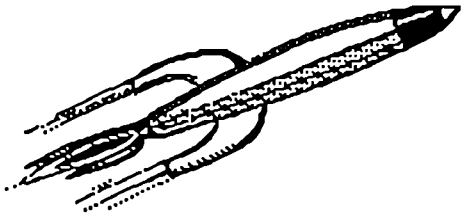
## Variation of Atmospheric Density with Altitude

Table of Values

Altitude m	Density kg/m <sup>3</sup>
0	1.256
2,000	1.01011
4,000	0.817345
6,000	0.65988
8,000	0.528835
10,000	0.41464
12,000	0.31123
14,000	0.22798
16,000	0.16703
18,000	0.1224
20,000	0.089725
22,000	0.06578
24,000	0.048225
26,000	0.035375
28,000	0.02595
30,000	0.01904
32,000	0.01397
34,000	0.01025
36,000	0.00754
38,000	0.005535
40,000	0.004065
42,000	0.0034602
44,000	0.0028554
46,000	0.0022506
48,000	0.0016458
50,000	0.001041
52,000	0.0008328
54,000	0.0006246
56,000	0.0004164
58,000	0.0002082
60,000	0.0

## Graphical Functions





A Systems Thinking Case Study in

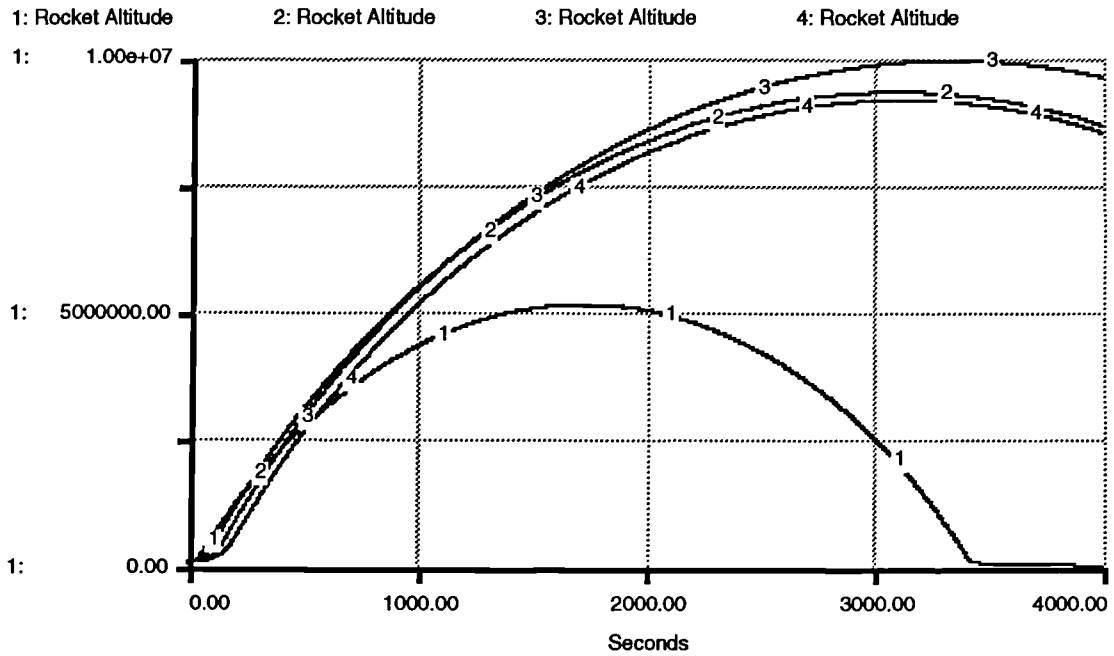
***Rocket Powered Flight***

**Part 2: Solution**

## Equation Listing for Base Rocket Model

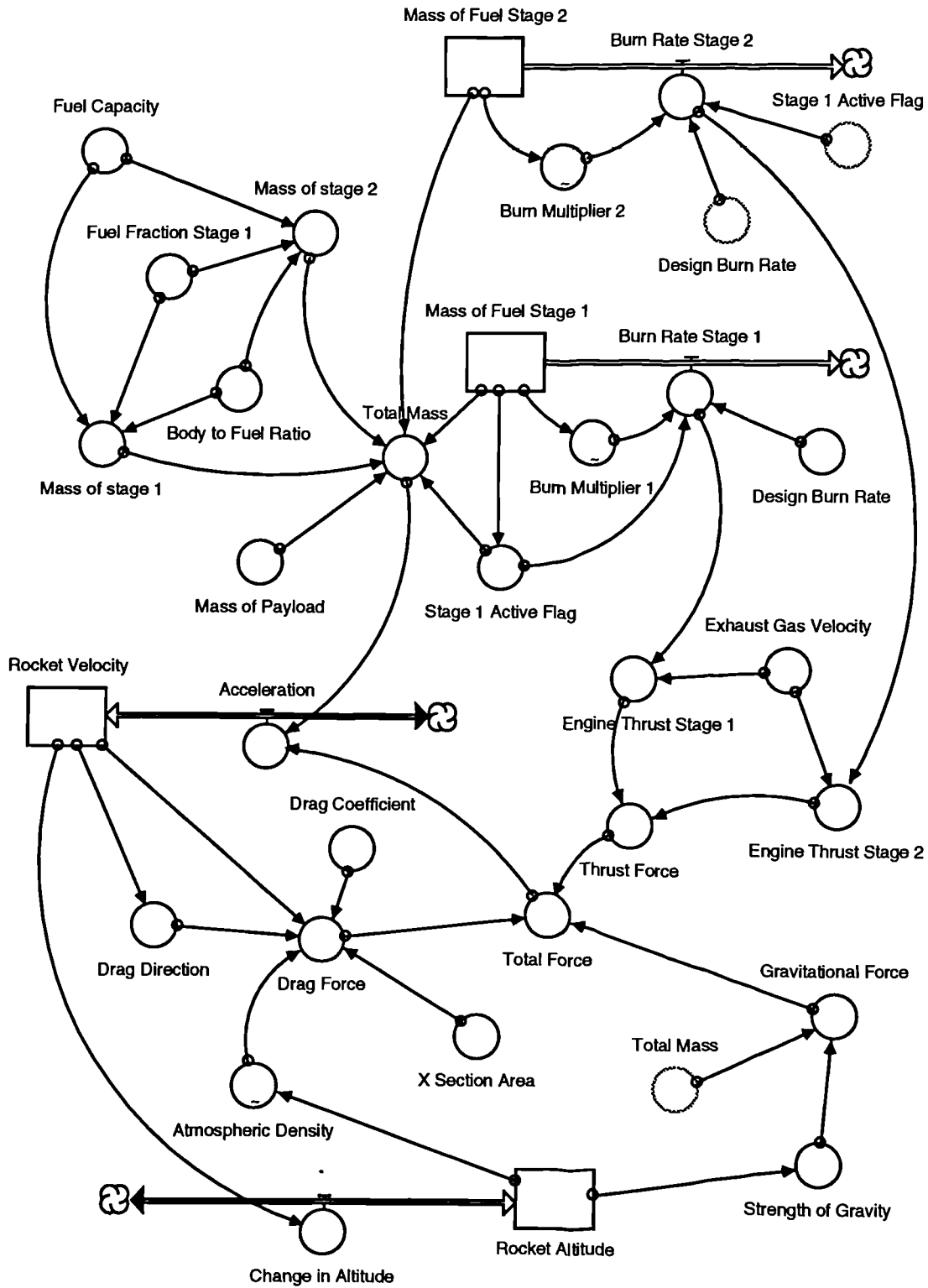
- $Mass\_of\_Fuel(t) = Mass\_of\_Fuel(t - dt) + (- Burn\_Rate) * dt$   
 INIT  $Mass\_of\_Fuel = Fuel\_Capacity$   
 OUTFLOWS:  
  - $Burn\_Rate = Design\_Burn\_Rate * Burn\_Rate\_Multiplier$
- $Rocket\_Altitude(t) = Rocket\_Altitude(t - dt) + (Change\_in\_Altitude) * dt$   
 INIT  $Rocket\_Altitude = 0$   
 INFLOWS:  
  - $Change\_in\_Altitude = Rocket\_Velocity$
- $Rocket\_Velocity(t) = Rocket\_Velocity(t - dt) + (Acceleration) * dt$   
 INIT  $Rocket\_Velocity = 0$   
 INFLOWS:  
  - $Acceleration = Total\_Force / Total\_Mass$
- $Body\_to\_Fuel\_Ratio = 0.075$
- $Design\_Burn\_Rate = 125$
- $Drag\_Coefficient = 0.15$
- $Drag\_Direction = IF Rocket\_Velocity < 0 THEN -1 ELSE 1$
- $Drag\_Force = (0.5 * Drag\_Coefficient * Atmospheric\_Density * X\_Section\_Area * Rocket\_Velocity^2) * Drag\_Direction$
- $Engine\_Thrust = Exhaust\_Gas\_Velocity * Burn\_Rate$
- $Exhaust\_Gas\_Velocity = 4000$
- $Fuel\_Capacity = 10000$
- $Gravitational\_Force = Total\_Mass * Strength\_of\_Gravity$
- $Mass\_of\_Body = Body\_to\_Fuel\_Ratio * Fuel\_Capacity$
- $Mass\_of\_Payload = 500$
- $Strength\_of\_Gravity = (6.67e-11 * 5.98e24) / (6.38e6 + Rocket\_Altitude)^2$
- $Total\_Force = Engine\_Thrust - Gravitational\_Force - Drag\_Force$
- $Total\_Mass = Mass\_of\_Payload + Mass\_of\_Body + Mass\_of\_Fuel$
- $X\_Section\_Area = 12$
- $Atmospheric\_Density = GRAPH(Rocket\_Altitude)$   
 (0.00, 1.26), (2000, 1.01), (4000, 0.817), (6000, 0.66), (8000, 0.529), (10000, 0.415),  
 (12000, 0.311), (14000, 0.228), (16000, 0.167), (18000, 0.122), (20000, 0.0897),  
 (22000, 0.0658), (24000, 0.0482), (26000, 0.0354), (28000, 0.026), (30000, 0.019),  
 (32000, 0.014), (34000, 0.0103), (36000, 0.00754), (38000, 0.00553), (40000, 0.00407),  
 (42000, 0.00346), (44000, 0.00286), (46000, 0.00225), (48000, 0.00165), (50000,  
 0.00104), (52000, 0.000833), (54000, 0.000625), (56000, 0.000416), (58000, 0.000208),  
 (60000, 0.00)
- $Burn\_Rate\_Multiplier = GRAPH(Mass\_of\_Fuel / INIT(Mass\_of\_Fuel))$   
 (0.00, 0.00), (0.01, 0.1), (0.02, 0.2), (0.03, 0.3), (0.04, 0.4), (0.05, 0.5), (0.06, 0.6),  
 (0.07, 0.7), (0.08, 0.8), (0.09, 0.9), (0.1, 1.00), (0.11, 1.00), (0.12, 1.00)

