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Visual Interactive Modelling: Some Guidelines for its Implementation and Some Aspects of its Potential Impact on Operational Research

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I would like to acknowledge the advice and encouragement I have received from many friends and colleagues while conducting this research. Bob Hurrion and Edward Fiddy helped me think though many early ideas; Colin Eden, as my supervisor, took on more than (perhaps) he realised in attempting to enlighten me as to the true nature of research; Peter Monk (definitely) aided me by reading and making many helpful comments on early drafts; and Valerie Belton provided much musing and reflection on Visual Interactive Modelling from a number of perspectives.

If only I were capable of building on all that strength.

CONTENTS

ABSTRACT

The thesis reports a research programme designed to answer two research questions. These are concerned with improving the practice of Visual Interactive Modelling in the context of an Operational Research activity and the potential contribution of Visual Interactive Modelling towards overcoming certain long term concerns which the Operational Research community has regarding the service it provides. The literature of Visual Interactive Modelling is reviewed, as is that of wider aspects of Operational Research concerned with the paradigm used by its practitioners and researchers. Two series of experimental studies are undertaken to collect data to help answer the research questions. Action Research is used for a series of six studies of Visual Interactive Modelling cases. The second series is more laboratory based to gain a type of data which is not available from Action Research. Results are presented in three forms. A 'body of experience' is collated from the data collected during the studies. This will form a base for future researchers in the Visual Interactive Modelling field. Secondly, a series of guidelines is tentatively proposed which could be used by practitioners as a basis for good practice in Visual Interactive Modelling. Finally, in the light of the data collected and reviews of the literature, a new way of considering the contribution of Visual Interactive Modelling to the Operational Research process is proposed. Suggestions for further research are offered.

... "and what is the use of a book," thought Alice, "without pictures or conversation?"

Alice in Wonderland / Lewis Carroll

CHAPTER ONE

I have been working in the Visual Interactive Modelling field for more than ten years and I am keen to see Visual Interactive Modelling used more effectively. To this end the research which led to the production of this thesis was originally aimed at producing a set of carefully researched guidelines on which anyone new to Visual Interactive Modelling could base their initial foray into the field. In conducting this research I developed some wider views about Visual Interactive Modelling's contribution to Operational Research. While I initially saw Visual Interactive Modelling as an interesting and valuable technical innovation, I have come to regard it as having a more significant contribution to make to Operational Research. This thesis attempts to explain and justify this view.

This thesis is directed at answering two research questions:

(i) What guidelines might be appropriate for Operational Researchers to follow when making use of Visual Interactive Modelling in aiding clients?

(ii) Are there any important ways in which Visual Interactive Modelling benefits Operational Research studies beyond those benefits previously suggested in the literature?

1 Introduction

1.1 There are three main subdivisions in this thesis.

1.1.1 The thesis begins by reviewing and discussing both the background to where Visual Interactive Modelling is positioned in the professional consultancy community, and certain descriptive and normative theoretical considerations on the actions of Operational Researchers. (Chapters Two and Three)

1.1.2 Secondly it reports the practical and laboratory work which has been undertaken in order to seek a set of guidelines to assist those who use Visual Interactive Modelling. (Chapters Four-Seven)

1.1.3 Finally, in the light of some of the discoveries in the second part of the thesis and the discussion in part one, it proposes certain extensions to the initial discussions which will perhaps be of relevance to those considering some of the strategic issues to do with how we conduct ourselves as Operational Researchers. (Chapter Eight)

It is Chapter Seven which reports the guidelines for Visual Interactive Modellers and Chapter Eight which argues the significance of Visual

Interactive Modelling's contribution to Operational Research. A ninth and final chapter looks at further work which is required to continue this research programme.

1.2 Visual Interactive Modelling

Visual Interactive Modelling (VIM) started in 1976 as an extension to discrete event simulation. In Chapter Three there is an account of some aspects of the history of the development of Visual Interactive Modelling because this will form some of the background for understanding the need for this research. This first chapter contains a few brief notes on the nature of VIM to provide the basis on which the remainder on the thesis is built. It may seem unusual not to start a thesis with an historical introduction. The reason for the chosen sequence is that the evolution of Visual Interactive Modelling should be understood within the context of certain movements in the Operational Research (O.R.) profession. The intention is that Chapter One will cover just sufficient ground to explain the aim and structure of the thesis.

1.3 Briefly, a Visual Interactive Model is a model imbedded within a computer program which uses a colour screen and high quality graphics to display the current state of the significant variables within the model and also provides interactive facilities which enable a user to adjust model parameters. When parameters are adjusted the graphics display is updated to allow the user to see how the significant variables have changed.

The idea is that the user should be able to gain an understanding of the relationship between the input parameters and the output variables.

The initial idea came from Hurrion (1976, 1978). He applied the idea to simulation and in this form the display of the significant variables is usually (but not always) in the form of a schematic map of the system being modelled. In this form the user can see what is happening inside the model as it runs. Very different forms of display are possible (and common). A Visual Interactive Model (also abbreviated as 'VIM') based on an optimising technique such as Linear Programming is not likely to display the internal manipulations of a simplex algorithm (unless this is useful to the user) but instead would display relevant variables from the final tableau in a manner which is understandable to the user in the context of the application.

In presenting this definition of VIM (along with more detailed definitions later in this thesis) it is accepted that alternative definitions exist. This issue is explored more fully in Chapter Three.

1.4 Example

The following example is designed to characterise some aspects of the use of a VIM to help the reader understand the nature of VIM.

The World Bank wants to decide how to allocate limited funds between a number of agricultural projects in a third world country. Each of these agricultural projects will be additionally resourced by the country which will provide labour and water. These resources are also limited but the limits vary throughout the year. Each of the projects have resource requirements which also vary throughout the year and with the level of funding.

The solution is not simple because there are many political and subjective risk issues which need to be taken into account. For a given level of funding of each project the screen might appear as in figure 1.4.A. The bar charts at the top of the screen indicate the match (or otherwise) between the amount of resource required and that available.

The bar chart at the base of the screen indicates the level of funding for each project.

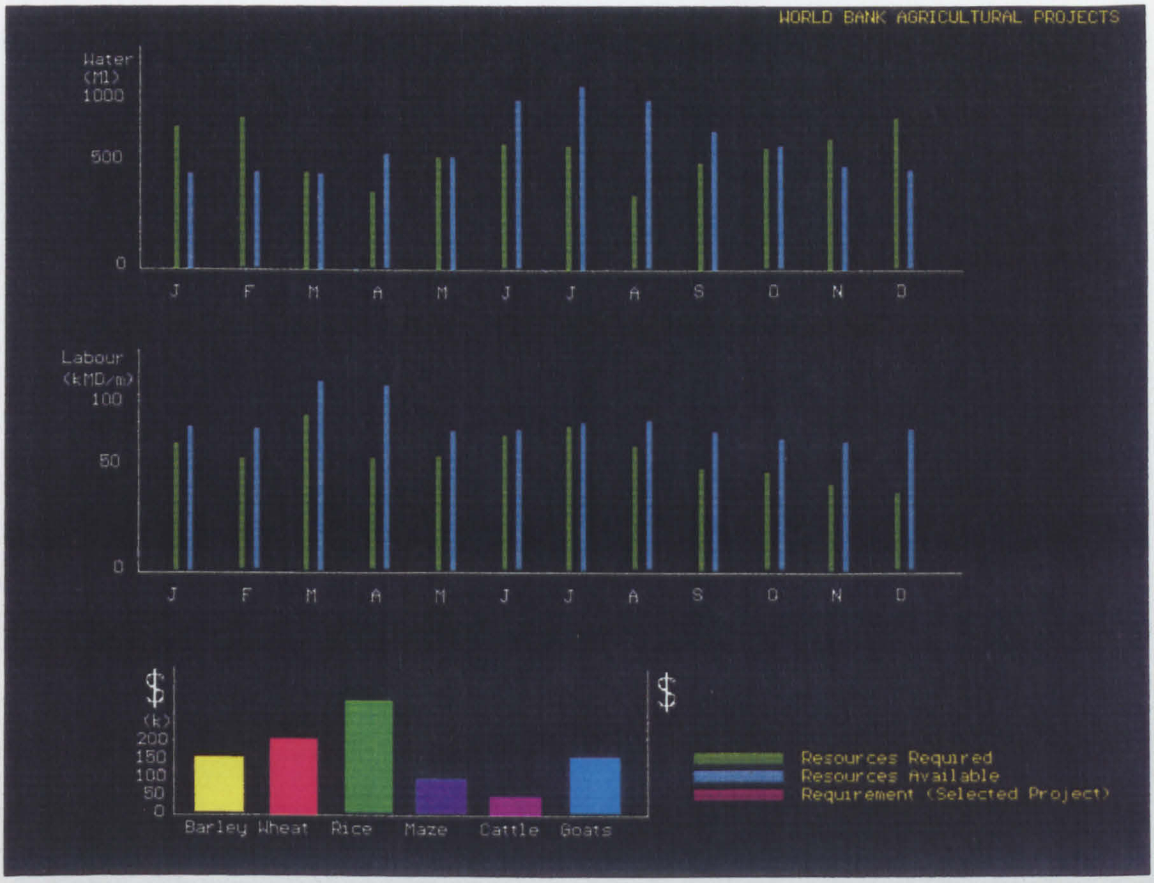

Figure 1.4.A

At this stage in the solution finding process there is clearly an imbalance between resources and requirements (a shortage of water in the southern hemisphere's hot months). But what is to be done about it? Assistance can be given in the form of figure 1.4.B where the top bar charts have been enhanced with information about the proportion of the resources used by one of the projects (wheat).

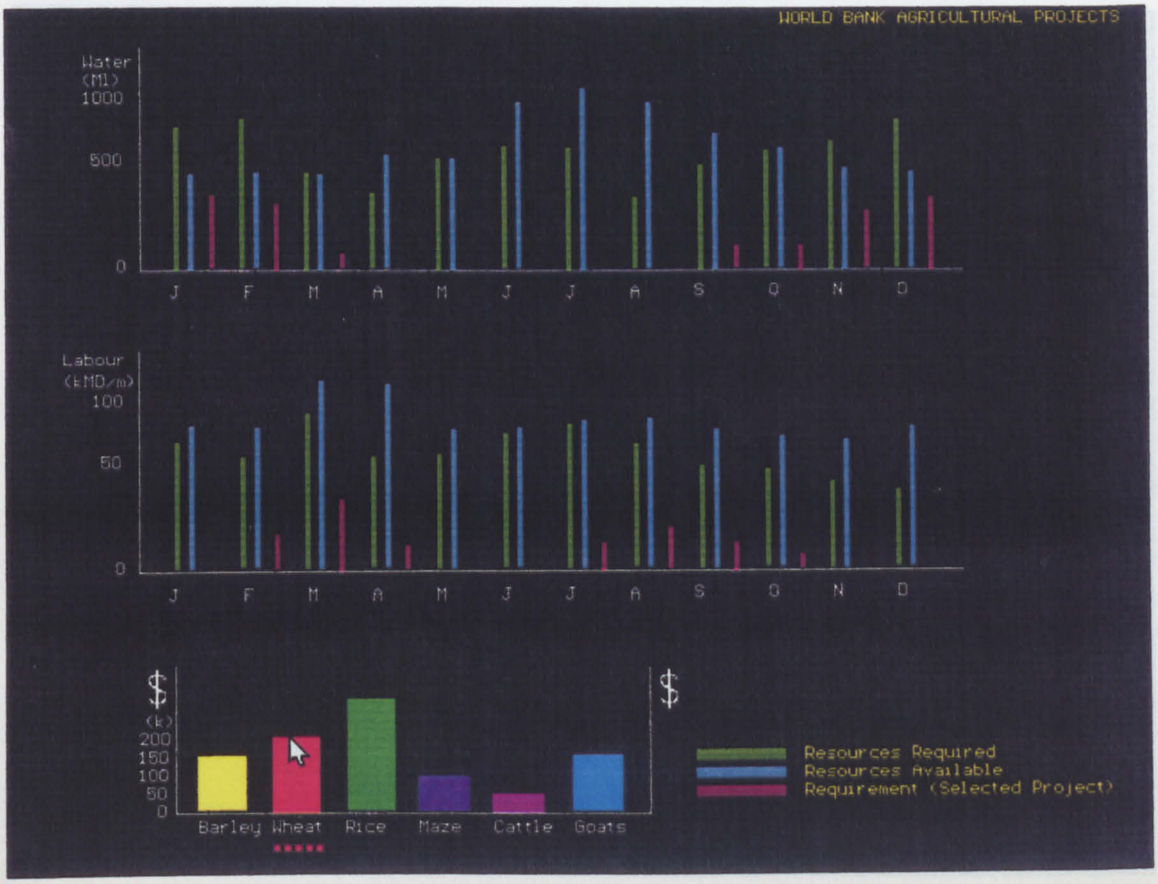

Figure 1.4.B

This gives an indication of one way to reduce some of the overload (Wheat has a high demand for water in the difficult months). If this is a potential feasible option the model can be adjusted to try this idea by dragging down the wheat bar at the base of the screen.

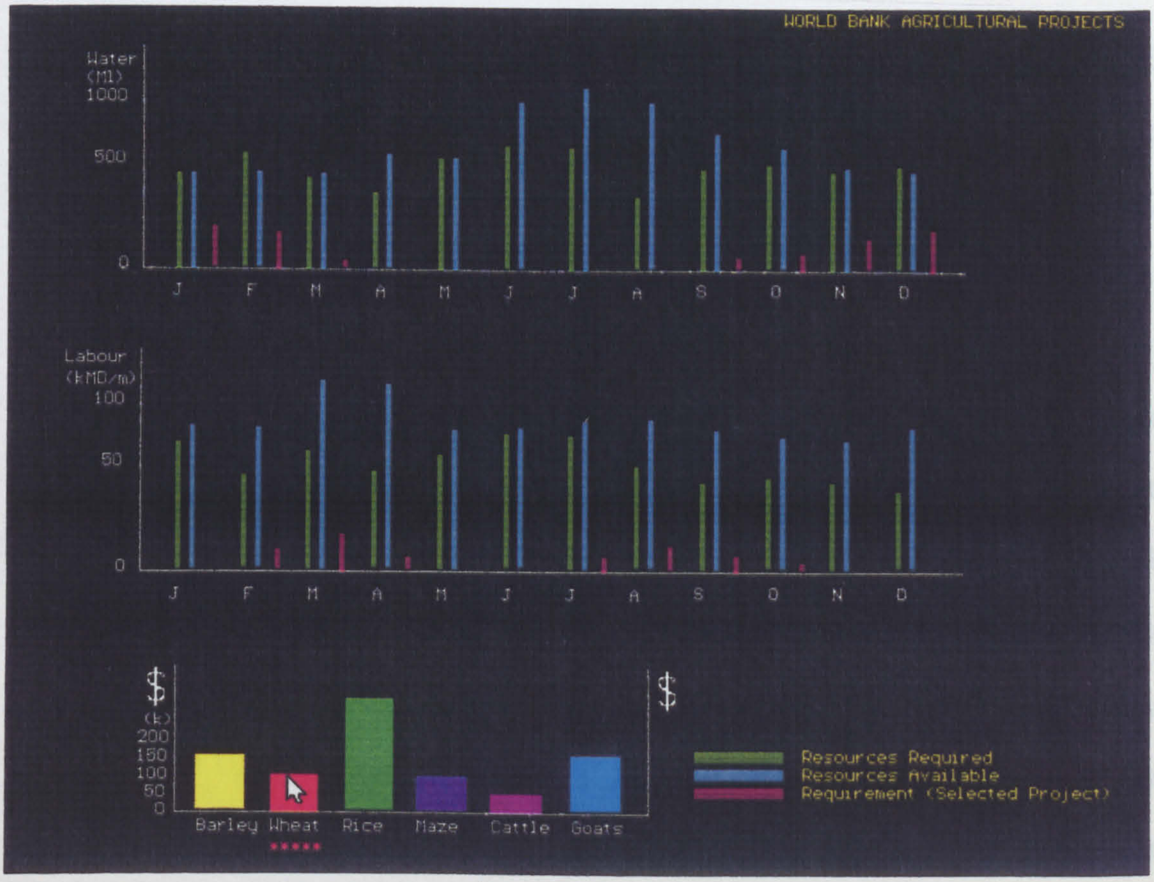

Figure 1.4.C

Thus, this VIM is being used to gain an understanding of which combinations of crops might be technically feasible while the user considers the other (subjective/political) issues.

1.5 An Initial Framework

Sections 1.3 and 1.4 are designed to introduce the basic nature of VIM. In this section some more specific definitions are offered to ensure the following words and phrases can be used in more complex discussions, throughout this thesis, without ambiguity.

1.5.1 Many of the Visual Interactive Models referred to in this thesis will be simulation models. (Models which use 'discrete event simulation' (Tocher 1963, Pidd 1992) as their underlying analytical technique). The phrase 'Visual Interactive simulation model' refers to a Visual Interactive Model which uses this technique. However, most Visual Interactive (VI) simulation models consist of much more computer code than that which represents the simulation model. Building a VI simulation model can often take rather longer than building a traditional simulation model. This is because the computer code necessary to allow the simulation to appear on a computer screen in a way which is appropriate, and that computer code which is necessary to allow the users of the model to easily interact with the model, can be more complex than the logic which relates to the simulation itself.

1.5.2 The phrase 'Visual Interactive Model' refers to the general case of a VIM which uses any underlying analytical technique. (A VI simulation is a special case of a VI model).

1.5.3 'Visual Interactive Model' (or 'Visual Interactive simulation') refers, not to the underlying model, but to the complete computing facility which is in use. It includes the underlying 'model' (in the mathematical sense of 'model') but also the visual and interactive facilities which surround it and also the necessary computer hardware which is in use and which makes the VIM a physical reality.

1.5.4 There is very little use of the word 'user' (as in the 'user' of a computer system) in this thesis. The discussions in later chapters will show there is some importance in distinguishing who is operating the keyboard, who is viewing the screen and who is present at a meeting (at any given time). Therefore the distinction is made clear by the use of words such as 'analyst' (which refers to an O.R. analyst) or 'client' (which refers to the commissioner of, and non-O.R. participant in, a study). Only if the nature of who is using the VIM is immaterial will the word 'user' appear. The word 'subject' will also be used in this context in Chapter Six where some experiments are performed and the user of the experimental VIM could be representing either a client or an analyst.

1.5.5 The phrase 'running' as in 'running a simulation' should be defined. A VIM is a computer program. The computer programme must be executing on the computer in order to have the visual and interactive facilities live and ready to interface between the underlying mathematical model and the user of the VIM. This 'execution' of the computer programme should not be mistaken for the 'running' of a simulation model. When a VI simulation model is 'running' it is modelling (with respect to time) the system (factory, hospital, dock etc) which it has been built to model. 'Simulated time' (usually displayed on the screen) will be moving forward. If a VI simulation model is 'stopped' then it is not 'running', even though the VIM software supporting the simulation is still executing. In this case the simulated time clock on the screen will be static (showing the simulated time at which the model stopped running).

The simulation models referred to in this thesis are mostly models which have been used to solve actual, industrial, O.R. problems. As such, they are all relatively large (many hundreds or thousands of 'entities') and complex (perhaps several thousand lines of computer code).

1.5.6 Operational Research is not defined here for reasons fully discussed in Chapter Two.

1.5.7 Within the context of O.R. we can assume that a Visual Interactive Model is used to help with some decision process. However, it will be argued that one cannot usefully include a Visual Interactive Model in a decision process without some deliberate actions to achieve benefits from its inclusion. If we assume for the moment that there are some potential benefits, then including a Visual Interactive Model in the decision process implies we are seeking these benefits. It is the taking of these necessary actions to seek these benefits which in this thesis will be termed 'The Visual Interactive Approach'. Visual Interactive Modelling is the complete process which includes the 'Approach', the building, changing, running and implementing of the model. 'VIM' refers to either a Visual Interactive Model or Visual Interactive Modelling.

To aid understanding of the above concepts as used in this thesis, a framework is offered in figure 1.5.7.A for identifying aspects of Visual Interactive Modelling.

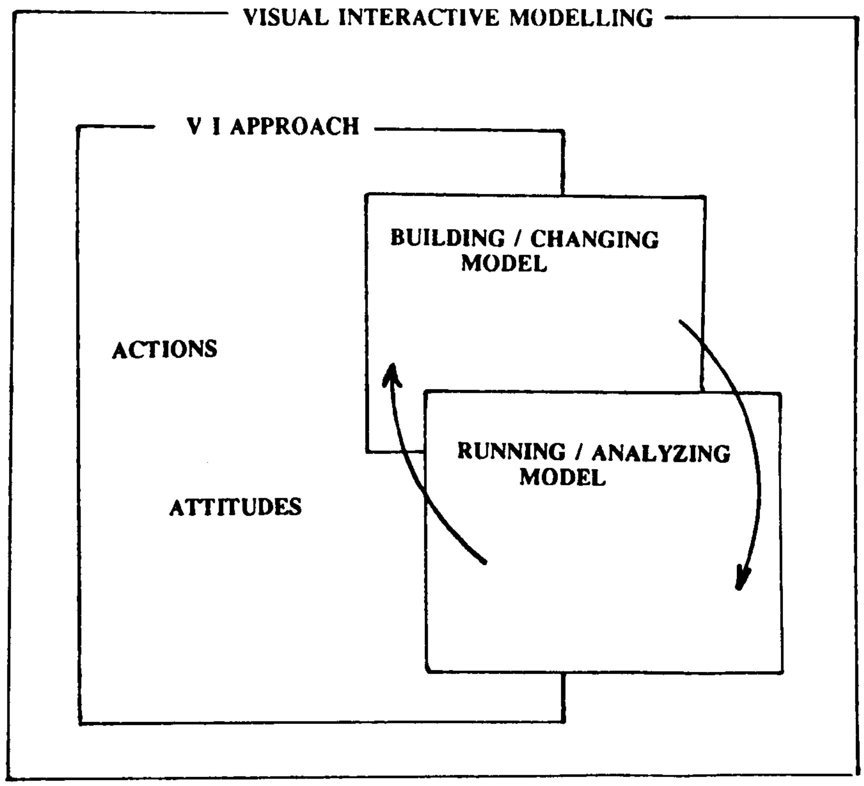

Figure 1.5.7.A - A Framework for Understanding Aspects of VIM

1.6 Research Method

This final section of this chapter summarizes the methods which have been used to conduct the research. Full details and arguments justifying each of the methods are given in Chapter Four and in the relevant experimental chapters.

The nature of the subject area of this research is such that it is difficult to conduct experiments in isolation from the real world. Broadly, this research is about how to improve the way we help decision makers. Because of the complexity of the task in which a decision maker is involved, and of the social/political situation in which most real world decision makers operate, research findings purely based on research in isolation from the real decision maker might be valid in only a particularly restricted set of circumstances. Therefore much of the research which has culminated in the production of this thesis has been conducted with real decision makers in real industrial situations. 'Action Research' experiments have been conducted with the researcher acting as a consultant to decision makers in order to collect data. Many of the facilities for this industrial based research were provided by The Rover Group at its various plants in the Midlands and South of England. One difficulty with this type of Action Research study is that it is not possible to replicate an experiment and verify that the same data would be collected under the same conditions. This difficulty, while not invalidating the data collected, made it desirable to test out some aspects of VIM using a different genre of experiment. Some laboratory trials were conducted in which some circumstances were repeated. These, more traditional, experiments led to further data which has also been used in formulating the findings of this research.

Chapter Two now describes the context in which this research and the development of Visual Interactive Modelling is based.

CHAPTER TWO

THE CONTEXT IN WHICH VISUAL INTERACTIVE MODELLING DEVELOPED

2.1 This is a scene-setting chapter. It explains the context in which Visual Interactive Modelling is usually performed and it explains the state of researcher and practitioner thinking, on which part of this thesis is built. This chapter is based on the literature relevant to this thesis, excluding literature specifically in the VIM field, (this will be reviewed in Chapter Three). As this chapter discusses certain aspects of O.R. an assumption is inherent here; that VIM is part of an O.R. activity. Chapter Three will establish the validity of this assumption (cf section 3.2).

Chapter Eight (which presents some of the results of the research programme) will draw on the foundations laid in this chapter along with the empirical evidence in Chapters Five and Six.

2.2 Some Boundaries

2.2.1 Some boundaries need to be placed on the scope of this research and thesis. Because of the assumption that VIM is used within O.R., and its potential significance to O.R., it would be limiting to restrict this thesis to discussing VIM without also discussing O.R. VIM, it will be shown, is a tool used by Operational Researchers and therefore it is necessary to also look at the objectives of O.R. people.

2.2.2 The term 'Operational Research' has many meanings. This section defines the species of O.R. which is relevant to the context of this thesis.

O.R. has different meanings in different countries. For the purpose of this thesis the term 'Operational Research' will be restricted to mean O.R. as it is undertaken in the UK and understood by those people who are members of the UK academic and professional community. This restriction does not cause the results of this research to, necessarily, only be applicable within the UK. O.R. is performed in other countries, albeit under different names and there are communities of people working under the name 'Operational Research' in other countries who are actually doing work which is different from what we, in the UK, would call Operational Research.

To clarify this a little; it is necessary to distinguish between UK O.R. and, for example, European O.R. which tends to concentrate its efforts on the *application of mathematics* to solving problems rather than the *solving of problems* itself.

Unfortunately, these above statements still do not clearly define the nature of the context in which this thesis is intended to be relevant. Even within the UK, Operational Researchers have different views on the nature of the profession's distinguishing features.

Operational Research is not defined by the UK Operational Research Society. Until March 1984 this professional body's Journal (The Journal of the Operational Research Society) defined O.R. as:

> "Operational Research is the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically."

Since this date the definition has been removed because of lack of agreement amongst members and because of a view that defining O.R. could restrict its application. (For one discussion on potential definitions, see Haley, 1984).

2.2.3 However, since the main part of this chapter will be looking at some of the problems within the Operational Research community, and as those problems are, to some extent, to do with the question: "What should we, as O.R. people, be trying to do?", it would be inappropriate to attempt to define Operational Research.

2.3 The Operational Research Paradigm[1] Debate

2.3.1 In 1978 Ackoff presented a pair of papers at the UK Operational Research Society Conference at York (Ackoff 1979a, 1979b) in which he described some problems with O.R.'s approach to assisting its clients and then proposed some solutions to these problems.

> "...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

[1] The term 'paradigm' is used throughout this discussion, although it is recognised that there are arguments for using different terms (see Gault 1982).

in turbulent environments."

(Ackoff, 1979a page 94)

"...the predict-and-prepare paradigm used by OR [should] be replaced by one directed at designing a desirable future and inventing ways of bringing it about..."

(Ackoff, 1979b page 189)

2.3.2 Around the same time Dando and Bennett (1981) conducted a literature survey which they use to discuss the possibility of a 'Kuhnian' crisis in the O.R. field. They say that:

"...from 1963 to 1978 the O.R. community has shifted from a widespread feeling of certainty about its role and optimism about the future to a state in which significant sections are experiencing and expressing considerable uncertainty and pessimism."

(page 93)

A Kuhnian crisis (Kuhn, 1970) is a social phenomenon which occurs in a scientific field when the central beliefs of that field are challenged. At an early stage such challenges have little effect but eventually may build up to sufficient of a 'critical mass' to overturn and replace the existing central theory. A classical example of such is the development of the theories of quantum physics. These contradicted aspects of Newtonian physics. Typically (according to Kuhn) fields cycle through a number of stages where they are:

content with current theory (minor developments occur which are complementary to, and extensions of, the current central belief),

partly discontent with the current central beliefs because they seem not to match some of the leading-edge work in the field,

in turmoil as a number of new competing central theories are suggested which should replace the old theory and which will embrace the leading-edge work,

and again content with the accepted central belief upon which further incremental work can be built.

It is the 'central theory' which is the 'paradigm' or 'model' upon which all contemporary work in a field is based. According to Kuhn, both the crisis, and the eventual 'paradigm shift', are social phenomena because people working in a field are likely to prefer the ground on which they are working to be stable. The natural tendency for people working in a field is to cling to the central concepts they have believed in for many years.

2.3.3 It was O.R.'s paradigm which Ackoff was challenging and which Dando and Bennett were saying appeared (from a growing lack of confidence) was due for a change.

Many other writers at this time also challenged O.R.'s paradigm directly or indirectly (for example Tocher, 1976 and Radford, 1978)

2.3.4 The foundation of O.R. in the early to mid part of this century was based on scientific discipline and rigorous modelling. This was appreciated by O.R.'s clients of the time who had to cope with running large scale industrial concerns. (See, for example, Lawrence, 1968)

2.3.5 Early O.R. provided help to its clients in the form of solutions to relatively well structured 'problems'. These often required the development or adaptation of some mathematics which could then be used to find some optimal solution to the problem. A report would be presented to management detailing the best actions for them to take. While 'management' was an unsophisticated profession and while issues of industrial efficiency had not been tackled by the first wave of O.R.'s mathematical armament, significant improvements in efficiency could be made. In the 1980s and 90s 'management' has become a rather more sophisticated and well trained profession rather than being promoted from the ranks. It has taken on some of the skills which were previously provided by O.R. For example, MBA courses train the manager of the future to make sense of data, apply simple statistical techniques and, in some cases, to understand when to apply Linear Programming.

2.3.6 Operational Research grew in size and sophistication. At the same time other 'Management Service' disciplines grew in their skills and became able to take on some of the services which O.R. people had provided. For example, Industrial Engineers (and others) learn simulation techniques at undergraduate level. Management no longer had so much of a need for the type of help which early O.R. had provided. The O.R. profession started to look for new ways in which it might help its clients.

O.R. practitioners became concerned that its traditional way of helping did not seem to be as acceptable to its clients as had been the case in the past.

2.3.7 Many authors have now written on these issues and this sub-section now delineates a number of categories of problem which have been identified with what Dando and Bennett (1981) termed 'Classical O.R.'. An important precept of the argument offered in Chapter Eight (on the contribution VIM perhaps has to offer O.R.) is based on an understanding of the problems with this 'Classical O.R.' paradigm and of the nature of some of the alternative paradigms (or less grand solutions) authors have offered.

The paragraphs below are not quoted directly from the literature because to do so creates a piecemeal series of statements with different authors' contributions either overlapping, or taking different emphasis. Therefore the following discussion is drawn from Rosenhead (1989), Keys (1987), Ackoff (1979a, 1979b), Dando and Bennett (1981), in a structure which indicates the key issues.

2.3.7.1 One of the most common criticisms of traditional O.R. methods is that they attempt to find solutions to problems by 'Optimising'. This is a blunt (rather than accurately focused) criticism because there is little intrinsically wrong with optimisation itself, the difficulty is really with some of what optimisation implies.

2.3.7.2 Optimisation implies we know <u>how</u> to optimise. If we assume for the moment that the typical client of O.R. is a manager of a division of a company, then we can imagine, even if we have not worked in such a role, that this person would have many conflicting objectives, and that the nature of the relative importance of these objectives is probably unclear, even to the manager.

A domestic example may clarify this point; purchasing a house. Would it be possible to give a complete specification of one's house buying objectives to an estate agent and then expect them to find a solution (house) from the available alternatives?

It is not possible to specify and metricate (in most practical cases) the trade-offs between the objectives. (cf Belton, 1990b)

2.3.7.3 Optimisation also implies we know <u>what</u> to optimise. We may not know of the existence of some of our variables. One manner in which our client probably needs help is with deciding what needs to be considered.

2.3.7.4 If our clients know what they wish to achieve (in terms of their objective) this does not necessarily imply they know all the options open to them. An important question for many clients may be: What are the alternatives?

An approach of, for example, linear optimisation implies that there is a feasible region which we can search for an optimal solution. This excludes the possibility of creative thinking generating alternatives which are structurally unrelated to initial thoughts about potential solutions.

2.3.7.5 Indeed, optimisation implies there is some structure to the problem to which some (necessarily rigid) mathematical technique can be applied.

2.3.7.6 Optimisation implies we know the relationship between our objectives and the issues we can control. For example, we can, perhaps, control the inputs to our factory, the resources we employ, etc, but how do these affect the outputs; such as profit?

2.3.7.7 Optimisation, alone, is perhaps futile if we are not in control of all the variables which affect our objective. We need to investigate our best option under different combinations of the uncontrollable variables.