## Results of Sensitivity Analysis



Run No	Fuel Capacity (kg)
1	12,000
2	24,000
3	36,000
4	48,000

### Ithink Map of the Two Staged Rocket Model

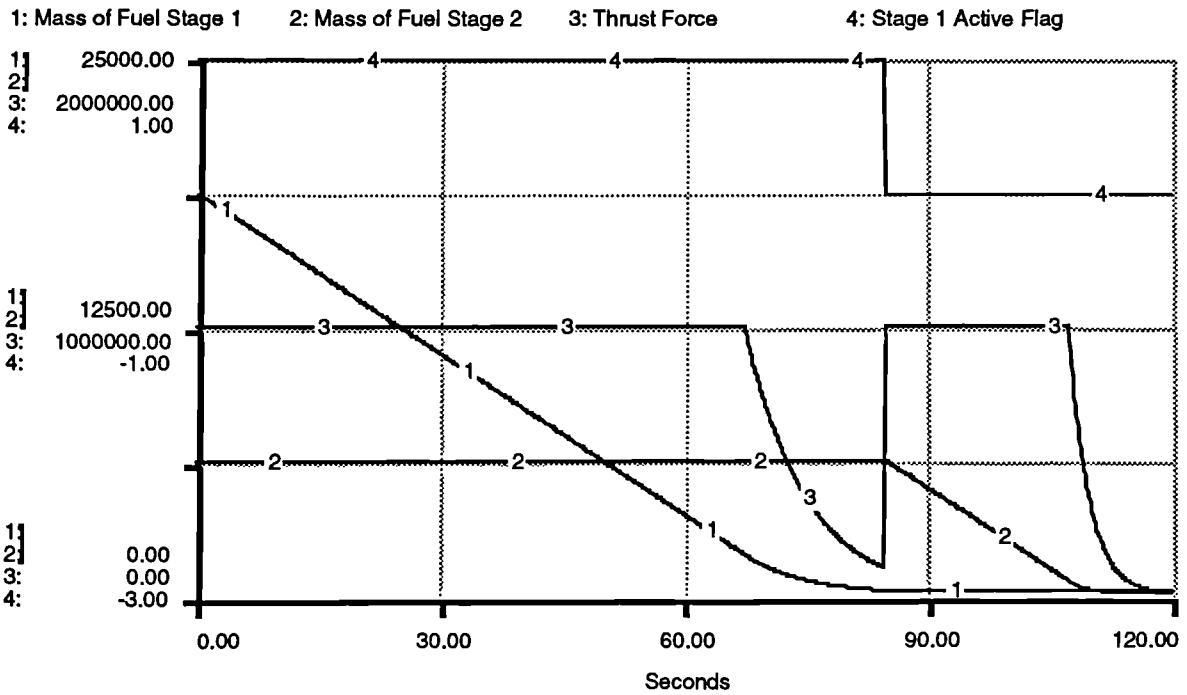
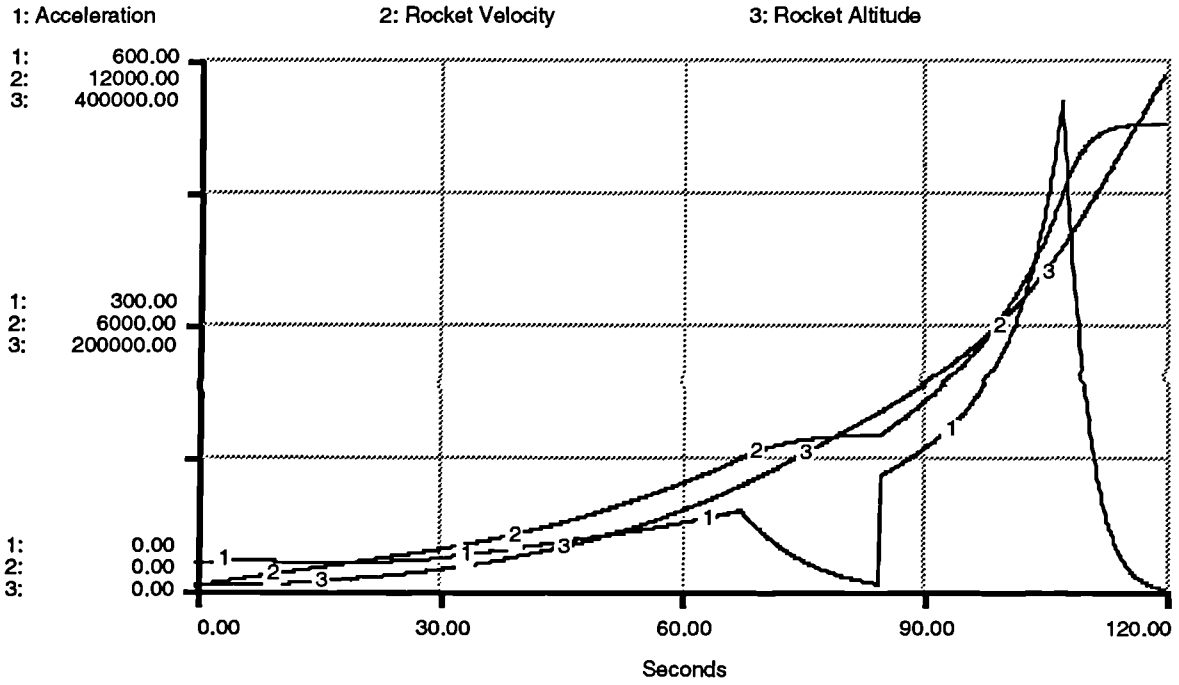




## Equation Listing of the Two Staged Rocket Model

- $Mass\_of\_Fuel\_Stage\_1(t) = Mass\_of\_Fuel\_Stage\_1(t - dt) + (- Burn\_Rate\_Stage\_1) * dt$   
 INIT  $Mass\_of\_Fuel\_Stage\_1 = Fuel\_Capacity * Fuel\_Fraction\_Stage\_1$   
 OUTFLOWS:  
  $Burn\_Rate\_Stage\_1 = Design\_Burn\_Rate * Burn\_Multiplier\_1 * Stage\_1\_Active\_Flag$
- $Mass\_of\_Fuel\_Stage\_2(t) = Mass\_of\_Fuel\_Stage\_2(t - dt) + (- Burn\_Rate\_Stage\_2) * dt$   
 INIT  $Mass\_of\_Fuel\_Stage\_2 = Fuel\_Capacity * (1 - Fuel\_Fraction\_Stage\_1)$   
 OUTFLOWS:  
  $Burn\_Rate\_Stage\_2 = Design\_Burn\_Rate * Burn\_Multiplier\_2 * (1 - Stage\_1\_Active\_Flag)$
- $Rocket\_Altitude(t) = Rocket\_Altitude(t - dt) + (Change\_in\_Altitude) * dt$   
 INIT  $Rocket\_Altitude = 0$   
 INFLOWS:  
  $Change\_in\_Altitude = Rocket\_Velocity$
- $Rocket\_Velocity(t) = Rocket\_Velocity(t - dt) + (Acceleration) * dt$   
 INIT  $Rocket\_Velocity = 0$   
 INFLOWS:  
  $Acceleration = Total\_Force / Total\_Mass$
- $Body\_to\_Fuel\_Ratio = 0.075$
- $Design\_Burn\_Rate = 250$
- $Drag\_Coefficient = 0.15$
- $Drag\_Direction = IF Rocket\_Velocity < 0 THEN -1 ELSE 1$
- $Drag\_Force =$   
 $(0.5 * Drag\_Coefficient * Atmospheric\_Density * X\_Section\_Area * Rocket\_Velocity^2) * Drag\_Direction$
- $Engine\_Thrust\_Stage\_1 = Exhaust\_Gas\_Velocity * Burn\_Rate\_Stage\_1$
- $Engine\_Thrust\_Stage\_2 = Exhaust\_Gas\_Velocity * Burn\_Rate\_Stage\_2$
- $Exhaust\_Gas\_Velocity = 4000$
- $Fuel\_Capacity = 25000$
- $Fuel\_Fraction\_Stage\_1 = .75$
- $Gravitational\_Force = Total\_Mass * Strength\_of\_Gravity$
- $Mass\_of\_Payload = 500$
- $Mass\_of\_stage\_1 = Fuel\_Capacity * Fuel\_Fraction\_Stage\_1 * Body\_to\_Fuel\_Ratio$
- $Mass\_of\_stage\_2 = Fuel\_Capacity * (1 - Fuel\_Fraction\_Stage\_1) * Body\_to\_Fuel\_Ratio$
- $Stage\_1\_Active\_Flag = IF (Mass\_of\_Fuel\_Stage\_1 / INIT(Mass\_of\_Fuel\_Stage\_1)) > 0.01 THEN 1 ELSE 0$
- $Strength\_of\_Gravity = (6.67e-11 * 5.98e24) / (6.38e6 + Rocket\_Altitude)^2$
- $Thrust\_Force = Engine\_Thrust\_Stage\_1 + Engine\_Thrust\_Stage\_2$
- $Total\_Force = Thrust\_Force - Gravitational\_Force - Drag\_Force$
- $Total\_Mass =$   
 $Mass\_of\_Payload + (Mass\_of\_stage\_1 * Stage\_1\_Active\_Flag) + Mass\_of\_stage\_2 + Mass\_of\_Fuel\_Stage\_1 + Mass\_of\_Fuel\_Stage\_2$
- $X\_Section\_Area = 12$
- $Atmospheric\_Density = GRAPH(Rocket\_Altitude)$   
 (0.00, 1.26), (2000, 1.01), (4000, 0.817), (6000, 0.66), (8000, 0.529), (10000, 0.415),  
 (12000, 0.311), (14000, 0.228), (16000, 0.167), (18000, 0.122), (20000, 0.0897),  
 (22000, 0.0658), (24000, 0.0482), (26000, 0.0354), (28000, 0.026), (30000, 0.019),  
 (32000, 0.014), (34000, 0.0103), (36000, 0.00754), (38000, 0.00553), (40000, 0.00407),  
 (42000, 0.00346), (44000, -0.00286), (46000, 0.00225), (48000, 0.00165), (50000,  
 0.00104), (52000, 0.000833), (54000, 0.000625), (56000, 0.000416), (58000, 0.000208),  
 (60000, 0.00)
- $Burn\_Multiplier\_1 = GRAPH(Mass\_of\_Fuel\_Stage\_1 / INIT(Mass\_of\_Fuel\_Stage\_1))$   
 (0.00, 0.00), (0.01, 0.1), (0.02, 0.2), (0.03, 0.3), (0.04, 0.4), (0.05, 0.5), (0.06, 0.6),  
 (0.07, 0.7), (0.08, 0.8), (0.09, 0.9), (0.1, 1.00), (0.11, 1.00), (0.12, 1.00)

## Behaviour of the Two Staged Rocket Model



# **Appendix 4**

## *The Beer Game*

## **The Beer Game**

The Beer Game dates back to the early years of System Dynamics. It was developed by the System Dynamics Group at the Sloan School of Management at the Massachusetts Institute of Technology in the early 1960's (Jarmain 1963). The Beer Game is a role playing simulation game of a four stage production and distribution system (Sterman 1984). The underlying model of the Beer game is a simplification of the classic production-distribution model described in Industrial Dynamics (Forrester 1961). Interest in the Beer Game has been maintained over the years; the "story" of the Beer Game as seen through the participants eyes is told in chapter three of "The Fifth Discipline" (Senge 1990) and the 1993 International System Dynamics Conference devoted a parallel session devoted solely to the Beer Game.

Further information on the history of the development of the Beer Game can be found in an annotated bibliography, prepared by John Sterman, in (Goodman, Kreutzer, Kreutzer and Sterman 1993). A training video is also available (MacNeil-Lehrer Report 1989).

## **Playing the Beer Game**

The Beer Game simulates a four stage production and distribution system. The four sectors are; Retailer, Wholesaler, Distributor and Factory (Brewery).

## **The Board**

The Beer Game is played on a large, long vinyl board (approximately 0.75 m by 2.5 m). Figure 1 shows the design of the board and the way it is set up at the start of play. Coins are use to represent cases of beer and small slips of paper are used to represent orders.

## **Aim of the Game**

The players are told that the aim of the game is to minimise the total team costs. The costs are made up of two elements, the cost of holding stock and the cost of being out of stock. The cost of the latter being the greater, to reflect lost orders. These costs are shown in Table 1.

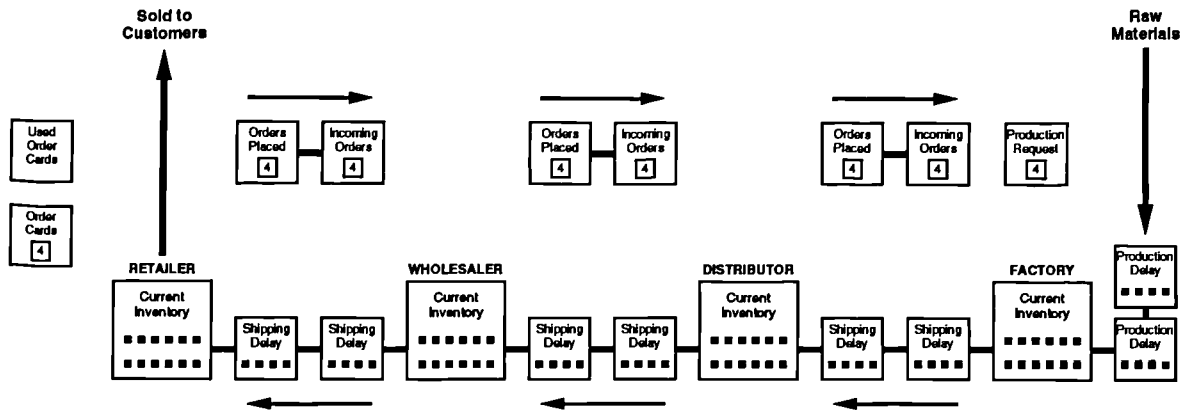


Figure 1 The beer game board at the start of play

Table 1 Beer game costs

Description	Unit Cost per Week
Stock	\$0.5
Backlog	\$1.0

### Length of Play

It is announced at the start of the game that the length of play will be fifty weeks. In fact the game is stopped after 35 weeks, this is to counteract any tendency of players to cut inventory levels toward the end of the game.

### Initialisation

At the start of the game each inventory contains 12 cases of beer, the shipping delays each contains 4 cases of beer and all the orders are for 4 cases of beer. These initial conditions ensure that the game is in a state of equilibrium. See Figure 1.

Note The order cards are placed face down so it is not possible to see the contents of orders placed and incoming orders during the actual play of the game.

### Allocation of Players

The game is played in teams, the number of teams varies depending on the number of participants. Multiple teams adds an air of competition to the

proceedings, but it is possible to successfully play the game with a single team. It is usual to have eight people per team, the players work in pairs, one pair per game sector. One person from each pair is given the task of score keeping. Communication between the sectors is forbidden, but the pairs may discuss amongst themselves.

### **Making the Moves**

The facilitator keeps the pairs and teams in synchronisation by calling out the simulation time; "week 1", "week 2", Etc. The first few moves are made slowly, to give the players a chance to learn the rules of the game, the speed of the game is gradually increased as the players become familiar with the mechanics of playing the game. The rules for playing the game are shown in Table 2.

Steps 1 to 4 are purely mechanical; it is only at step 5 that the players are required to make a decision.

**Table 2 Rules for playing the beer game**

<b>Step</b>	<b>Action</b>
1	Receive inventory and advance shipping delays
2	Fill orders
3	Record inventory or backlog on record sheet
4	Advance the order slips
5	Place orders

### **Typical Behaviour**

In the years since its invention the Beer game has been played by thousands of people from many different backgrounds. The same pattern of behaviour occurs each time. Experience seems to count for little, teams of senior managers create the same crisis in supply as first year university students (Sterman 1988).

The Beer game typically generates the following behaviour. Initially all goes well, this is because the game is started in equilibrium and demand is constant for the

first four weeks. The step increase in demand from four to eight cases per week, that occurs in week five causes the retailers inventory to decline resulting in stock out (unless the retailer places larger orders in advance of the step increase, the size of the step increase, the delay between ordering and receiving beer and the size of the initial inventory makes a stock-out inevitable).

The fall in inventory and ensuing stock-out prompts the retailer to order more beer, but this takes time to arrive and the so the retailers backlog of orders continues to increase. The retailer reacts to this worsening situation by placing larger and larger orders.

The wholesaler cannot keep pace with the retailers ordering and is soon also out of stock. The wholesaler responds to declining inventory and stock-out in the same way as the retailer, the size of orders placed with the distributor are increased and increased again.

The distributor and the factory in turn, experience stock-out in a similar manner, by around week fifteen it is usual for all of the players to have large order backlogs. These backlogs continue to grow until about week twenty five, when they start to decline as factory output rises in response to the large orders that were placed during the period of growing backlogs.

Inventory levels rise rapidly from week twenty five onwards, because customer demand is still constant at eight cases per week. The rapidly rising inventory levels cause a sharp decline in orders, soon everyone has a large excess of beer and ordering falls to zero.

### **After the Game**

At the end of the game, the record sheets are collected and used to calculate weekly and total costs. The team with the lowest total costs is declared the winner. A spreadsheet is often used to perform this task, this provides the added benefit of allowing graphs of behaviour to be easily produced.

The players who took the roles of wholesaler, distributor and factory are asked to sketch their prediction of the actual retail demand pattern. The players who were retailers are not asked to participate, because they actually know what retail demand pattern was. The participants usually sketch out some sort of oscillating demand pattern, with demand first rising sharply and then falling away. Most of the player are very surprised when the retail demand pattern is revealed to be a simple step.

## Lessons from the Beer Game

The game is usually followed by a debrief and discussion session. The Facilitator makes the following points.

- 1 Problematic behaviour is generated by the systems structure, not by external events.
- 2 Delays have an important effect on system behaviour.
- 3 Relatively simple systems can be very difficult to manage.
- 4 Organisation boundaries are a source of problematic behaviour. Each sector is trying to behave in an optimal way, but the overall system performance is poor.

## References

- Forrester, J.W. (1961). *Industrial Dynamics*. Cambridge MA: MIT Press. pp 358.
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- Jarman, W. E. (1963). *Problems in Industrial Dynamics*. Cambridge MA: MIT Press.
- MacNeil-Lehrer Report. (1989) *Risky Business - Business Cycles*, Video, US Public Broadcasting System.
- Senge, P.M. (1990). *The fifth discipline: the art and practice of the learning organization*. New York: Doubleday.
- Sterman, J. D. (1984). *Instructions for Running the Beer Distribution Game*. (Memo No. D-3679). MIT System Dynamics Group.
- Sterman, J. D. (1988). *People Express Management Flight Simulator*, available from author, Sloan School of Management, MIT, Cambridge, MA, USA.



# **Appendix 5**

## *The Supply Chain Model*

## The Supply Chain Model

This appendix describes the development of a supply chain model for use as a microworld in the learning laboratory. The microworld was implemented using the itthink software. It also provides an overview of the supply chain workshop's simulation exercises.

### The System

The system on which the itthink model is based is that of a generic three stage supply chain, consisting of a factory sector, a wholesale sector and a retail sector, see Figure 1. The retail and wholesale sectors represent all the companies that handle the producer's product. Each sector will now be briefly described.

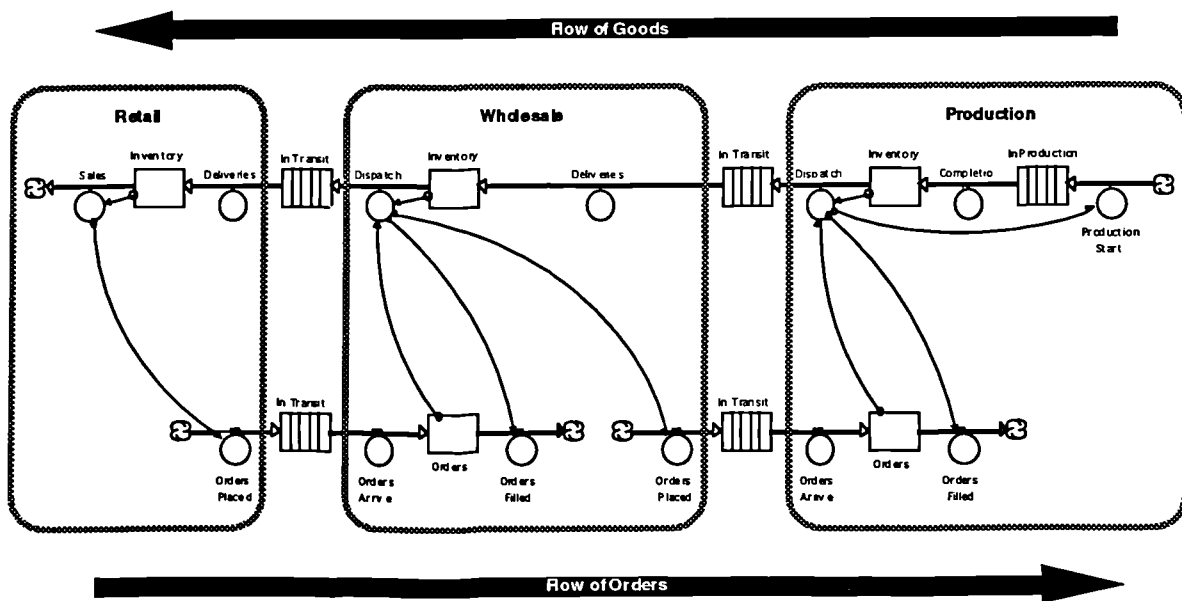


Figure 1 The generic supply chain system

#### Retailer

The retailer receives orders from the public. If stocks are available, then the customer is supplied straight away. If the retailer is out stock then the customer's order has to wait to be filled. As lead time increases, customers become discouraged from placing orders and sales are lost. The retailer obtains supplies of product from the wholesale sector. There is a one week delay between an order

being placed and the goods being delivered. This assumes that the wholesaler has stock available. If the wholesaler is out of stock, then this delay will obviously be longer.

### **The Wholesaler**

The wholesaler behaves in a similar way to the retailer. Orders are received from the retail sector, orders are filled if product is available, otherwise they are added to a backlog of orders to be filled. It is assumed that the retailer will not cancel orders as lead time increases. The wholesaler obtains supplies of product from the production sector. There is a minimum delay of a two and a half weeks between an order being placed and the goods being delivered. If the factory is out of stock then this delay will again be longer.

### **The Factory**

The Factory receives orders from the wholesale sector. Orders are filled from stock if product is available, otherwise they must wait until the product has been manufactured. It is assumed that the wholesaler does not cancel orders as lead time increases. There is a two week delay between an order being placed and the goods becoming available.

### **The Ithink Model**

The map of the itthink model is shown in Figures 2a-2c. The structures and equations found within the model are all conventional systems dynamics formulations, so they will not be described in detail.

It is however worth making a couple of points at this stage. The first is that the material delays are modelled as first order delays and that there are no delays in the flow of information between the sectors. The second is that the model is set up so that it will run in equilibrium until it is shocked by a test input. The feature of the model that is of real interest is the user interface and this will now be described.

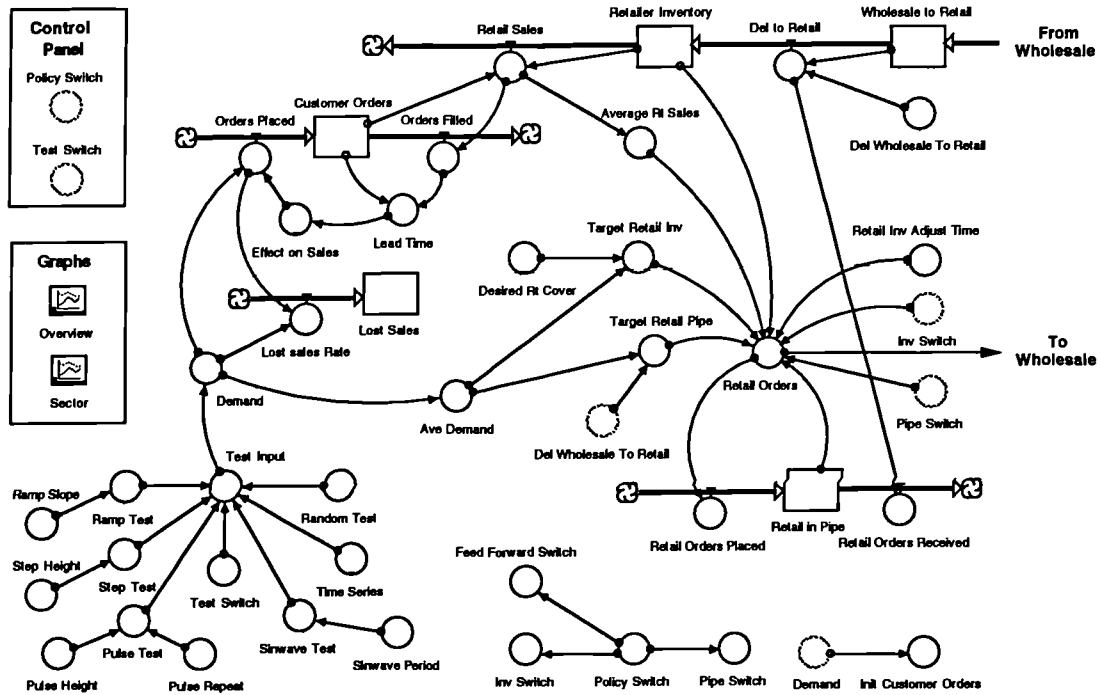


Figure 2a The supply chain model retail sector and control panel

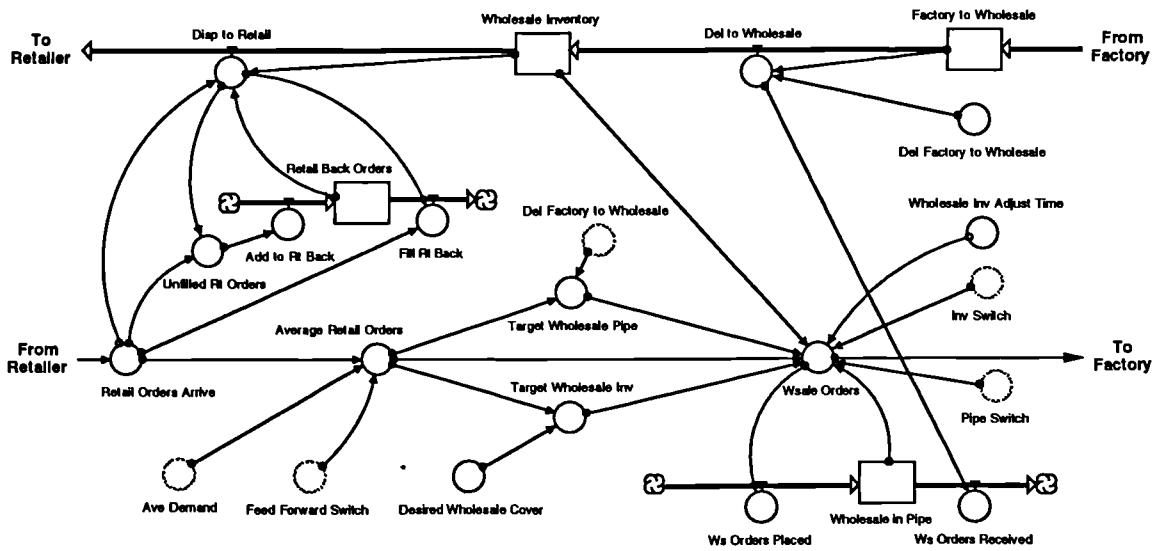


Figure 2b The supply chain model wholesale sector

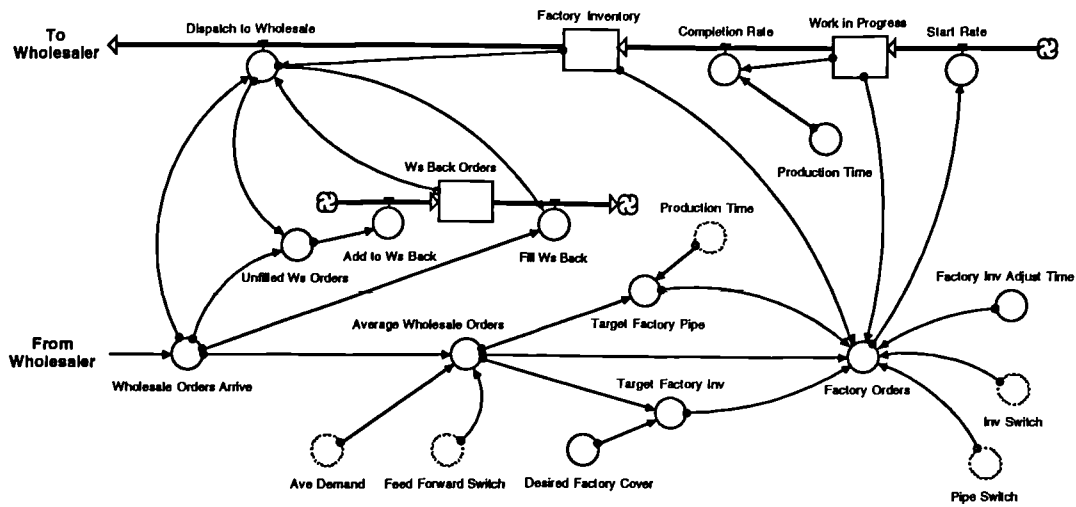


Figure 2c The supply chain model factory sector

### The User Interface

In order to make the model as easy to use as possible a control panel has been created so that the user can select an ordering policy or a test input by simply typing a number into a dialog box.