2.3.7.8 Optimisation tends to imply that the problem is static. In other words, it implies that we can find one solution which will be correct until we are asked to solve it again. Of course we could implement an on-going system which would regularly optimise as variables change without the need for O.R. intervention. But even this implies a static structure to the problem. If the client realises the structure has changed and calls in the O.R. person to restructure the on-going solution there may not be time to re-optimise before the structure has changed again. Most clients in real situations exist in a quickly changing dynamic environment.

2.3.7.9 Many clients of O.R. are probably interested in finding a solution to their situation which will not only be good, but robust too. So, accepting the quickly changing dynamic environment, simple optimisation without consideration of potential (but unknown) future scenarios, is avoiding part of the client's real problem.

2.3.7.10 Optimisation implies there is just one definition of the 'problem'. Again, in a real situation there will usually be a group of clients who have different perceptions of the 'problem'.

2.3.7.11 Most classical O.R. methods do not see the client as anything other than a 'Decision Maker'. The reality is perhaps more that Decision Makers have to also be politicians, social workers, and negotiators. Solutions must not just take this into account in terms of 'the solution found' but also in terms of the 'process for finding the solution'. For example, it may be important that the solution finding process is (perceived to be) 'participative'.

2.3.7.12 Even if there is no-one other than an all-powerful, unilateral decision maker as the client of an O.R. study, then this client will probably be interested in the nature of the solution finding process. Most classical O.R. methods are opaque in their operation and therefore difficult to explain and thus make the task of convincing a client of their validity difficult.

2.3.7.13 The opaque, non-participative, nature of many traditional O.R. solution methods is regarded as an inherent limitation to their value.

As a first, simple, example consider a decision maker's problem which involves some trade-offs to be made between different objectives (cf section 2.3.7.2). If we do not know the nature of these trade-offs then the decision maker will need to be involved in the solution finding process in order to make judgements. If the solution finding process is non-participative in nature then this will be difficult. It would be interesting to explore questions about what 'judgemental' means and whether judgemental issues can be beneficially extracted from the mind of a decision maker. This is beyond the scope of the research reported here; the word 'judgemental' is being used in its common sense. The issue of requiring non-O.R. people to participate in the solution finding process because of their possession of 'judgemental' capabilities (perhaps of various types) is an important aspect of some of the discussion which appears later.

2.3.7.14 There are, however, reasons outside those which could be classified as 'judgemental' which require non-O.R. people to participate in the solution finding process. Ackoff (1979b) has argued that some decision making should be humanised and some should involve consideration of ethics. Social issues should sometimes be considered. While decision aiding experts such as some O.R. people are able to consider ethical issues, they are not necessarily the most appropriate people to consider these issues in every context. Again, without the ability for non-O.R. people to participate, along with the O.R. techniques in solution finding, it will be difficult for the decision process to consider these types of issue.

2.3.7.15 It has been argued (Eden et al, 1979) that decision making is a social process. People in an organisation interact with each other to consider alternatives in an evolving, negotiative manner to reach a decision rather than thinking in a manner analogous to the approaches in the natural sciences. If traditional O.R. is non-participative it perhaps excludes this social process from the solution finding.

2.3.7.16 Section 2.3.7.7 considered the problem of simple optimisation if the decision maker was not in control of all the variables. However, this problem becomes more difficult if the decision maker is operating in some competition or conflict with other decision makers. Traditional O.R. techniques, it is argued, do not enable consideration of hostile third-parties. (See, for example, Bennett et al, 1989).

2.3.7.17 Traditional techniques emphasize a 'predict the future and prepare for it' paradigm, rather than a more proactive approach of attempting to design the future. Like the issue in section 2.3.7.15, traditional techniques do not account for the possibility of the decision making process itself affecting the problem system. Traditional O.R. techniques are non-interactive in that they do not facilitate a cyclical process of solution finding and then re-finding in the light of the changes the first solution suggests.

2.3.7.18 Section 2.3.7.5 suggested optimisation is dependent on knowing the structure of the problem. Some authors critical of the traditional O.R. paradigm go further than this. It is argued that, due to the non-participative nature of the techniques, it is difficult to use them to help with problem structuring.

2.3.7.19 The ability to solve problems iteratively and participatively is important from another point of view. If (as suggested in section 2.3.7.4) we may not know of some alternatives then perhaps part of the solution finding process should facilitate creativity. A process which is opaque can, perhaps, not achieve this. Creativity will depend, to some extent, on being informed by the solution finding process of the nature of inadequacies in the intermediate solutions.

2.3.7.20 Constraints which exist in any problem system can be of different levels of importance. Some constraints may be softer than others in that, under some circumstances they could be relaxed a little. This may especially be the case if they are seen to have a large cost effect on what would otherwise be an acceptable solution to the decision maker. If the decision maker cannot participate in the solution finding then it is perhaps difficult to take the softness of some constraints into account.

2.3.7.21 Decision making is a wide process which involves much more than the singular activity of deciding which alternative is best. Many authors have described real 'problems' as 'messes'. Traditional techniques attempt to abstract, from the mess, certain aspects of the complete problem and deal with these in isolation. They handle too small an area of real problem 'messes' to be of use in real decision making.

2.3.7.22 *Implementation* of O.R. solutions has at least an anecdotal reputation for difficulty. The critics of the traditional paradigm argue that a cause of this difficulty has been the solution finding process. Excluding difficulties caused by the non-participative nature of the techniques, there remains the difficulty of ensuring a solution can be used on a day-by-day basis. If a solution is not understood by the decision maker or it is so complex that it is difficult for the decision maker's staff to operate it then it may be impractical to implement without continuous assistance from O.R. people.

2.3.7.23 A further criticism of traditional techniques is that they depend heavily on the availability of good data. Sections above have discussed the unavailability of subjective data. (For example, when trade-offs between different objectives are unknown). Sometimes factual data is unavailable. Proponents of some alternative paradigms suggest that, as decisions must be made, O.R. must learn to cope with situations where assumptions must be made about data by allowing consequences of the assumptions to easily be considered.

2.3.8 It would appear that it is only the more radical of authors who advocate a sweeping away of traditional O.R. methods to replace them with new methods (see Hindle's, 1990 review of Rosenhead, 1989). Other authors (eg Bryant, 1988) would take an almost opposite stance and, while agreeing with the criticisms of traditional O.R. techniques taken on their own, would argue that many O.R. practitioners are capable of utilising these techniques in such a way that most of the problems are in practice overcome. Some of the proponents of some of the new methods which have emerged in recent years (cf section 2.4) would take a stance between these two extremes. While these new methods are designed to deal with the 'messy' and judgemental issues in a problem, their approaches incorporate the option to use traditional techniques when this is shown to be necessary.

2.4 Proposed Alternative Paradigms

While Dando and Bennett (1981) did suggest that there were paradigms competing to replace the traditional O.R. paradigm, the Kuhnian perspective on this (based on natural science) would be simply that the force of evidence for a (single) new paradigm eventually causes the old to collapse. Their reason for suggesting there is more than one potential new paradigm is that they perhaps saw the opportunity to encourage a debate on some aspects of the role of O.R. by looking at the possibility of changing O.R. more than was necessary according the Kuhnian model. According to Dando and Bennett the competing paradigms are 'reformist' and 'revolutionary'. (Other authors have suggested there are still further competing paradigms, or subdivisions within these, see, for example, Gault 1982). The revolutionary paradigm takes on board the ideas of the reformists but further questions who the actors are for whom O.R. should be working and where the consequences of O.R. work can impinge. In asking these questions it considers whether O.R. should be proactive in its choice of clients.

Dando and Bennett do not offer a formal statement of the stance of either of the new paradigms they identify. Rather, they cite a number of other authors to show that it:

> "...seems to bear a close relationship to Ackoff's proposals."
>
> (page 96)

These other authors' arguments will not be repeated here because further work by these authors has led to their thinking now being seen as distinguished from each other and so such a discussion would cloud the current issue.

Rosenhead (1989) gives an interesting way of examining the potential (single in his case) new paradigm. He state what he regards as the dominant characteristics of the traditional paradigm and then inverts these to give potential characteristics for an alternative. (see Rosenhead 1989, page 12).

Apart from making the above comments to establish the background it is beyond the scope of this thesis to examine issues with regard to competing paradigms. It is sufficient for the argument here to consider the existence and nature of problems with the existing paradigm and note that, if there are competitors to replace it, they have a significant common ground in agreeing with many of the criticisms of the traditional paradigm.

The existence of this debate is interesting to note because it contrasts with some of the *practical* actions that have been occurring to bring about a shift from the traditional (criticised) paradigm towards *something* better. People conducting (or attempting to conduct) O.R. from the stance of the traditional paradigm were challenged by its inadequacies. Approaches had to emerge which would overcome these problems or O.R. would be rejected by its clients.

As examples, the O.R. units in British Leyland, Alcan and British Steel all felt that the solutions they were finding to clients' problems were not adequately accounting for all the issues which the clients regarded as important. (See Fiddy et al 1981 and Hollocks 1983).

It is in this context which Visual Interactive Modelling emerged. However, it is not intended to imply here that there was any conscious activity on the part of VIM researchers to develop VIM as a response to the debates which were occurring over the O.R. paradigm. Indeed, there appears to be little evidence[2] of any link between the literature of VIM (see Chapter Three) and the literature on the O.R. paradigm debate. It is the case, however, that VIM was starting to emerge at around the same time as the debate was taking place. Issues related

[2] There is one work, that of Parker (1985), which draws a connection. The contribution of this work will be discussed in Chapter Eight.

to VIM and the O.R. paradigm debate will be discussed more fully in Chapter Eight.

In contrast to VIM, there are other approaches which have emerged during the same time period as the O.R. paradigm debate has been taking place, which appear to have been explicitly associated with the debate. Rosenhead (1989) discusses the debate and then describes six 'methodologies' (Rosenhead's phrase) for problem structuring and then he compares these to a potential specification for an alternative paradigm.

2.5 Soft O.R.

Given some of the dissatisfactions felt with the traditional paradigm, it is not surprising that some people who recognised these have been working to overcome and find ways around them. Some of these approaches (especially those described in Rosenhead 1989) have become known as 'Soft O.R.'[3]. The phrase itself is not particularly important except that it is perhaps useful to be able to contrast these approaches with what has become labelled 'Hard O.R.'. The latter label has been applied to the techniques that are associated with old O.R. paradigm.

Some of these approaches have developed 'trade names' (almost in the sense

[3] It is recognised that this is not a universally accepted phase for this collection of 'methodologies'.

that the 'techniques' of the traditional paradigm had names like 'linear programming', 'simulation' etc.).

Examples of some 'Soft' O.R. approaches:

'Strategic Options Development and Analysis' (SODA) (Eden 1989)

'Soft Systems Methodology' (Checkland and Scholes 1990)

'Hypergames' (Bennett et al 1989)

Some aspects of the field 'Multicriteria Decision Aiding' (MCDA) (Phillips 1989).

'Strategic Choice' (Friend 1989)

These approaches have been developed in recognition that the human, political, social/group pressure, judgemental and unstructured aspects of problems cannot be ignored.

2.6 Conclusion

Given one statement in section 2.4 (that it is within the context of the inadequacies of the traditional O.R. paradigm that Visual Interactive Modelling emerged) this chapter perhaps raises more questions than it answers. This chapter is intended to be a contextual, scene setting, chapter which will be used to build later argument. It is the discussion on which Chapter Eight draws in attempting to answer the second of the research questions which were posed at the start of Chapter One.

CHAPTER THREE

THE CURRENT STATE OF VISUAL INTERACTIVE MODELLING

3.1 Introduction

This chapter discusses the literature on Visual Interactive Modelling with the aim of:

(1) showing the current state of the research field and the practice and

(2) indicating a purpose for some of the research output of this programme (showing why the research questions posed in Chapter One should be answered).

3.2 Emergence of Visual Interactive Modelling

The point in time when any research field starts to become distinguishable from other research fields is probably always difficult to define. This is especially the case if different researchers in the field have different definitions of the field itself. Nevertheless, most researchers (and practitioners) seem to concur that VIM started with the work of Hurrion. Hurrion's concepts of the aims of VIM (see Hurrion and Secker 1978), evidence of benefit (Hurrion 1978), and software (VISION - see Hurrion 1980a) formed an initial foundation on which later research and commercial companies would build.

Almost simultaneously with the work of Hurrion, Lembersky and Chi (1984) were also working (in 1977) on a VIM but from within a commercial organisation. For patent reasons the publication of this work was delayed but it shows many similarities, in terms of aims and methods, with the work of Hurrion.

Several other authors had published in related areas before this time (for example Palme, 1977, Donovan et al, 1969) but, as is illustrated in section 1.4 and discussed further in section 3.3.4, the simple addition of interactive and graphical computing facilities to a model does not constitute Visual Interactive Modelling. Nevertheless, the work prior to Hurrion's was of importance because, as section 3.6 will argue, the emergence of VIM was technology constrained.

Hurrion's early work was quickly exploited by commercial organisations. The O.R. Unit which provided the facilities for the 'Action Research' discussed in Chapter Five was the first to produce a commercially available Visual Interactive (VI) simulation software package (SEE-WHY). Some of this O.R.

unit's aims in developing and using this system are stated in Fiddy et al (1981). They state that communication between analyst and client could be improved so that clients were more likely to implement proposed solutions. Hollocks (1983) gives a well argued historical account of why an O.R. unit at British Steel required Visual Interactive Modelling and how its existing discrete event simulation package (FORGE) was converted to meet these Visual Interactive needs. This O.R. unit found a need to take an approach with its clients which differed from that which had been its earlier approach. Its clients were less willing to take 'solutions'. Instead, they wished to be involved in the solution finding process and the British Steel O.R. units found a means by which they could cater for this desire. The resulting package (FORSIGHT) was also made commercially available. By 1980 the O.R. unit at Alcan Aluminium was using the SEE-WHY package.

VIM can be based on any underlying modelling technique. While VIM applications have been dominated by simulation (and initially Hurrion was working with simulation), Lembersky and Chi used dynamic programming. Hurrion then looked at exploiting the ideas on other techniques. For example Hurrion (1980b) discussed potential improvements to truck-routing algorithms by adding a VI interface to them and then Fiddy et al (1982) considered scheduling applications (based on heuristic models).

By 1983 Istel (see Istel 1984) was exploiting the truck routing research and INSIGHT (1983) had launched packages in the scheduling arena.

The most recent research will be reviewed in section 3.8, however, the dominance of the commercially based research seen in the current section will continue. Section 3.3 references little publication from the commercial side of the VIM community however the evidence is there of this research in the form of their software products and from the academic review literature which is referenced in section 3.3. Confirming this, Bell (1985a) has stated that

> "...much of the impetus for developing VI models has come from practitioners. ...the development and marketing of VIS was a practitioner to practitioner phenomenon."
>
> (page 30)

He also noted in the same year (Bell 1985b) that

> "While practitioners have embraced the VIM concept and played a leading role in its development, the academic O.R. community has had difficulty seeing a scholarly component to much of the work being done."
>
> (page 975)

Some potential reasons for this will be discussed in section 3.9 and Chapter Four will discuss some ways in which we might overcome some of the problems related to academically valid VIM research.

The UK was the main source of VI software products (the world wide market being supplied mainly by UK companies). The North American simulation packages (for example SIMON, GPSS) spawned visual additions which they termed 'animation' and which the literature distinguishes from VI simulation (see, for example, Bell 1986).

VIM within the O.R. community had become widespread by 1985 (see Kirkpatrick and Bell, 1989, for a report on a survey conducted in 1985) and in 1988 the first academic conference devoted to the subject was held (Belton and Elder 1991b). The then president of the UK Operational Research Society claimed in 1988 that:

> "..visual interactive modelling...is probably the most important OR development on micros in the 1980s."
>
> (Ranyard 1988 page 1084-5)

The commercial organisations would claim that most O.R. units (in the UK) now make use of VIM. However, while its use may be widespread, we shall see in the next section that our understanding of how to make best use of it is perhaps still in its early stages.

3.3 Literature of Visual Interactive Modelling

The VIM literature is not extensive. While section 3.2 has alluded to much research and exploitation taking place in the commercial and practitioner O.R. community, little of this has been published. This section discusses the published research. Rather than detailing each publication this section reviews the literature by looking at the main researchers and their themes within the context of the research presented in this thesis. It also suggests some criticisms of these works which will be explored further in section 3.9.

A final sub-section of section 3.3 restates a number of the definitions of Visual Interactive Modelling which appear in the literature. This is left until section 3.3.4 so that the background to the researchers can be discussed first.

3.3.1 Main Stream Researchers

Although Hurrion was first to write directly on VIM, by far the most prolific author has been Bell. At IFORS (Rand 1987), Euro (Belton and Elder 1991b) and UK (Belton and O'Keefe 1986) Operational Research conferences he has given major review papers (Bell 1987, 1991, 1986). He has conducted surveys of VI model builders (Kirkpatrick and Bell 1989) and VIM decision makers (forthcoming with Elder). He has compiled, with O'Keefe, a detailed historical account of the development of VI simulation (Bell and O'Keefe 1987). He has inspired other researchers in his group at University of Western Ontario and keeps in touch with the commercial activities in the field by visiting many of the software companies annually.

Bell's publications are substantially reviews or well guided speculations. He has assessed some of the probable effects of VIM and categorised some of the different types of activity which have occurred in VIM practice. For example Bell's (1986) conference paper distinguishes between 'iconic' and 'representational' visual displays. An 'iconic' display looks like the real system which is the subject of the model, such as map of a factory which is being simulated. By contrast, a 'representational' display would communicate between the model and user by bar charts and similar types of displays which are common in spreadsheet packages. Hurrion (1986) publishing in EJOR the same year describes these as 'schematic' and 'logical' displays.

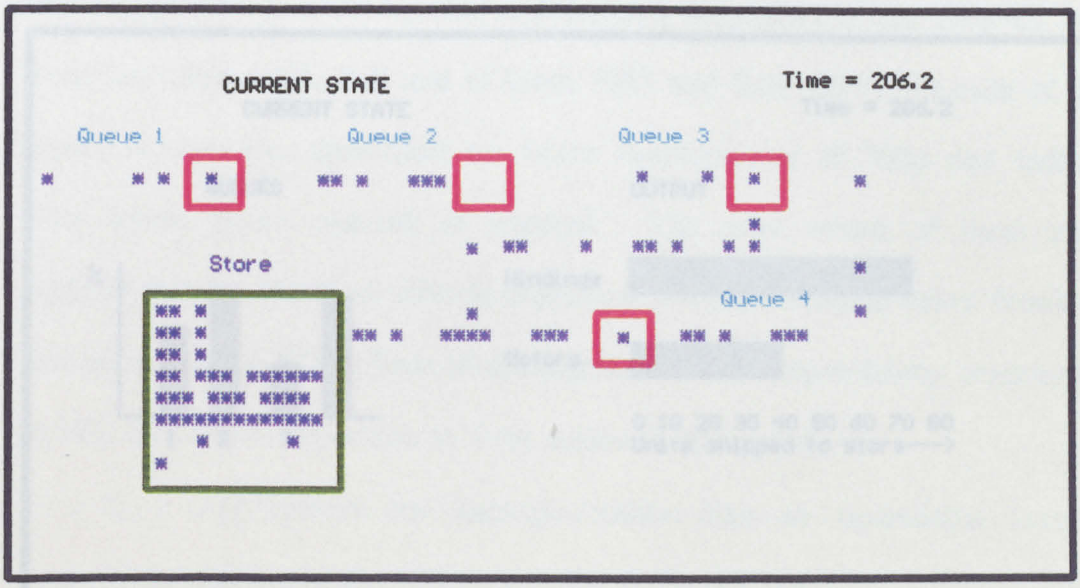

Figure 3.3.A - An 'iconic' or 'schematic' display.

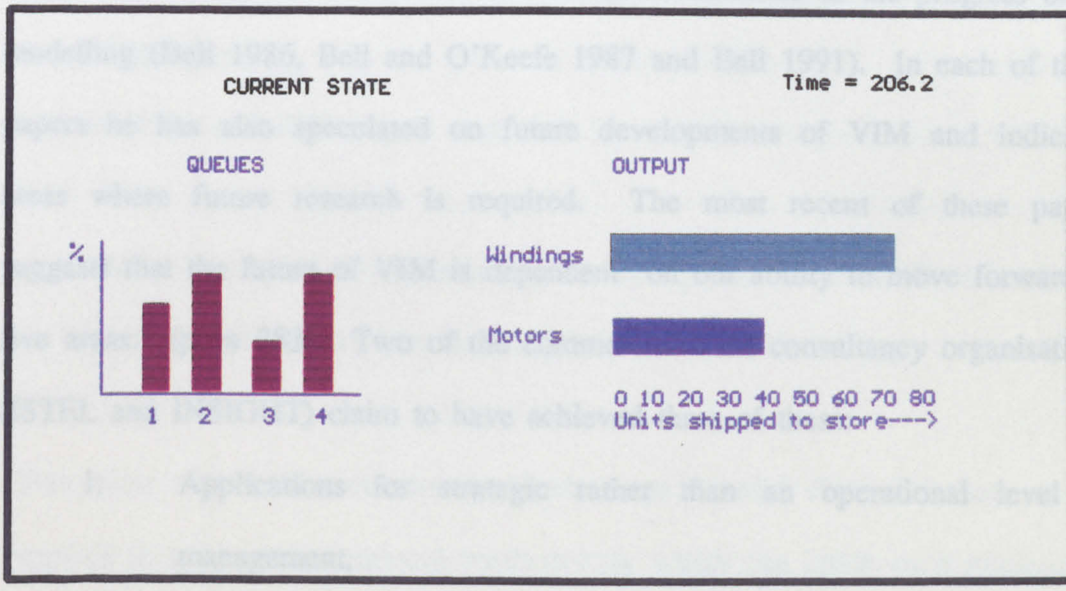

Figure 3.3.B - A 'representational' or 'logical' display.

While the 'iconic'/'representational' distinction is potentially interesting, and may affect decision makers' ability to benefit from the model, it does not seem to distinguish between many VI models. From the photographic reproductions of model displays in the literature it would appear that most models use a combination of both types of display. (For examples see Bell 1985a, Turban and Carlson 1989, Bell and O'Keefe 1987 and Hurrion 1980a.) The model builders were presumably using whatever display design appeared most appropriate for the specific problem being addressed.

Bell has published some accurate and detailed summaries of the progress of VI modelling (Bell 1986, Bell and O'Keefe 1987 and Bell 1991). In each of these papers he has also speculated on future developments of VIM and indicated areas where future research is required. The most recent of these papers suggests that the future of VIM is dependent "on our ability to move forward in five areas:" (page 283). Two of the commercial VIM consultancy organisations (ISTEL and INSIGHT) claim to have achieved three of these:

1: Applications for strategic rather than an operational level of management,

2: integration of models into company systems,

3: exploitation of faster and more advanced PC based hardware and operating systems.

Although there is no published evidence of this, these organisations are able to quote cases where these have been achieved. In addition INSIGHT claims to have at least partially achieved Bell's fourth requirement for progress of

4: incorporating expert systems and natural language into the model development cycle. (Bell's discussion sees these as being important for *use* of the model too. See Hurrion, 1991, for a detailed discussion of the use of expert systems in model use.)

Bell's fifth area is regarding methodology. All of Bell's review papers note that

> "..no unique VIPS [problem solving] methodology has emerged." (Bell 1986 page 4)

and the 1987 and 1991 papers state that:

> 5: we need a methodology to ensure we address the client's real problem and that the model is validly analyzed.

This issue of a VIM methodology needs some detailed discussion because Bell appears to mean an operational methodology which can guide each implementer of VIM as they go about using VIM in the context of O.R. and because one of the research questions to be addressed by this thesis is related to guiding O.R. people as they use VIM.

He gives (in the 1991 paper) an example of something which might be included in such a methodology. He says (page 285) that:

> the problem owner should specify the inputs to the model and the required outputs to appear on the display.

This is taken as an indication of the level at which Bell would like to see a methodology emerge. He does not appear to be specifying a requirement for a strategic methodology (which might state the type of problems which are amenable to VIM) or a technological level of methodology (which might state the types of graphics screens required for effective VIM). In a paper presented at IFORS 87 he discussed reasons why a traditional O.R. methodology (eg Wagner 1969) should not be followed when conducting an O.R. study using VIM. However these reasons appear to be general reasons for not following a traditional methodology (cf Chapter Two) rather than specific reasons for not following a traditional methodology when using VIM. Thus Bell is perhaps less specific than is required to move towards a methodology for VIM. Bell's (1987) reasons for not using a traditional methodology are:

> "When the decision maker was a generalist without the technical background to understand a mathematical model"

> "When the decision maker had an incomplete understanding of the decision options or the system to be modelled."

> "Where there was no prior 'visual model' of the problem or system."

> "Where the problem definition had more 'soft systems' characteristics"

> "When the VIM supported a managerial function...rather than a specific problem"

"When the VIM was designed for use in group decision making"

"When the person or group doing the modelling has had difficulty implementing their work."

(pages 101-103)

VIM methodologies have been used and have appeared in the literature. Parker's VIM to aid the 'Corporate Cash Management' problem (Parker and Bell 1989) used a methodology proposed in Bell and Parker (1985). This methodology contains little of a specific nature to direct the VIM builder or user. Nevertheless it seems reasonable to assume that its general structure is likely to help the model match the problem as perceived by the client and to cause the VIM to be more usable by the client.

Bell and Parker (1985) suggest four phases (not as separate stages but as elements of a cyclic design process):

1: Design a Visual Model with the client (ie mock up some computer images of what would appear on the screen).

2: Design the interactive components of the model by looking at the client's decision variables and deciding what facilities are required in the model to enable the client to change these variables.

3: Design appropriate algorithms.

4: Program the VIM and build the required database.

The paper gives more detail and the context (of the particular problem). The above is given as an example of the methodological discussion in the VIM literature. It is not appropriate to discuss, in this chapter, the efficacy of this methodology because there is empirical research to be reported in Chapters Five and Six which will contribute to such a discussion. Chapter Seven draws together a body of experience from the experimental chapters which can then be used to postulate certain guidelines both at the level which Bell's 1991 paper suggests might be appropriate and at the slightly more general level of the Bell and Parker (1985) paper (which will be discussed further).

Section 3.2 noted that most commercial development of VIM has occurred within the UK and that North American commercial activity in the closest area has been that of simulation 'animation'. Bell has discussed this issue and has termed the 'Visual Interactive Simulation' as initiated by Hurrion as 'active' VI modelling (Bell 1987 page 99) and the simple 'animation' as 'passive' VI modelling. However Bell goes a little further than this, stating that the 'passive' VIM relates to those applications where the model building and the creation of the graphics are separate activities. Passive applications are using the graphics as an implementation vehicle whereas Bell regards Hurrion's work as 'active' VIM because (as Hurrion 1978 describes) the nature of the problem solving (and possibly the solution) is changed by the use of VIM. As indicated by the example given in Chapter One, this research programme is concerned with 'active' VIM. Passive VI modellers are using the graphics to 'sell' the results of their separate analysis.

This distinction between active and passive VIM is useful because it will assist a discussion in Chapter Eight related to the second research question which this thesis tackles.

Hurrion's contribution to VIM literature has been different in character from that of Bell. While Bell's contribution has been one of drawing together others' observations and concluding general consequences of the aggregated pieces of individual research, Hurrion has concentrated more on conducting and publishing his own empirical research. Hurrion initially described VI simulation as "An Aid to Decision Making" (Hurrion and Secker 1978). Emphasizing it as being part of the decision making process, he contrasted it with the previous work of Palme (1977) which separated the simulation modelling from the communication of results to the client. He then illustrated its positive benefit with some empirical research (Hurrion 1978). Bell and O'Keefe (1987) and O'Keefe and Pitt (1991) both assert that, although many sing the praises of VIM, much of what is said is folklore, experiential and anecdotal. While this is partly true (and will be discussed in section 3.9), Hurrion's early work did set up a clear experiment to show that VIM had some benefits. Hurrion looked at the 'Job-Shop' problem (that of finding a rule for deciding which job a machine should do next when choosing between the jobs queuing at that machine, when there are many machines and many jobs to be processed by the machines in a workshop). He found that using a schematic visual display to show a simulation model running, and an interactive means of changing the rules, enabled a user to find a better rule than when examining the usual statistical output at the end of a simulation run. In conducting and reporting these experiments Hurrion was also showing that the nature of the problem solving process was being changed by the inclusion of VIM. Human judgement could be drawn into the solution-finding (possibly optimising) process.

Hurrion produced a VIS computer software package (VISION, Hurrion 1980a) to illustrate the VIS concepts and as a basis for further research. His PhD students have examined the use of VI simulation in continuous process industries (Fisher 1981), the extent to which it is possible to reduce the programming workload for the model builder by the creation of 'Domain Specific' VI simulation packages (Withers, 1981, Withers and Hurrion, 1982; See also O'Keefe and Haddock, 1991 and Clark, 1991) and the use of some of Hurrion's VI concepts in the Decision Support System field (da Silva, 1982). VISION was also used as the basis for the commercial development of SEE-WHY (Fiddy et al 1981).

Hurrion extended his VI ideas beyond simulation with his foray into vehicle routing (Hurrion 1980b) which was successfully exploited by ISTEL (Istel, 1984).

One of the first VIM case studies was published by Hurrion (1985) and is, also, non-simulation based. This paper is important because it is the first which discusses the relationship between Decision Support Systems[1] (DSS) and VIM and also because it illustrates the first deliberate use of a VIM to

> "exploit the cognitive human attributes while the system could deal with the well-structured part of the planning process"
>
> (Hurrion 1985 page 140)

Since the early 1980s Hurrion's research has, however, moved away from mainstream VIM. He now concentrates his research effort on overcoming some of the problems which have come to light as a result of VIM. For example, VIM has made it easier for decision makers, who are untrained in simulation theory, to engage in simulation themselves. The unfortunate consequence is that models are not always used in a valid manner. Hurrion is working on the concept that 'Artificial Intelligence' techniques can be used to help guide the naive user. (See Hurrion, 1991).

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[1] Discussed in section 3.7

3.3.2 Expansion of VIM beyond Simulation

> "A major development...has been the extension of the approach beyond simulation models to more general VIM"
>
> (Bell and O'Keefe 1987 page 113)

In this paper the authors list some problem types which have been tackled using VIM but without using simulation as the underlying modelling technique. However they do not describe the modelling techniques which were used. This is worth exploring because it leads onto an interesting question. Lembersky and Chi reported the use of dynamic programming within a VIM in 1984 and Hurrion (1980) used the 'savings algorithm' (Webb 1974). Linear and Goal programming have been used by Buchanan and McKinnon (1991). Belton and Vickers (1989) have used Multicriteria models as part of a VIM and, most recently, Belton has also enhanced Data Envelopment techniques using VIM (Belton 1992). However, when Kirkpatrick and Bell (1989) conducted a survey of VIM builders the only techniques used by respondents were simulation and 'heuristics'. Heuristics are often used as the underlying solution-finding method in VIMs used for scheduling applications (see, for example, Jones, 1988 and Walker and Woolven, 1991, for VI models applied to scheduling). One of the UK commercial VI consultancy companies (INSIGHT) claims that scheduling models, using heuristics, make up a 'large' proportion of their workload. Both INSIGHT (1991) and ISTEL (AT&T ISTEL 1990) sell products aimed at the VIM scheduling market. Thus, while other techniques have been used, VIM practice would appear to be dominated by simulation and heuristics. Jones and Maxwell (1986) state:

> "..a primary goal of an interactive scheduling system is to give a large measure of control to the user.."
>
> (page 302)

and later:

> "If it is desired to have the computer fix problems in the schedule, a scheduling algorithm could be invoked: the user would be required to invoke the algorithm explicitly.."
>
> (page 303)

Thus, in their case, an algorithm (or heuristic) is not of central importance to the VIM. An interesting question is: Is the VI aspect of the VIM more important in solving the problem than the model itself?

3.3.3 Other Researchers

Both Kirkpatrick and Parker have made major contributions to VIM research under the direction of Bell at University of Western Ontario. Kirkpatrick's survey has, to date[2], been the only attempt at a obtaining an understanding of the consensus of views of VIM model builders (Kirkpatrick and Bell 1989 but also extensively discussed in Bell 1986). As the authors state, this is not an unbiased sample as it would probably be impossible to obtain an unbiased sample, however it has provided some usable evidence by which we can learn about the use of VIM and is discussed further below.

Parker's work in the Cash Management field (Parker and Bell 1985) was important because, from case material, it illustrates how VIM can aid the combining of an algorithm (in the traditional O.R. mould) with human judgement to account for complex, subjective, multicriteria elements of the problem.

> "The support provided would include both recommendations for cash transfers resulting from the execution of an optimising algorithm and an experimental environment to enable the cash manager to explore tasks that had too little structure to allow algorithmic solution."
>
> (Parker and Bell 1989 page 299)

(Parker's work is discussed again in Chapter Eight).

---

[2] The author of this thesis is currently engaged in a second VIM survey (with Bell). This is surveying ***decision makers*** who use VIM.

This is also one of the few publications on VIM which make any reference to the work of the 'soft' O.R. community (cf section 2.5).

The O'Keefe and Pitt (1991) paper, presented at the Warwick VIM conference, has already been mentioned for its view that there is little more than folklore in publications on VIM. This view is used as a valid basis for then offering some empirical research on problem solving via a VIM. This paper is important because it is one of very few published papers on empirical VIM research. A simple problem was given to 25 student subjects. The problem consisted of making decisions about the best number of trucks to allocate to three different jobs within a coal yard. A VI simulation was provided which the students used to explore the problem. They could run the model as many times as they felt they needed until they had reached a conclusion. At any stage they could select one of two different displays (iconic or representational, in Bell's terms). The computer automatically logged the actions of the subjects and the subjects recorded their decision and 'confidence in decision' at the end of their session. Unfortunately (at 95% significance levels) it was possible to discern few clear findings from these experiments. There was some correlation (0.54) between subjects' confidence and the time they spent finding their decisions. A "marginally insignificant result" was discerned when attempting to match the Jungian (Jung, 1971) cognitive style perception dimension (sensing-intuition) to display usage. While insignificant, this result indicates that those students who were classified 'sensing' by a Myers-Briggs Type Instrument (Myers, 1977) preferred the representational display whereas the 'intuitive' students preferred the iconic display. However O'Keefe and Pitt state that they found the subjects' performance "mediocre" in that only half the subjects found the "correct" answer to the problem. O'Keefe and Pitt appear disappointed by this stating

> "If VIS folklore is to be believed, then decision performance using a VIS should be good."
>
> (Page 344)

They did not, however, look at the performance of the students using a non-VI model. They note this themselves in their suggestions for further research.

Billington (1987) and Gravel and Price (1991) report two cases of interest. Billington reports the use of a non simulation VIM to help a bank's personnel department make manpower planning decisions. A model had been previously available and the introduction of the VIM did not significantly change the underlying model.

> "The reason for the introduction of Visual Interactive Models was to increase the **impact** of the *assumptions* and the eventual *results* on the user."
>
> (Page 83, my italics, Billington's emphasis)

Billington notes that it is not simply communication of results of a study which is important but also some of the background understanding which is required to appreciate those results.

Gravel and Price (1991) report a case where a non-VI model was used to determine that introducing a 'Kanban' manufacturing policy would benefit a manufacturer of clothing for mountain and arctic use. However the management of this company were not willing to introduce this change of policy on the evidence of the non-VI model (see page 28 for the production manager's comments). A second (VI) model was built which was used to build the confidence of the management. Once the management agreed to move forward the model was used by a working group commissioned to implement the new policy.

3.3.4 Some Definitions of Visual Interactive Modelling

It is interesting that the major authors who have offered definitions of Visual Interactive Modelling have kept them at a physical level.

Hurrion (1986):

> "...Visual Interactive Modelling...is the general term being used to encompass the interactive O.R. modelling skills which incorporate animation, visually dynamic and graphics representation."
>
> (page 282)

"The technique of Visual Interactive Modelling consists of:

(1) developing a model of the system under investigation

(2) incorporating a method of animating the model."

(page 282)

Bell (1986):

"Visual Interactive Modelling (VIM) is the process of building and using a visual interactive (VI) model to investigate the issues important to decision makers. The VI model has three essential components; a mathematical model, a visual display of the status of the model, and interactions that permit the status of the model to be changed."

(page 1)

However, given the reasons for the existence of VIM, perhaps a definition which is indicative of the aims of its advocates might be more appropriate.

Turban and Carlson (1989):

"..visual interactive decision making is a technique that uses computer generated graphic displays to interactively show the impact of different decisions."

(page 226)

Lembersky and Chi (1984):

"..a DS [Decision Simulator - their name for a VIM] provides an interactive, visual (instead of numerical) simulation of the actual decision-making scenario, including the consequences of the decisions made."

(page 2)

Thus different authors have understood VIM at different levels. This is also reflected in the way authors have perceived benefits of VIM, which are the subject of the next section.

There is a further issue which will not be discussed in the remainder of this thesis but is nevertheless, outstanding and of some relevance to the current topic. The literature in this chapter perhaps raises the question: "What is *NOT* Visual Interactive Modelling?".

It is recognised that these definitions perhaps embrace rather more than the authors intended. Much development is taking place of computer systems which are both interactive and visual in fields which have a different main focus from that of the VIM field. For example, the Group Decision Support Systems field (Eden, 1991) has developed software such as COPE (Eden et al 1983) and Strategic Choice (Friend, 1991) which would fit within the Turban and Carlson (1989) definition above. Indeed, while the authors of these systems might not regard such an association as relevant to their work, it may be reasonable to consider this work to be a form of VIM (from the perspective of research into VIM). However, while this possibility is recognised, it is outside the scope of the research programme documented in this thesis.

It is also possible that some researchers may consider their work to be within the VIM field, but that the mainstream VIM researchers would not consider their work to have the relevant attributes. For example, Mareschal and Brans (1991) apply interactive computing and visual displays but do not permit adjustment of parameters to enable a decision maker to investigate different decisions, and thus might not be considered to be Visual Interactive Modelling by some definitions.

3.4 Some Benefits of Visual Interactive Modelling

There are many statements of benefits of Visual Interactive Models but, as has already been mentioned, few of these statements are based on evidence which is more than anecdotal. This section looks at the benefits which have been stated in the literature, the evidence for them, where this exists, and which authors have discerned them.

In this section it is also worth considering some questions about the nature of 'benefits' in general. Perhaps the question of whether an attribute is considered a benefit can only be answered in the context of an understanding of purpose. It is also possible that purposes can change as benefits are perceived. One of the research questions posed at the start of this thesis relates to changes in perception of benefits. As this chapter principally treats existing literature, issues of purpose will only be examined where these are covered in the literature; however, this important consideration is revisited in section 3.9 and further in Chapter Eight.

Some benefits can be postulated on logical grounds and some are pure conjecture unless reinforced by empirical evidence.

For an example of a benefit which can be postulated on logical grounds, consider a VI simulation of a factory which shows its user the current position of each product at a particular point in time. If the interactive elements of the VI simulation allow the user to direct products to one machine or another then the user can decide (looking at the current position of the products and states of machine) and instruct the VI simulation to send a particular product to a particular machine. Thus it is possible to include in a simulation model control rules based on human judgement in the way that they might be applied in a real factory. If non-VI simulation had been used then it would not have been physically possible to see the current state of the model at the appropriate times, and therefore not possible to input ad hoc instructions. Thus (on logical grounds) we can see it is possible to include decision rules based on human judgement in the running of a simulation model when VIM is used. This is perhaps a benefit if modelling reality is important.

As an example of a conjectured benefit, some would say that VIM increases the quality of communication between the analyst and the client (over and above the quality achievable by traditional methods of communication, which would continue to be used along with a VIM). While it is possible to imagine that this might be true, however, there do not seem to be any logical grounds on which this can be rigorously proved by argument alone.

Some of the benefits stated in the literature fall into one or other of the classes outlined above. The remainder of this section discusses the benefits stated in the literature.

As different authors state similar or identical benefits in different ways the benefits have been restated and then the different authors' elucidation and evidence is examined.

There is some interdependence between some of these benefits. For example, many of them depend on the benefits described in sections 3.4.1 and 3.4.3.

3.4.1 Better Client Understanding of Model

Bell and O'Keefe (1987) summarize their investigation of a number of VIS cases as follows: (The context of the discussion is such that 'user' means 'client')

> "...VIS was popular because it allowed users to understand the model and take an active part in using and experimenting with it."
>
> (page 110)

O'Keefe (1987) states that the visual displays facilitate decision maker understanding of the behaviour of a simulation model.

Kirkpatrick and Bell (1989) report a survey they conducted of VIM builders in which 74% of respondents stated that their client's understanding of the model was enhanced at least moderately by the use of VIM. (A similar percentage believed their client's understanding of the modelling technique and the results had been enhanced too).

Many of the benefits discussed below presuppose that better understanding of the model is achieved by the client. If this was not the case then much of what the literature says on VIM would probably be difficult to accept. We will assume for the purposes of this look at the literature that VIM does enable the client to better understand the model than would have been possible without VIM but we will return to discuss this, along with other assumptions in section 3.9.

3.4.2 Better Client and Analyst Understanding of Problem

Hurrion (1986) states:

"Visual Interactive Modelling techniques have improved the communication, understanding and insight of an O.R. model"

(page 286)

However, the validity of this statement is questioned in section 3.9.

Bell and Parker's (1985) experience of implementing a VIM leads them to state that the "easily understood environment" provided by VIM "can increase the problem owner's involvement in the important 'problem formulation' step.." (page 785). It does seem reasonable that being able to see the way a model is performing in a clearer way will allow better understanding of the model, and then how the model does or does not fit the real world. Use of an easy to understand model will then also perhaps enable one to learn about what issues are important in the problem, and to loop around and re-formulate the problem.

Bell (1986) regards one of the "major benefits" of VIM as being to "..push the problem solver to address the 'right' problem.." (page 5) and he attributes this to the increase in communication which becomes possible when a VIM is used (and when an appropriate methodology is used - cf Chapter Seven).

3.4.3 Increased Client Participation in Solution Finding

If clients can understand a model they are probably better able to participate in the O.R. solution finding process. This is perhaps both intrinsically and extrinsically important. First, a participating client is more likely to feel as though they 'own' the solution. This is not limited to Visual Interactive Modelling, it is likely to apply however the client can be brought into the solution-finding process. If the client 'owns' the model and solution they are perhaps more likely to implement it. (cf section 3.4.12) Secondly, there are specific qualities which the client can bring to the solution finding process. See, for example, section 3.4.11.

Billington (1987), reporting a case study, states:

> "...Visual Interactive Modelling is not a new technique. It is a way of involving 'clients' to a much greater extent by being able to illustrate much more forcibly the models that have been developed by operational research..."
>
> (page 83)

3.4.4 Use of Decision Maker Knowledge and Experience

If clients can understand a model and, because of this, be involved in the solution-finding process then it is possible that their knowledge and experience can be used in the solution finding process. This may lead to a wider set of alternative strategies and potential decisions being explored. (Hurrion and Secker 1978).

Hurrion and Secker (1978) also state that this can lead to clients being able to point out at an early stage when an analyst's idea for a solution involves unrealistic assumptions.

3.4.5 Faster Location of Problem Areas/Better solutions found

Hurrion and Secker's (1978) argument for this is based on an assumption that having an easier means to find a good solution probably results in better solutions being found on some occasions. They give an example from an experimental model. This example does not depend on the involvement of the client in the solution finding process. Their example concerns a coal depot where coal is delivered by trains and removed by lorries. If there is no coal in the depot and a number of lorries are waiting when a train arrives:

> "..lorries take up these coal stocks then a heavy demand is transferred to the weighbridge. Under a FIFO schedule, this meant that, whilst the weighbridge was handling lorries trying to leave

the system, lorries wishing to enter were jammed outside, causing under utilisation of machinery in the depot. ... If several full trains arrived early in the simulation...no problems arise .... However, if little coal was seen to arrive in the first part of the experiment...problems were enormous. The two-stage, 'pendulum' bottleneck effect...threw the depot into chaos."

Their contention is that it would not have been possible to identify why some runs of the model gave higher utilizations of the machinery than others, without a VIS.

Hurrion (1978) has shown how, for one particular type of problem (job-shop scheduling), better solutions can be found when using a VIS when compared with using a batch simulation method. Hurrion (1980b) shows similar results for the travelling salesman problem.

There has been very little empirical testing of VIM. Few other published experiments of this kind (comparing VIM with non-VIM) exist, however very recent work by Bell and colleagues at University of Western Ontario appears to confirm these results of Hurrion's. This work is, however, in its early stages. The assumptions made and exact nature of the results remain to be published[3].

[3] Personal communication from Bell, March 1992

The Kirkpatrick and Bell (1989) survey of VI model builders found that 65% of respondents judged that the solution was different from the solution they would have found if VIM had not been used. This does not necessarily mean the solution was more optimal, or better.

3.4.6 Improved Model Validation

Hurrion and Secker (1978) state that, because clients can watch the model in action, they can contribute to the validation of models. They state that this can improve this aspect of a study by bringing to bear client knowledge and experience which the analyst, in isolation from the client, could not have used.

Hurrion and Secker (1978) also state that VIM improves model validation independently of client participation in the validation. They say that the visual and interactive facilities combine to make it possible for the analyst to step through the model, one stage at a time, viewing progress and interactively interrogating the model to ensure it behaves as the real world.

Crookes and Valentine's (1982) review of simulation discusses the benefits of VIS for validation and verification for both the analyst and client. In Kirkpatrick and Bell's (1989) survey 88% of respondents believed that validation of models was faster using VIM.

3.4.7 Increased Client Confidence

Client confidence is probably important in bringing about change. If clients are not confident in methods employed or solutions found they are not likely to commit themselves to cost or risk by making changes suggested by an O.R. study. Hurrion and Secker (1978) cite client involvement in validation and verification of models as a reason for increased client confidence.

> "The visual aspect, when coupled with interaction, has a very beneficial effect on user acceptance of models."
>
> (Bell and O'Keefe, 1987, page 115)

Bell (1985a) also (citing others) concludes

> "..that one important benefit of iconic VI models is the confidence decision makers gain because they personally validate models."
>
> (page 28,9)

3.4.8 Inclusion of Human Rules

Hurrion and Secker (1978) state that an interactive model enables priorities to be changed dynamically. This may seem a dangerous action during a simulation experiment. However they argue (page 422) that a fixed priority system in a simulation model is sometimes a simplification of reality in that, in the real world, decisions are taken (by, say, a foreman) to change priorities as and when areas of a system become clogged. Thus it seems sensible to enable a model of a system to use the same dynamic control rules.

> "User interaction with the running simulation allows for inclusion of decision making in the simulation; thus, a large number of systems can be more accurately modelled."
>
> (Bell and O'Keefe 1987 page 115)

> "... the user can actually be incorporated into the model. Decisions which are too difficult to encapsulate in the model can be referred to the user at run time..."
>
> (O'Keefe 1987 page 274)

Fiddy et al (1991) discuss how this concept can be extended to decision rules in non-simulation models.

3.4.9 Improved Communication

Hurrion (1986) states that VIMs improve communication "..at the multiple interface between client, analyst and model." (page 281). This is more than model-analyst and model-client communication. Hurrion (1986) also believes the application of VIM improves the analyst-client interface: "The Visual Interactive Model acts as an interpreter between the different cultures".

> "The visual animations produced during the modelling process were a useful communication tool between the modeller and the user to ensure that the model reflected reality which in turn increased confidence in the model"
>
> (Porter 1991 page 288)

Communication is also an important element of implementation. Once a decision maker has accepted an O.R. solution this then needs to be effectively communicated throughout an organisation.

"[The VI] model could provide the core to that communication exercise"

(Porter 1991 page 288)

"..major benefits came from the use of the model to communicate to all levels"

(Porter 1991 page 291)

3.4.10 Training

Lembersky and Chi (1984) showed how a VIM could be used to train lumber cutters. The objective was to increase the profit of the company by training the cutters to make decisions closer to those which a dynamic programming algorithm would make. Lembersky and Chi claim:

"The foremen readily...understood the utility of the dynamic programming algorithm."

and that the benefit to the company of the training of the employees via their VI model was $7 million per year.

3.4.11 New Types of Problem

Some suggest that VIM allows the tackling of new types of problem which previously (without VIM) would not have been amenable to O.R. techniques. At least they would not have been amenable in a practical setting to O.R. techniques. Bell (1985a) states:

> "Managerially friendly VI models overcome a central difficulty with using O.R. to solve senior management problems: that of identifying the decision maker's criteria..."
>
> (page 31)

If the decision makers can be involved in the solution finding process then there is perhaps less need to explicitly identify such criteria. The decision makers can use their own judgement to compare potential solutions which are provided by the model (cf section 2.3.7.2 and Chapter Eight).

The discussion in section 3.4.8 also indicates further types of problems which might be tackled now that VIM is available.

3.4.12 Increased Implementation

Section 3.4.3 has alluded to the notion that VIM might increase the chance of implementing an O.R. solution. Gravel and Price (1991) report a case in which they found a solution to a problem using non-VI simulation but were unable to convince the management of the organisation to implement their solution. They subsequently built a VIS to show the benefits of the solution and which persuaded management to move ahead with a strategy for implementation.

3.4.13 Hidden Agenda 'Benefits'

Bell (1985a) suggests that some benefits are not directly of importance for the decision maker or the quality of decision but are related to the objectives of the O.R. unit supplying the service. He suggests that VI models can raise the profile of O.R. groups and broaden their area of application. Although, presumably, this is partly due to decision maker satisfaction with previous VI models.

The act of using VIM on a problem will not automatically achieve all (or even some) of the above benefits. As with most techniques it is probable that there are effective and ineffective ways of applying VIM.

"..the attainment of these benefits [a subset of those above] requires some effort on the part of the VI model builder..."

(Bell 1986 page 5)

A large part of the research reported in this thesis is aimed at finding the nature of these efforts.

3.5 Some Criticisms of Visual Interactive Modelling

Any new technique can bring disadvantages with its benefits. There is little self-criticism in the VIM literature, however, this section attempts to explore the issues which some authors have raised against VIM.

Some of the comments at the start of the previous section are also relevant here. Disadvantages should perhaps be understood in the context of purpose. As an example, Bell's papers, when reviewing disadvantages, take the perspective of the O.R. unit. For example, he cites (in Bell 1986) cost and non-portability of computer systems and boredom of coding the models. Disadvantages for a client are also disadvantages for an O.R. unit seen as a service provider, and so disadvantages for clients are also covered. This section is written from the stance of the ultimate receiver of the service, the client.

Bell's (1985b) particularly positive "Visual Interactive Modelling in Operational Research: Successes and Opportunities" was only negative in aspects related to technology (which he considered constrained the further use of VIM). This provoked a response in the form of one of the very few (published) criticisms of VIM. The fact that this came from a practitioner is particularly relevant because many undocumented criticisms have come from academics in a conversational, but unpublished, form. Smith (1986) criticizes VIM on several points some of which are related to one of Everett's (1984) criticisms mentioned below.

Some advocates of VIM suggest that problem definition may change as the use of the model and the study progresses. Smith accepts that this may be appropriate in some cases but is

> "...deplorable as a general philosophy" (page 1018).

This claim seems to be based on the notion that the aims of a simulation experiment should at least be tightly specified at the start of the experiments, even if the experiments lead to insights which demand a change in problem definition. This view is used as part of the argument developed in Chapter Eight.

Smith (1986) then turns his attention to statistical issues. (It is these which have most concerned academics in the unpublished conversations mentioned above). Without a training in the statistical aspects of simulation how will a manager know the meaning of 'steady-state' and be able to answer questions about how long to run a simulation model to obtain valid results? This is not a direct criticism of VIM but of the way it can potentially be used (by handing a model over to a client). It is a valid criticism which (as Smith suggests) appears to be untackled, to date, by either academic researchers or commercial software providers. This issue is important and will be discussed further in Chapter Seven. Chapter Seven will also discuss two further difficulties which Smith classifies as 'statistical'.

He states that sometimes

> "..strategy A and strategy B are good individually but bad when put together. Of course such effects do not appear on the VIS - it is necessary to be aware of the problem in advance, to plan a series of experiments designed to catch the interactions, and properly to analyze the results afterwards."
>
> (Page 1019)

Again this is a skill issue. In this case, the relevant skill is more difficult to teach than statistical skills; one which comes from a knowledge of the way a simulation model functions and from experience in tackling problems via simulation.

The final criticism Smith has for VIS is that, having performed an experiment and perhaps discovered that the modelled strategy is in need of improvement, VIS does not provide a means of discovering a way to make such an improvement. He states that

"At least...careful analysis of the results is needed."

(Page 1019)

This again suggests a requirement for a skill which the client might not possess.

He makes a call for a clear understanding that simulation can be used in two forms; firstly to explore, in an ad hoc manner the dynamics of a problem situation, and secondly (more rigorously) to conduct specific experiments. He believes the two should be distinct.

Smith (1986) also makes further criticisms. They relate to the marketing of VIM packages in an "aggressive" and "irresponsible" manner which seeks to hide some of the disadvantages mentioned above.

The Kirkpatrick and Bell (1989) survey found some evidence that studies using VIM take longer than studies using other techniques (page 75). However, this appeared to be inversely correlated to the experience of the model builder (the more experience the less extra time the study took) and there were respondents who judged VIM studies took less time. There is anecdotal evidence for the model building aspects of studies taking longer. Everett (1984) (quoted by Bell 1986), with experience of several VIM models built within his O.R. unit, states that time and attention to detail is necessary for the visual aspects of the model. Some of the responses to the Kirkpatrick and Bell survey indicated that increased complexity of software (necessary for the VI aspects) was a cause of the increase in time to build the model and also was the cause of errors in model building.

Bell (1986), in referring to the original data from the Kirkpatrick and Bell survey, notes that some respondents stated that a disadvantage of VIM to their clients was a tendency to "blindly accept the results" (page 8). Perhaps with the less convincing (visual) displays of traditional methods they are more inclined to question the process of reaching the solution.

In Everett's (1984) conference paper (again quoted by Bell 1986) he discusses the issue of clients not appreciating some of the variability issues in simulation experiments. One set of random numbers will produce different results from another: "we may not wish to destroy faith by indicating that it is possible to get quite different results by simply repeating the run" (Everett, 1984). This relates to one of Smith's (1986) points above and will be discussed in Chapters Five, Six and Seven.

3.6 Technology of Visual Interactive Modelling

A deliberate decision has been taken in this research programme to avoid technology related issues because the rapid development of (especially computer related) technology would reduce the longevity of such research.

Nevertheless, in this chapter on literature, it is worth reviewing some historical issues related to technology because of the way they have affected the literature and development of VIM.

Why is it that Visual Interactive Modelling did not emerge until the late 1970s? Lembersky and Chi's (1984) work in 1977 used (initially) very expensive computer hardware ($300,000 per application) to achieve realistic visual images. Hurrion's (1980a) system used an early colour graphics display which required direct connection to a mainframe computer. The development of VIM was technology constrained. Significant practical use of VIM (in a real decision setting) was not easy until micro computers became available. Bell (1991) gives a review of the historical progress of the hardware which has been used by the VIM community.

The software has also acted as a constraint. Once micro computers became available the hardware only had a minor impact on the service which could be provided to clients. However, software was only produced by a relatively small number of specialist software houses which devoted limited resources to development. Until 1987 (AT and T ISTEL 1988, Clark 1991) model builders using commercially produced VIM software had to write their models using traditional high level languages such as FORTRAN. Although the benefits of more interactive methods of VIM building had been recognised earlier (Withers and Hurrion 1982, O'Keefe 1987) the software houses were slow to respond to what was seen a small market.

The commercial software houses see their software products fitting into the framework shown in figure 3.6.A[4]

[4] Source: personal communications with the software houses

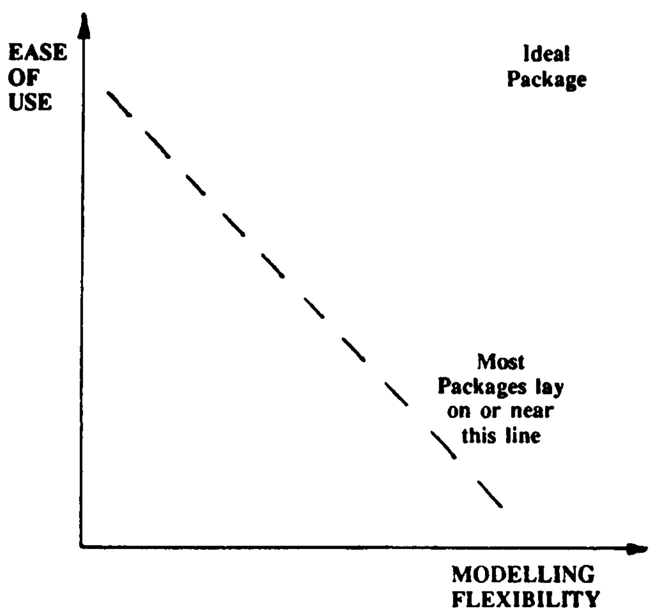

Figure 3.6.A - Framework of VIM Software Products

They state (see, for example, Fiddy et al 1991) that to provide to model builders the flexibility which will enable them to design models exactly matched to decision problems requires software products with many features. Further, they note that the introduction of many features increases the complexity of the software. A certain level of programming skill (and time) is then required by the model builder. This would appear to be acting as a technological, and economic, constraint on the application of VIM. (See section 3.8)

3.7 Related Literature

3.7.1 Symbiotic Systems

The 'Symbiotic Systems' research field has some objectives in common with those of Visual Interactive Modelling. Section 3.4.8 discussed how it is possible to include a human decision maker in a simulation model by using VI simulation. One of the aims of workers in the Symbiotic Systems field is to combine the good attributes of the computer and the good attributes of the human mind so that the combination is much more powerful than the two in isolation. Scriabin et al (1988) give an example of a nurse scheduling system which appears to have much in common with some of the more recent applications of VIM (for example, Walker and Woolven 1991). In nurse scheduling there are a large number of complex rules to be taken into account, such as minimum time off between shifts, in combination with less formal rules such as the nurses' personal preferences which form an important part of the management process of building a 'good' schedule. Application of these less formal rules requires considerable human judgement. A formal computer model may not be best suited to this task. Scriabin et al (1988) define a Symbiotic

System as:

> "... one in which the human visual capabilities is [sic] combined synergistically with the computer's sequential processing speed in such a way that each component (computer or human), helps the other component to continue in its own way to provide further improvements to the current solution."
>
> (page 227)

For further discussion of the contribution of Symbiotic Systems researchers to this research programme see section 8.5.

3.7.2 Simulation

Some research is related to VIM but not of direct relevance to the research reported in this thesis. Pidd, at Lancaster, and Paul, at London School of Economics, have each made important contributions to simulation research in recent years. (See, for example, Pidd, 1984 and Paul, 1987). Partly because of Hurrion's (Hurrion and Secker 1978) initial work in the VI simulation field and partly because of the dominance of simulation as the only technique available in commercial VIM software for the early years (see Fiddy et al 1982), any work in simulation tends to relate to VIM. However Pidd and Paul have worked mainly at the simulation end of the field, Pidd (1988), for example, describes

"Interactive Graphical Simulation" (the title of the only chapter of his book which makes reference to VIM) almost as an after thought (the chapter having not existed in the first edition).

3.7.3 Interactive Computing

The research fields of computer science and psychology both have important contributions to make to the process of Visual Interactive Modelling in the form of specific recommendations on how to build usable interactive computer systems and on designs of visual displays. For example Foley and Van Dam (1982) make recommendations about the type of feedback which should be provided to users of interactive computer systems. Where appropriate to guiding the actions of Visual Interactive Modellers these are reported in section 7.5.2.1.

While much of this research is relevant to lower level tasks than we would expect decision makers or O.R. workers to be involved in, much of it is applicable to all interactive computing. It is not within the scope of this thesis to examine the validity of the research in this field. Where recommendations apply, they are noted, discussed and drawn upon in building the recommendations made in Chapter Seven. For a discussion of the underlying theories which cause computer users to require particular types of facilities see Shneiderman (1987, pages 42-52).

3.7.4 Decision Support Systems

Symbiotic Systems is a small field referred to in section 3.7.1 which has objectives which appear to overlap with those of VIM. Decision Support Systems (DSS) is a much larger field (see, for example, Eom and Lee 1990) which also appears to have objectives overlapping with VIM. Belton and Elder (1991a) have examined the nature of the joint goals of these two fields. The theme of that paper was that both DSS and VIM were enabling decision makers to learn in a number of different ways. While this is important for the future development and understanding of VIM, and is also important when understanding aspects of why some of the discussion in Chapter Eight is important, it is not central to the discussion here. The purpose of looking at similarities between DSS and VIM here is to see if VIM can benefit from examination of existing DSS literature.

Angehrn and Luthi (1990), believe DSS can benefit from taking on some of the principles of VIM. Angehrn and Luthi's understanding of VIM appears to be based on those aspects of the VIM literature which have been the sources of the more 'purpose' based definitions (see section 3.3.4), rather than the more technical definitions (eg Bell 1986, who despite his extensive VIM publications is not referenced by Angehrn and Luthi, 1990). Angehrn's literature (Angehrn and Luthi 1990, Angehrn 1991) and DSS implementations (for example, Angehrn 1990) relate more to the work of Turban and Carlson (1989) and

Belton and Vickers (1989). Belton's work, in particular, is distinct from much other VIM work in that it models thought processes and subjective values. (see, for example, Belton and Vickers 1990, Belton 1990b) Most traditional VIM studies have modelled physical or logical relationships. (See, for example, most of the case studies published to date: Hurrion (1985), Billington (1987), Parker and Bell (1989), Bell et al (1990), Walker and Woolven (1991), Porter (1991) and Gravel and Price (1991)).

Angehrn and Luthi's concern is to

> "...provide decision makers with tools for interactively exploring, designing, and analyzing decision situations in a manner compatible with their mental representations."
>
> (page 18)

To achieve this Angehrn and Luthi make use of ideas from Symbiotic Systems (see section 3.7.1) and Visual Interactive Modelling.

However, VIM can make use of concepts in the DSS field too. Sol's (1983) definition of the DSS field includes:

> "...increase the effectiveness of decision makers in situations where the computer can support and enhance human judgement..."
>
> (page 1)

Decision Support Systems is an important literature for the Visual Interactive Modeller because it shows how perhaps our work should be more than aimed at enabling a client to understand a model (cf section 3.4.1), and more than embedding the client's skills within the model (cf section 3.4.8) but it should perhaps be providing a means by which clients can be empowered to take on their own problem solving.

This issue will be explored further when Chapter Eight attempts to draw together the experimental evidence and some of the discussion in Chapter Two.

3.8 Current Research

3.8.1 Academic

Bell's group at University of Western Ontario are actively examining the differences for users between non-VI models and different types of VI model under strictly controlled experiments. Initial results show significant differences, not only between the non-VI models and the VI models, but also "interesting" differences between the type of VI model. These findings have not yet been written up but Bell[5] expects to have results available by the fourth quarter of

[5] Personal Communication

1992.

Belton and Elder are researching a number of issues related to VIM; for example, whether teaching of Linear Programming can be improved by using Visual Interactive Linear Programming (Belton et al 1991). A Multi-Criteria approach to production scheduling is also under test. The idea here is to use some ideas from the multi-criteria research field (Belton and Vickers 1989) to overcome some of the practical problems which occur when using VIM to help with large production scheduling problems (Walker and Woolven 1991, Elder and Belton 1992). How do the VIM and DSS fields help users learn and what categories of learning are affected by VIM and DSS? (Belton and Elder 1991a).

3.8.2 Commercial

Section 3.6 referred to the current, technology related, constraints on the further implementation of VIM. Current commercial research appears to be aimed at bending the dotted line in figure 3.6.A (shown in section 3.6) closer towards the top right of the graph.

As Bell (1985a and 1985b) has discussed (quoted in section 3.2) much of the leading edge work in VIM research has been conducted by commercial companies. While their motives sometimes cause them to overstate their achievements (see, for example the Blightman (1986) / Smith (1986) discussion in the Journal of the Operational Research Society), the development of

Hurrion's original ideas and the expansion and elaboration of software to make these ideas achievable by O.R. units does appear to have been undertaken by the commercial groups.

Discussions with these groups has indicated that this development is continuing.