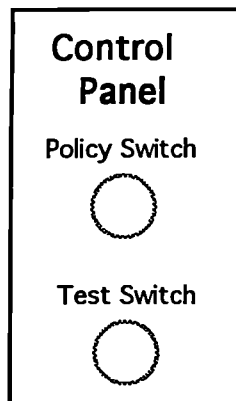


Figure 3 The itthink model control panel

The ordering decision equations have been set up so that the ordering policy used depends on the value of the model variable "Policy\_Switch". There are four different policies available and these are listed in Table 1.

**Table 1 Supply chain model built in ordering policies**

<b>Policy</b>	<b>Description</b>
1	Average Orders
2	Average Orders + Inventory Control
3	Average Orders + Inventory Control + Pipeline Control
4	Retail Demand + Inventory Control + Pipeline Control

The demand equation has been set up so that the test input used depends on the value of the model variable "Test\_Switch". Seven different test inputs are available to the user; these are listed in Table 2.

**Table 2 Supply chain model built in test inputs**

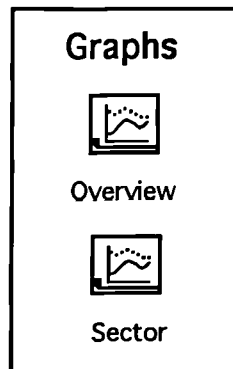
<b>Test Input</b>	<b>Description</b>
0	Constant
1	Step
2	Pulse
3	Ramp
4	Random
5	Time Series
6	Sine Wave

In order to allow the user to see the effects of their experimentation with the model a number of graphs were created, see Table 3.

**Table 3 Supply chain model built in graphs**

<b>Graph Pad</b>	<b>Page No</b>	<b>Graph Subject</b>
Overview	1	Inventories
	2	Flow of Goods
	3	Flow of Orders
Sector	1	Retail
	2	Wholesale
	3	Production

To promote ease of use, the graphs were grouped together in two graph pads that were situated next to the control panel, see Figure 4.



**Figure 4** The itthink model graph pads

### The Use of the Ithink Supply Chain Model

The importance of providing a reflective learning environment has already been established, in Chapter 4. To achieve this, a workbook was produced, to guide participants in their experimentation with the model. Each experiment detailed in the workbook has the following structure:

- 1 The nature of the simulation experiment is introduced.
- 2 Participants are asked to predict outcome of simulation run, by sketching their prediction of system behaviour on a blank graph.
- 3 The simulation experiment is performed.
- 4 Participants are asked to explain the systems behaviour and to account for any discrepancy between predicted and actual behaviour.
- 5 The correct simulation output is presented and an explanation of system behaviour is given.

### An Example Exercise from the Workbook

An example exercise using the five staged experimental structure is shown in Figures 5a-5d.

### Ordering Policy 1

The simplest possible ordering policy; orders placed equals average orders received. To calculate an average of the orders received one of the built-in functions is used, in this case SMTH3(), the exponential smoothing function.

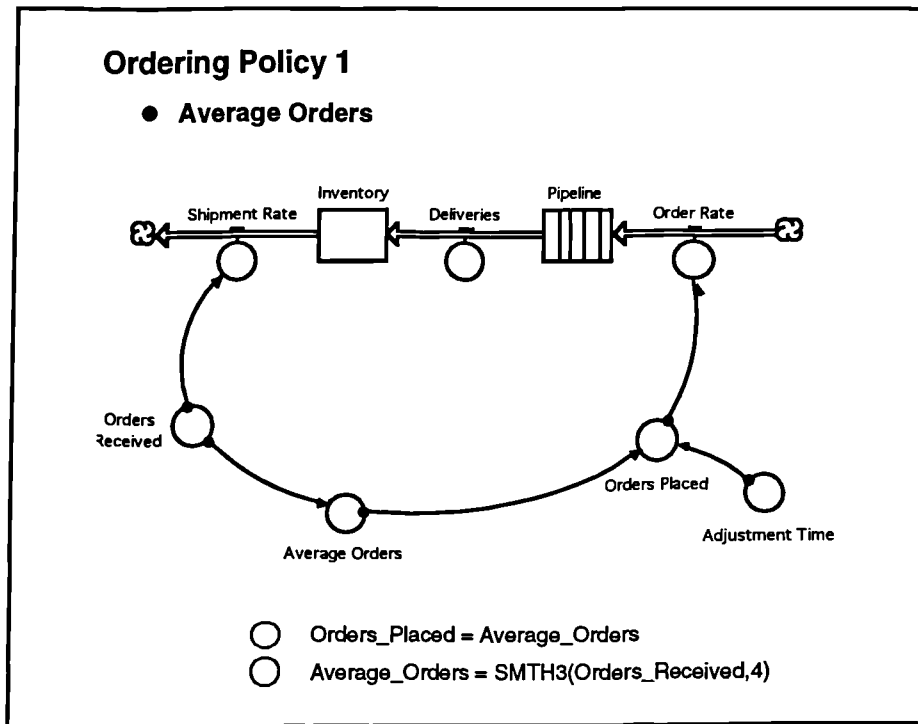


Figure 8 Ordering Policy 1

Select the ordering policy.

- 1 Double-click the Policy Switch icon in the Control Panel.  
The policy switch dialog will appear.
- 2 Enter a 1 to select Ordering Policy 1.
- 3 Click the OK button to confirm your choice of ordering policy.  
The policy switch dialog will close.

Figure 5a Example exercise page 1



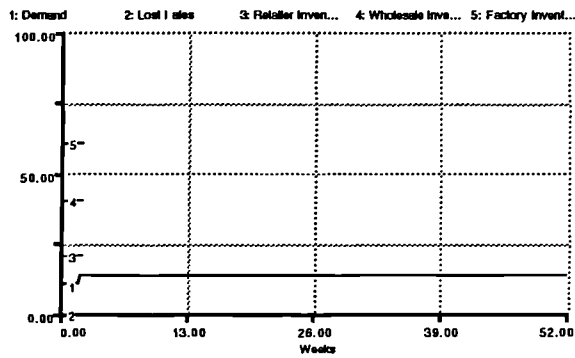
**Testing Ordering Policy 1**

- 1 Predict how you think the system will behave.**  
Use the blank graphs below to sketch your prediction of system response.
- 2 Choose Run from the Run menu.**  
The simulation will start.
- 3 Compare your prediction with what actually happened.**  
Try to explain the systems behaviour in terms of its structure.
- 4 Go on to the next page for an explanation of system behaviour.**  
*It is important that you spend some time trying to understand the systems behaviour, before you look at the answer.*

**Step Test Input**

**Ordering Policy 1**

**Inventories**



**Flow of Orders**

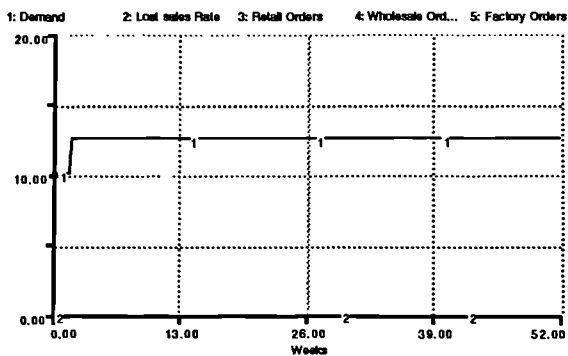


Figure 5b Example exercise page 2

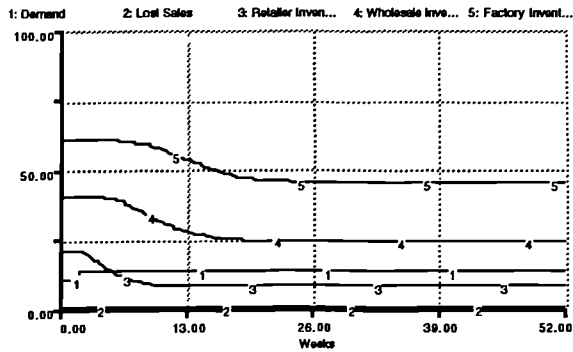
**Test Input 1**

- Step

**Ordering Policy 1**

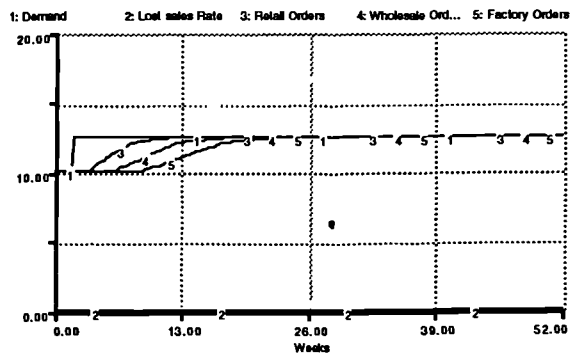
- Average Orders

**Inventories**



- Inventory levels are not maintained.
- There is a delay between demand increasing and inventory falling. This delay increases up the supply chain.
- There is a smooth transition to the new inventory level.

**Flow of Orders**



- There is a delay in orders responding to the new level of demand, this delay increases up the supply chain.
- Order rates take time to rise to equal the new level of demand.
- There is a smooth transition to the new order rate.

Figure 5c Example exercise page 3

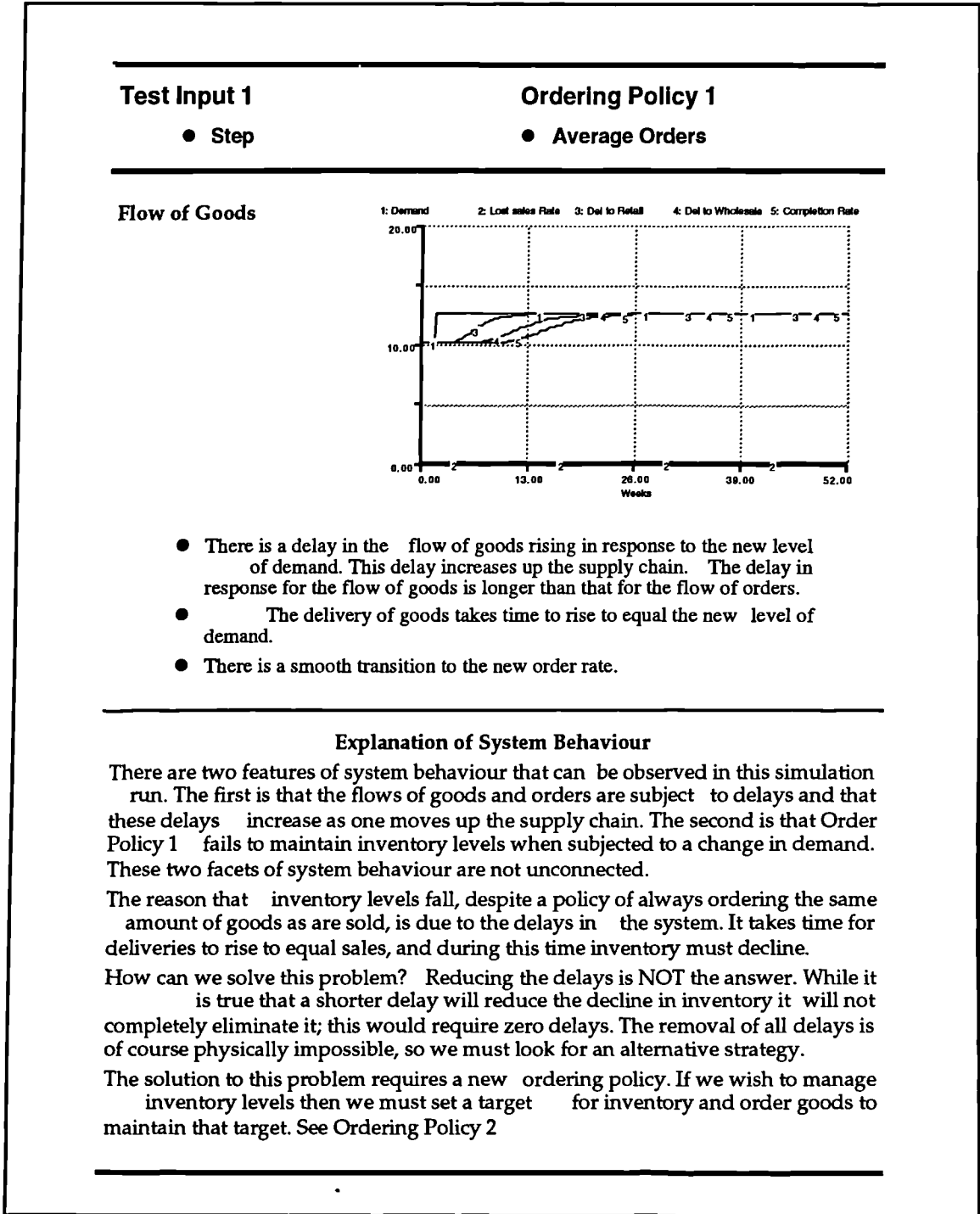


Figure 5d Example exercise page 4

### The Workshop Simulation Exercise

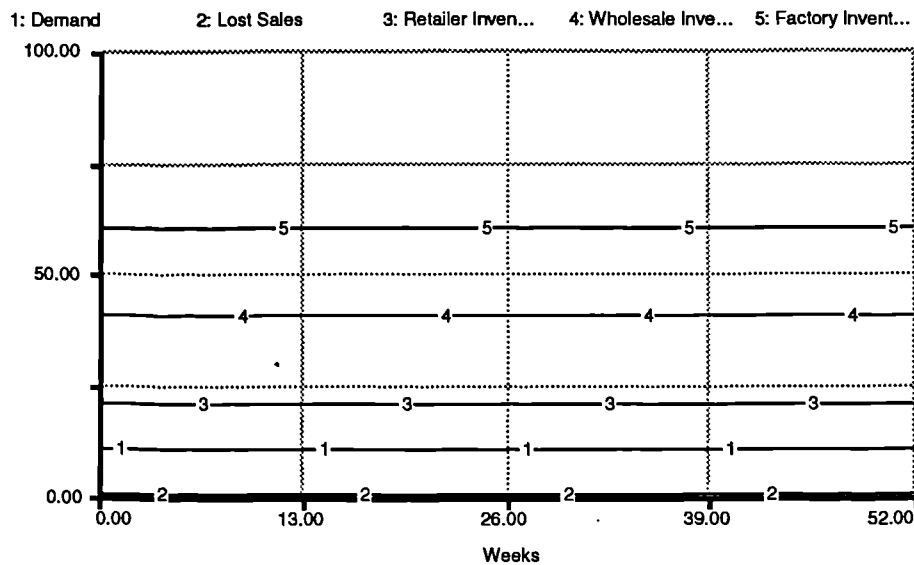
The workshop contains a number of simulation exercises with the supply chain model, see Table 4. The model behaviour demonstrated by these simulation exercises will now be described.

**Table 4 Simulation exercises with the supply chain model**

Exercise	Description	Test Input	Policy
1	Equilibrium	Constant	1
2	Policy Comparison	Step	1
		Step	2
		Step	3
		Step	4
3	Seasonality	Random	3
		Sine Wave Sensitivity	3
		Random	1

### Equilibrium Run

The purpose of this simulation exercise is to demonstrate that the model is capable of running in equilibrium, see Figure 6.

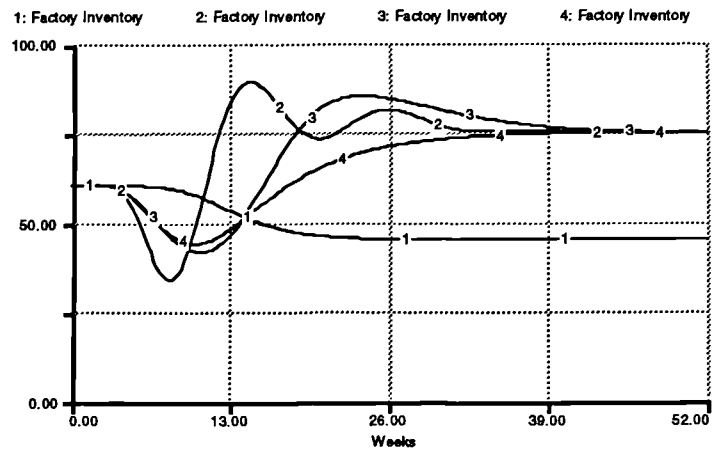


**Figure 6 Supply chain model in equilibrium**

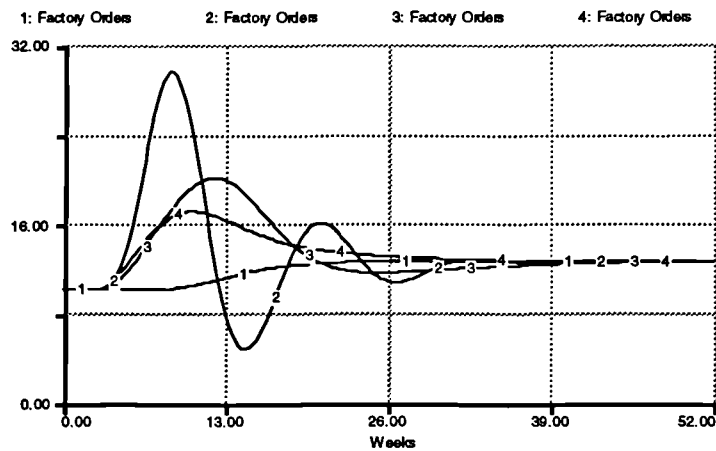
### Policy Comparison Runs

This simulation exercise uses a step test input to demonstrate the effect that different ordering policies have on the behaviour of the supply chain model. In particular it clearly shows the need to take goods in the pipeline into account when designing an ordering policy. The model's behaviour is summarised in Figure 7.

#### Inventories



#### Flow of Orders



#### Flow of Goods

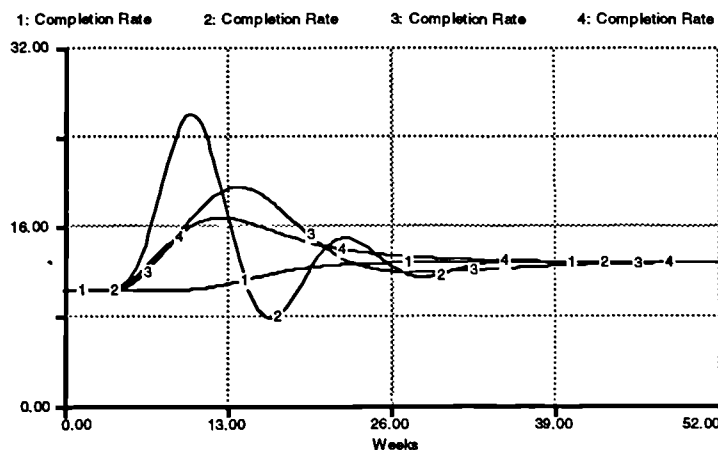


Figure 7 Behaviour of supply chain model with a step test and policies 1 to 4

### Seasonality

This simulation exercise uses random and sine wave test inputs to demonstrate that the supply chain model is capable of the endogenous generation of pseudo-seasonal behaviour. The model's response to a random test input, when using policy 3, is shown in Figure 8 and an extract of this time series, which appears to show seasonal behaviour is shown in Figure 9.

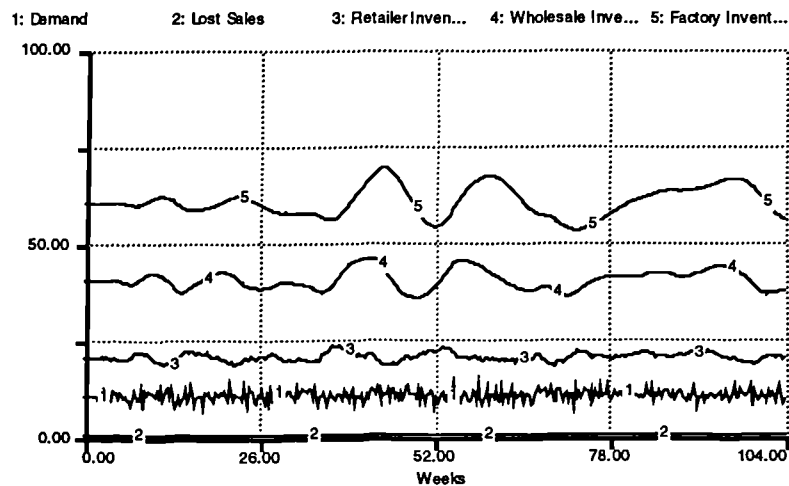


Figure 8 Response of the supply chain model to a random test input

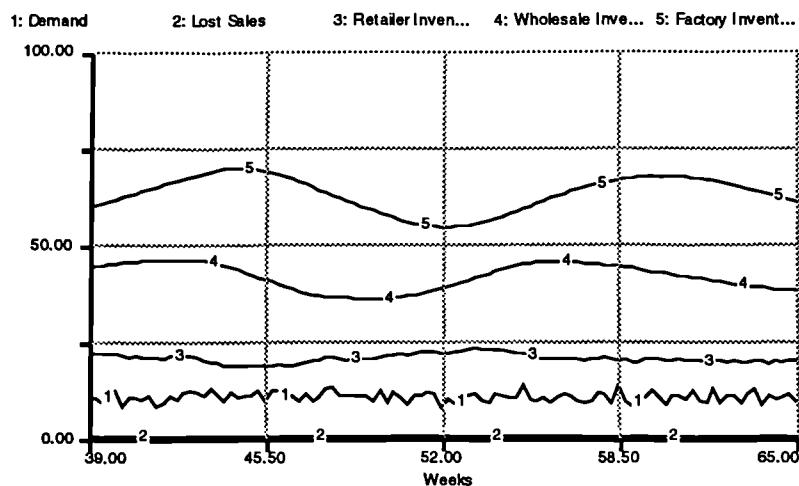


Figure 9 A 26 week extract from the time series shown in Figure 8

A sine wave sensitivity run with the supply chain model using policy 3 shows that the supply chain is selectively amplifying input fluctuations of certain frequencies, The three runs of the model shown in Figures 10 and 11 use sine wave test inputs

who's periods are respectively 13 weeks, 26 weeks and 52 weeks. It can be seen that the 26 week period sine wave causes the greatest swings in both inventory and ordering at the production sector.

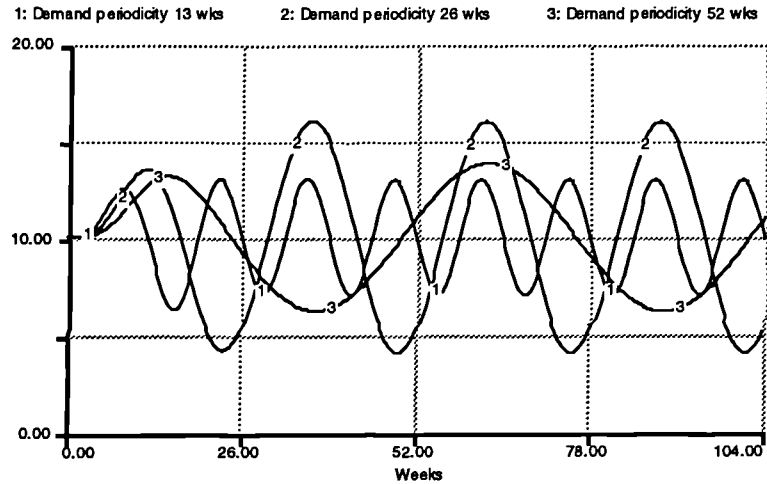


Figure 10 Response of production sector ordering to the sine wave sensitivity run

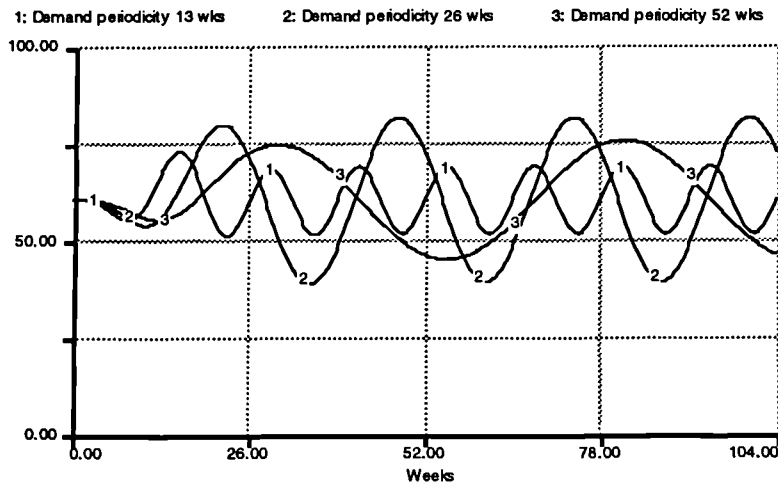
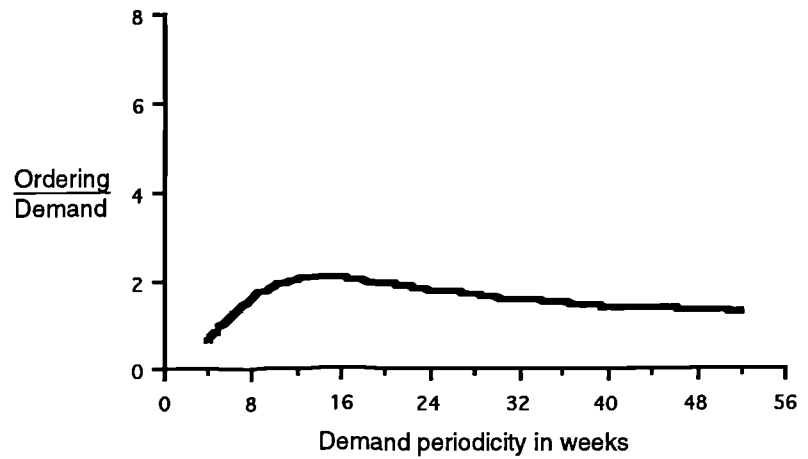


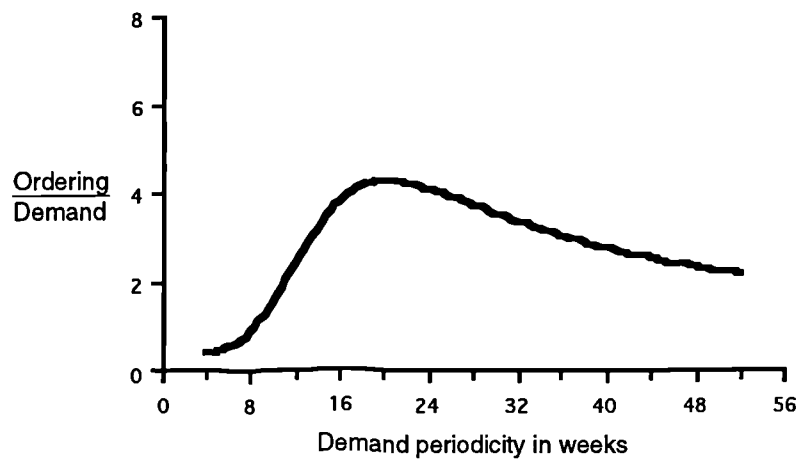
Figure 11 Response of production sector inventory to the sine wave sensitivity run

It is possible, by combining the results of a number of such simulation runs, to create a frequency response for each of the sectors within the supply chain model, see Figure 12.