3.9 Critique of Published VIM Research

While all the individual publications within the VIM arena make contributions to the development of the field, this section attempts to provide a critique of some aspects of these publications. There are two reason for offering this critique. The first is that, in making the review of VIM literature necessary for this thesis, it has been possible to discern considerations which some authors have omitted to discuss in their individual contributions. Second is that, there appear to be some more wide reaching issues which have not been considered (or have been considered to a minor extent) and which are perhaps important. This second area of criticism leads onto the next section (3.10) where the potential contribution of the research reported in this thesis is considered.

3.9.1 As stated in section 3.4.1 the precept that clients can better understand a model is seen as fundamental to much of VIM. The research which has been conducted into VIM has had little to say with regard to this assumption. Bell and O'Keefe's (1987) statement that:

> "...VIS was popular because it allowed users to understand the model and take an active part in using and experimenting with it."
>
> (page 110)

(cf section 3.4.1) is made from the authors' reading of others' reports of VIM studies. These studies themselves (for example Brown 1978 and Hurrion 1980a), while arguing that this increased understanding probably occurs, do not present clear empirical evidence for such. While 74% of model builders responding to Kirkpatrick and Bell's (1989) survey said their client's understanding of the model had improved, this is only a subjective view, based on their experiential evidence; it is not based on any form of scientific 'test'. This issue is discussed here because of the fundamental nature of this assumption, not because of any evidence that the assumption may be invalid. While the empirical research reported in Chapters Five and Six does not contribute any scientific evidence to verify the assumption, it also does not contradict the assumption.

Many of the statements which appear in the literature are of the same nature of that mentioned in the previous paragraph. For example, Hurrion and Secker's (1978) statement that "..visual representation....aids the verification.." (referred to in section 3.4.6) is based on what appears to be a valid argument, but not on any form of scientific test, and might be subject to counter argument. For example, it could be argued that seeing the visual display can create impressions in the mind which come from transient effects rather than from the steady state, these transient impressions can mislead, whereas, with traditional simulation there would be no alternative to careful examination of steady state statistics. Again this does not imply that Hurrion and Secker's statements are not worthwhile, simply that we do not have hard evidence for their truth.

The nature of these statements discussed above and the possibility of collecting better evidence on some of these statements will be discussed further in Chapter Four.

3.9.2 Some empirical research, related to VIM, has been conducted. O'Keefe and Pitt's (1991) recent study has examined user's solution finding and display preference and their relationship to cognitive style. This study (and its validity) is worth examining in a little more detail than that in section 3.3.3 because it is similar in nature to some example VI models (Hurrion 1980a, Hurrion and Secker 1978) used in the literature in that it omits to consider an important issue. The nature of this issue is discussed with specific reference to the O'Keefe and Pitt paper and then the discussion is broadened to consider how we should be conducting research should we wish to avoid this issue.

O'Keefe and Pitt (1991) state:

> "If VIS folklore is to be believed, then decision performance using a VIS should be good."
>
> (Page 344)

They do not specify exactly which piece of folklore they are referring to; however, they make their statement in the context of what they perceive as the "mediocre" performance by their experimental subjects in finding exactly the right combination of coal trucks to coal yard jobs in their experimental problem. This is a specific task; it does not take into account the whole coal yard problem (about which we do not know), or issues related to problem definition. A coal yard manager (or whoever would make this decision in the real world) would have knowledge of the whole coal yard problem and would use the VIM to solve this specific allocation problem in the light of all the other issues. This is not to suggest that the 'right' solution is not important. However there may be many factors which affect the 'right' solution and what VIM (in a real situation with a real manager) would do is allow these factors (excluded from the O'Keefe and Pitt experiment) to be taken into account. (The fact that O'Keefe and Pitt do not compare performance with a non-VI model is also important, but is discussed in section 3.3.3). The issue here is that, although some may conjecture that VIM improves specific solution-finding sub-tasks, these are not the main target of VIM's solution finding enhancement. The real aim is to improve the whole solution by allowing important wider issues to be included in the solution-finding process. Specific experiments like those of O'Keefe and Pitt are not designed to look at this wider issue.

3.9.3 One way in which some evidence can be collected and lessons learned is via case studies. Unfortunately, despite evidence of considerable use of VIM (Kirkpatrick and Bell 1989) there are few published case studies. Exceptions are: Hurrion (1985), Billington (1987), Parker and Bell (1989), Bell et al (1990), Walker and Woolven (1991), Porter (1991) and Gravel and Price (1991). While there is much agreement between these cases and the other literature, single cases are perhaps limited in their usefulness. In conducting and reporting a single study its author is perhaps unlikely to be able to distinguish those features of the study which are consequences of the features of the individual problem and those which are consequences of, say, VIM. Further, these cases tend to report the attributes of the study affected by VIM, rather than a more detailed analysis of which aspects of how VIM was implemented appeared to work well. This, latter, option would have been particularly relevant to this research programme. (An exception is Parker and Bell, 1989, who do reflect on this issue and their contribution is discussed in section 8.5).

3.9.4 The previous two sections have discussed the lack of evidence for some of the literature based reasons for using VIM. Nevertheless many people are using VIM and thus, accepting that this use exists, the literature can be criticised on a second flank. There appears to be little published research on how VIM should be conducted. Bell (1987) has given some reasons[6] for having a methodology specific to VIM and Parker and Bell (1985) used a methodology which they designed specifically for VIM. (Although, interestingly, Bell (1987) only references this earlier paper in a different context). They separated the design of the visual and interactive aspects of the model from the design of the algorithm. From their discussion, they believe this brought some benefits and, as will be shown in Chapters Five and Seven this appears to match findings in this thesis; however, their work is based on the experience of only one study, and suggests only one (albeit important) methodological change from a traditional approach. Bell and Parker's (1985) paper is an important foundation for the research reported in this thesis. It will be referred to in both the chapters which attempt to answer the research questions posed in Chapter One. However it is just a first step, upon which this thesis attempts to build.

[6] Although section 3.3.1 has noted that these are not particular to VIM.

3.9.5 Bell and Parker's (1985) paper does not discuss methodological issues in much depth, but those areas which it does consider are at one particular level. They consider the issue of how to go about doing VIM when the decision to use VIM has already been taken. (Although it does allude to wider issues and the paper's contribution to such will be discussed in Chapter Eight). The issue of when VIM should be used has had very little consideration. Most research literature in the VIM arena makes some mention of benefits (cf Section 3.4). But benefits must be seen in the context of purpose and there is little reflection in VIM literature of what the overall objective might be.

Why, for example, do we consider it an advantage to increase a client's understanding of a model? This section is not intended to sow doubts that this might not be beneficial, or that the O.R. practitioner community might have taken up VIM with such keenness (Kirkpatrick and Bell 1989) if there had not been purpose.

However it seems worth reflecting on:

1) Why are some of the benefits (or attributes) in section 3.4 seen as beneficial?

2) Is there a literature which suggests we need some of these benefits, even though the VIM literature appears not to consider

the wider implications of why it is providing its postulated benefits?

It is perhaps worthwhile reflecting on these issues because, if we wish to provide some help to those who apply VIM (in the form of some guidelines on how to go about using VIM in a better than ad hoc fashion), then having some idea of strategic purpose is perhaps going to assist us in formulating those guidelines. This discussion is continued in Chapter Eight.

3.10 Conclusions

This Chapter has examined the literature in the field of Visual Interactive Modelling. The aim, specifically in section 3.9, has been to indicate some shortcomings in this literature. The research reported in this thesis will fall far short of answering all the issues raised. Nevertheless, in formulating this criticism, one is led to pose a method for attempting to answer some of them. Chapter Four will look at research methodology issues in an attempt to overcome some problems with previous research; Chapters Five and Six will report research which is aimed at conforming to the discussion in Chapter Four and then Chapters Seven and Eight, respectively, will attempt to draw together some guidelines on conducting VIM and attempt to explore the wider issues posed by both Chapter Two and section 3.9.

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 Introduction

Chapter One set out the aims of this thesis and then the following two chapters established, by a discussion on the research literature relating to Visual Interactive Modelling and certain aspects of Operational Research, a context within which this research is being conducted.

Following the current chapter there are two chapters presenting and discussing the substantive element of this research programme.

The purpose of the current chapter is to present, and argue the validity of, the research methodology used in conducting the entire research programme but with particular emphasis on the substantive elements.

In particular, the status of the evidence which is presented in the substantive chapters is discussed. This is especially important in the case of Chapter Five which reports the conduct of six 'Action Research' studies. There is a fine dividing line between 'Action Research' and 'Consultancy' and it is important to establish where the programme reported in Chapter Five is based.

4.2 Methodology for this Research Programme

Section 3.3 established that, while there is a body of academic research literature on VIM, this is mainly literature reviewing the technique, reporting case studies, or postulating future uses of VIM.

There is little evidence of experimental research work undertaken to discover if VIM actually benefits its users. (For exceptions see section 3.8.1 and O'Keefe and Pitt, 1991) Neither is there any prescriptive literature attempting to suggest how VIM should be implemented. Few of the case studies appear to be based on any underlying theories. They simply use the available software, in an ad hoc manner, to help the particular client/problem.

There is little in the VIM literature which constitutes a "body-of-experience" which can be referenced to infer what might be beneficial in the practice of VIM or what might reduce its potential benefits. As Chapter Three has noted, there are specific pieces of research which have been conducted to examine certain aspects of the practice of VIM. However, while making a contribution to knowledge of some value (see section 3.3.3), this research is mainly of a specific nature rather than examining the use of VIMs in the context of the whole O.R. study. They, for example, examine the benefits of different types of display without first examining how to reach a design for either type of display or who might actually make use of the display, or whether the display is likely to be used in isolation from other sources of information. There are wider questions which, in the context of some of the issues raised in Chapter Two, this research programme will concentrate on.

The intention is that this thesis should do *no more than* postulate a series of guidelines aimed at good practice in Visual Interactive Modelling. It would be much too ambitious to attempt to prove, at this stage in the development of the VIM field, that one set of guidelines is 'better' than any other set. However, these guidelines cannot be presented without evidence that they have some potential for being better than an entirely speculative set of suggestions.

The methodology used to produce the guidelines has been to conduct empirical research to build a body of catalogued experience and to draw on this, and also on the available literature, to derive by argument a set of guidelines. It cannot be argued that these guidelines have been tested.

The only testing which has occurred has been that some early forms of some of the guidelines were used during some of the empirical research and, where relevant, it has been noted that their efficacy has not been refuted. However, the nature of the empirical research (see sections 4.3 and 4.4) is such that it was not set up in a manner which would make refutation easy.

Much further research is necessary and Chapter Nine discusses areas where the guidelines could usefully be examined in detail. The guidelines form a framework or approach for conducting VIM studies. As such detailed examination of individual aspects of the guidelines is worthwhile within the context of the approach to the whole study. This does not the exclude the possible need for further research and testing of the framework itself.

The empirical research took two forms: a series of six Action Research studies and a series of laboratory based experiments.

4.3 Action Research Studies

The decision to use an Action Research methodology for part of this research programme was grounded firmly in the context of Visual Interactive Modelling being an O.R. activity. The discussion in Chapter Two has established the nature of some of the activities of those who conduct O.R. and the nature and difficulties encountered by those who are clients of O.R.

If improving the conduct of VIM is part of improving the conduct of O.R. then, as O.R. is attempting to help its clients in the context of their real-world 'messes', improvements in the conduct of VIM are only relevant if they apply in those real-world 'messes'.

The consequence of the above statement is that research into effective conduct of VIM probably has to be conducted in a way which enables that research to take full account of the organisational, political and social situation in which VIM will be used.

4.3.1 Social Science Research

The requirement stated in the previous paragraph is also true of most of the research which relates to activity in management, or indeed any human-based system. It is a difficulty because the notion of 'research' implies a search for 'facts' which are in some sense precisely observable under replicatible circumstances, or, at least, are subject to some statistically measurable experimental error which has been established by multiple experiments by the researcher; it is both difficult to 'experiment' with human beings and difficult to replicate many experiments. This is especially the case with 'management' type research where variety of management situation and rareness of opportunity for experiment makes it unlikely that even broadly similar situations can be found for replication.

Furthermore, much research is about observation rather than testing; about gaining *insight* by watching for clues about potential relationships. Observational research conducted in isolation from some of the issues which are important when actually conducting O.R. would probably reduce the chance of gaining insights which would apply to the real world.

While there are a number of epistemological traditions in scientific research, an assumption which runs through most of these is that it should be possible to replicate an experiment and observe consistent results. The observations should not be dependent on either the observer, or the number of times the experiment is conducted.

However, research in the social sciences cannot necessarily conform to these assumptions. Research which is related to human activity, where the observer is human, and where the observed are conscious that they are under observation is itself part of that activity. That the research itself is taking place will affect the activity, and the activity will affect the research.

This difficulty should not be a reason to abandon research in the social sciences on grounds that it is doomed to be unscientific. Some activity in social science which has the aim of improving a social system would seem a worthwhile activity. Discovery of relationships between actions and results in a social system, while much less predicable than in some scientifically observable system, can still be of benefit to human kind.

Susman and Evered (1978) provide a critique of 'positivist' science from the point of view of research in social science. They state that they find positivist approaches "...to be deficient in their capacity to *generate knowledge* for use *by* *members of organisations* for solving the problems they face" (page 585, my italics). They then offer a detailed argument to explain their statement.

Lewin (1946) proposed the term 'Action Research'. Action Research accepts the non-repeatability of social science research, it accepts the involvement of the researcher in the activity which is subject of the research and that this will probably change the system which is under observation. Indeed an element of significance for many of the writers on Action Research is that the system under investigation is in need of some *change*. Rapoport (1970) states:

> "Some social scientists have differentiated action research from the larger field of applied research by the existence of a client with a problem to be solved"
>
> (page 499)

However the main emphasis of Action Research is that the researcher and the observed systems are interacting with each other and that, while each may have their own goals, they accept the presence of each other in their combined system, and that the presence of each is likely to affect the other.

> "Action research aims to contribute *both* to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration with a mutually acceptable ethical framework." (Rapoport, 1970, page 499)

Susman and Evered (1978) review the validity of Action Research. They question and discuss the grounds on which it can be regarded as scientific and show that it overcomes the difficult issues inherent in using a positivist approach to social science research. They argue that Action Research is *not* science if considered from the same philosophical viewpoint as positivism, however, they further argue that there are other established philosophical viewpoints from which Action Research can be legitimised. The detail of these arguments is beyond the scope of this research, however, their existence is important for establishing that the methodology adopted for Chapter Five is valid. Susman and Evered (1978) is accepted here as a basis for the validity of Action Research.

4.3.2 Action Research for this Research Programme

The previous section has established that Action Research is both legitimate and appropriate in some research in the social sciences. Two important questions remain:

(1) Is Action Research appropriate in this particular case? and

(2) Are the studies which will be reported in Chapter Five genuinely Action Research?

Section 4.3 above noted that the nature of O.R. activity means that research into the conduct of O.R. should probably always take cognisance of the client's organisational, social and political situation. As this research relates to O.R. activity it is important that this research is conducted in a way which has been established as valid for other research which needs to take cognisance of the client's organisational, social and political situation.

Susman and Evered (1978), in discussing the nature of the contribution which Action Research can make to the growth of knowledge, state that the shift away from a 'positivist science' perspective enables contributions to knowledge to shift away from prescription of rules towards:

> "...the emergence of action principles or guides for dealing with different situations."
>
> (page 599)

As one of the research questions posed in Chapter One is attempting to find potential *guidelines* for Visual Interactive Modellers it would seem that Action Research might be viewed as appropriate for this research programme by Susman and Evered.

In order to conduct a series of studies which would take as complete an account as possible of the real world situation in which O.R. practitioners might wish to employ VIM an arrangement was made to conduct some real O.R.

studies, with the researcher performing the role of Operational Research analyst. Chapter Five gives further details of the arrangement but here it is important to establish whether the studies undertaken can genuinely be regarded as Action Research, and if not, whether they remain legitimate and valid.

A normal O.R. activity is not Action Research because an important element of Action Research (and any research programme aimed at gaining knowledge) is that the researcher should gain as well as the client. In normal commercial O.R. activity the only (intentional) gain by the O.R. worker is the consultancy fee. Simply conducting consultancy does not necessarily contribute to knowledge and, if it does contribute to knowledge this is likely to be in an ad hoc and inefficient manner.

The studies reported in Chapter Five were all conducted by using a regime designed to *both* conduct the study in a way which would minimise the way in which the study was affected by the additional aim of gaining knowledge *and* maximise the insight gained by the researcher.

Each of the studies took place over a period of weeks or months and some of them overlapped with each other. Interaction with the clients was sporadic and dependent on their availability, progress of model construction and other constraints. However the most rich source of data for this research was the interaction with the clients. This normally took the form of a meeting which would last between an hour and a whole day. Usually there would be several people at the meeting, some of whom would be familiar with the study (and this research programme), others might be new to the study (and might not be part of it again). These meetings usually concentrated on solving the client's problem to the almost complete exclusion of consideration of the research programme reported here. The research programme gained by the researcher being able to conduct (or attempt to conduct) the meeting in a manner which was cognisant of the progress of the programme and insights which required testing. (See the descriptions of the individual studies in Chapter Five). The most important time (with respect to the meetings) for this research programme was the period of reflection which always followed the meetings. The evening, or day, after each meeting was spent writing notes on insights from the meetings. This period of reflection led to further ideas for trial at later meetings to building the body-of-experience which is reported in this thesis.

The above discussion is used as a basis for *both* claiming some legitimacy for the design of the part of the research programme based on studies of VIM in real situations, *and* claiming that the design of the conduct of the studies adheres to the principles of Action Research.

It is interesting to note a framework used by Susman and Evered (1978) when they expand on Rapoport's (1970) definition of Action Research. This is illustrated in Figure 4.3.2.A

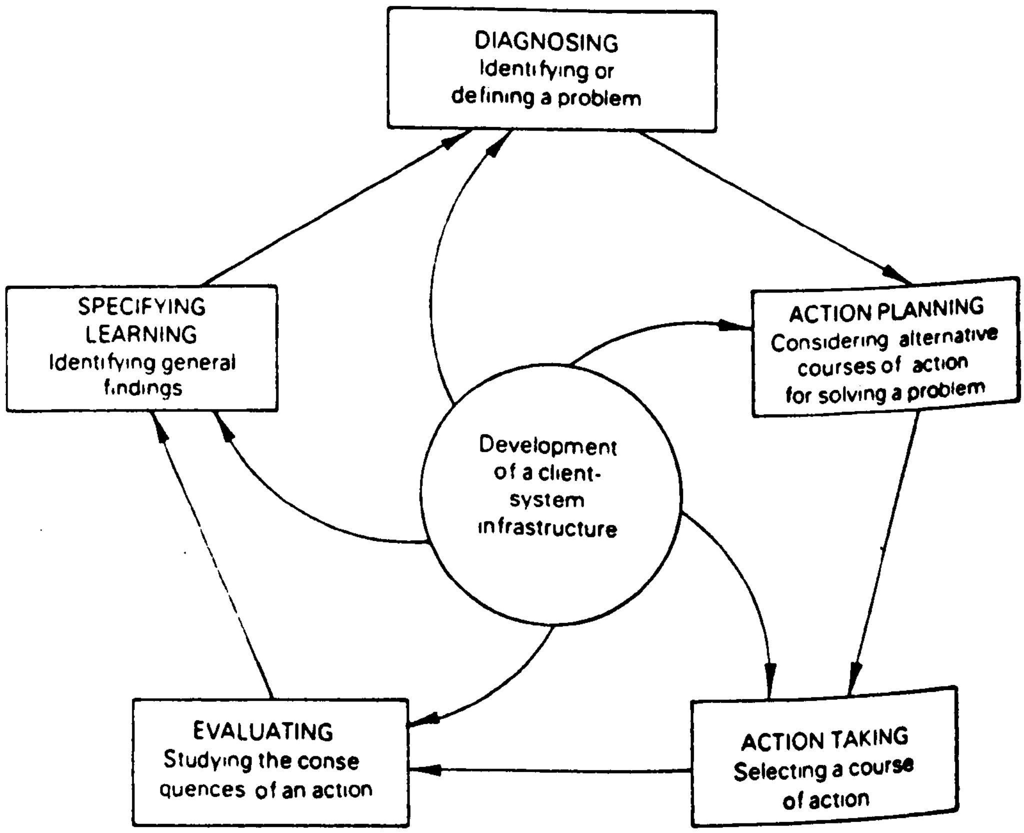

Figure 4.3.2.A - From Susman and Evered (1978)

There is some commonality between this framework and the process used to conduct the Action Research studies reported in Chapter Five.

4.3.3 Summary

This section has discussed the need for Action Research (as opposed to a methodology based on, for example, 'positivism') in the field of social science research. Further that this is appropriate for research into improving the conduct of O.R. and, within O.R., Visual Interactive Modelling. The section has then argued that the particular set of studies which are reported in Chapter Five validly constitute Action Research studies.

As such, the observations and evidence reported in Chapter Five and used in the results chapters (Seven and Eight) must be regarded with the status appropriate to evidence from Action Research studies. It is not 'hard' evidence in the 'positivist' sense, rather it encapsulates insights and perceptions which are a different form of contribution to knowledge and which perhaps could not have been gained by more conventional means.

4.4 Experimental Research

Section 6.1 discusses how Action Research studies may have certain limitations. For this reason further empirical evidence was collected by a different method. Many aspects of the Action Research studies are difficult to draw clear conclusions from. The nature of Action Research is such that each of the studies differs from the previous in many respects other than those which the researcher has chosen to change. The method chosen to supplement the Action Research studies was a series of experiments away from the live O.R. studies.

This series of experiments used a number of graduate students as research subjects. These subjects attempted to find a set of control rules which would make part of a factory operate efficiently. To do this they used a Visual Interactive Simulation Model.

While this series was designed to reduce the number of variables changing in order to ease the process of drawing conclusions about the use of VIM, these experiments cannot be described as 'Controlled Experiments'. Controlled experiments are strictly controlled, changing only the independent variables which are under examination in the experiment. Chapter Six will discuss this issue further and describe the exact nature of these experiments. Methodologically they were not 'controlled' but, nevertheless it was possible to observe some effects which were opaque in the Action Research Studies.

4.5 Summary

This chapter has argued the case for using Action Research and experimental, laboratory based, research, to build a body of experience which can then be used, along with research in the published literature, to develop a set of guidelines for Visual Interactive Modelling.

CHAPTER FIVE

ACTION RESEARCH STUDIES

5.1 Introduction

5.1.1 Discussions in section 4.3 argued for some of this research programme to be conducted in an industrial environment to help ensure applicability of any research output. If a series of real studies could be undertaken it might be possible to build up a comprehensive understanding of how to conduct studies using VIM.

The plan was that for the first study an initial, simple, set of concepts would be used to determine the actions to be taken during the study. These would then evolve over the course of the series of studies into a set of guidelines. (Presented in Chapter Seven). While it would not be possible to rigorously test (in a Popperian sense, see Popper, 1972 and Magee 1973) these guidelines, they would, nevertheless encapsulate a body of experience to be used by practitioners as a basis for studies and by academic researchers as a basis for further, perhaps more rigorous, research.

5.1.2 Location of Studies and Role of Researcher

The facilities to conduct this 'Action Research' were provided by the Operational Research (O.R.) unit of B.L. Systems Ltd. At the time of the studies, the O.R. unit conducted the majority of its work for the various divisions of the Rover Group. However, all of the studies which this O.R. unit undertakes are done on a 'consultancy' basis. (ie as though the unit were an independent external firm).

In the case of most of this O.R. unit's work the clients initiated each study. The client is in some situation which the client believes may be helped by the O.R. unit's (well advertised) services. The client has to pay for the study to be carried out. Their relationship with the O.R. unit is as it would be to a firm of external consultants. Indeed there is nothing to stop these clients using any firm of consultants. Thus, to summarise the implications of the above statements, the problems tackled are all of significant interest to their respective clients and the clients will voice their disapproval if they are disappointed with the way their study has been conducted.

The researcher was able to act as an analyst in each of the studies. These studies were undertaken by a team of two people; a project leader and an analyst. The project leader's time involvement was quantitatively small (although important). The leader ran several projects concurrently, and so could devote only a small amount of attention to each. The project leader's task was mainly to set up the project; to agree terms of reference and costs with the client. The project leader's role was also to interface with senior levels of management on the client's side should any difficulties arise. Thus the analyst (the researcher in this case) performed all the day to day tasks involved with the study.

Consequently, the researcher was able to obtain direct experience of using the VIM and the experience was on studies conducted in a normal environment to be found in an industrial O.R. group.

5.1.3 How was Data from these Action Research Studies Collected?

In discussing the decision to use an Action Research methodology for part of this research programme, section 4.3.2 described some aspects of data collection during Action Research. The purpose of the current section is to give details of the designed data collection method used during these studies.

The research reported in this chapter is attempting to gain data which might be useful for Chapter Seven, which will attempt to build a body-of-experience on VIM. The source of data is the researcher's individual experiences from these Action Research studies. The experiences and other aspects of the studies can be compared and contrasted but before this is possible the experiences must be gained and documented.

Many meetings with clients occurred during the studies. After each of these meetings (within 24 hours) a period of reflection was organised. This was used to document those aspects of the meeting, which appeared to the researcher to be of significance. In particular, this period of reflection was of importance for considering how activity at this meeting related to activity at previous meetings or ideas which were forming. This cannot be regarded as a perfect process, observers will tend to see only those aspects which they want to see. Nevertheless, as discussed in Chapter Four, this is a way of gaining insights in a context from which it might not otherwise be possible to gain any data. It is this documentation which forms the basic data collected during the Action Research studies.

5.1.4 How is Data from these Action Research Studies Reported?

Data alone does not constitute results. In Chapter Seven (the first of the two 'results' chapters) the data collected during the whole of the research programme is brought together to form a body-of-experience. This is not the task of the current chapter. Nevertheless, to report raw data would also not be useful. Each of the studies is reported in the form of a narrative which describes the data collected from the viewpoint of the end of the study, and in the context of a knowledge of the data collected in the other studies. The data is also collected together under headings which:

a) group data in a particular study in a structured (rather than random) sequence and

b) allow contrasts between studies to be made more easily when it has been possible to use similar headings in different studies.

The studies are reported chronologically by study, but the data within a study is reported under these headings. The wording of section headings is designed to allow the matching of *related* data from *different* Action Research studies. For example, sections 5.3.3.1 and 5.5.2 both have the same heading (Responsibility) and discuss related data, from different studies.

5.2 Limitations on Generality

The only Visual Interactive hardware/software combination available to the researcher was a commercially available VI simulation package. The consequence of this was that all the studies carried out were of situations where simulation was likely to be of benefit.

However this restriction is less constraining when considered in the context of the objectives of the research programme. Two issues are relevant here:

5.2.1 It might be said that the research reported here would only be applicable to VI simulation and not to VI modelling in general.

One of the research questions posed in Chapter One considers the possibility that VIM may potentially be a partial solution to some of the problems with the 'old O.R. paradigm'. However this research cannot test more than a few aspects of O.R. with VIM and so, while the testing is restricted to one class of model, it will be argued that some of the body of experience established from the simulation arena might give clues about how to improve O.R.'s effectiveness on a wider front. Chapter Eight discusses this in detail.

This chapter necessarily concentrates on aspects of VIM which are relevant to simulation studies but, it is argued in Chapter Seven, that many points are relevant whatever underlying technique is being used.

5.2.2 The term 'simulation' is perhaps too restrictive as a description of the technique available. It is true that the VI package available was designed as a discrete event simulation tool with a VI interface. However, in practical use, 'VI Gaming' might be a better term. 'Simulation' is often synonymous with 'Monte-Carlo' methods. It is often used to determine the nature of the long term stability of a system; to see how a system will perform in the steady state.

It may not be the steady state that is most important in many systems. It may be more relevant to learn about unusual or extreme circumstances. It may be more important to examine specific events that occur and the circumstances that surround them. In developing a set of control rules or in designing a piece of plant it is often easy to make it cope with normal running conditions but less simple to design a control system for special conditions (eg start-up or shutdown, tea breaks and breakdowns).

Therefore the notion that the action research studies were entirely related to 'simulation' would be misleading. However, in all the studies the models that were built did simulate, with respect to time, the behaviour of the relevant systems.

5.2.3 Further note on the use of Simulation

The above section noted that all the action research studies were conducted using *simulation* modelling. It is recognised that some of these studies could have been undertaken using different techniques. Furthermore, it is possible that other techniques might have been more appropriate. However, as stated above, simulation was the only Visual Interactive technique available and was therefore the only technique which could be used in the context of this study. If the researcher (or the project leader) had considered simulation to be against the interests of the client, then the researcher would not have proceeded with the study (and another analyst would have been found). Nevertheless, further consideration of the appropriateness of simulation, relative to other techniques, is outside the scope of this research programme.

As the opportunity to conduct these studies was provided by an organisation based in the UK car industry a further limitation on the generality of any findings must be considered. Perhaps any results of this research programme will only be applicable to either the car industry, or the particular car manufacturer. It is perhaps easy to believe one's findings have general applicability when they have not been tested and one has no experience of other industries. This issue will be discussed further in Chapter Nine, however, it is raised here because the conduct of these studies was affected by this concern.

The first five Action Research studies were conducted in the car industry but the opportunity arose for the final study to be undertaken with a company who manufacture desk-top photocopying machines. This opportunity was taken on the grounds that it might lead to different insights, but with the acceptance that one study, in one different industry, is by no means a 'test' of generality.

The remainder of the chapter discusses each of the six Action Research studies in chronological order.

Only the features of each study which make a contribution to the theme of this thesis are discussed.

5.3 Longbridge Strategic Case

5.3.1 Introduction

At the time when this research started it was still a year before B.L.'s award winning Metro would be launched.

There was much planning to be completed. While decisions had already been taken about the physical design of the factory's machinery, the logical way in which it would be used was still to be determined.

There are very many different derivatives of a type of car. For example, taking the case of a particular car, table 5.3.1.A illustrates the meaning of and number of 'derivatives'. This table considers only one type of trim level, engine size and number of doors. It has not considered any other options (including colour) each of which would multiply the size of the total list of Metro derivatives.

Model	Trim	Engine	Doors	Auto	Sunroof	RearWW
Metro	L	1.0	3	n	n	n
					y	
				y	n	
					y	
			5	n	n	
					y	
				y	n	
					y	

Table 5.3.1.A - A Partial List of Metro 'Derivatives'

It would not be cost efficient to produce the derivatives of the Metro in a random sequence.

For example, if 50% of the cars to be built will have a 'sun-roof' then the production line where these are fitted will be allocated sufficient labour to cope with the extra work involved on 50% of the cars. Once this is decided it will not be possible to build 'non-sun-roof' cars all morning and 'sun-roof' cars all afternoon. In this case 'sequence constraints', as they are known, would probably state that no more than two in every four consecutive cars can have sun-roofs.

Similar constraints exist throughout the production process. They make the problem of designing control rules particularly complex. In the past the problem had been overcome by 'over-manning' the production line, (eg in an extreme case allocating sufficient men to fit a sun-roof to every car).

The Operational Research unit was heavily involved in designing control rules for various parts of the Metro works at Longbridge. These control rules had two purposes:

1) To decide which derivative is best to make next at a given stage in the process...

2) ...while at the same time allowing maximum flexibility in choosing which derivative to make next at other stages.

At a particular stage of the process there will be a limited choice of which derivative can be made next. In the current circumstances one of these will be better to make than the others (for the given stage). However the decision made may affect the choice available at other stages of the process.

It would be possible to design control rules which made one process highly efficient at the expense of the efficiency of other processes.

5.3.2 Why Build a VI Simulation Model?

Simulation models of several stages of the process existed but there was not a model which covered the whole plant. A model which could show the interaction between different areas of the plant might be beneficial.

While the O.R. unit could specify (from an analysis of the output of several models) what problems a particular set of control rules in one area would cause in another, they could not easily convey these results to the Longbridge management.

A VI simulation model would be of major assistance in bridging this communication gap and it would also be of use in future analysis. It would be able to answer one-off questions to do with hour-by-hour control. If, for instance, a process broke down the model could be used by the production personnel to predict the consequences in the next few hours and to try out alternative emergency measures. Most importantly it would allow a global view to be taken by any of its users. They would be able to see the effects in other areas of decisions taken in their own area.

There was no specific 'problem' in the case of this study. Rather it was felt that a VI simulation model of this plant could assist with communication and future hour-by-hour control. The study was requested by senior management at the plant. They purchased the computer equipment required for the study and committed themselves to a large consultancy fee because they regarded such a model as of strategic importance.