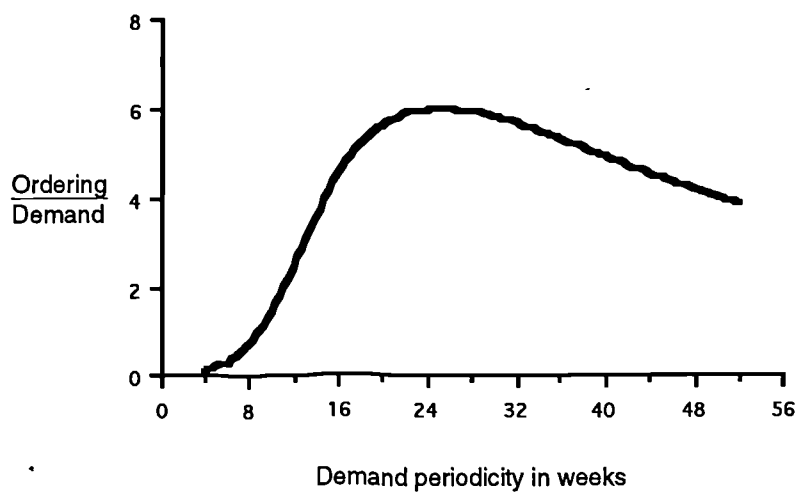
**Retail Sector**



**Wholesale Sector**



**Production Sector**



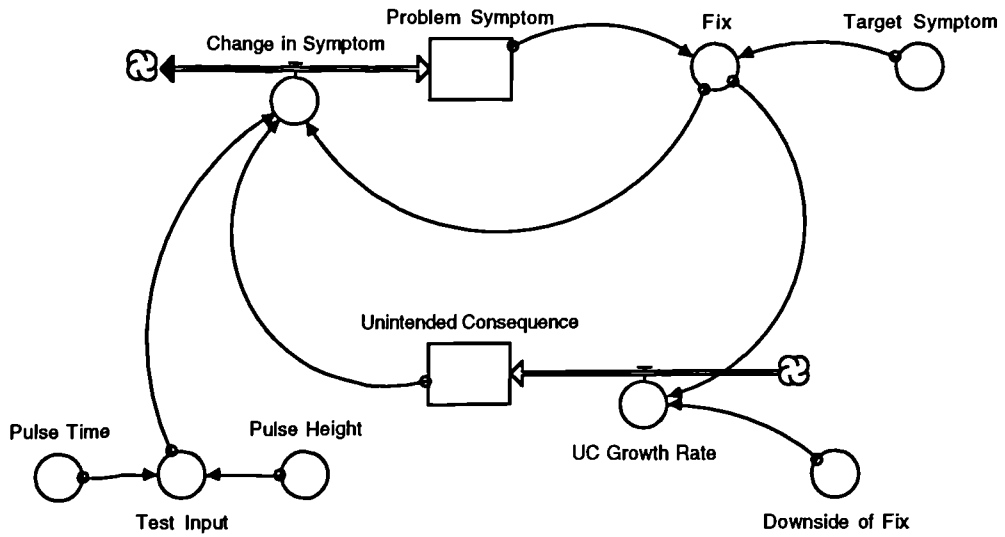
**Figure 12** Frequency response of the supply chain model by sector



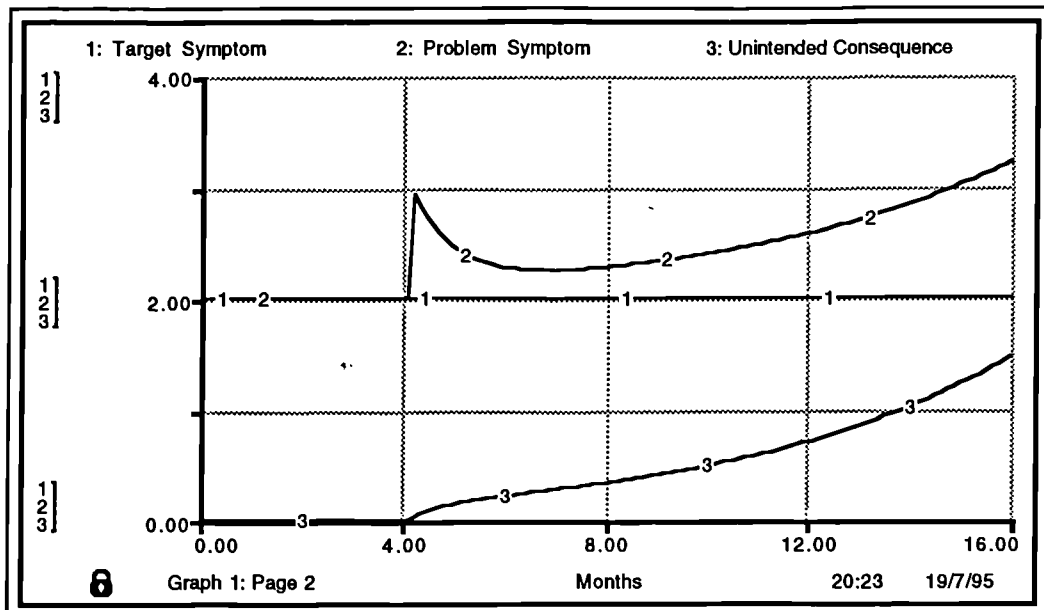
# **Appendix 6**

## *Models of Simple Loop Structures*

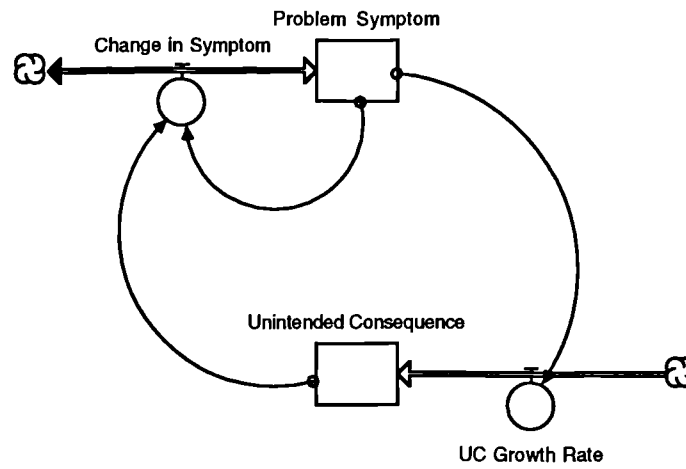
### Fixes That Fail



- $Problem\_Symptom(t) = Problem\_Symptom(t - dt) + (Change\_in\_Symptom) * dt$   
 INIT Problem\_Symptom = 2  
 INFLOWS:  
 Change\_in\_Symptom =  $Unintended\_Consequence - MAX(Problem\_Symptom - 2, 0) + PULSE(1, (STOPTIME - STARTTIME) / 4, STOPTIME + 1)$
- $Unintended\_Consequence(t) = Unintended\_Consequence(t - dt) + (UC\_Growth\_Rate) * dt$   
 INIT Unintended\_Consequence = 0  
 INFLOWS:  
 UC\_Growth\_Rate =  $0.22 * MAX(Problem\_Symptom - 2, 0)$

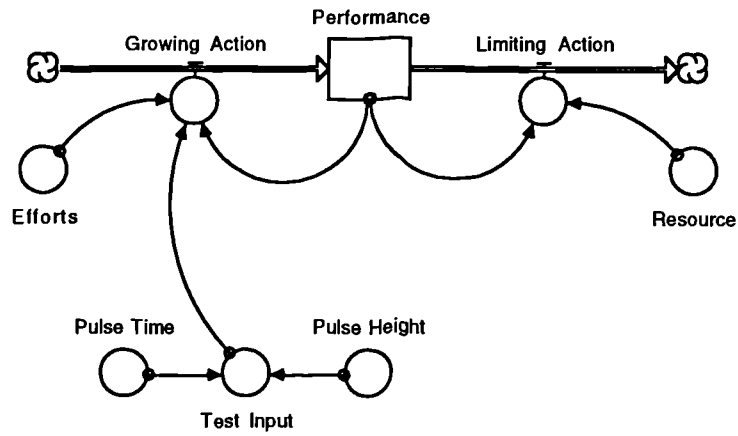


## Fixes That Fail

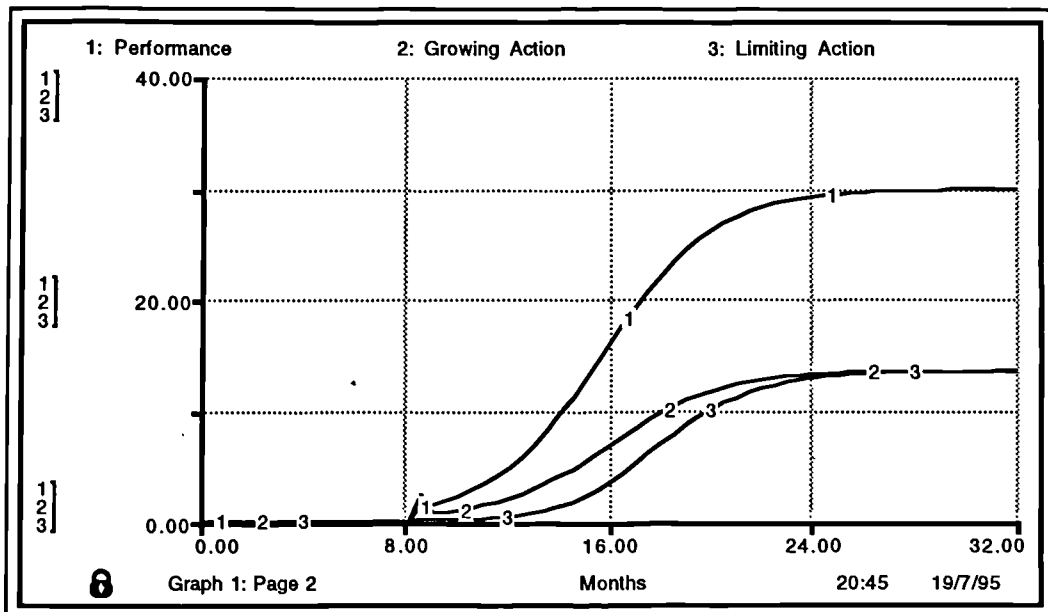


- $Problem\_Symptom(t) = Problem\_Symptom(t - dt) + (Change\_in\_Symptom) * dt$   
 INIT  $Problem\_Symptom = 2$   
 INFLOWS:  
 $\leftarrow \rightleftarrows$   $Change\_in\_Symptom = Unintended\_Consequence - MAX(Problem\_Symptom - 2, 0) + PULSE(1, (STOPTIME - STARTTIME) / 4, STOPTIME + 1)$
- $Unintended\_Consequence(t) = Unintended\_Consequence(t - dt) + (UC\_Growth\_Rate) * dt$   
 INIT  $Unintended\_Consequence = 0$   
 INFLOWS:  
 $\leftarrow \rightleftarrows$   $UC\_Growth\_Rate = 0.22 * MAX(Problem\_Symptom - 2, 0)$

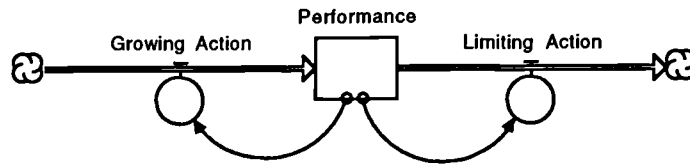
## Limits To Success A



- $Performance(t) = Performance(t - dt) + (Growing\_Action - Limiting\_Action) * dt$   
 INIT Performance = 0  
 INFLOWS:  
 Growing\_Action = Performance\*Efforts+Test\_Input  
 OUTFLOWS:  
 Limiting\_Action = 0.45\*Performance\*(Performance/Resource)
- Efforts = 0.45
  - Pulse\_Height = 0
  - Pulse\_Time = (STOPTIME-STARTTIME)/4
  - Resource = 30
  - Test\_Input = PULSE(Pulse\_Height,Pulse\_Time,STOPTIME+1)

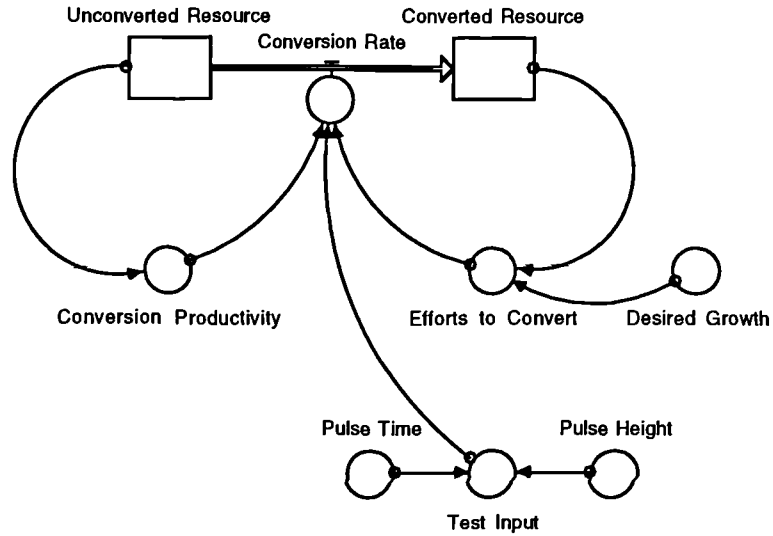


## Limits To Success A

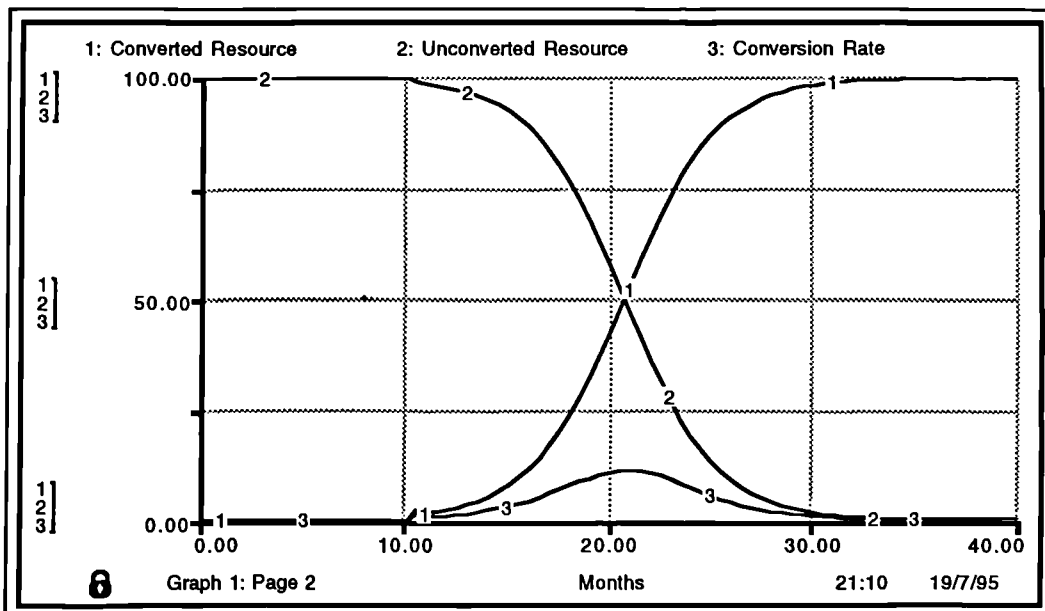


- $Performance(t) = Performance(t - dt) + (Growing\_Action - Limiting\_Action) * dt$   
 INIT Performance = 0  
 INFLOWS:  
 ⚡ Growing\_Action =  $Performance * 0.45 + PULSE(1, (STOPTIME - STARTTIME) / 4, STOPTIME + 1)$   
 OUTFLOWS:  
 ⚡ Limiting\_Action =  $0.45 * Performance * (Performance / 30)$

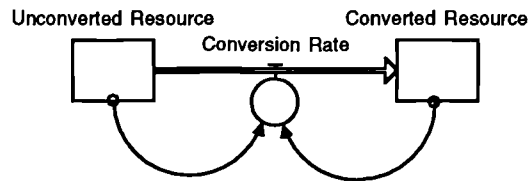
### Limits To Success B



- $Converted\_Resource(t) = Converted\_Resource(t - dt) + (Conversion\_Rate) * dt$   
INIT  $Converted\_Resource = 0$   
INFLOWS:  
    ⊕  $Conversion\_Rate = Efforts\_to\_Convert * Conversion\_Productivity + Test\_Input$
- $Unconverted\_Resource(t) = Unconverted\_Resource(t - dt) + (- Conversion\_Rate) * dt$   
INIT  $Unconverted\_Resource = 100$   
OUTFLOWS:  
    ⊖  $Conversion\_Rate = Efforts\_to\_Convert * Conversion\_Productivity + Test\_Input$
- $Conversion\_Productivity = Unconverted\_Resource / INIT(Unconverted\_Resource)$
- $Desired\_Growth = 0.44$
- $Efforts\_to\_Convert = Converted\_Resource * Desired\_Growth$
- $Pulse\_Height = 0$
- $Pulse\_Time = (STOPTIME - STARTTIME) / 4$
- $Test\_Input = PULSE(Pulse\_Height, Pulse\_Time, STOPTIME + 1)$



## Limits To Success B



- $$\text{Converted\_Resource}(t) = \text{Converted\_Resource}(t - dt) + (\text{Conversion\_Rate}) * dt$$

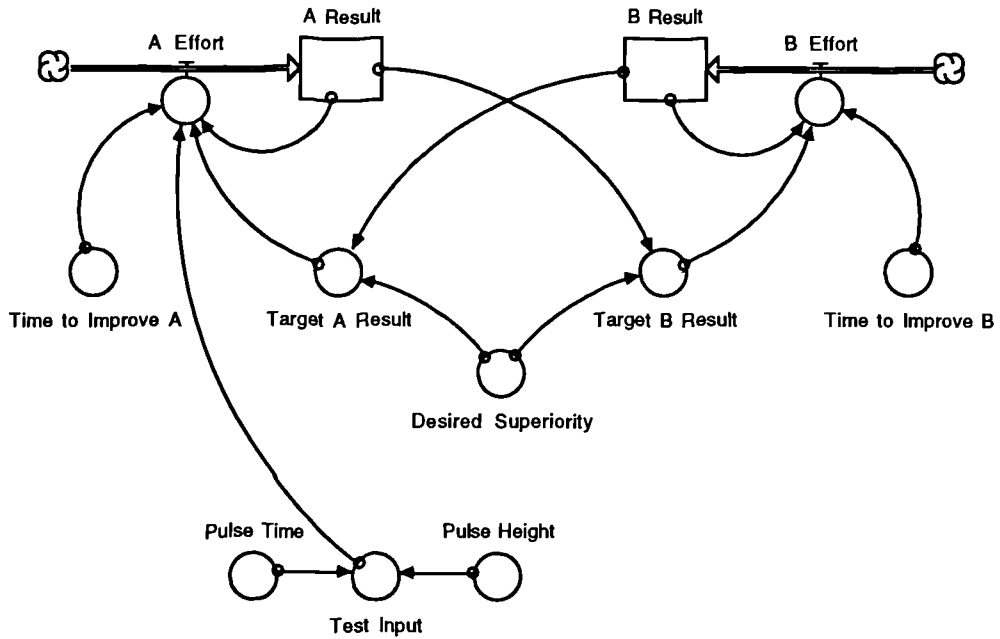
INIT  $\text{Converted\_Resource} = 0$   
 INFLOWS:

  - $$\text{Conversion\_Rate} = \text{Converted\_Resource} * 0.44 * \text{Unconverted\_Resource} / \text{INIT}(\text{Unconverted\_Resource}) + \text{PULSE}(1, (\text{STOPTIME} - \text{STARTTIME}) / 4, \text{STOPTIME} + 1)$$
- $$\text{Unconverted\_Resource}(t) = \text{Unconverted\_Resource}(t - dt) + (- \text{Conversion\_Rate}) * dt$$

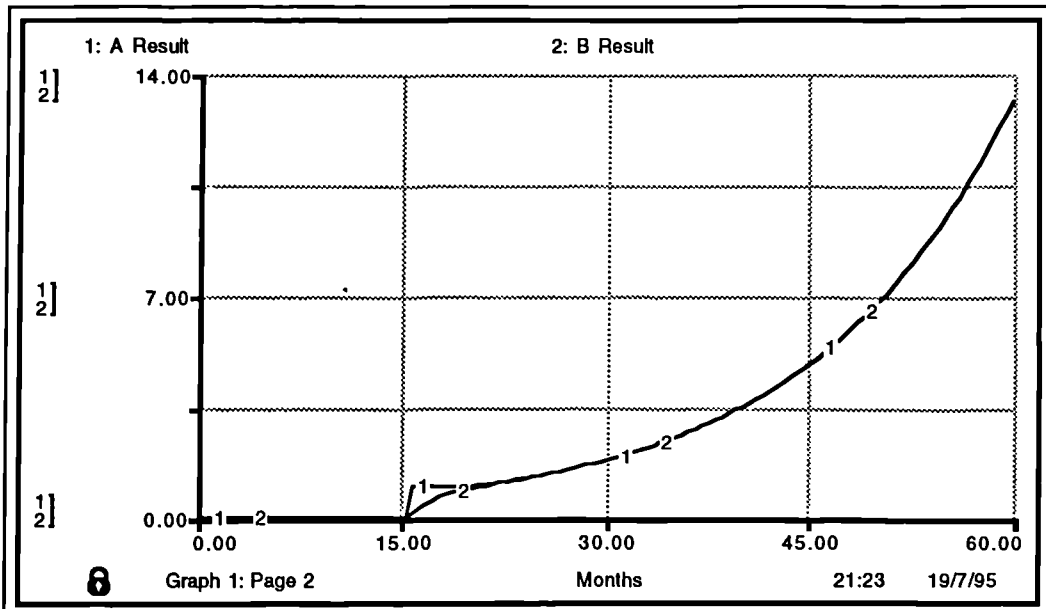
INIT  $\text{Unconverted\_Resource} = 100$   
 OUTFLOWS:

  - $$\text{Conversion\_Rate} = \text{Converted\_Resource} * 0.44 * \text{Unconverted\_Resource} / \text{INIT}(\text{Unconverted\_Resource}) + \text{PULSE}(1, (\text{STOPTIME} - \text{STARTTIME}) / 4, \text{STOPTIME} + 1)$$

### Escalation

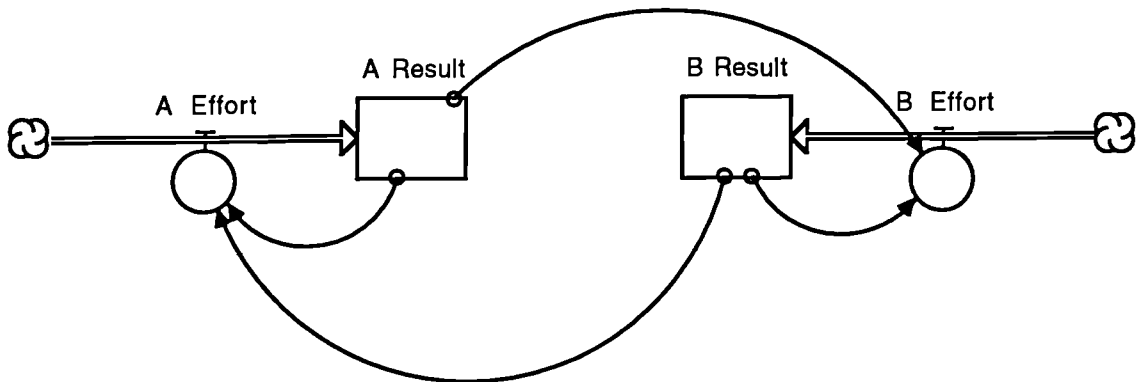


- $A\_Result(t) = A\_Result(t - dt) + (A\_Effort) * dt$   
 INIT A\_Result = 0  
 INFLOWS:  
     ➔  $A\_Effort = (Target\_A\_Result - A\_Result) / Time\_to\_Improve\_A + Test\_Input$
- $B\_Result(t) = B\_Result(t - dt) + (B\_Effort) * dt$   
 INIT B\_Result = 0  
 INFLOWS:  
     ➔  $B\_Effort = (Target\_B\_Result - B\_Result) / Time\_to\_Improve\_B$
- Desired\_Superiority = 0.2
- Pulse\_Height = 0
- Pulse\_Time = (STOPTIME-STARTTIME)/4
- Target\_A\_Result = B\_Result\*(1+Desired\_Superiority)
- Target\_B\_Result = A\_Result\*(1+Desired\_Superiority)
- Test\_Input = PULSE(Pulse\_Height,Pulse\_Time,STOPTIME+1)
- Time\_to\_Improve\_A = 3
- Time\_to\_Improve\_B = 3