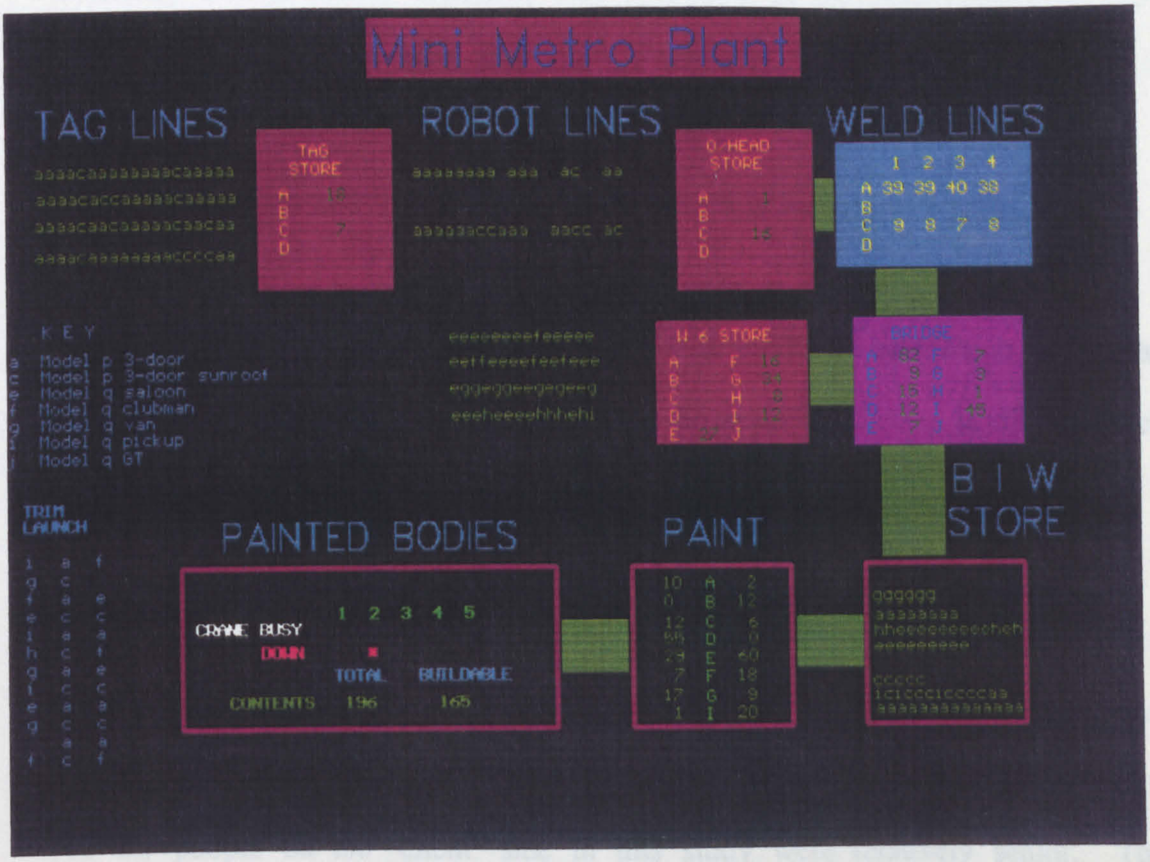

Figure 5.3.2.A - The Longbridge Strategic Model Screen

5.3.3 The Role of the Researcher in the O.R. Project

The involvement of the researcher was as follows:

1) Collating data on the physical characteristics of the plant.

2) Building the model.

3) Attempting to put the model into use along the lines described above.

Collating the data and building the model were relatively simple tasks.

However, it did not prove possible to put this model to significant use. The analysis of the reasons for this failure do however contribute to the research programme and these are discussed below.

5.3.3.1 Responsibility

All the people on the 'client' side in this study were relatively senior. The clients consisted of the people whose responsibility it was to run the Metro part of the plant once production started. They were already running the production of the existing Longbridge cars (Mini and Allegro).

The organisation of the production side of the Longbridge plant is such that each process manager reports directly to the plant director, who is the only person who has overall control of the whole plant.

This caused difficulties in the use of the model. The plant director was really the only person who was interested in how the plant performed as a whole.

Individual managers would verbally recognise the importance of global efficiency but in reality appeared only interested in the performance of their stage in the process.

Their reaction to the VI simulation model fell into two categories.

1) Some were verbally very enthusiastic and eager to work with the model and to get it set up ready for solving hour by hour problems as they came along.

2) Others declared themselves against the model. The reason stated by the plant director for this reaction was that some individual managers were worried that their stage would be identified as the cause of the global problems. This may have been true; this is a plant where relationships between areas were bound up in customs and practices. However in fairness to the people concerned this may not have been the only reason. It may also have been that they genuinely believed that this VI model, in taking what could be said was a 'general' rather than an 'complete' view would not actually assist them in coping with production control problems.

If the plant director was right then he was the person who ought to be using the model. With overall control he was in a position to determine the 'best' operating rules for the whole plant and pass these down as instructions.

However the plant director felt he could not spare sufficient time for this task and that it should be delegated to one of his subordinates. But as he said, "...there's nobody in the right position to enforce anything that's decided."

5.3.3.2 Perception of Model Detail

It was decided that if the model was going to be of any use it would have to prove itself. Therefore the plant director suggested that those areas which were interested in using the model should go ahead and use it and, if this use was successful, he thought the rest would follow.

At this stage further difficulties were encountered. Without exception the various managers said that they could not see accurately what was happening in the part of the model which related to their own area of the plant. Conversely, they each said they thought more than enough detail was shown of areas other than their own.

This was indicative of several of the difficulties with the model. Individual area managers did not know what was important in areas of the plant other than their own. In attempting to take into account global considerations they tended to do so on simplified assumptions that overlooked the difficulties faced by managers in other areas of the plant.

It appears from these observations that, when people do not actually have to cope with the day to day problems in an area, they perceive the model as showing sufficient detail.

As there had been no initial, specific, 'problem' that the model was built to solve it had to be written in a 'general' form. By this it was intended that it would be general to any (or most) problems in the Metro plant. It was built to include sufficient level of detail to allow the global effects of control rules to be seen. With this goal in mind it was thought unnecessary to include very specific details which might have been included in a more accurately focused model. Every model is a simplification of reality but unfortunately this model was an oversimplification.

There are two difficulties here:

1) The area managers' ignorance of areas other than their own.

2) The oversimplification of parts of the model.

The matter of oversimplification is dealt with first.

5.3.3.3 Forms of Oversimplification

An example of this oversimplification is in the treatment of the storage area for car body shells awaiting the paint process. It consists of a number of lanes as shown in figure 5.3.3.3.B.

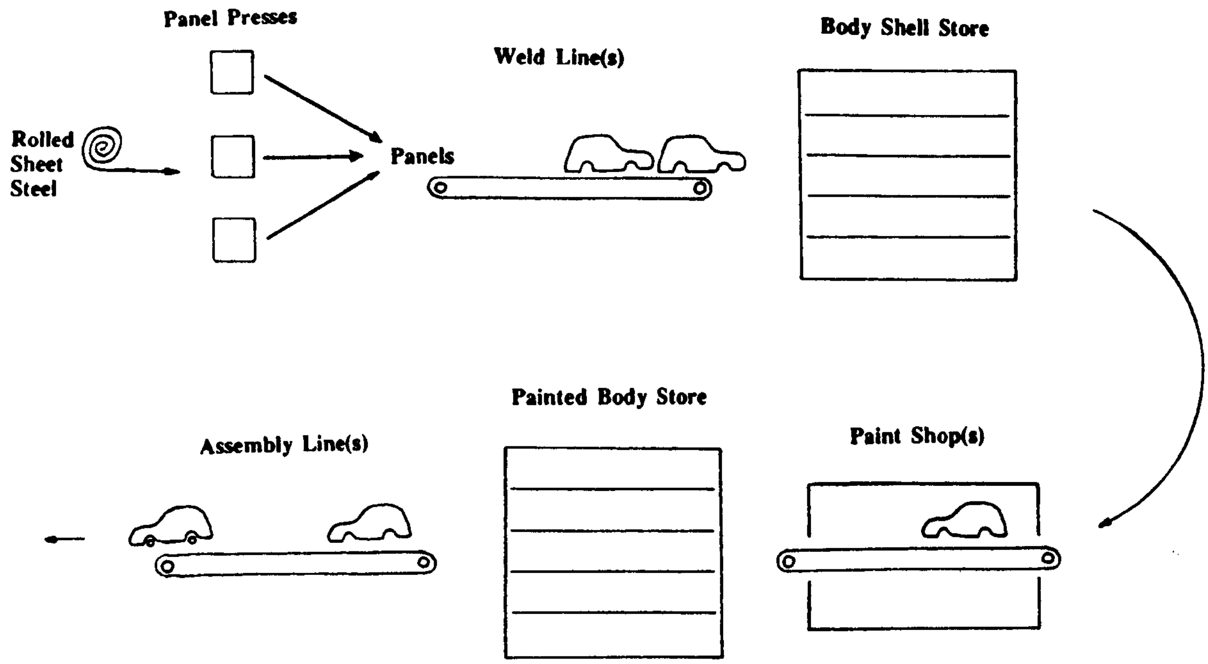

Figure 5.3.3.3.A - The Car Production Process

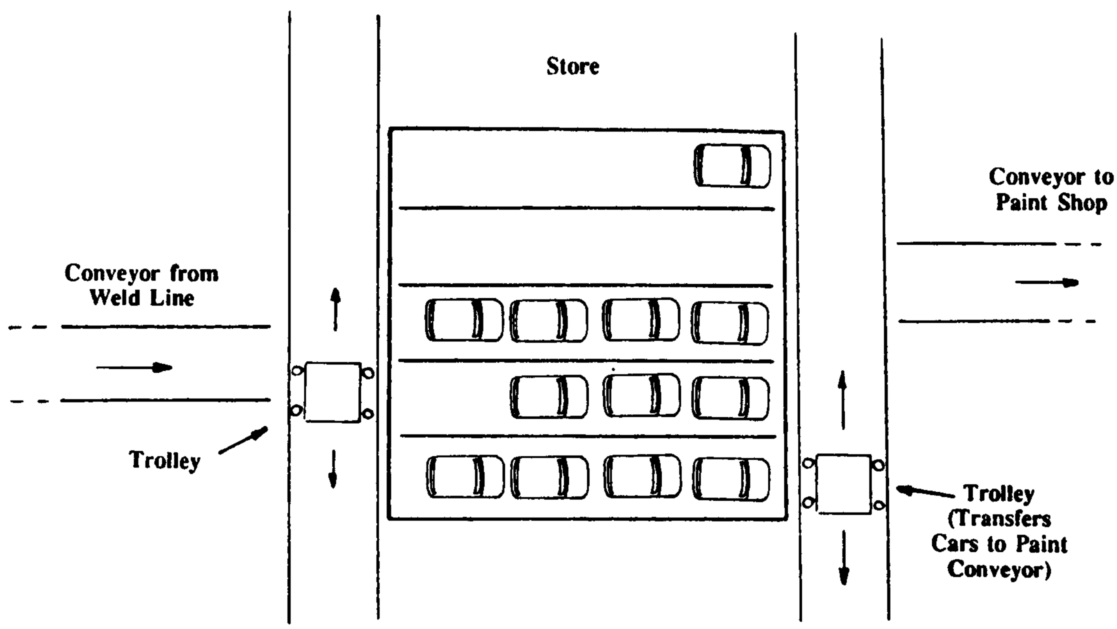

Figure 5.3.3.3.B - The Pre-Paint Store

Cars are selected for painting from the front of any lane. The mechanism that feeds cars into the rear of the store is limited in that, under certain circumstances, it cannot feed two consecutive cars into the same lane. The model was simplified by ignoring this complication.

While it was only in extreme cases that this simplification would have made a difference to the results of model runs it is often the extreme cases that are most important (see section 5.2.2).

Another example of the problem of over simplification can be illustrated by the case of conveyors which move cars from one stage to another. Conveyors are used in many places in car factories and at first glance have little effect on the logical flow of production. They cannot change the sequence of cars; they merely introduce a delay between processes. However, the type of conveyors used (a 'dog and chain' conveyor) consists of chain in a slot in the ground which drags along hooks which protrude from the slot. Car body shells are normally manoeuvred on trollies and when one of these car/trolley combinations is ready to go to the next process it is placed over the slot. When the next dog comes along the trolley will be hooked up automatically and conveyed to its destination. The model assumed that cars would arrive at the destination process at the same rate as they left the source process. This is unfortunately not the case. Individual circumstances vary but an extreme case of no buffer store at the source process will illustrate the problem. When the source process is running at less than the maximum rate of the conveyor the fastest the cars can arrive at the destination is half the maximum rate of the conveyor, because the car joining the conveyor always has to wait for the next 'dog'. The car will not be pulled by the conveyor at the instant the car arrives at it. (The source process, having no buffer store, has to stop.)

When writing a model at a high level it is easy to overlook the implications of apparently minor simplifications.

Simplifications are not always conscious. During the 'data collection' phase of building this model information about the plant was obtained from various sources, one of which was verbal communication with the Longbridge management. The oversimplification of the logic of the storage areas (mentioned above) occurred because the Longbridge personnel failed to mention a feature of the store which they considered to be unimportant but which a separate study (not conducted by the researcher) showed to be of major importance.

Every model must, by definition, be a simplification of reality. The problem is knowing how much of a simplification and in which parts.

The problem of conscious simplification is rather similar to the problem discussed in section 2.3.7.4. You can only tell which parts of the model will be important once the model exploration process is under way.

However, unconscious simplification is a more intractable issue. To some extent the act of going through the modelling process may show up differences between the behaviour of the model and reality but this is not always the case. (Especially when the system may not yet exist in reality). Establishing the right level of simplification prior to the model exploration is important for making effective use of a VI model (See section 5.5.5).

It is necessary to leave further discussion of this issue of simplification until Chapter Seven. There are perhaps methods of avoiding the problems of over simplification but in developing these ideas it will be necessary to draw on the experience gained from later Action Research studies. These will illustrate for example a difference between 'strategic' models of a whole plant and models of specific areas. (See sections 5.4.8 and 5.5.5).

5.3.3.4 Manual Decisions

There is a further class of simplification. The smooth running of a plant of the size of the Metro facility is not achieved merely by logical control rules which operate automatically like a piece of machinery. There are many places in a plant where choices are made by a human decision process. Highly complex situations sometimes exist and it is necessary to take a decision based on an appreciation of the relevant factors 'on the ground'. It is not possible to devise a rule book to cover these situations and in the same way it is not possible to write a program in a computer simulation to emulate these human decisions.

At the Longbridge Plant these 'human decisions' were rare interventions. They were applied during unusual circumstances; when the plant was not running normally. It was decided to ignore these human decisions and only simulate the operation of the automated control rules that would be used under normal (or ideal) running conditions.

In some systems which are simulated it may be that some decisions are made by human judgement even under normal running conditions. In this case the simulation could be simplified by attempting to emulate the human decision with automatic control rules. This would be a simplification but sometimes it might be satisfactory for the problem under study.

At Longbridge this was neither attempted, nor would it have been appropriate. Occasions of human intervention would be specific exceptions to handle unusual conditions. Thus it appeared that ignoring them would still make the model useful for simulating normal running conditions. However, it emerged that, Longbridge management did not feel they required assistance with normal running conditions. An ambition was that the model would be used as a tool for investigating what action to take in extreme situations. It was not normal running conditions that the model would be simulating.

An example of the problems caused by this situation was 'holes in the wall' (as they were known by Longbridge Management).

There are stores between each major process. However these were really designed for resequencing the cars and could only cope with limited amounts of buffering. If there were major stoppages of processes (as was likely due to potential 'teething' troubles during the first few months of Metro production) the simulation would show a dramatic reduction in the overall capacity of the plant. However a management decision could be taken in these circumstances to remove cars temporarily from the system by carrying them outside to the employees' car park on fork lift trucks (through 'holes in the walls').

The lack of 'holes in the wall' in the model was a major limitation to its usefulness. A way out of this problem can be seen in a later Action Research study (see section 5.6.4). Rather than ignoring the human intervention or simplifying it to automated control rule logic, it is possible to include the human decisions in the simulation as it progresses. The VI simulation model should have been designed so that the significant human elements of the system could have been easily and efficiently integrated into the model.

This principle is used throughout the remaining studies reported in this thesis. (See also Chapter Six).

5.3.3.5 Remaining Questions

Even if all the over simplification problems could have been ironed out of the model, could it have been successfully used?

The second major difficulty encountered in this study was that the personnel from one area of the plant often did not know the important features of the other areas.

There was nobody involved in this study whose job had responsibilities over the whole plant. However, would this difficulty have still existed if the plant director had been involved in the study? Perhaps that particular individual does not know sufficient detail about any of the individual areas.

There may be alternative solutions to this difficulty other than involving the plant director. Chapter Seven will continue this discussion and will draw on the results of later studies. (See also section 5.7.5).

Due to the difficulties already mentioned this first study did not reach the stage of actually being used to analyze the Longbridge plant. However the knowledge gained from this failure both contributed to the later studies and to the proposals in Chapter Seven. Some of the later studies also cover the whole (or large areas) of a plant. Those can perhaps be regarded as being more successful. (See especially section 5.8). The next study is also successful but in contrast covers a small area of plant. Parts are 'sub-assembled' and sent to the main production line.

5.4 Bolt-on-Items Conveyor System Case

5.4.1 Introduction

Like the previous study this also concerns the Metro plant at a time prior to production starting.

The study was undertaken for a team of industrial engineers. One of their tasks was to efficiently allocate labour to a particular sub-section of production facilities. This allocation was subject to the constraint that such an allocation should not cause any problems for the larger, more costly elements of the factory.

Doors, bonnet, tailgate and front wings are built separately from the rest of a Metro body shell. They are produced on six automatic welding machines. Then a single conveyor system collects the parts from each machine and transports them to the correct places on the main production line. These items are then bolted to the car before it reaches the paint process.

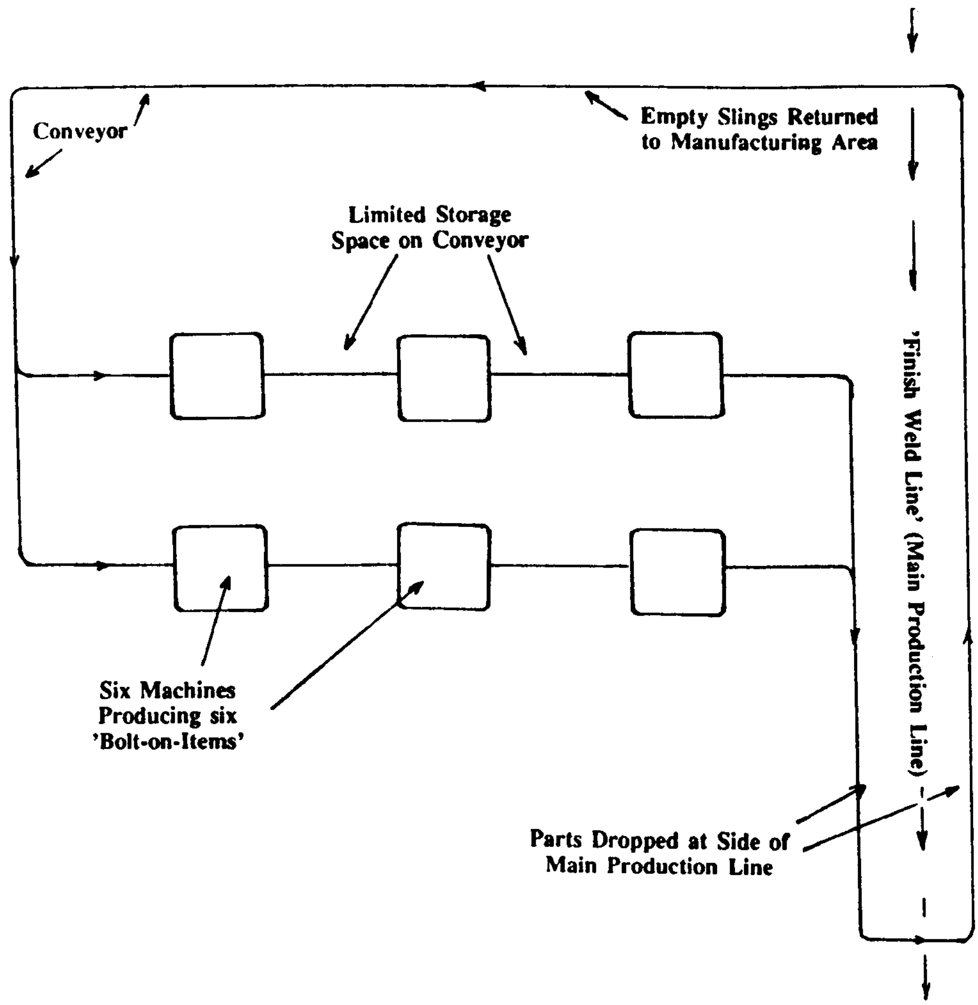

Figure 5.4.1.A - Bolt-on-Items Conveyor System

5.4.2 Objectives and Constraints

The 'bolt-on-items' production area is designed so that the 'items' can be produced in batches by moving labour about between the machines. The problem the industrial engineers had was to determine how this batching should be organised for various different levels of production.

There were large cost savings to be made by batch building, however there were also large penalties to be incurred if the main production line had to be halted because its supply of parts was interrupted. There was only a limited amount of storage space on the conveyor and there was also a limit to how often the labour could be moved between machines. However, the exact value of this second limit was unknown. It was a 'subjective' constraint (cf section 2.3.7.13).

The machines were well understood by the company's engineers so distributions of breakdown repair times could easily be obtained. It was a simple matter to simulate the system and show the effects of any desired combination of batch working.

5.4.3 Multiple Interests

The industrial engineers were not the only people with an interest in this area of the plant. In this sense it was similar to the strategic study of Longbridge (see section 5.3.3.2). The parts handling department were interested because batch production of the bolt-on-items would affect their plans for distribution and storage of 'raw-material' parts to the machines. It was the responsibility of the transport department to provide the necessary conveyors. (The conveyor itself was already installed but more 'slings', which carry the bolt-on-items on the conveyor, could be purchased.) Ultimately, also, the storage space on the conveyor could be increased by altering the conveyor's route. This would have been an expensive option but nevertheless was one of the options considered. Another party involved was the manager of the 'Finish-weld-line' process; where these items are bolted on to the Metro body shells. He was interested because he wanted to know if the chosen scheme would lead to any hold-ups on the main production line. Also there was a possibility of storing some of the bolt-on-items at the side of the main line, off the conveyor. He wanted to be involved to ensure that this option was not chosen. He considered it would increase the risk of damage to the items.

The main participants in the study (the industrial engineers) had experience of modelling by simulation from previous studies with the O.R. unit. It was the industrial engineers who specifically asked for this study to be carried out after seeing the strategic VI simulation model of the Longbridge plant (Section 5.3).

This study appeared not to encounter the difficulties of encouraging the various different departments to use the model. There are many possible reasons for this. For instance, it may be just that they saw the model as more relevant to their current problems than the clients of the earlier study saw their model. A significant difference between the two studies was that a much lower level of management was involved. Although they did see themselves as separate departments there may have been less rivalry and/or interdepartmental 'politics' at this level. In addition people at this level are perhaps more interested in technical matters than are the higher echelons. Senior management may see this type of assistance as being at a too technical level to help with their 'strategic' problems. A further reason why the several departments were all keen to use the model was that they were all involved in all the modelling sessions. They were always present to put forward their point of view. Whereas in the previous study it was planned that individual departments would use the model in isolation, merely seeing what effects an action produced in other departments.

5.4.4 Client Enthusiasm

From the start of this study all the participants appeared very keen to use the model. They saw it as an opportunity to try out ideas they personally had rather than handing the problem over to the O.R. unit for 'analysis'.

Even prior to the availability of VI modelling, the O.R. unit would not have simply presented 'the answer' to a client. However, VI modelling seemed to be improving a particular dimension. According to the project leader of this study the clients appeared better able to suggest potential solutions and he said he thought this was because they could see the results of a simulation of their ideas almost immediately. There was an atmosphere of 'exploration' in the sessions with these clients. The participants were not just looking at results. They were analyzing the relationships between variables in the model.

Statements like "...the size of the stock of slings here [pointing to part of the screen] seems to affect the work rate of both sets of machines..." were typical.

The people involved felt as though they owned the model. They even called it "our model". The atmosphere at the meetings felt very different from those during the Action Research study reported in section 5.3.

5.4.5 A Difference from the Longbridge Strategic Model

The study was set up to solve a specific problem. From the start the model was designed to look into that particular problem. During the use of the model no discrepancy was discovered between the level of detail required to answer the relevant questions and the level of detail at which the model had been written.

Why was the level of detail right this time?

5.4.5.1 The model was designed to analyze a specific problem. Experience of model building perhaps enables one to judge what level of system behaviour may be relevant to the given problem.

5.4.5.2 The problem owners (and solvers - see section 7.5.5.2) were involved in considerations about the model before the model building commenced. A specific question was asked by the analyst (researcher): "What pieces of information do you want displayed on the screen?" (See section 5.4.6 and 7.5.2). So the model builder knew what aspects of the system were important to the client.

5.4.5.3 At an extreme there is a level of detail beyond which there will be no difference in the results whichever aspects of the logical behaviour of the plant one is interested in. Obviously this level of detail will vary between industry and possibly between plants in the same industry (using different techniques). However this level of detail is not difficult to reach in the case of the Longbridge car plant.

All three of these potential reasons probably played some role in tuning the model to the right level of detail. They certainly all had a chance to play more of a role than in the case of the previous study. It is not always possible to model to an extreme level of detail; this can produce some undesirable effects (see sections 5.8.7 and 5.7.3). Rather there is an optimum level of detail which every model or study requires. This important point will be covered further in later studies and in section 7.4.6.

5.4.6 Designing Screens

There are two distinct models within a VI model:

1) The actual computer program that simulates the logic of the real system.

2) The visual representation of (1) depicted on the screen. The visual representation can, and usually does, differ in its level of detail from (1). It is the visual representation that is the client's model. There can be a tendency for the analyst to design the screen representation around the logical computer program. The analyst may be accustomed to thinking of the simulation in terms of queues and service times while the client will perhaps have a different image of the problem system.

The screen layout for the model in this study was designed twice. First by the researcher:

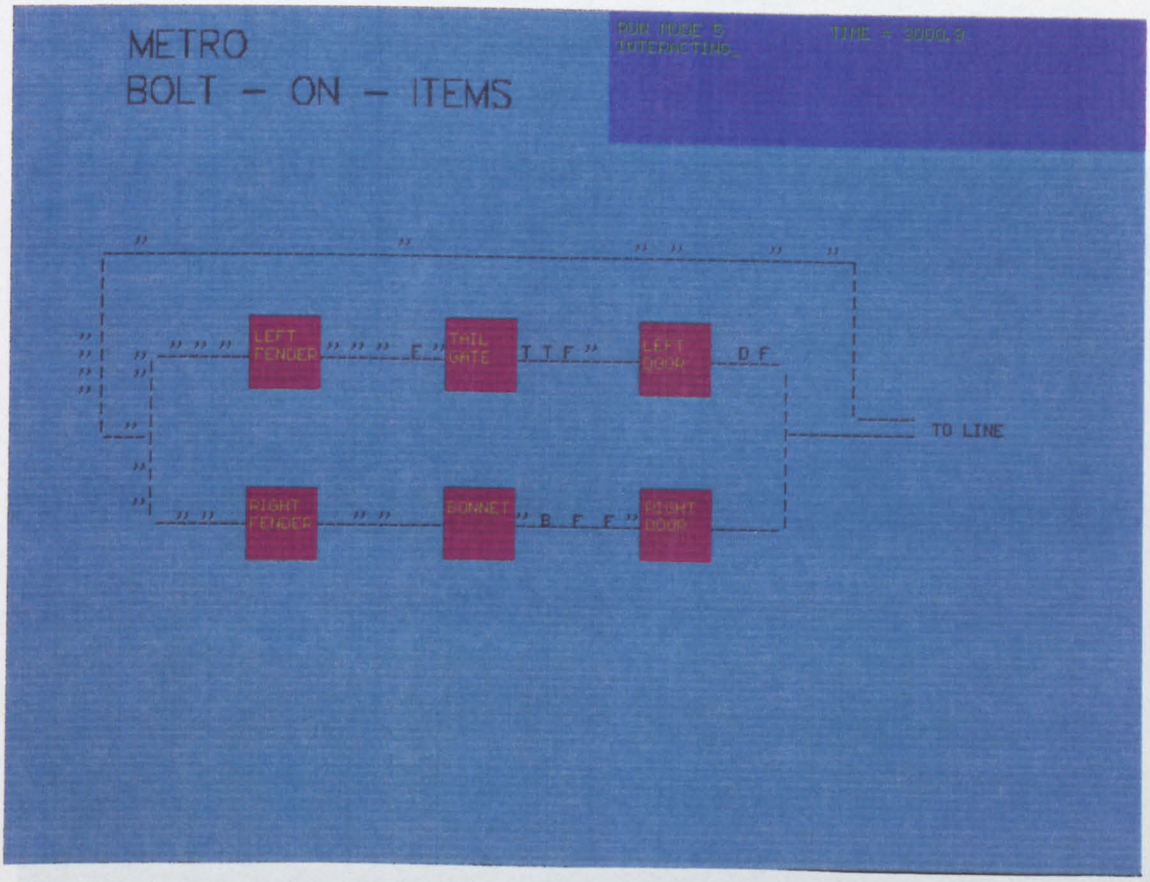

Figure 5.4.6.A - Screen Design by the O.R. Analyst

Secondly by the Industrial engineers:

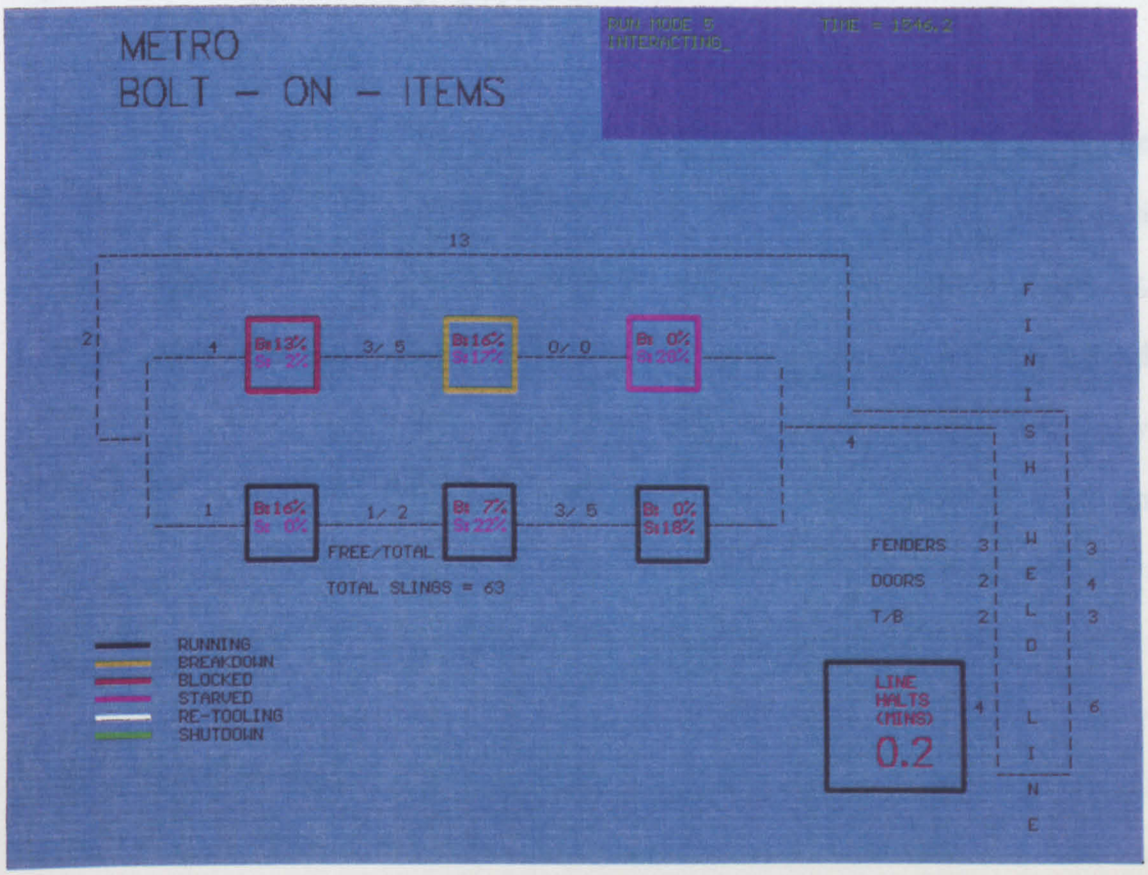

Figure 5.4.6.B - Screen Design by the Clients

Some significant differences can be seen between figures 5.4.6.A and 5.4.6.B (In fact the redesigned version does also show additional information. This is because the model had not been completed before the original version was abandoned.) In this case the clients did not want to see a pictorial representation in the various legs of the conveyor. Instead they asked for numeric information on a static, schematic diagram showing the parts of the plant in their approximate geographic location.

The different design of screen probably helped the exploration stage of the modelling process. But notwithstanding this, the act of designing their own screen appeared to help the clients become involved in the modelling process. It was probably because they had designed the screen that they felt they owned the model. They were better able to understand the model because they knew exactly what every number, symbol and sign meant; they had asked for them all.

5.4.7 Implementation

Having established that clients appeared able to become involved in the modelling process, there is a question posed by the early chapters of this thesis which required further exploration: Do the theoretical benefits of involving clients (section 2.3.7.13 and 3.4) exist in practice? And if not, why not?

One of the most significant points to come out of this study was that all the clients felt, after the study, that the solution which was finally implemented would not have been found if the VI simulation model had not been used.

There are perhaps three reasons why they were able to implement this solution.

5.4.7.1 In watching the model run the clients were able to 'get a feel' for how the system would work. They were able to 'play' with it to see how it reacted to various circumstances. Several of them said they no longer felt 'in the dark' about the system. They felt able to think up ideas and were confident that they would be able to make a comparison between them. They felt they had overcome the complexity barrier between themselves and the system.

5.4.7.2 They were able to try out 'wild' ideas. The expense or effort involved in working through an idea without the computer's assistance usually means the imagination is suffocated into only considering a few alternatives. (The notion of the difficulty of testing ideas hindering thinking is discussed by Audley, 1967). A 'wild' idea that was put forward during one of the client/model sessions eventually proved to be the best solution and was implemented.

5.4.7.3 The solution that was implemented caused considerable additional expense for the parts handling department. However the manager of this department was wholly behind the solution. The other interested parties had been able to explain to him the logic of the solution by using the model.

5.4.8 Model Changes

One of the difficulties which occurred during this study was that of making changes to the model. This is part of the act of exploring the model.

To understand the argument here it is first necessary to understand the nature of exploration of both traditional simulation and VI simulation models. Exploration of a traditional simulation model can only sensibly proceed in a series of carefully considered experiments. For each experiment data will be entered to the simulation model and a run (or a number of runs) will be performed and then the output statistics will be analyzed. With VI simulation there is the additional opportunity to simply set the model running and watch the screen. While this latter mode lacks scientific rigour it has the effect of inculcating the viewer with a comprehension of how the model is behaving.

The visual part of the VI model conveys information from the model to the user, but does not communicate in the opposite direction. VI models are called 'interactive' because they allow the user to interact with the model during the session. It is not necessary to merely insert all one's ideas at the start and then wait until the end of a model run before a change can be made. However, while being an improvement on the batch approach, this level of communication is still not as good as the visual, holistic channel used in the model-to-client direction. The same problem also occurs in later studies and only parts of it can be overcome. See section 5.5.5.

To be more specific, the difficulty of imposing interactive changes on the model existed in this study in a form similar to the 'level of detail' difficulty in the strategic Longbridge study. It is only when you start to explore the model that you start to find out what experiments you need to conduct. It is not possible to build into a model, in advance, the necessary computer code to handle all possible experiments.

Each session with the client ended with a list of amendments that needed to be made to the program of the model in order to continue the experiments. This was a frustrating experience for the clients. As soon as a session started they would have a new idea that they wanted to try out only to be told that the model could not handle the idea and they would have to wait until the next session. This interrupted the continuity of their exploration and must have had a detrimental effect on their solution-finding process.

5.4.9 Summary

To summarise, this study had helped the clients far more than the strategic Longbridge study. They had obtained a solution to their problem which they felt could not have been obtained with a conventional O.R./client relationship.

5.5 A and Q Building Circulator Conveyor System Case

5.5.1 Introduction

This section reports more than one study but the use of only one model. The model was originally built to solve one particular problem; however it was thought at the time that it would play a useful role in the future as circumstances changed. Indeed the model was used on numerous occasions over an 18 month period.

The model simulates a complex conveyor network in two buildings at 'Cowley Body Plant' at Oxford. Thirty five interconnecting conveyors act as a railway shunting yard sending various different types of car to and from different processes and stores.

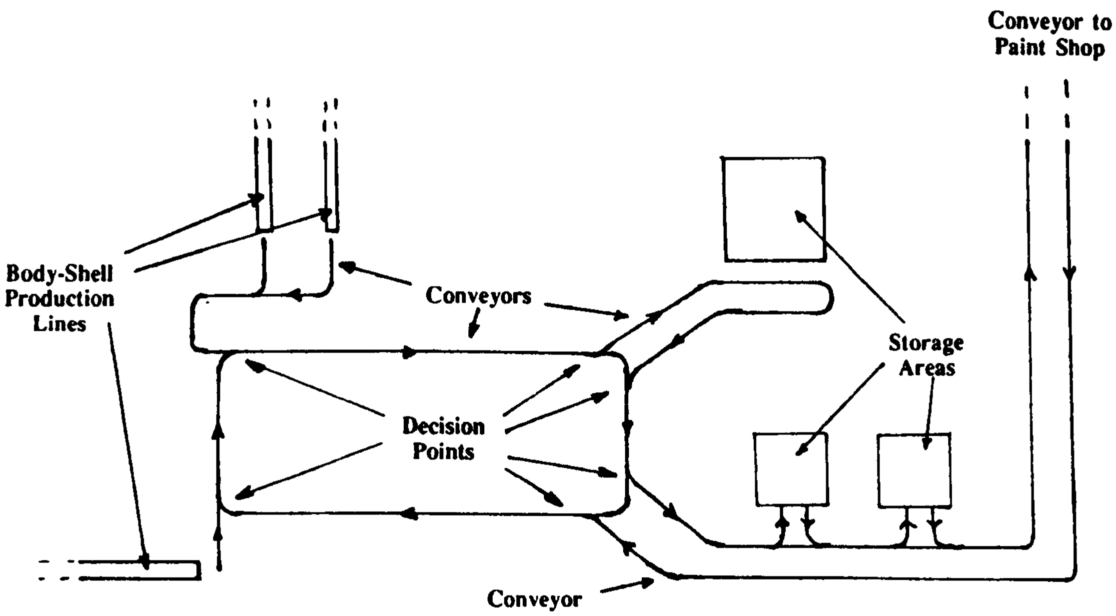

Figure 5.5.1.A - The A and Q Buildings Conveyor System

The problem was that the system had a limited capacity which was frequently illustrated in practice. Cowley's plant director thought that applying better control rules would solve the immediate problem and that partial redesign would enable the system to cope with the planned Triumph Acclaim production.

5.5.2 Responsibility

Originally it was intended to set the study up so that the modelling would be carried out in conjunction with the people who ran the system and with the facility designers who would make any changes necessary to accommodate the Acclaim. However, it quickly emerged that this was not possible because no one was in charge of running the system on a day-to-day basis. Two foremen gave orders to the labour who controlled the flow of cars. These foremen simply obeyed some very basic rules they had been given when they were moved to that area of the plant. In addition, they also followed ad hoc commands from the managers of the adjacent processes. (Furthermore, foremen who worked on different shifts appeared to work with different sets of rules). The people who ran the processes which the conveyor linked together simply pushed cars into the system or took them out. They expected the system to function, in terms of not holding up their process, and otherwise they were not interested in its operation. They assumed the facility designers would ensure the system would operate satisfactorily. At the time this attitude was accepted by the O.R. unit and the modelling took place with the facility designers as the only 'client'. (But, see the next section). The facility designers were interested in the future control rules and would also help redesign the current rules to help relieve the congestion.

5.5.3 Level of Detail/Screen Design

As with the previous study the clients designed the screen layout and specified the information which was to be continuously displayed. It is believed this helped tune the model to the level of detail which the clients needed to solve their problem. In fact over an 18 month period while this model was being used by several different people within the facility design department there was only one occasion when the level of detail had to be changed. This was to do with the working of a store which was later used for a completely different purpose from its purpose when the study began.

The clients wanted a considerable amount of statistical data collected as the model ran. There was a lack of space on the screen so this was normally not displayed but could be called up when required. However there is, perhaps, an advantage in not displaying such information continuously. (See sections 6.5.5.1 and 7.5.4)

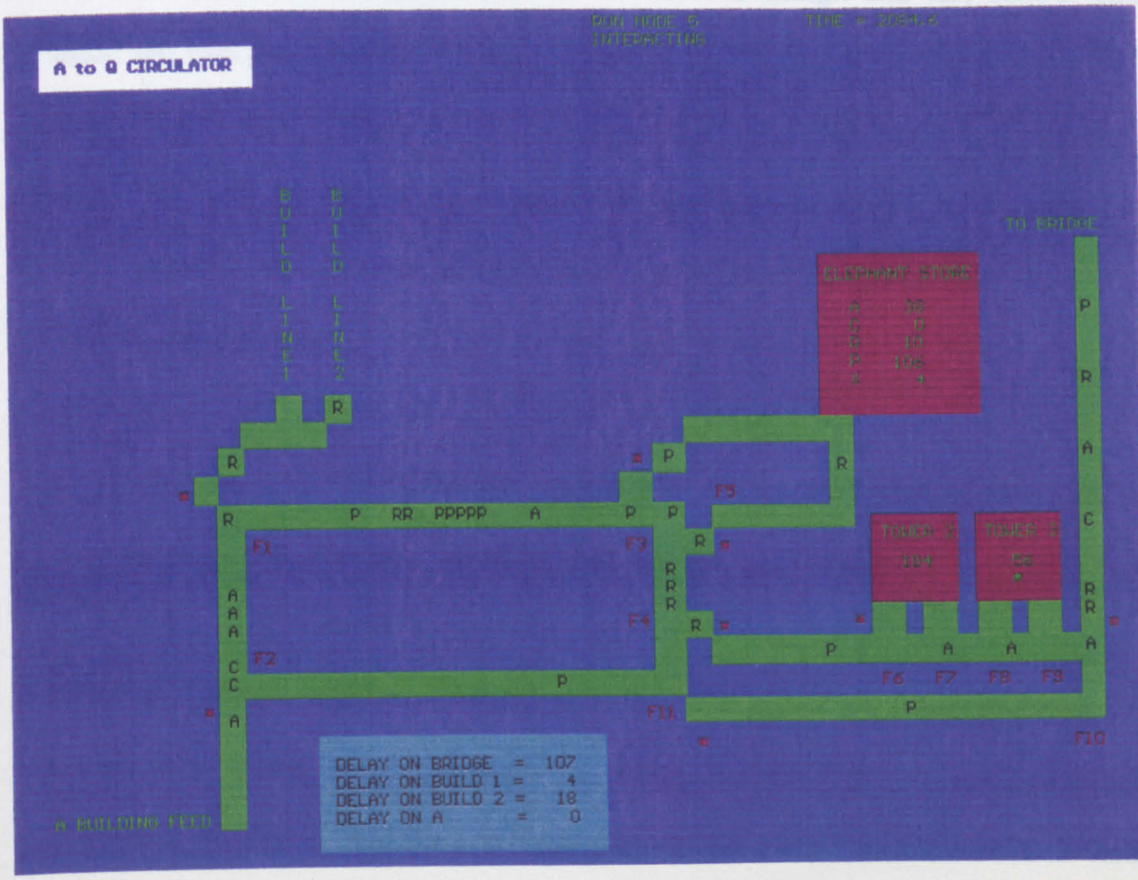

Figure 5.5.3.A - The A and Q Conveyor Model Screen

5.5.4 VI Model Contribution to Control Rules

It was envisaged that this action research study would provide an interesting contribution to the research programme as it would not have been possible to undertake the study without the use of Visual Interactive techniques. This assertion needs some explanation. To be able to design and test control rules there are two prerequisites:

1) To have an overall appreciation of the state of a system so that it is possible to take an holistic view of what action might be best at a particular time.

2) To be able to see individual instances of the control rules in action to see if they make the best possible choices.

Traditional batch simulation would not facilitate either of these requirements. While with some simple systems it would be possible to use traditional simulation to find a workable set of rules, to do so in the case of this study would probably have been impossible. The sheer complexity of the system would make it impossible to gain an appreciation of how it was behaving from a static printout. Looking at the statistics printed out at the end of a traditional simulation run can be useful, but it can perhaps also hide the richness of information which was available as the model was running. For example the printout might show that a particular conveyor was blocked for 10% of the time but it would not be able to indicate what was occurring simultaneously and thus it would be difficult to interpret the cause of the blockage. Furthermore, having invented a control rule it is simple to test its performance against another control rule by using traditional simulation. However, this process of evaluation does not indicate possible methods for improving the control rule to the same extent as might occur when using VI simulation. This is because, using VI simulation, it is possible to watch each individual instance of a control rule in action. For example, when a car reaches a junction in the conveyor system and, obeying a control rule, it turns left, it is possible for the observer (taking into account a holistic view of the state of the system at that time) to decide that turning right on that occasion might have been a better decision. If this is observed sufficiently often then the observer might decide to make a small amendment to the control rule.

5.5.5 Model Changes

The first difficulty encountered in this study was in the same class as that mentioned in section 5.4.8. How can the model be changed sufficiently quickly to avoid interrupting the client's learning-towards-a-solution? The problem manifested itself in two forms in this study. These will be dealt with separately as the solutions to them are different.

1) The first form is where changes are required to the model structure. This is usually very difficult to deal with quickly. For instance, the client might say;

> "I want an additional storage area at X for car types
> Y and Z. One of its lanes will run in both directions

for redistribution purposes. Also if there are more than 136 cars in the store put car type Z in car park W."

It would then be necessary to adjust the program of the model for this new type of store and make other changes necessary for its control rules. The task of simply thinking out the logic of how the model should handle this new feature usually takes more time than the client is prepared to wait. Thus that particular experiment must be delayed until the next session.

However, in the case of this model, there were many individual parts of the system which were similar to each other. This made it possible to build most of the model as a series of parameterised blocks. It was possible to change the length, speed and route of any individual conveyor leg in a much shorter period of time than would normally be necessary to alter the structure of a model. This principle of parameterising parts of a model is not new (AT and T Istel, 1988) and has been followed in all other studies reported in this chapter. Unfortunately this was the only study where most of the system is made up of similar pieces; the large number of individual conveyor legs. Usually elements of a model will differ and changes the client requires will mean adding elements to the model which are not similar to any existing element.

2) The second form of change required was in building up control rules (see Chapter Six). One of the purposes of this model was to find a set of control rules for operating the system. When building such a model it is possible to make a guess at a set of control rules which will work or alternatively to install an existing set (if the system already exists) just to get the model running. Then the process of finding a new 'best' set of control rules proceeds by a series of experimental amendments to the installed set. The model was programmed so that many different sets of rules could be selected at each junction, thus minimising the probability of needing to re-program when a change was required. Simple interactive commands were used to select a new rule or change a parameter. However even this method of searching for a good set of rules proved to be slow and laborious.

To improve the interactive nature of the model it was modified so that all the control points could be either controlled by the pre-programmed rules (as above) or controlled manually. At these manually controlled points cars would flow in a particular direction until a command was entered to alter it. (Eventually these commands became single key strokes, making it possible to control several points at the same time easily and without causing interruptions in the running of the model.) Leaving control points under manual control made it possible to build up a knowledge of what control was required (and what such control should be based on) at each control point in the model. This knowledge was attained by the team who were analyzing the model.

Each rule could then be programmed into the model (or selected if already programmed as an option).

To summarise the above: It was found that the difficulty of having to make changes to the model to keep up with the client's learning process can sometimes be overcome. This was achieved by parameterising building blocks of the model and by leaving rules that are liable to amendment out of the model (program). The latter point had a more important advantage of making it easier to use human intuition to develop rules.

5.5.6 Absence of Those Affected and Implementation

The next difficulty encountered in this study occurred because not everyone who would be affected by the results was involved in the study itself. In retrospect more persuasion should perhaps have been used to encourage the people who ran the processes adjoining the conveyor system to be represented at the modelling sessions (especially given the experiences encountered in the study in section 5.3).

The solution reached by the people involved in the study was not implementable. This was because it required one of the adjoining processes to halt production under certain conditions. Doing so would make the plant as a whole more efficient but the process itself would (appear to) be less efficient.

Unlike the case mentioned in section 5.4.7.3 the department concerned did not believe that the conclusion could be correct. If they had been involved in the study they might have come to the same conclusion as the people who did participate.

A modified version of the ideal strategy was implemented. It is perhaps interesting to note that the process of implementing the amended solution involved using the model to demonstrate the new control rules to shop floor personnel. Everyone who saw the model was able to recognise the layout of the conveyor system and in discussions that took place many used the screen as a blackboard to explain their thoughts to colleagues.

5.5.7 Written Reports

This model was not only used for the original study, it was used intermittently over the subsequent 18 month period to re-analyze the system as the flows in the factory changed. The repeated use of the model led to the emergence of one of the recommendations to be discussed in Chapter Seven. Some of these subsequent studies were short (a single, two hour, session). Sometimes the people (or person) involved in the study had not been involved in the previous studies with the model. They did not know the details of results that had been found in the past and the memories of those who had been involved tended to fade over time. In addition some of the conclusions drawn had been fairly subtle and often there were personal preferences for various control rules and often at the end of a meeting, although general agreement had been reached, it would have been possible for the individuals to change their minds following the meeting. This was in contrast to the 'Bolt on Items' study reported in section 5.4.

A written report had been usual at the end of studies by the O.R. unit. However no report was produced at the end of the 'Bolt on Items' study. In the case of the studies reported in the current section of this thesis it was important to produce regular summaries of findings. These proved particularly useful for clarifying and reminding. The production of such aide-memoires and attention focusers is part of the analyst's role in the visual interactive modelling process. (See section 7.5.4).

These written summaries do perform a further role which is particularly important to the clients of VI modelling. This is a new concept to many people. Even though they are solving problems for themselves, they still need the backup of written evidence from the O.R. unit. Although the clients want to find the solution for themselves it is not necessarily the safest strategy for them within their organisation. As argued in Chapter Four, this point should not simply be dismissed as being a matter of organisational politics and not therefore of research interest. This research program is largely based on aiding decision making within a live organisational context which is thus subject to human activity. The whole 'system' which makes up the O.R. study is only part of the larger system of 'change within the organisation' system. Organisational politics is also part of this system and so O.R. must interface with it. Chapter Seven will discuss this issue further.

5.6 Triumph Acclaim Introduction to Cowley Case

In order to minimise the lead time to the market launch of the Triumph Acclaim B.L. management decided, where possible, to produce the car on existing production lines. The O.R. unit was asked to build a strategic simulation model of the whole of the facilities at Cowley so that the effect of various options could be evaluated.

At the time the area of the plant which was of most concern to Cowley's management was the store between the paint process and the assembly track (see figure 5.3.3.3.A). Did it have sufficient capacity to resequence the cars into the sequence required for assembly? (see section 5.3.1). However there were many other parts of the plant, the operation of which could affect the answer to this question. The model had to cover the plant from the first stage where the cars are put into a sequence to the last point where the sequence was of significance.

Concurrently with the building of the Longbridge strategic model (see section 5.3) a strategic model of Cowley had been built. An analyst employed by the

O.R. unit built it and followed the same principles as had been used for the Longbridge model. Thus the model was designed to be sufficiently general to be usable to answer any general questions about the capacity of the plant or the effect of various flows of cars.

The researcher therefore investigated the possibility of using this model for the current study. Unfortunately the model had deficiencies similar to those of the Longbridge model.

5.6.1 Level of Detail

While the model would be able to answer many questions it lacked specific details which were key to the introduction of the Acclaim. There were two departments who would be affected by the sequencing issue. While the other areas of the plant affected the problem and therefore had to be modelled there was no reason for these other areas to be shown on the screen. Conversely there were important aspects relating to these two departments which were not shown. It was decided to build a new model designed specifically to look at the problem that was relevant to the study's clients. The two departments involved were the 'Paint Scheduling Department' and the 'Assembly Scheduling Department'. They each allocated a senior manager to the study.

5.6.2 Multiple Interests

These two departments are traditional rivals. It is unfortunately often the case that a schedule of cars that the paint shop would like to paint is incompatible with obtaining maximum efficiency on the assembly lines. It was mentioned in section 5.4.3 that the many departments in the 'Bolt on Items' study were willing to work together more than the many departments in the Longbridge study. One of the reasons postulated for this was that there was less conflict between the departments. This hypothesis can be rejected on the evidence of the current study. The two departments were very willing to work together with this model. They both saw it as being a good way of tackling their joint problems.

It was quickly determined that the existing store (section 5.6) was sufficiently large to cater for the minimum degree of resequencing capability acceptable. However the two clients were interested to see how they could improve on this. The more resequencing that was possible the less the man-power costs would be on the assembly line. Also, if more flexible paint schedules were possible, efficiency in the paint shop could be increased.

The Assembly Scheduling Department manager learned the nature of the relationship between the way the store was used and the sequences which could be obtained. He discovered a very simple change to the way of allocating cars to lanes in the store which made what he described as a "major improvement" in the sequencing. (However, such sequencing savings were difficult to quantify; see section 5.6.3).

The paint shop scheduler also learned, using the model, more about the way the real system works. He was able to discover the effect of different paint reject rates (see section 6.4) and batch sizes on the contents of the resequencing store.

By the end of four half-day sessions with the model the two departments had reached agreement on the way paint schedules could be drawn which would meet the goals of both departments. There were still unresolved issues but it was clear that the VI model helped the two departments gain an understanding of each other's problems.

5.6.3 Subjective Measures

As mentioned above it was very difficult to evaluate different levels of resequencing ability. This was mainly because, at this early stage of planning, the way the assembly work would be allocated to the various stages on the assembly line had not yet been finalised. The only way the resequencing ability could be evaluated was by the personal judgement of the assembly scheduling manager. Using the visual display it was easily possible for the manager to see in what ways his 'ideal' sequence was not met and the seriousness of any deviation from the 'ideal'. ('Seriousness', being a subjective measure belonging to the assembly sequencing manager). This also then gave the manager ideas on how the stores control rules might be adjusted to help avoid such a deviation in the future. By involving the client in the modelling process it was therefore possible to compare potential strategies that could not have been compared without such involvement.

5.6.4 Manual Control Rules

Section 5.5.4 discussed the notion of leaving control rules to manual, rather than programmed, control in a model. It can sometimes be easier to build up control rules by leaving the decision points under manual control. There is another, rather different occasion when it is also preferable to leave a decision point under manual control.

The next sentence appears to contradict itself. Sometimes control rules exist but are unknown. A decision maker (or in this case the paint shop scheduler) may be able to decide which car (from the available choice) would be best to send through the paint shop next. However, the decision maker is not necessarily able to state the complete set of logic used in making the decision. (cf section 5.5.4)

In the case of the Cowley paint shop in this model there are two feed conveyors to the paint shop entrance. One brings three types of car to the process the other brings two other types of car. The paint shop scheduler has a list of orders which dealers have placed for cars and knows what colour is currently being painted. (There is a set up time associated with changing paint colour.) The decision about which car to paint next, and what colour to paint it, is complex because it requires an appreciation of the importance of many interacting variables. This 'appreciation' probably could not be explained in a form such that it could be translated into an structured computer program. (There are issues in this discussion which relate to the aims of research fields such as Expert Systems, Artificial Intelligence and Neural Networks, however these will not be discussed here because the time investment required to build the databases required by such systems would have been inappropriate within the particular context of simulation modelling for aiding the types of decisions in these studies).

It was therefore decided that the paint shop scheduler should take part in the simulation.

This method had a considerable advantage over the other option of using a programmed approximate 'rule' to make the decision. It meant that the clients had confidence that the model was simulating an exact flow of cars that would be likely to flow through the system when Acclaims started to be built six months later. At no time did they have cause to think that the model's predictions were wrong because they "would not have done it that way".

However, during the first session with the model a considerable difficulty emerged. The process of making the decision; "what car to paint next?", and entering this into the computer took so long that the session progressed too slowly to be useful for trying ideas. It was decided to compromise. A programmed rule had to be inserted if the model was to run sufficiently fast. However the rule only automated those aspects of the decision which the paint scheduling manager could specify in rule terms. Whenever the situation fell outside the conditions embedded in the rule the model would stop and ask the manager to make the decision manually. The model could also be stopped by the manager if it was seen to be doing something with which the manager disagreed. This method solved the difficulty because the program was able to cope automatically with more than 90% of the decisions. Finding the right rules took several passes because the rules the manager initially specified turned out not to be the rules he actually used! (cf Section 5.7.2)

5.6.5 Written Reports

At the end of the study a report was required by the clients. This was for much the same reason as presented in section 5.5.7. The clients needed evidence from the O.R. unit stating 'why' they had reached the conclusions they had reached by analyzing the model.

5.7 Rover transfer to Cowley Case

5.7.1 Introduction

In May 1981 a decision was made by the company's main board of directors that the Rover saloon car factory at Solihull would be closed and the only current Rover car (the SD1) would be painted and assembled at Cowley. (The body shell was already being made at Cowley and shipped by road to Solihull.) Like the case in section 5.6 the SD1 was to use existing production facilities where possible. Also like the case of section 5.6 the O.R. unit was asked to simulate those production facilities as an aid to investigating potential problems. Exactly the same facilities would be covered by this study as that in section 5.6 but the problem emphasis was on different areas of the plant and thus a new model was written for this study.

The SD1 was different in a major respect from any car previously within the experience of the Cowley management. It was a 'luxury' car. All the other cars built at Cowley were high volume, mass-production, products. There are many options a customer can order on a mass-production car but the number of different combinations of options actually ordered tends to be fairly small. Most orders actually come from dealers for their own stock, with customers buying a car from the dealer stock (or from the stock of another dealer). However, in the luxury car market, dealers hold relatively low stocks. Customers want to order a car which fits their requirements exactly. They order a specific car with specific options and there are many more options available than in the case of a mass production car. These options have a major influence on the way production is organised. Approximately twice as much direct labour time was required to assemble an SD1 with all options as an SD1 with no options. Consequently the task of sequencing SD1 onto the assembly line is far more complex than with mass-production cars. (cf section 5.3.1).

5.7.2 Level of Detail

While sequencing was important in the Triumph Acclaim study (section 5.6) it could be handled in an easier way. It was within the experience of Cowley personnel and the rules for generating the sequence were less complex (fewer options). In addition, at the time of the study in section 5.6, the manner in which the Acclaim would be built had not been finalised. Not all the sequence rules existed so any results from the model were at an 'order of magnitude' level. The SD1 production was however well defined. It was possible to state precisely the best sequence in which to build a list of SD1s. Therefore this area of the model had to be programmed at a greater (more complex) level of detail.

Conversely the paint shop did not need to be programmed in as much detail as in the model for the study discussed in section 5.6. As a consequence of that study it was decided that the rules for selecting cars into the paint shop were now so well understood that they could be completely programmed with no significant effect on the simulated stream of cars leaving the paint shop. (See section 5.6.4).

The above two differences further illustrate the need for individual models which are designed for assisting with particular client-problems.

5.7.3 Multiple Interests/Inter-Client Communication

There were many 'clients' in this study. Earlier studies (see sections 5.4.3 and 5.5.6) had indicated that all the groups who may be affected by a study should be involved in the model analysis process. The people who initiated this particular study were the facility planners and they in turn had been commissioned by the managing director of the company. The managing director wanted to know if the existing facilities could cope with the additional work load of the SD1 production and if not, how problems could be alleviated. The facility planners were particularly concerned about the store prior to the paint process. However, as in the study in section 5.6, most other areas of the factory would have an influence on the efficiency of that store and would also be affected by any inadequacy of the store.

The researcher's job (acting as an O.R. analyst) was largely as a coordinator of the decision process. The model was relatively simple and took little time to build. However it acted as a focus of the debate between the various departments.

The move of the SD1 to Cowley was an urgent task. However different departments (on different chains in the management hierarchy) were not working in synchronisation with each other. The model had to be changed often as more information became available. It acted as a statement, to all concerned, of the current state of knowledge of how the SD1 would be produced at Cowley.

The major difficulty encountered in carrying out this study was in satisfactorily answering the question of how alternatives should be evaluated and compared.

The process of overcoming this difficulty was of interest to this research programme. This difficulty was particularly pronounced when attempting to evaluate the cost of deviating from the ideal production sequence.

In the case of mass-produced cars, when there is no order for a car which will reasonably meet the sequence constraints then a car is built for stock. Stock cars are built to a popular specification, which meets the sequence constraints and will probably be required by a dealer when the next batch of orders arrives. However this would not be possible with luxury cars. The set of specifications chosen for a 'stock' car might not be ordered by a customer for months. There was no advice on this issue available from the old Rover factory in Solihull because they had no sequencing problems. Their store had more than enough capacity to cope. The Cowley store was not only smaller but was already being used for two other models of car.

A method of evaluation was developed over a series of meetings with clients. One member of the facility planning team worked permanently with the researcher to advise on potential methods of evaluation. But the decision about what method was finally acceptable was made by all the client groups together. They acted as critics of the potential methods until they all felt a reasonable method had been found. The model was used throughout. It acted as a common medium which all parties accepted as an unbiased record of the group's work to-date. However the act of using the model to reach this 'method of evaluation' was of help to the clients in other ways. It showed up several areas where problems would exist that had not been considered. For example, the (previously simple) task of determining which car to build next was revealed to be impossible to complete by manual means in the 2 minute cycle[1] time available. A computer system had to be installed to search through all the orders to find the one closest to the ideal sequence.

The parties involved said they believed communication and cooperation between departments was increased because they had been brought together by the

1 The time between each successive launch of a car onto the production line.

sessions with the VI simulation model. There were many occasions when the phrase "I didn't realise that" was used. Information came out of the discussions around the model which would probably not have been communicated otherwise.

5.7.4 Which Study Phase Aids Clients

In the case of this study there was very little 'running' of the model done during the sessions with the clients. Rather than analysis of the results of model runs, it was the modelling process itself (the act of model building) which aided the clients. The researcher's role in the sessions was to prompt. Explanations were given of how the model treated various aspects of the resequencing etc. Some suggestions were made, but mainly it was the clients themselves, brought together in an environment where the model was a common statement of their current beliefs, who had the ideas.

5.7.5 Absence of Decision Maker

Actually using the model to then determine the best store size was trivial. Having reached a 'decision' on a new size and operating strategy for the store a subsequent difficulty arose. It is of particular interest in relation to determining a strategy for the use of VI modelling. The 'clients' with whom the researcher had been working were not the real 'decision makers'. As mentioned earlier, the facility planning department was commissioned by the Managing Director of the company. They made recommendations to him based on the results of the modelling sessions. In this particular company (other organisations may differ, see section 5.8) those who have to make the recommendations go through the modelling process and gain a good understanding of what effect a solution will have. This understanding is not fully conveyed in 'recommendations' handed up to a decision maker.

The real decision makers did not accept the recommendations. They were said to be too costly. The people who had made the recommendations felt that the written report given to the managing director was perhaps too equivocal. As it had not been possible to give an accurate costing to the act of not meeting the ideal sequence the cost of rebuilding the store was not 'justifiable'.

It was felt that it might be possible to convince the decision maker if the potential problems of operating without the enlarged store were illustrated to the managing director by using the VI model. Unfortunately, the researcher was unable to take part in this session. The session with the managing director did not change the decision but those who were at the meeting had the view that the model had not had the desired effect for the following reasons:

1) The model covered too wide an area of the plant and therefore, in the time available, it was not possible to concentrate on the nub of the

problem.