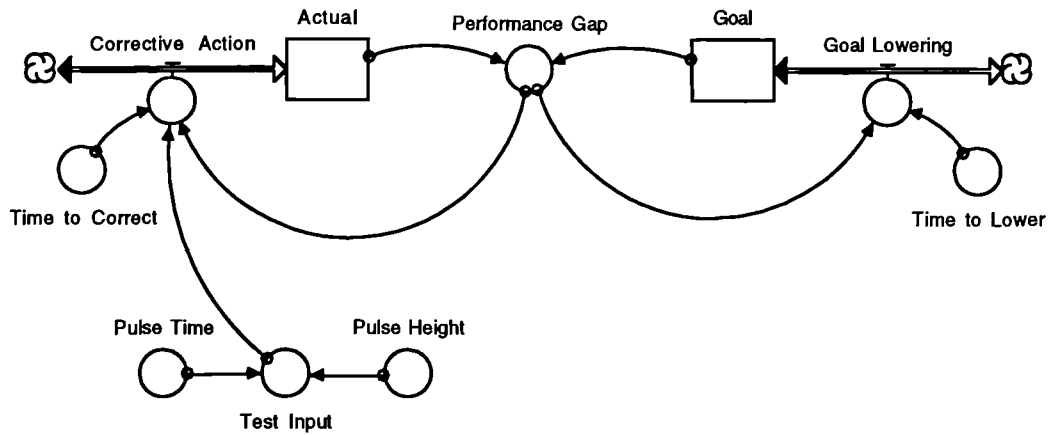


## Escalation

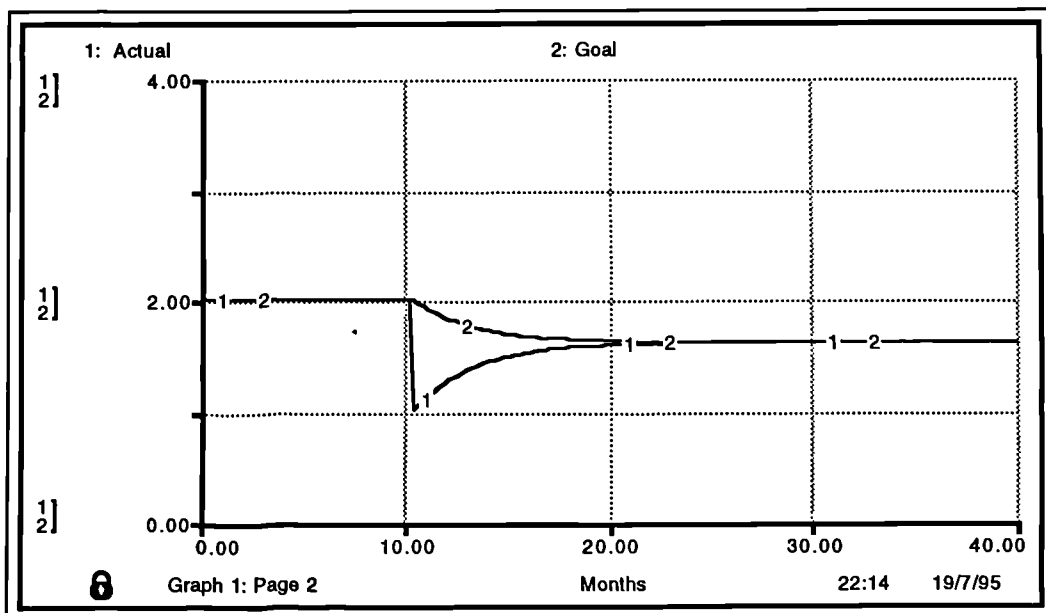


- $A\_Result(t) = A\_Result(t - dt) + (A\_Effort) * dt$   
 INIT A\_Result = 0  
 INFLOWS:  
 ⌚ A\_Effort =  
 $(B\_Result*(1+0.2)-A\_Result)/3+PULSE(1,(STOPTIME-STARTTIME)/4,STOPTIME+1)$
- $B\_Result(t) = B\_Result(t - dt) + (B\_Effort) * dt$   
 INIT B\_Result = 0  
 INFLOWS:  
 ⌚ B\_Effort =  $(A\_Result*(1+0.2)-B\_Result)/3$

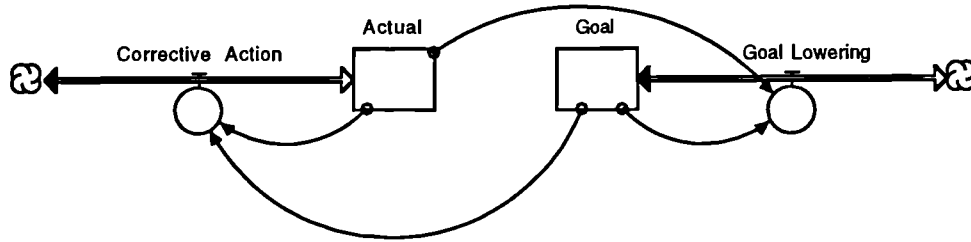
### Drifting Goals



- $Actual(t) = Actual(t - dt) + (Corrective\_Action) * dt$   
 INIT Actual = Goal  
 INFLOWS:  
 ⚙️  $Corrective\_Action = Performance\_Gap/Time\_to\_Correct + Test\_Input$
- $Goal(t) = Goal(t - dt) + (- Goal\_Lowering) * dt$   
 INIT Goal = 2  
 OUTFLOWS:  
 ⚙️  $Goal\_Lowering = Performance\_Gap/Time\_to\_Lower + PULSE(-,10,1000)$
- $Performance\_Gap = Goal - Actual$
- $Pulse\_Height = 0$
- $Pulse\_Time = (STOPTIME - STARTTIME) / 4$
- $Test\_Input = PULSE(Pulse\_Height, Pulse\_Time, STOPTIME + 1)$
- $Time\_to\_Correct = 5$
- $Time\_to\_Lower = 8$

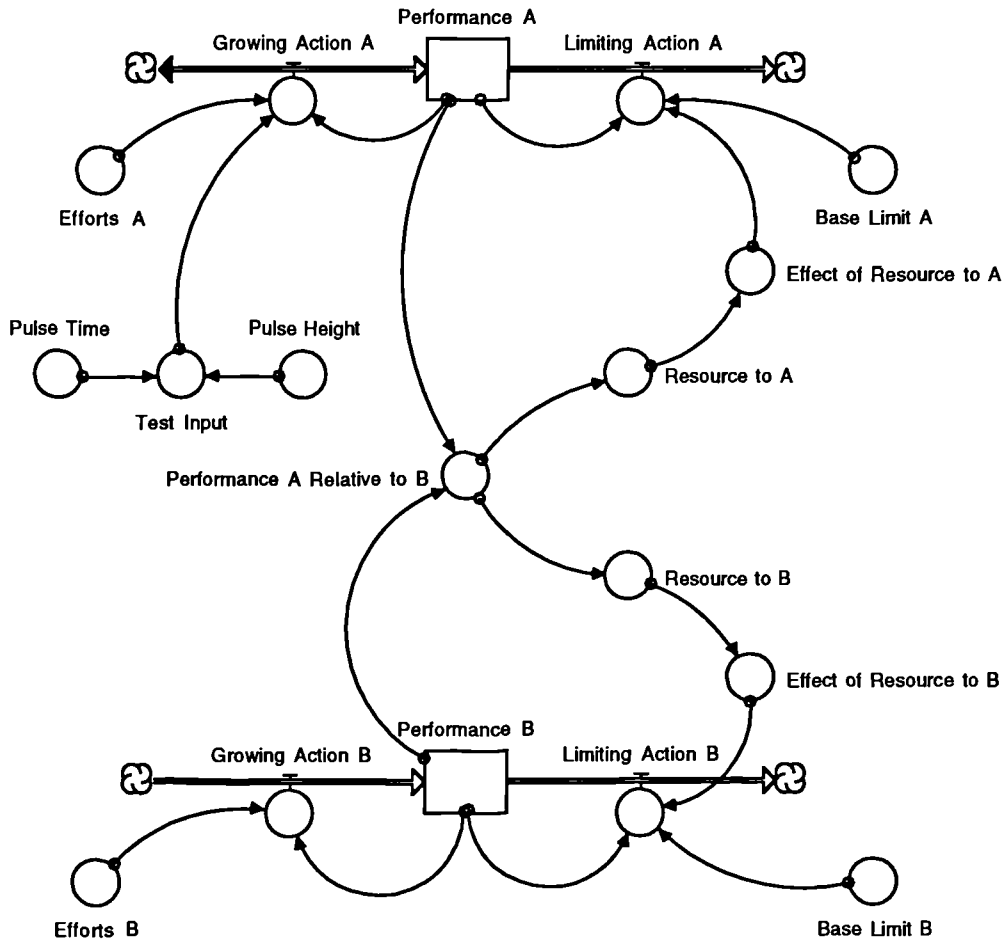


## Drifting Goals



- $Actual(t) = Actual(t - dt) + (Corrective\_Action) * dt$   
 INIT Actual = Goal  
 INFLOWS:  
      $\leftarrow \rightarrow Corrective\_Action = (Goal - Actual) / 5 + PULSE(-1, (STOPTIME - STARTTIME) / 4, STOPTIME + 1)$
- $Goal(t) = Goal(t - dt) + (- Goal\_Lowering) * dt$   
 INIT Goal = 2  
 OUTFLOWS:  
      $\leftarrow \rightarrow Goal\_Lowering = (Goal - Actual) / 8 + PULSE(-0, 10, 1000)$

## Success To The Successful



□  $Performance\_A(t) = Performance\_A(t - dt) + (Growing\_Action\_A - Limiting\_Action\_A) * dt$   
 INIT  $Performance\_A = 8$

INFLOWS:

⊕  $Growing\_Action\_A = Performance\_A * Efforts\_A + Test\_Input$

OUTFLOWS:

⊖  $Limiting\_Action\_A = Performance\_A * Base\_Limit\_A * Effect\_of\_Resource\_to\_A$

□  $Performance\_B(t) = Performance\_B(t - dt) + (Growing\_Action\_B - Limiting\_Action\_B) * dt$   
 INIT  $Performance\_B = Performance\_A$

INFLOWS:

⊕  $Growing\_Action\_B = Performance\_B * Efforts\_B$

OUTFLOWS:

⊖  $Limiting\_Action\_B = Performance\_B * Base\_Limit\_B * Effect\_of\_Resource\_to\_B$

○  $Base\_Limit\_A = 0.15$

○  $Base\_Limit\_B = 0.15$

○  $Effect\_of\_Resource\_to\_A = 1.5 - Resource\_to\_A$

○  $Effect\_of\_Resource\_to\_B = 1.5 - Resource\_to\_B$

○  $Efforts\_A = 0.15$

○  $Efforts\_B = 0.15$

○  $Performance\_A\_Relative\_to\_B = Performance\_A / (Performance\_A + Performance\_B)$

○  $Pulse\_Height = 0$

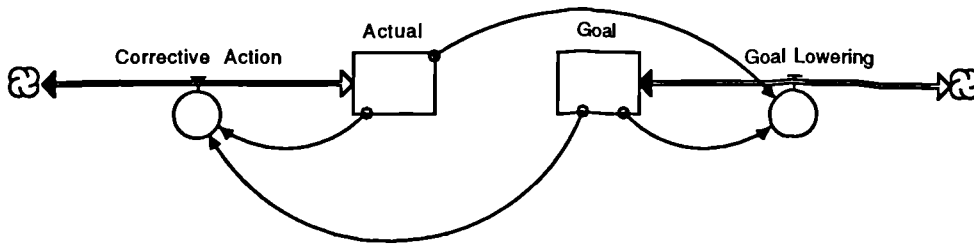
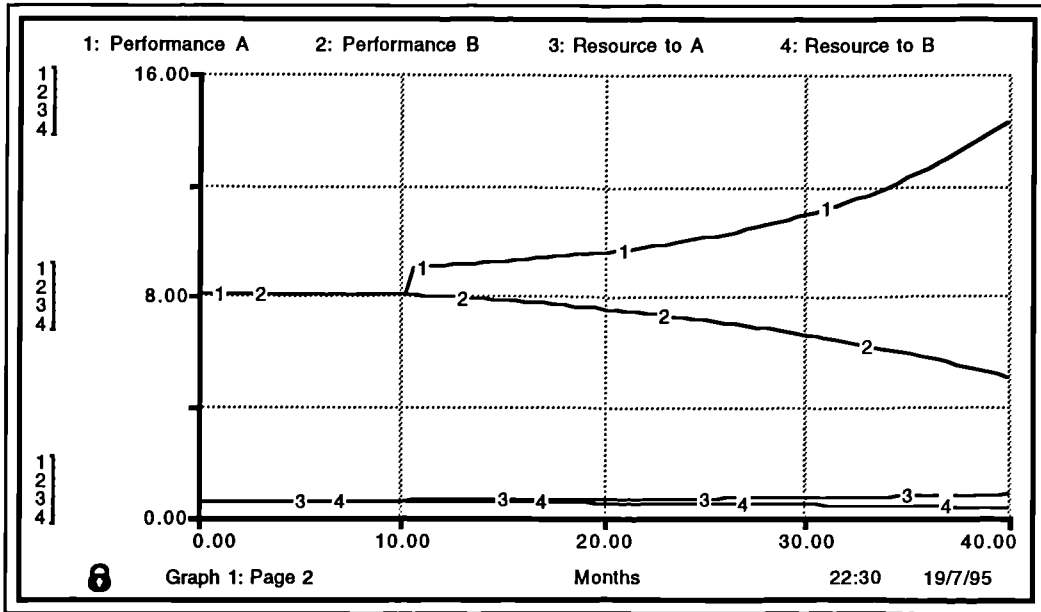
○  $Pulse\_Time = (STOPTIME - STARTTIME) / 4$

○  $Resource\_to\_A = Performance\_A\_Relative\_to\_B$

○  $Resource\_to\_B = (1 - Performance\_A\_Relative\_to\_B)$

○  $Test\_Input = PULSE(Pulse\_Height, Pulse\_Time, STOPTIME + 1)$

### Success To The Successful



$Performance\_A(t) = Performance\_A(t - dt) + (Growing\_Action\_A - Limiting\_Action\_A) * dt$   
 INIT Performance\_A = 8

INFLOWS:

Growing\_Action\_A =  
 $Performance\_A * 0.15 + PULSE(1, (STOPTIME - STARTTIME) / 4, STOPTIME + 1)$

OUTFLOWS:

Limiting\_Action\_A =  
 $Performance\_A * 0.15 * (1.5 - Performance\_A / (Performance\_A + Performance\_B))$

$Performance\_B(t) = Performance\_B(t - dt) + (Growing\_Action\_B - Limiting\_Action\_B) * dt$   
 INIT Performance\_B = Performance\_A

INFLOWS:

Growing\_Action\_B = Performance\_B \* 0.15

OUTFLOWS:

Limiting\_Action\_B =  
 $Performance\_B * 0.15 * (1.5 - (1 - (Performance\_A / (Performance\_A + Performance\_B))))$