2) The model's design was such that, although it worked well at conveying an understanding of how the variables in the problem interrelate, it did not make points in a clear and unambiguous manner in a short meeting.

In summary of this point, it was not possible to give the clients support in convincing their superior of their findings by using the model.

It has since been learned that the managing director concerned visited the factory two days after seeing the model and discussed with the plant director means of making cheaper improvements to the store's capacity. Minor improvements were implemented. Since production of the SD1 started at Cowley a solution similar to the original recommendations has been implemented.

5.7.6 Summary

There were two main features of this study. The clients appeared to learn more about how to introduce the SD1 to Cowley from the modelling process than from the model itself. As the actual decision maker was not involved in the modelling process it was not possible for him to agree with the conclusions of the study as he did not have the same rich picture in his mind of how the conflicting variables interacted as had been obtained by those involved in the study. More is said on both these points in Chapter Seven.

5.8 Parts Distribution Conveyor Case

5.8.1 Introduction

All the previous studies have taken place within the car industry. This concentration on one particular industry may have had a limiting effect on the generality of the lessons learned. Some of the previous studies have shown that, for example, the car company's particular organisational structure may have implications for the way a study using the approach developed in this thesis should be carried out. It was possible to conduct the final study of this series for a company in a completely different industry. (It was an O.R. study conducted by B.L.'s O.R. unit for an external client.)

The study concerned an autonomous factory which was under construction. Basic parts and raw materials were to arrive at one end of the factory and the completed product (desk-top photocopiers) would leave at the other end. Part of the new factory consisted of an automated warehouse with unmanned cranes for picking/placing parts. Some parts were first distributed from the warehouse to an area which sub-assembled the basic parts into more major components which were then returned to the warehouse before being picked for distribution to the main production lines (where the finished product was assembled). All distribution was by conveyor belt transporting plastic 'totes' which contain a quantity of a particular part.

The study differed on several significant dimensions from the previous studies. It was interesting to see if the experience of conducting this study refuted some of the ideas which had been established by the previous five.

5.8.2 Organisational Structure

The car company was organised on a function related basis whereas this company was organised by product. It was part of an international group of companies which is of a size on a par with the Rover Group. All the decision-making related to a particular product is made by the team associated with the product. The person who had to make the decisions about the design of the facilities in the plant was the person who commissioned this study.

In addition to affecting the decision making that would result from the study, this product orientated organisational structure would also affect the analysis phase of the study. In the car company facility designers are always designing facilities, production managers are always managing production. At this company the man who was appointed to run the factory when it was in full production had to design and build it first. The previous statement is a slight exaggeration of the real situation. Assistance and advice is available from the entire company but nevertheless responsibility is with the people who will ultimately run the factory. A difficulty this can cause is that people making decisions about facility design may be inexperienced in this field. When the study started the relevant people were not confident that their proposals would result in an efficient system. However, by using their VI simulation model of their proposals they were able to experiment with their proposals and understand quickly how the plant would work. In other words, the VI model was a tool which enabled people to cope with a complex task with which they were not familiar.

5.8.3 Written Reports

A third difference was also apparent. The clients involved in this study had no previous experience of O.R. studies or traditional simulation. This meant that certain preconceptions about how O.R. work was conducted did not exist. One postulated benefit of VI modelling (cf section 3.4.2) is that it conveys to the decision maker an understanding about the problem-system which the written word cannot convey. If all findings of a study have to be encapsulated in an end-of-study report some of this understanding will be lost. None of the people involved in this study expressed any desire for a written report of the findings. They made their own notes when necessary and the study finished with the people involved (rather than the organisation) having an understanding of how their system would behave.

5.8.4 Greenfield Site

A fourth difference between the previous studies and this study was that studies for clients in the car company were all related to existing factories. The studies were therefore constrained by what changes could physically be made (within the available money). Modifications to control rules were also constrained (albeit to a lesser extent) by customs and practices. The study was different because the proposed factory was almost a 'green field site'. The factory building had been built by the time the study started, but no equipment had been installed. Plans had been drawn up but any of these were potentially open to change if the modelling process showed this to be necessary. Virtually no control rules had been thought about at the start of the study. There were no 'customs and practices' which could constrain the controls developed by the modelling process. Indeed one of the purposes of the client initiating the study was because there appeared to be no other means of working out a set of control rules.

In summary, the clients were more able to benefit from any potential learning about how to run their plant. The study might illustrate features of this learning process which were inhibited in previous studies.

5.8.5 Learning by Clients

On analyzing the concepts that were learned by the clients during the study it appeared that the learning experiences fell into six categories. These categories are stated here because it was during this study that most client learning took place and therefore where they became apparent. However, looking back to previous studies, it is possible to place learning experiences from those studies into the same categories. Section 7.5.1 makes use of these categories in attempting to overcome some of the difficulties associated with ensuring the model does not limit the client's learning.

Type of Question	Question exists prior to use of model	Question unknown prior to use of model
Trivial to answer	A Answered before model use	B Unexpected need shown by model and answered
Complex to answer (must use a model)	C Model used for analysis to provide answer	D As above, except may be necessary to make amendments to model to fully answer question
Model cannot provide direct answer	E Use model to learn about potential solutions (may be necessary to amend model during learning)	F As left, except unexpected need shown by model

Table 5.8.5.A

The following examples will help clarify the distinction between each cell in the table:

A n/a
B The sub-assembly area is a net consumer of plastic totes.
C The number of men who move totes from the conveyor to the storage area at the side of the production line *can* keep up with the peaks in the rate of supply
D Only 2 cranes are required in the warehouse.
E The best way to recover from a particular conveyor breakdown.
F Best method for controlling empty 'tote' supply.

5.8.6 Model Changes

As occurred in some previous studies, (cf section 5.4.8) difficulties were encountered when the model used for this study needed to be changed because it would not 'model' an option the client wanted to try. (Categories D, E and F in table 5.8.5.A). It was however possible to avoid the problem during some of the later sessions with this model. In modelling sessions the analyst often takes on the role of chairman. The analyst has to answer queries about the model, act as a prompter to keep the session reasonably to its agenda, regularly summarises and clarifies what various parties are saying and performs various other tasks which make up the 'analyst role' (cf section 7.5.4). Consequently, the analyst has little time available for making changes to the model during the sessions. If the analyst dropped the role of chairman to make a change to the model then there would often be a gap in the continuity of the session. A second study was to start with this company and so a second analyst attended the last few sessions of this study to be introduced to the relevant people. The presence of this second analyst had an unexpected benefit. With two analysts present it is possible for one to make changes to the model while the other chairs the meeting. This may seem a trivial point but its consequence was that a model could be changed without breaking the continuity of the session or the learning process (cf section 5.4.8). The addition of the second analyst did not simply double the amount of analyst effort, rather, it changed the nature of the service which could be provided.

5.8.7 Level of Detail

In the study in section 5.3 the level of detail programmed into the model was found to be inappropriate for several areas of the plant. In later studies the level of detail proved to be correct for the designed purpose. It has been postulated earlier that this improvement had been due to the client's involvement in the model building process. Although this hypothesis cannot be refuted by the evidence so far presented it could also, simply, have been due to the increased level of the researcher's experience in car plants. However, the factory which was the subject of the current study was different from a car plant and yet the level of model detail was still correct. This was not simply because the model was highly focused on a specific area of the plant. The model covered the whole of a very complex factory. Too much detail would have caused the model to be slow and cumbersome to use, conversely, too little detail would have caused the same problems as were experienced with the strategic model of Longbridge. (Account would not have been taken of features which would affect the outcome of simulation experiments). Therefore, it would appear that obtaining the right level of detail is not related to the analyst's experience of the problem environment.

5.8.8 Client Perception of Early Stages of Model Building

However, the amount of time which elapses before a model is running and ready for use is probably related to the analyst's experience of the problem environment. Over a number of studies, in a particular environment, it is possible to build up methods for handling common structures in that environment. These are both of a mental and a physical form. The analyst develops ways of treating recurring situations and sometimes creates physical libraries of programs which help in modelling. However, in the different environment presented by this company's product, it was necessary to work without this assistance.

At the time of this study all VI models consisted of computer programs written in a standard 'high level' (third generation) language (For example: Fortran or Pascal). Any particular VI model would therefore progress through the phases:

Actual state of Model	Ostensible state of Model
Early stages of program creation	Model not usable
Testing, validation and debugging	Model usable *
Model validated	Model usable *

The similarity of these two phases, in the perception of the client, is enhanced by the desire on the part of the analyst to involve the client in the modelling process as early as possible.

The benefits of the clients being fully involved in the modelling process had been emphasised during the setting up of the study. This, combined with the fact that the model was behind schedule in its development, caused the clients to keep a close watch on the development of the model. As with most computer programs, there was a period when the model appeared to be running correctly but was not modelling exactly as the programmer had intended. If the clients are present (or try to use the model) during this phase they can quickly lose faith in the model. To people who are not accustomed to computer programming the art of debugging can be disconcerting. A model which produces invalid results modifies what they thought was a precise way of helping them, into something which may be putting their jobs at risk! Lessons learned from this episode are discussed in Chapter Seven.

5.8.9 An Effect of Inconsistent Model Speed

A particular feature of the system modelled in this study was that it did not run steadily. Simulated time did not pass at a rate which was constant with respect to real time. A large element of this model concentrated on the distribution of parts and raw materials around the factory from an automated warehouse. At any given time there might be only a trickle of parts flowing around or the system might be working at full capacity. This was an inherent feature of the system but it caused difficulties in the model analysis phase of the project. Watching the model over too short a period of time would lead to incorrect conclusions. A typical example of this effect occurred in the testing of 'recovery times'. This was the time it takes the factory system to return to a normal state after a major breakdown. If, in the first simulation of a recovery, the system regained its normal state quickly but in later experiments it recovered slowly, then these latter results were dismissed by the clients as "unlucky". The reverse would also occur. The experimental work in Chapter Six treats this difficulty in more detail.

5.9 Summary

This chapter has discussed observations taken during a series of Action Research studies. As there is currently little understanding of how to best use VIM to help clients it has not been possible to test other researchers' findings. The chapter has merely collected some data. Chapter Six collects some further data from a slightly different methodological perspective.

Chapter Seven will then draw together this data into a body of experience which may be of some use to VI modellers and future researchers.

CHAPTER SIX

EXPERIMENTAL MODELLING SESSIONS

6.1 Introduction

The Action Research form of studies reported in the previous chapter are useful for generating insights. As argued in that chapter they are an appropriate method of examining the use of VIM because many of the benefits claimed for VIM (Kirkpatrick and Bell, 1989) are associated with interactions between O.R. people and their clients. However, Action Research is not a universal panacea. Some detailed aspects of studies using VIM need to be tested or examined in ways which are not possible with Action Research. For example, it is not possible to replicate Action Research studies. This means that a detailed aspect of the study such as the benefit or otherwise of showing a particular piece of data on the screen would be very difficult to distinguish from the variation between studies due to other more major differences (such as the nature of the decision problem).

6.1.1 Purpose

In undertaking Action Research it is possible for the researcher to be too involved in 'solving the problem'. For example, due to the intensity of activity which sometimes occurs while assisting a client to reach a decision, it is not always easy to withdraw and make an assessment of the effect of using VIM. Secondly, the nature of Action Research is such that it is only possible to have one trial of each study. Therefore it is difficult to see which of many factors may have caused an observed effect. Therefore, to supplement the Action Research, a series of experimental modelling sessions were devised. They were designed to replicate certain aspects of a real VIM study, in a way which held more variables constant than was possible between each of the studies reported in Chapter Five. Their purpose was to see if there were further lessons to be learned which could not be discovered in a practical setting, but might nevertheless be useful data towards answering the research questions posed in this thesis. These experimental modelling sessions were not designed as controlled experiments to examine the effect of one (or a small number) of variables. This research is at an early stage; before these experiments were conducted little was understood of the nature of the way VIM was assisting its users. Like the Action Research studies, this work was aimed at producing empirical insights which could be used to help focus future research. Ideas for a second series of (more controlled) experiments will be discussed in Chapter Nine.

An example of the type of information which might be obtained from these experimental sessions is some indication of whether the individual client's cognitive style may have some effect on how VIM should be used. Perhaps, if the character, or some other dimension of the psychological aspects of an individual, has some influence on the way VIM should be used this may not be possible to identify in a series of one-off Action Research studies, but might be observable in a series of experiments where many other aspects of the study are kept constant between sessions. It is questionable whether it would be feasible to design models with particular cognitive styles in mind, however, this does not necessarily make such an insight worthless.

6.1.2 Scope

The experimental work reported in this chapter is not intended to be of relevance to the full breadth of concepts and theories treated by this thesis, or even relevant to the full extent of the guidelines which will be reported in Chapter Seven. The chapter considers some specific aspects of the VI approach. The experiments were conceived of to supplement the Action Research in Chapter Five with respect to some detailed issues which it was necessary to investigate further as part of the process of building a body of experience to apply to the guidelines discussed in Chapter Seven.

In Chapter One it was stated that the framework in figure 1.5.7.A would be used as a frame of reference to recognise certain distinctions between elements of an O.R. study.

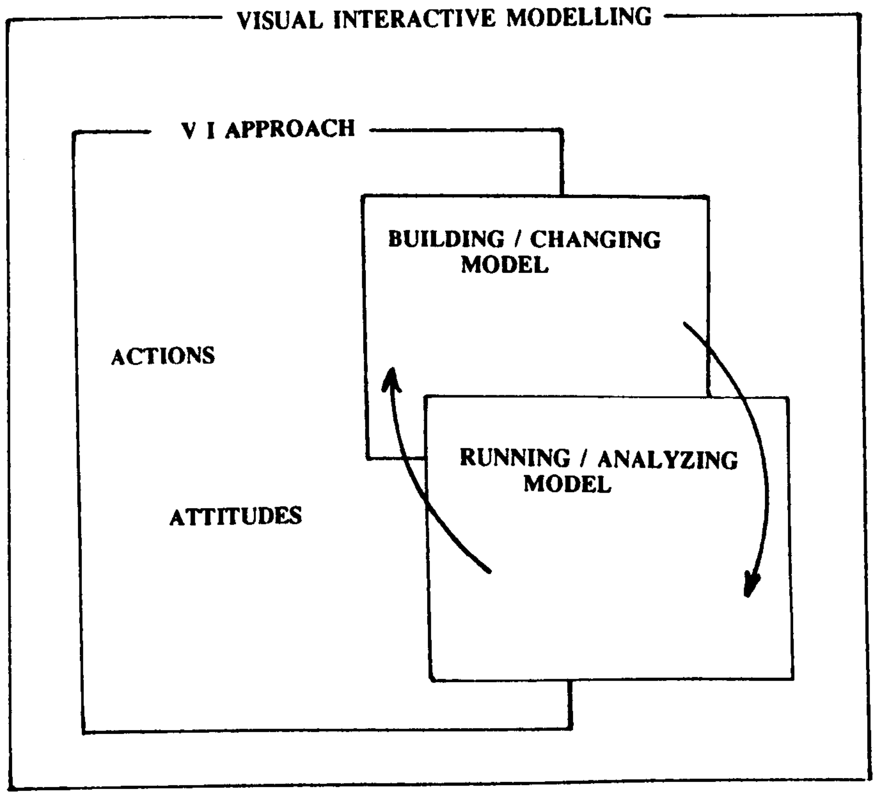

Figure 1.5.7.A - A Framework for Understanding Aspects of VIM

This chapter is concerned with the 'model running and analysis' phase of a study.

6.1.3 Structure of the Chapter

The remainder of this chapter is divided into four sections. The first of these is an introduction to the use of literature from the field of psychology of learning. The next two sections give an outline of how the experimental modelling sessions were carried out and a description of the 'problem' and model which were used. Section 6.5 is divided into subsections and gives a full discussion of the observations from the experimental sessions.

6.2 Some Psychology Literature.

This section discusses the Psychological literature which is directly relevant to the experimental modelling sessions. The previous section alluded to the possibility of cognitive and other differences between clients being an important VIM design consideration. Before any investigation into this possibility it seems relevant to consider psychological research.

However, first consider the type of task our decision maker clients are undertaking. They are not involved in solving a puzzle which has a defined set of rules and a clear objective. They are attempting to find a solution to a complex open problem. In 'solving' an open problem a decision maker is not seeking the answer, but rather, is going through a process of learning about a system which includes the problem until it becomes sufficiently clear that a set of actions has been found which the decision maker feels will be worth undertaking as the next step forward for the problem system.

How can psychologists help us to understand how people learn in these situations? Unfortunately, "Psychologists generally agree that a theory of adult learning is thus far incomplete." (Dempster, 1980 page 177).

Work in the field of human learning or problem solving has not concentrated on the type of tasks which are relevant to VI modelling sessions. Newell and Simon's (1972) seminal work on 'Human Problem Solving' is concerned with low level problems such as cryptarithmetic and games such as chess. These are not problems which are necessarily simple, programmable, or highly structured, nevertheless, they are different in important characteristics from the types of problems decision makers face. It is not in question that the processes used by humans to solve these low level 'problems' are indeed complex and an understanding of this area is required before a unified theory of decision maker 'solution finding' can be approached. However much more research is required before psychology can shed light on the processes which a human mind uses when analyzing a complex industrial system.

The gap between research in psychology and what is needed to assist with real problems is recognised. Neisser (1976) says:

> "...Allan Newell tabulates no fewer than 59 experimental paradigms of current interest. He wonders explicitly whether another generation of such work, and development of still more techniques, will make us any wiser. Fifty-seven of the paradigms on Newell's list are based on artificial laboratory situations; the only ones with a shred of ecological validity are playing chess and looking at the moon."
>
> (page 7)

A similar gap has been reported more recently by Bainbridge (1981). She reports that designers of interfaces between human operators and industrial process controls are only assisted by research related to low level tasks. She shows how human behaviour differs between 'fast control tasks' and the longer term control tasks to be found in industry. Most existing theories treat the human mind as a logical machine rather than an inference and image collator.

This section of this thesis has to be rather negative because there are few results from the psychological field which can be applied specifically to the problem of learning via a VI model.

However some theories from cognitive psychology are potentially useful. Cognitive style (Hudson, 1968) will be referred to and other psychological research is relevant to issues such as screen design and will be referred to in

6.3 Experimental Method

The experimental sessions reported in this chapter were not designed to test a hypothesis. Rather they were designed to provide the researcher with a number of similar modelling sessions which could be observed to gain some further insights. This section states how the data was collected. Section 6.4 will describe the 'problem' and model used for the experiments.

Twenty one graduate students on Warwick University's O.R. course were used as 'subjects' in these experiments. They all had some idea of what the technique of simulation could be used for.

The task for each subject was to spend up to one hour using a supplied simulation model of a particular problem (cf section 6.4) and to attempt, in this time, to discover a good set of rules for controlling the piece of plant which was modelled by the simulation. Each of these twenty one attempts by the subjects was recorded by:

1) The researcher making notes during the progress of each session.

2) The computer recording the actions of the subjects.

3) The subjects' answers to some specific questions asked at points during the modelling sessions.[1]

All the students (as a group) were given an introductory lecture (by the researcher) about the purpose of the experiments and the nature of the 'problem'. It was regarded as important that the researcher should not talk about the 'problem' during the modelling sessions because different statements might be, inadvertently, made to each subject. To back up the lecture a detailed handout was prepared and given to each subject. This document is contained in Appendix A. A second document (in Appendix B) explained the nature of the automatic control rules (cf section 6.4) which could be used in the model.

Data collection method (3) above was used as a means of eliciting some data on the growth of ideas for control rules in the minds of the subjects. A questionnaire was used for this purpose. It was not a questionnaire in the usual sense of a document completed by the subject. It was used as a formal list of questions to be asked by the researcher in a specific sequence, again, so as not to influence the progress of the sessions differently by inadvertently using a different sequence. The modelling sessions were interrupted at approximately 10 minute intervals, and the subject's reply elicited, before the subject was

[1] This was used for sessions 4-21. It was deemed necessary after the first three sessions which were used to 'pilot' the design of the sessions.

allowed to continue to use the model. The model was 'stopped' during the asking of the questions so that simulation time did not pass during the answering of the questions.

One manner in which this data was analyzed was to map, in a graphical form, the changes (over time) in the control rules tried by the subjects. These graphical logs are shown in Appendix D.

6.4 The Experimental Problem and VI Model.

The 'problem' used for the experimental session had to be sufficiently simple so that it could be described to the subjects in a reasonably short period of time. If it was too complex they might have either not spent sufficient time reading the handout, or they could have misunderstood the problem.

Conversely, the problem also had to be sufficiently complex to make solving it non-trivial.

The problem chosen is again from the car industry and relates to a set of linked conveyors (cf Section 5.5) adjacent to a 'paint shop'. The conveyors transport cars which have failed a quality check immediately following the main paint process. The cars are carried around the conveyor system on 'slings' which hang from the ceiling-fixed conveyor mechanism. The cars have to be transported to a paint-repair shop. (Or they can be sent, on a temporary basis, to a storage area). Full details of the 'problem' are contained in Appendix A.

Figure 6.4.A shows the model screen.

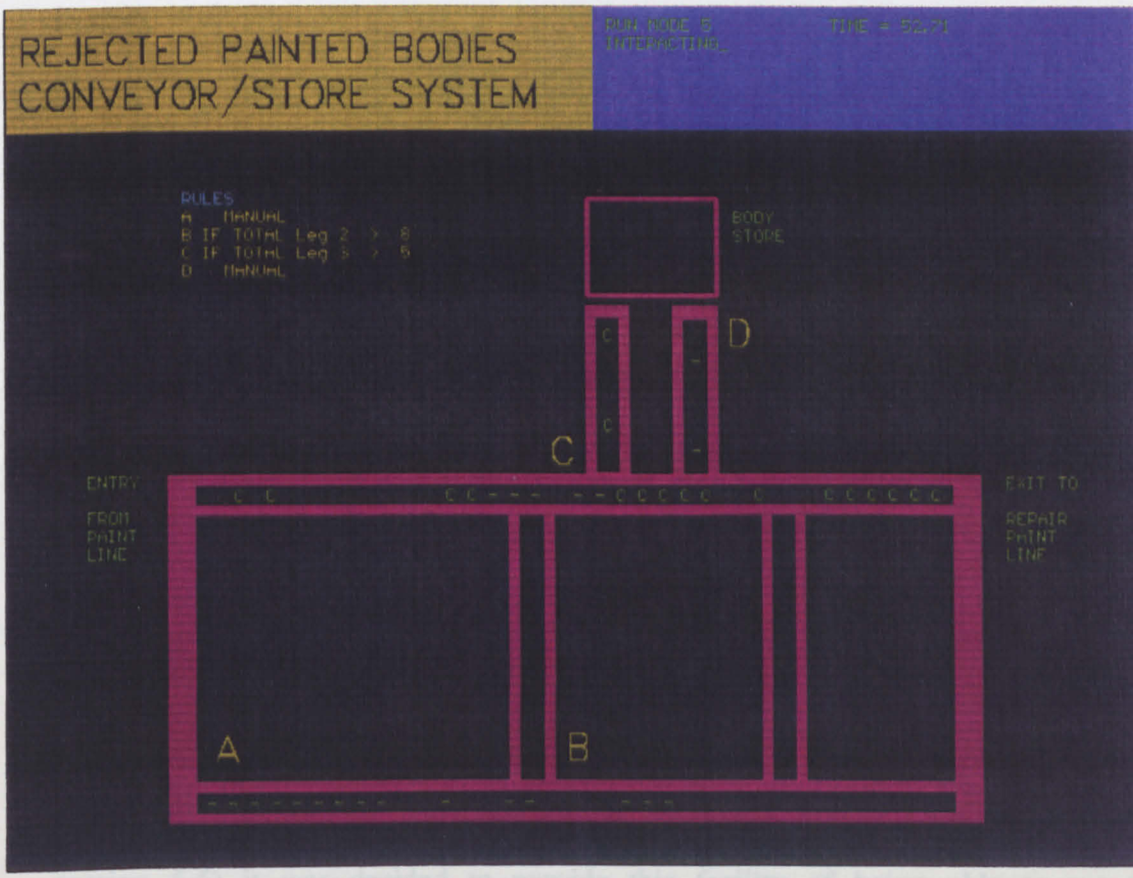

Figure 6.4.A - The Experimental Model Screen Display

The task given to the subjects was to use the model to discover a set of control rules for operating the plant. The objective of running this piece of plant was to ensure that the conveyor system was always able to take rejected cars away from the main paint process (otherwise it would block and stop the main paint process) *while* also ensuring the repair shop was fed with a smooth flow of repair work. The conveyor systems could act both as a buffer and a transport system.

Four decision points controlled the flow of either empty slings, or loaded slings, around the system.

Each decision point could either be controlled manually (the user would decide when to change the direction of flow) or via a decision rule obeyed by the simulation model. The decision rules for each control point were parameterised and the parameters could be changed by the user. Appendix B gives details of the decision rules.

Following observations from the Action Research studies (see, in particular, section 5.5) it was decided to provide this facility of being able to run the model both manually and automatically because it was considered possible that allowing users to 'play' with a model for a while might enable them to understand the behaviour of the model more quickly than by using a more formal experimental method.

The next section discusses the observations from the experimental modelling sessions.

6.5 Collated Observations

As discussed in Chapter Four, both the Action Research studies and the research reported in this chapter have led to a 'body of experience'. This body of experience is encapsulated in the guidelines in Chapter Seven. What follows is a discussion of the specific findings from the experimental studies which have contributed to that body of experience. This is in the form of a discussion under headings where each heading collects together related observations from the computer logs, graphical logs, questionnaire responses, and researcher's notes. Appendix D contains some of the raw data collected from the experimental sessions (the graphical logs of control rules used).

6.5.1 Cognitive Style

The experimental modelling sessions cannot be treated as a series of trials which can easily be compared with each other. This is because each session differed in at least one major respect: the human subject. (The people used in the sessions are described in section 6.3).

da Silva (1982) has noted that Decision Support Systems need to be user dependent i.e different users will require different means of understanding identical tasks.

> "The problem solving process used in semi-structured problems is finely connected with the cognitive style of decision makers. Thus it seems important that a DSS interface should include the ability to be tuned to different users."
>
> (da Silva, 1982, page 96)

'Cognitive Style' is the term used by psychologists to mean the approach taken by an individual to thinking and problem solving.

Many dimensions have been distinguished which go together to form an individual's cognitive style. The table 6.5.1.A lists some of these dimensions, with the authors who distinguished them:

<------------Dimension---------->		**Author**
Field-dependence	Independence	Witkin (1969)
Focusing	Scanning	Bruner et al (1962)
Convergent	Divergent	Hudson (1968)
Serialist	holist	Pask and Scott (1972)

Table 6.5.1.A

Some of the definitions of these dimensions overlap. For instance the 'holist' to 'serialist' dimension of Pask and Scott is similar to the 'scanning' to 'focusing' dimension of Bruner et al.

The important issue here is not that there are a number of different dimensions, but that there is agreement that people do have cognitive styles which differ and that:

> "...certain kinds of teaching materials and teaching strategies fit well with a serialist way of learning but are uncongenial and difficult for holist, whilst others suit a holist very well and are unpalatable to a serialist."
>
> (Floyd, 1976 page 24)

If this applies to teaching, then it seems likely also to apply to learning about a system from a model.

6.5.1.1 Different Strategies by Different Subjects

In the experimental modelling sessions some subjects exhibited tendencies which appeared to be at different locations on a 'serialist' to 'holist' dimension. For example some subjects would spend the majority of their session controlling the system manually, playing with the relationships, then towards the end, specify a set of automatic control rules. (For example, see Appendix D, sessions 11 and 16). They would change these little and be reasonably successful. Other subjects would introduce a set of rules early on. (See sessions 2 and 15). They would then experiment with, and amend, these and again finish with a reasonably successful set. However another set of subjects would prefer to work manually on one area of the system at a time. (See sessions 5 and 9) They would install one rule at a time as they felt it was good enough.

This latter strategy is serialist, whereas the first two were variations on a holist strategy.

As a consequence (with the relatively small sample size available) it would not be possible to make statistically sound tests between the sessions because of the large variation in model use introduced by these different strategies.

However, an issue which requires consideration is: Does this mean that account must be taken of clients' cognitive styles when VI models are designed?

The experimental aspects of this thesis make use of VI models in a particular class of application (cf section 4.3.2). There are several issues relevant in answering this question in relation to these applications.

It would be difficult, in 'live' studies, to test the client's cognitive style. Clients would be unlikely to accept a psychological test prior to the model building (or at any stage!). Such a test would not be compatible with the nature of a conventional analyst-client relationship. Furthermore, there is often more than one client (or more than one individual in a client group. cf Each of the studies discussed in Chapter Five). While it is possible that all the individuals may be from similar backgrounds, this does not cause their cognitive styles to, necessarily, be similar. Hudson (1968) reports some correlation between an individual's cognitive style and their preferred school and college subjects. However there was, as stated above, a difference between the problem solving strategies of people on an O.R. course. So it would not be of benefit to design a model around a particular cognitive style. (It is accepted that, in some cases, it may be possible to design a VIM for a specific person who will use it.)

There are sometimes cases when a number of different users will demand different interfaces to the same model. (cf da Silva, 1982) The researcher has been involved, subsequently, with the building of a VI model used for budgeting within a large organisation. Each budget holder insisted on being able to select a preferred display method when attempting to adjust project costs/durations to match total budget constraints. Although this insistence may not have been based on a need to work with different problem solving strategies it is nevertheless illustrative of the potential for one model being designed to meet many cognitive styles.

6.5.1.2 A Potential Solution

The strategy used for handling this may need to be different when a group of clients use a model together. Perhaps a model which can be used flexibly (with respect to cognitive style) would be a satisfactory compromise. Ideally, the strategy used to find a solution should not be limited by the model. The overall O.R. or modelling 'process' must be successful whatever the client's cognitive style; so the model needs to be cognitive-style-independent.

The model used for the experimental modelling sessions was used by people pursuing quite different problem solving strategies. As each of the decision points could either be manually controlled or automatically controlled the problem solvers had a complete choice of how much of the problem to tackle at a time. (cf section 7.4.3 for discussion of other flexibility requirements).

The conclusion that a model should be sufficiently flexible to cope with different client problem solving strategies is important on a different level too. An individual sub-group of clients (say from a particular department) may wish to approach a problem from a different angle from other sub-groups. The model would be potentially less useful if it did not allow such an alternate approach because, restricted in this way, a sub-group might become alienated from the problem solution-finding process (cf section 2.3.7.10).

6.5.1.3 Summary

To summarise, this sub-section has reported how different problem solving strategies were used by different individuals to 'solve' the same problem using VI simulation. This section has reasoned that in the case of the type of study considered here, it is not possible or of benefit to develop models designed around particular problem solving strategies. It has continued this argument (in the light of certain aspects of the experimental modelling sessions) to conclude that the solution to this dilemma is that models should be cognitive-style-independent. The model needs to be flexible. Exactly how this flexibility is achieved will be described in section 7.5.3 because it is relevant to problems other than that in this subsection. The problem solving strategies of individual people or groups should not be allowed to have a limiting effect on the solution finding process.

6.5.2 Use of a Mid-Session Questionnaire

As described in section 6.3 a mid-session questionnaire was used at approximately 10 minute intervals during most of the experimental modelling sessions. The original purpose of this was to record the subject's current beliefs about the modelled system. This information would then have been used to plot the changes in the subject's 'mental model' of how the system behaves. Unfortunately the subjects were unable to answer the questions in a sufficiently clear, unambiguous and consistent manner in order to make it possible to distinguish when and in what way their beliefs were changing.

6.5.2.1 Reflection Break

However the questionnaire resulted in an additional benefit. Approximately every 10 minutes the model would be stopped (ie made to wait in its current state without simulated time passing) and the subjects asked a series of questions. It was in the period immediately following each of these interludes that the subjects tended to make changes in the rules they were using to control the modelled system. Forty percent of all changes were made at this point. The remaining changes being spread evenly over the period until the next questionnaire interlude.

This is taken as evidence that the questioning helped the subjects structure their thoughts. By taking the subjects through a series of questions they were encouraged to sort out their 10 minutes 'experience'. In order to answer the questions they needed to form some logically consistent statements which encapsulated 'findings' from their 10 minutes. The experience became more explicit during the questioning. This led the subjects to be able to understand the nature of the thoughts in their minds and to therefore be able to decide what experiment they would like to carry out next.

The conclusion to be drawn from this is that 'questioning interludes' may be beneficial even when the answers to the questions are not required by the analyst.

We will extend this conclusion later (section 6.5.7) after discussing some further evidence from the experimental modelling sessions. The next section looks at a variation on the above observation.

6.5.3 Groups rather than Individuals

Since conducting the experimental modelling sessions the model has been shown to two separate groups of about 12 graduates who were attending courses on quantitative methods as part of their industrial training. These sessions took the same form as the experimental modelling sessions. (Each session was one of a series of lectures the graduates received on simulation). The only difference which was particularly significant between these sessions and the experimental modelling sessions was that the groups worked as a whole in trying to find a good set of rules.

The groups, working as a whole, progressed towards their solutions much more quickly than occurred in the individual sessions. In both cases the groups homed in on a set of rules with which they were satisfied much more quickly than tended to happen in the individual sessions. The measure of satisfaction was that the more vocal of the people in the groups believed the group had reached a consensus after only 15 minutes in the case of each group.

Perhaps, when an individual works towards a solution, the rate of evolution of ideas is slower than when they work in a group because their ideas are not criticised. Any ideas, unless rejected immediately on logical grounds, must be tested in the model before they can be rejected. The group setting provides opportunities for members to criticise each others' ideas. Thus, as a first screening will take place before any idea is tested within the model, evolution of thinking towards a solution is probably faster.

This group criticism of ideas before they are tried in the model is not necessarily advantageous. The Action Research studies have indicated (cf section 5.4.7.2) possible benefits in being able to try out ideas which the group might initially consider to be a waste of time.

This observation is reported here because it comes from use of the experimental model and also because it shows how these experiments, based on individual people, are perhaps removed from the reality of real decision making. (Because they are based on *individuals* using a model.) Further laboratory experimental research, specifically aimed at group analysis of models, would be necessary before drawing conclusions.

6.5.4 Display by Exception

In this section we look at a finding from the experimental modelling sessions which reinforces views from the academic computing community.

Recent years have seen a shift in emphasis in the application of computers. Rather than improvements in efficiency, computer specialists are aiming for improvements in effectiveness. (For evidence of this see Keen and Scott-Morton, 1978).

One of the axioms of the 'Decision Support System' school is that only the information required by the user should be supplied. The older 'Management Information Systems' school tended to supply all information that might have a use and then let the decision makers sort out what they needed.

Some decision makers may require different information (cf section 6.5.1) but any information which is displayed should be relevant and meaningful to the current user. Otherwise it may mislead or hinder the user.

An example of this occurred during the experimental modelling sessions. The introduction to the 'problem' (cf section 6.4) which was given to the subjects (both written and verbal) clearly stated that the store was of infinite capacity. However for increased realism the screen displayed the number of cars currently in the store. This piece of information was not relevant to the objective of the stated decision problem. In the first three experimental modelling sessions the subjects mistakenly noted this variable as though it was of some importance.

"The number in the store is starting to increase...",

and

"I'll have to try to reduce the number in the store...",

were comments made by two of the three subjects. If information is known to be irrelevant it should not have been displayed. For the fourth and subsequent sessions the display was altered to remove the data. No further subjects mentioned the magnitude of the contents of the store.

While in practice it will often be difficult to determine which variables are relevant this finding does show time spent designing the display is of some value.

The next section examines how data which should be of value can sometimes be misinterpreted.

6.5.5 Overreaction

This section continues the theme of the user or client being misled by aspects of the model. Sometimes relevant statistics can be misinterpreted by the users of the model.

Given that the users of a VI simulation watch it 'running', progressing through time, they see the exceptional conditions as well as the average conditions. This feature of VI modelling is often an important reason for its application to a problem. (cf section 5.5.4). However it would appear that it might cause the decision makers to overreact because these conditions did cause some of the experimental subjects to overreact.

6.5.5.1 Forms of Overreaction

As discussed in section 6.3 a typical experimental session proceeded through a number of phases:

a) Manual intervention for control

b) Testing and changing of postulated automatic control rules

c) Final statement of rules

The overreaction problem could occur in two distinct forms:

1) In the first, manual, phase where the subject is making manual decisions at each control point, the subjects often act at a tactical rather than a strategic level. They sometimes unnecessarily reject a hypothesis and so extend the process of reaching a coherent understanding of the system.

2) As mentioned in section 5.8.9, when watching the model's behaviour after having set up an automatic rule the subjects can be heavily influenced by what they first see, rather than taking into account their observation over a longer period.

An example has been given of case (2) above in section 5.8.9 but there are few occurrences of this type of 'overreaction' in the experimental sessions. (see session 15 graphic log in Appendix D). However case (1) occurred in the majority of sessions. There is perhaps an important interaction between the relative occurrence of 'overreaction' case (1) and (2).

This point will now be discussed but first an example will be given of the first case of 'overreaction' as it occurred in the experimental modelling sessions.

6.5.5.2 Example

A subject might, for example, decide that, as it is necessary to be ready to pick up rejected cars at point A (referring to figure 6.5.5.2.A) then they should maintain a queue of at least 10 slings at this point.

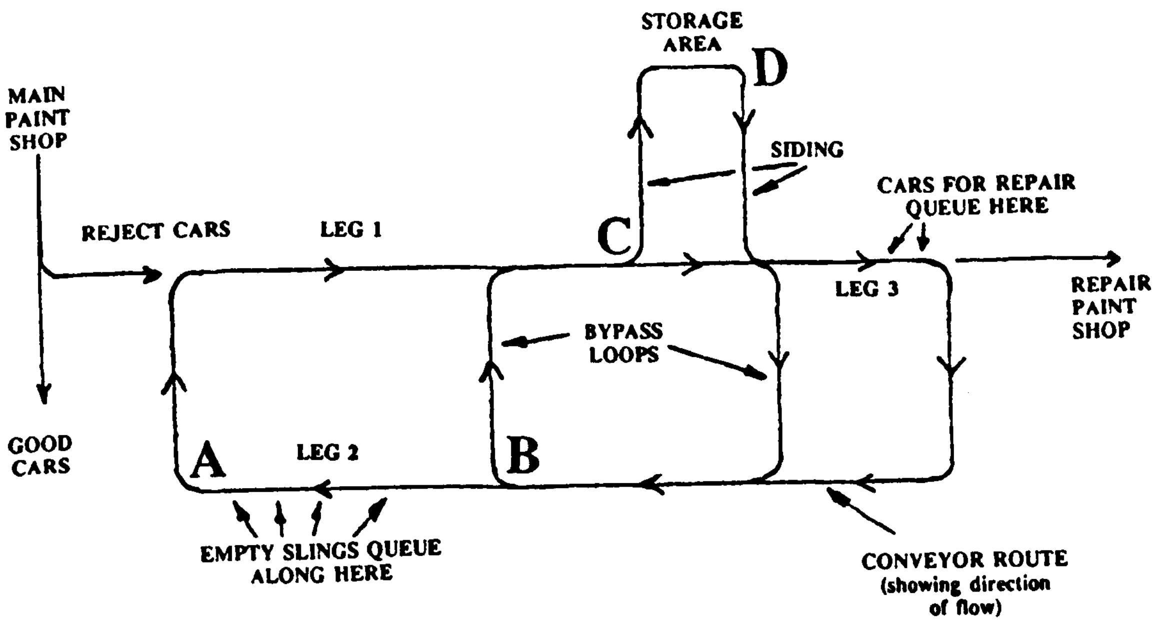

Figure 6.5.5.2.A - Schematic of Experimental Model

Having decided this and set up the queue of slings it might be that no cars will be rejected in the next half hour of simulated time. In which case the subject may decide to use some of the queue of slings at A to collect cars out of the store to keep the repair shop running. Then as (say) 5 of these 10 slings are on route to the store a sudden batch of rejects would arrive and the remaining queue at A would be unable to cope.

6.5.5.3 Analysis

What should the subject have done? If the subject had been logically testing a hypothesis that a queue of 10 slings at A was strategically a good idea, then they should have left them at A. They would then have been able to see if 10 was enough and whether the rest of the system would cope without help from those 10. On the other hand, when the subject is still in the phase of controlling the system manually, should the subject be making logical experiments? Perhaps in this early learning stage of searching for an understanding of the system's dynamics an apparently random 'play' is more efficient. Of course the 'play' is not random but is guided by human intuition. Later, having built up an understanding, the subject can then start to perform more logical experiments, based on the ideas generated during the first phase.

If the above 'playing' method is accepted as being a more efficient method of learning, then it is possible to see why, in the experimental modelling sessions, there was so little of the type of overreaction that occurred in the Action Research Study reported in section 5.8 (ie case (2) above). The subjects understood more about the dynamics of the system before they started to go on to learn how it could be better controlled. They realised that it was subject to large variations and that any control rules they tested would have to be robust to all variations. Thus their experimentation phase was reasonably 'scientific'.

The next subsection deals with the problems of conducting these experiments when the system is highly variable in nature.

6.5.6 Controllable Randomness

This section discusses how the subjects in the experimental modelling sessions tested their rules for robustness.

As has been discussed in section 5.2.2, the word 'simulating' could perhaps be replaced by the word 'gaming' in the case of some VI simulations because it is often not the steady state situation in which we are most interested.

Once a modelling session had reached the stage of evaluating alternative sets of rules the subjects found it difficult (or at least time consuming) to test out the rules, given the extremely variable nature of the system. Their rules would work under reasonably calm conditions but they had to wait for the right type of extreme conditions to prevail in order to see if the rule could cope.

To avoid this frustrating waiting time a three-way switch was installed into the model. The three settings of the switch were:

NORMAL: The random number streams were used to decide whether each car was a reject (this was how the model worked prior to the installation of the switch).

FAST: Every car was rejected.

SLOW: No cars were rejected.

The latter two settings allowed the subject to generate, at the touch of a button, the conditions under which they wished to see the rules operating. Out of the eight sessions where this facility was made available to the subjects 5 wanted to use it. All of those 5 said they found the facility very useful. They said they felt they had been able to test their rules thoroughly. There is not a statistically valid comparison which could be made between these 5 sessions and those prior to this facility being available. However all 5 of these subjects appeared to the experimenter more confident about their results than was typical for the subjects in the other sessions. Of the 3 who did not use this facility once it was available, two of them did not specify any automated rules until the very end of their session.

This facility of controllable randomness is of considerable hindrance during the initial manual control phase. It is only useful when the user has reached what they would regard as sufficient understanding of the system to be able to experiment with a specific control rule. One subject was allowed to use the facility before they had reached this stage. This individual became unable to cope with both controlling the causes and remedies simultaneously.

While it could have some purpose, the dual role of learning about the behaviour of a system at the same time as deliberately changing some aspects of its behaviour may perhaps be too complex for some decision makers.

This technique of 'controllable randomness' is not a universal solution to this difficulty presented above because real life problems are usually more complex in their randomness. In addition it is often not only random variables which cause apparently random events to occur. Complex deterministic interactions can cause highly variable activity in parts of the system. (The volume of parts currently in transit in the study discussed in section 5.8 is an example). The purpose of reporting this adjustment to the model is not as a solution but so that the limitations of such a solution can be noted. Bell (1989) discusses other potential methods for coping with random behaviour of models in the presence of decision makers.

A method for controlling the variability in more complex models could be to repeat particular combinations of events which cause the conditions under which a rule is to be tested. However this might lead to a set of control rules which is designed to cope only with one particular stream of difficult events.

The conclusion of this sub-section is that some form of influence on random events is a help in testing the robustness of rules. However the method by which this should be provided in many practical circumstances is undetermined.

6.5.7 Restricted Search of Decision Space

This section reports a finding which, if it applies to practical cases of individual decision makers solving their own problems with VI models, could present a serious issue for VI model builders.

Careful examination of the graphical logs of the experimental sessions (see Appendix D and section 6.3) shows that many of the subjects reached conclusions they regarded as satisfactory which were rather different from others' satisfactory results. This, in itself, is not a problem. What is a problem is that in most cases these results were reached in ignorance of the alternative strategies. Subjects appear to scan around the solution space until they find a strategy (set of rules) which looks as though it might have some potential, and then concentrate entirely on adjusting and fine-tuning this strategy without at any stage taking a step back and looking to see if there could be alternative strategies with even more potential.

See, for example, the graphical logs in Appendix D of the manual and automatic rules experimented with by some of the subjects. Sessions 3, 8, 9, 10, 11, 15, 16 all illustrate this approach to a considerable degree by starting with control of a decision point being based on the magnitude of the contents of a particular conveyor leg, and then only adjusting the size of this control magnitude. They do not attempt to control each point via a different conveyor leg. Other subjects exhibited this tendency to a lesser degree.

If this behaviour extends to the case of real decision makers working with VI models then it indicates a need for the presence of a trained analyst during the model analysis sessions to prompt the decision maker into occasionally stepping back and reviewing alternatives.

6.6 Conclusion

This chapter has discussed data collected from the series of experimental sessions which have contributed towards the creation of the body of experience which will be drawn together in Chapter Seven.

Without this series the results of the research programme would have lacked certain evidence of a slightly more detailed type than can be drawn from the Action Research Studies discussed in Chapter Five. These experiments were not designed to be a set of fully controlled experiments. Visual Interactive Modelling is at too early a stage to make such necessarily focused work of benefit, but unfortunately, because of the lack of control, it is not possible to draw firm findings from the current chapter. Knowledge has only progressed by some small addition to insights about VIM. Chapter Seven now attempts to draw together the body-of-experience.

CHAPTER SEVEN

DISCUSSION AND GUIDELINES

7.1 Introduction

This is the first of two results chapters which attempt to provide some answers to the two research questions posed in Chapter One.

Chapter Seven has to make some assumptions; that Visual Interactive Modelling has some value. It assumes that the benefits discussed in the literature (cf Chapter Three) are sometimes attainable and discusses *how*, in the context of data collected (cf Chapters Five and Six), these benefits might be better achieved.

Chapter Eight will make further examination of the benefits discussed in Chapter Three and postulate extensions in the context of data collected (cf Chapters Five and Six) and the discussion in Chapter Two on the 'O.R. Paradigm debate'.

The assumptions we make about benefits are important because the nature of the benefits we want to achieve could affect the actions we take and tactics we adopt as we apply VIM. As this chapter is attempting to suggest some such actions and tactics we should first note the extent of our aims.

Chapter Eight suggests certain *possible* further benefits of VIM. Rather than assume the benefits discussed in Chapter Eight here, Chapter Seven discusses the data from Chapters Five and Six in the context of *only* the *current* literature on VIM and the benefits it postulates.

To do more would make Chapter Seven's findings contingent on Chapter Eight's conjectures.

7.2 How to Answer the Research Question

The first question posed in Chapter one was:

> What guidelines might be appropriate for Operational Researchers to follow when making use of Visual Interactive Modelling in aiding clients?

Chapter Four considered difficulties in answering this question from the current literature and argued for a series of Action Research studies and some laboratory based work. The argument was that a related series of studies which had the specific aim of providing data to answer this research question would enable comparisons to be made and patterns to be discerned which would lead to a 'body of experience'. By the phrase 'body of experience', it is intended to denote a series of statements which encapsulate what happens when going about Visual Interactive Modelling and what different actions appear to lead to what outcomes. This 'body of experience' could then be called upon to:

1: distil and argue for a specific set of guidelines and

2: be used by other researchers as a basis for further experimentation and research to broaden the applicability of this research and to clarify (or attempt to refute) the guidelines.

Currently, when each Visual Interactive Modeller starts building their first model, they must do this without guidelines on what methods to employ to best achieve the benefits for which they are presumably aiming. As they are using VIM they may be aiming for the benefits described in the existing literature. But this literature does little to guide the new Visual Interactive Modeller, or to guide the experienced Visual Interactive Modeller who may have built and used models in disparate avenues without the time, or consistency of modelling situation, to be able to reflect on, and learn from, experiences.

In this situation, if the benefits discussed in Chapter Three are to be best achieved it seems worthwhile attempting to provide some guidance to these people.

The next section discusses some difficulties in achieving this.

7.3 Some Deficiencies in the Data and Restrictions on Results

This section discusses some problems with the data that has been collected. These problems are partly related to the methodology chosen for the research programme (cf Chapter Four).

The aim of the chapter is to report a set of guidelines which are both specific enough to follow in a pragmatic setting and are rigorously argued in the context of a research programme which has the aim of contributing academically valid findings to the research community. However, a good deal of the data collected and reported in the previous two chapters is conjectural in nature.

It has therefore been decided to restrict the nature of the results reported here. A 'body of experience' is developed in which we can only conjecture about relationships between our actions and their effects. As a consequence we can only conjecture (rather than rigorously argue) a set of specific guidelines. Chapter Nine will discuss this shortcoming (along with others) and will suggest the nature of further research which can build on this restricted set of results.

The results here should be regarded as a set which is based on *some* evidence; evidence which is further to that previously available (cf Chapter Three). It is further to this previous evidence in both quantity and quality. The quality is enhanced because it is evidence collected from a purposefully designed *series* of studies. Nevertheless it is insufficient evidence to be able to postulate statements which would be categorical in nature. The body of experience and guidelines can only be offered as results on which others can build (perhaps by refutation).

7.4 Results - Body of Experience

This section draws together the observations from the data chapters under a number of headings which related observations from different studies and experiments. This forms a 'body-of-experience' on VIM which increases the knowledge available both within the research community and for use by practitioners.

7.4.1 Involvement of Client Actors in Study

Several of the Action Research studies noted issues related to the presence, or otherwise, of the client during various phases of the study. (cf sections 5.3.3.1, 5.4.4, 5.5.6, 5.7.5, 5.8.8).

The studies differ in their consideration of who is the 'receiver' of the study. There appear to be a number of roles on the 'client side' of a project (in contrast to the 'O.R. side'). Some of these roles are often played by the same actors. If the 'client' is the person who is paying for the project this may also be the same person as has the technical knowledge to judge the acceptability of the solution and to input technical data required by a study. However, these could be different people. Similarly the person responsible for implementing an outcome of a study may be the same, or different from, the actors playing either of the above two roles.

Further, the roles mentioned in the previous paragraph could be played by more than one actor. For example, in section 5.4.3 we saw how there were a number of departments, who were potentially in conflict with each other, who wanted to be involved in the study. (This was also reported in sections 5.6.2 and 5.7.3). These actors considered they had technical input to make and considered themselves responsible for implementing any decisions which the study might lead to. Thus they wanted to be involved in the study to ensure their point of view was taken into account.

Sections 5.4.7.3 and 5.7.5 note different degrees of ease of implementation when the people responsible for implementation were involved, or not, in the study, and these sections speculated a causal relationship between the involvement and the ease of implementation.

Sometimes it appears possible for a study to proceed without people in a role which may be important. The first Action Research study noted this (cf Sections 5.3.3.1 and 5.3.3.5). While there was a sponsor who commissioned the study, this person was not in a position to implement findings. None of the people involved in the study (or who could be persuaded to be involved in the study) were responsible for the areas of the plant who would have to take the consequences of the study's conclusions. This project failed and section 5.3.3.5 speculated that one of the reasons for this was the absence from the study of a person with responsibility for the resources required for implementing any outcome.

While the observations in this sub-section are perhaps relevant to any O.R. study, they are of particular relevance to a VIM based O.R. study because of the involvement *possible* by the client's side.

Section 7.4.6 also comments on the presence of some of the actors in the study.

7.4.2 Types of Learning

The previous sub-section (7.4.1) discussed some advantages in having certain of the actors on the 'client's side' of a study involved in the analysis. This sub-section discusses findings from the Action Research studies related to how these client actors *learn* during their involvement with the study.

Table 5.8.5.A distinguishes six types of learning about a problem situation which it is believed may have occurred to clients while using the VIMs in the Action Research studies. (There are other dimensions on which learning via VIM could be measured. For example, a very different analysis is pursued by Belton and Elder 1991a). Such analyses are potentially useful if they can enable us to see how we may need to provide different facilities if we wish to enable or enhance such learning.

It is worth reviewing here some of the learning which occurred in the six studies and how it fits into these categories.

Table 5.8.5.A is reproduced here to aid readability.

Type of Question	Question exists prior to use of model	Question unknown prior to use of model
Trivial to answer	A Answered before model use	B Unexpected need shown by model and answered
Complex to answer (must use a model)	C Model used for analysis to provide answer	D As above, except may be necessary to make amendments to model to fully answer question
Model cannot provide direct answer	E Use model to learn about potential solutions (may be necessary to amend model during learning)	F As left, except unexpected need shown by model

Table 5.8.5.A

Any of the right hand (**B**, **D** or **F**) categories could have helped the managers of areas of the Longbridge plant understand the operating needs of other areas of the plant. Learning related to 'Manual Decisions' (cf Sections 5.3.3.4, 5.5.4, 5.6.4, and 7.4.3) are either of category **E** or **F**. The apparently simple category **B** is potentially important for problems where multiple interests are at stake (for example, sections 5.4.3, 5.6.2 and 5.7.3) because different perceptions of a problem area might make apparently simple facts become opaque to some actors. (However, the example given with the table in section 5.8.5 occurred through an incorrect assumption made by the single client who owned the problem). Although category E was formulated in the context of questions which required some problem-solving skill to answer, a variant on E relates to subjective issues such as those discussed in section 5.6.3. Chapter Eight discusses the notion that VIM can *provide examples* which can enable clients to think more clearly about which options *they prefer*. For example, just as VIM can be used to show potential options for recovering after a conveyor breakdown (the success of which can be described by objective measures), VIM could also be used to show potential options which can be compared manually against subjective measures (see sections 7.4.4 and 8.4).

These categories are not offered as a new method of understanding what happens when clients are involved in studies, but merely as a way of understanding the different types of client learning for which we might want to aim.

7.4.3 Control Rules Based on Human Intervention

In conducting the Longbridge Strategic Study (5.3) it was observed that the model had been simplified in a way which would render its behaviour different from the real world in a respect which might be important (see section 5.3.3.4). Certain unstructured operations are performed in the real factory as contingency measures. They are decided upon by the experienced staff in any particular area of the factory when the normal 'systems' fail. Assumptions that these contingencies do not occur are sometimes made by model builders to simplify the modelling process.

Section 5.6.4 reported how a skilled operator of part of a plant may use rules to operate the plant without consciously externalising the rules. A VI simulation could be built which stops and asks the operator for the decision which would be taken in the plant. Rules, which in a traditional (non-VI) simulation would have to be programmed (and therefore might be simplified or omitted) could be included in the modelling process by human intervention with the model. Thus the model would behave more like the real world. Furthermore, section 5.7.2 described how, with sufficient practice with a model, it is possible for some of these subconscious rules to be brought out by the operator and verbalised so that they can then be programmed.

The method used in the studies in sections 5.6 and 5.7 could not have been used directly to completely solve the difficulties faced in the strategic study of Longbridge (5.3.3.4), but it would have perhaps advanced the model some way towards increasing its match with the real world.

By a related procedure, section 5.5.4 reported how an effective set of control rules was discovered by first operating parts of the system 'manually'. As an understanding was learned of what aspects of the manual control influenced which aspect of the system, some automated rules were postulated and tried, and refined over time.

To summarise, the option of including rules in a model which are (at least during an early stage) entirely under the control of human judgement appears to provide potential for:

(a) Modelling unstructured and non-predetermined aspects of the control of a plant

(b) Modelling aspects of a plant which are under the control of 'experts' who cannot necessarily externalise all the rules they use.

(c) Discovering new rules which can only be discovered by incremental adjustment of other rules via a process which involves the use of human intuition.

The experimental model (section 6.4) offered the experimental subjects the opportunity to control the model by hand and also to programme into the model rules to replace their manual control. Section 6.5.1.1 has described how some subjects preferred to spend much of their time controlling the system manually, whereas others preferred to invent and test rules early in their session. This section speculated that preference here might be related to cognitive style. Although research has been published in this area it has not led to any statistically significant evidence that cognitive style is an important issue in

Visual Interactive Modelling. The data in Chapter Six also provides no evidence for this but, nevertheless, it is possible that restricting a user's options (when to programme and when to control manually) could restrict their ability to find a set of rules in the way that is best for them (and thus reducing the rapidity or quality of their performance).

Section 6.5.7 noted a concern related to this approach of using manual, and then automated rules. It states that there is some evidence that users get locked into a particular avenue of investigation, which they probe in much detail, but which was perhaps only one of a number of strategies they could have investigated.

7.4.4 Subjective and Judgemental Evaluations

The Action Research study reported in section 5.4 involved taking some decisions about risk. The Manager of the 'Finish-Weld' line wanted to be involved in the study because he wanted to ensure that the process which was subject of the study would not cause problems for his own production line. Ultimately, there is always a risk that the design chosen will cause him some delay, but he was satisfied, at the end of the study, that this risk was sufficiently low. He used his judgement. There were perhaps two reasons why he had to be involved in the study:

(a) Involvement in a study can perhaps create emotional commitment to the study and its outcomes.

(b) He could not delegate the judgemental question of the level of risk he could take because of its subjective nature. This is a subjective issue because he has his own understanding of the value he attributes to continuous production. It affects his reputation and the morale of his staff, as well as his costs. (But the effect on even the simple 'cost' factor is complex and he is not likely to be able to state it clearly).

Section 5.6.3 also reported the use of judgement by a client during one of the Action Research studies. It was not possible for an objective measure of the cost of a solution to be used because the plans for how production would be organised had not been completed. However, the people involved could make a series of, probably complex and interrelated, assumptions which they could consider by a judgemental process against the technical issues the model reported.

7.4.5 Can Visual Interactive Models Mislead Clients?

Certain aspects of VI modelling appear to lead clients (and possibly analysts) towards conclusions which are not necessarily valid.

Section 5.8.9, reporting the use of a complex simulation model, suggested that inconsistency of model speed can affect clients' perception of the real time it would take to perform an operation. VI Simulation models usually show a time clock on the screen which indicates 'simulated time'. Analysts grow used to watching this to note the time at which events occur. However the time clock does not necessarily move at a constant rate, with respect to real time. If the computer programme running the model has to perform a large number of operations in a small period of simulated time, the time clock may run slower than it does at other times. The study in section 5.8 modelled a situation where the activity varied greatly from one hour to the next.

The experimental modelling sessions highlighted a number of aspects of models which may be a cause for concern if we wish to be careful not to mislead the untrained observer.

Section 6.5.4 conjectured that displaying unnecessary information on the screen can hinder the client's path towards a conclusion. A particular example of this is given. To make any firm statements about this further tests would be required. However, it is possible that automatic display of only the information which seems relevant to a particular investigation, with the ability to select more information when required, would not be difficult to achieve and might help clients structure their thinking in a less cluttered environment.

An important aspect of training in simulation modelling (see, for example, Pidd 1988) relates to ensuring that results are taken from 'steady-state' performance (where such exists) rather than from 'transient' stages of a model run. Even if simulation time progresses at a rate consistent with real time, the viewing of only a short period of this time may create an incorrect impression of long term performance. This is because the nature of the events occurring in a short time frame may not be typical of the events which occur over a longer time frame. Some experimental sessions illustrated a tendency for subjects to react too quickly to observations on the screen. Section 6.5.5 discusses this issue in some detail and gives an example. The conjecture made by that section is that subjects do not take a strategic approach to viewing the performance of the model. They appear to watch models until they think their current hypothesis is rejected or proved (perhaps by only one observation). If this occurs in real (rather than experimental) settings it could have a considerable influence on any considerations about 'untrained' clients solving their own problems via VI simulation.

7.4.6 Appropriate degree of Modelling Detail

The appropriateness of the degree of modelling detail used in each of the models reported in Chapter Five appears to have been an issue affecting the success of the studies. The discussions in Chapter Five (see, for example, sections 5.3.3.2, 5.4.5 and 5.8.7) indicate that the degree of modelling detail affects both the accuracy of the results and the usability of the model. Too much detail can slow down the running of a model and also create a larger amount of information to be absorbed by the model user. Thus, too much detail in all, or parts, of a model can make use of the model cumbersome. However, too little detail might reduce the value of a model because it will not represent the real world with sufficient accuracy to predict the behaviour in which we are interested.

The requirement to ensure an appropriate level of modelling detail might not have been identified as an issue had this not have been one of the reasons postulated for the failure of one of the projects. The project reported in section 5.3 (the Longbridge Strategic Study) was the first of the studies undertaken. The failure of a project at such an early stage was useful because it led to identification of potential causes for failure and, subsequently, careful analysis of such issues in other studies. In the discussion of these studies the accuracy of the models was regarded as appropriate because, during the use of the model, inconsistencies did not arise. Several causes were suggested for the later success at finding the appropriate level. (See, for example, sections 5.4.5.1-3)

With the exception of the first study all the models were built to help with a specific problem. It could be suggested that this helps direct the model design process which leads to a specific level of model detail being chosen.

Further, the latter models were all built with some degree of assistance from the client. Sometimes (for example see section 5.4.5.2) the client was asked specific questions about what type of output data they needed from the model in order to help them solve their problem. Sometimes the design of the screens were undertaken by the clients.

The final study questioned whether the more appropriate degree of model detail in the later studies was due to the increasing level of experience of the model builder in the car industry problems. The final study was of a non-car industry problem and appeared also to attain an appropriate level of modelling detail. It is, however, not possible to reject the hypothesis that this is simply due to an increased level of *modelling* experience.

Section 5.6.1 noted that if the 'problem focus' is an important issue in ensuring the right level of detail is built into the model, then, if the problem changes, it may be necessary to re-build a model, even when the subject matter (system) of the problem is the same as the original problem.

Some of the studies (for example 5.4) looked at much more focused issues than the first study. A hypothesis could then be formulated that it is much easier to get the level of detail right when the study is not just focused on a specific problem, but when that problem is highly focused on a specific issue or part of a plant. However, one study (section 5.8), while focused on a specific set of problems, was not focused on a specific part of a plant. The model covered a large area of a plant. This study also benefitted from the close involvement of the client in the model building and analysis process.

It was noted in section 5.3.3.3 that some detail in the real system can seem unimportant for the problem under investigation. However, with proper validation it can emerge that some such details can significantly affect results.

While it is not possible to determine how important 'level of detail' issues are in attaining successful conclusions from a study, it is possible to conjecture that it is important and this section has reviewed some observations from the studies which indicate how we can improve the chance of the level of detail being appropriate.

On a related issue, it was observed that when people from different departments come together to use a model which covers their several departments it may appear to the participants that areas of the model not covering their own part of the plant include too much detail. This is probably caused by their much better understanding of their own area. Nevertheless, this effect needs to be handled and perhaps a VIM can be a useful vehicle for resolving the issue by communicating an understanding of other areas of the plant to the various participants.

7.4.7 Structural Changes to Models

An observation which came from several of the studies (see sections 5.4.8, 5.5.5 and 5.8.6) was that there can be some difficulty in coping with the need for the model to change as the problem (or problem focus) changes through use of the model. The client and analyst, investigating potential solutions to the problem will have ideas about how to solve the problem and some of these ideas will not be modellable without making changes to the model. Sometimes these changes can be simple to make (such as adjusting parameters to a model). However, often, because of the open nature of most problems being tackled by an O.R. study, the model will not have been built with the appropriate aspects of the problem in parameterised form. Such changes are referred to here as 'structural' changes.

Such structural changes can take some time for the analyst to perform and section 5.4.8 discussed the frustrations which can be caused by the delay this introduces into the solution finding process. It is interesting to note that a significant proportion of the development effort which has been put into improving commercial VIM packages in recent years has been directed at reducing the time (and skill level) required to build and modify models (See, for example, AT and T Istel 1988 and Insight 1988). It may be that there is a limit to how much improvement can be made in reducing the time required for this activity because, no matter how well a software package is designed to help with this difficulty, the nature of a 'structural' change is that some thinking time is required by the analyst for the purpose of deciding how to represent the new problem structure in the model.

There is a continuum between changes which are described as structural in nature and those which are described as parameter based. The study of the Cowley conveyor system (section 5.5) required the model to be changed in a manner which could be regarded as structural, except that such changes had been predicted by the model builder and facilities for such apparently structural changes built into the model. This is described in section 5.5.5 which also discusses a type of change to a model of a different nature. The model was used to investigate alternative control rules. In controlling a factory shop floor, a decision maker will take into account many factors when making each decision. If a series of rules are to be developed for automating the control of some part of the factory, then it will be important to be able to consider (in the logic for the automated rules) all the factors which might have been considered in a manual decision. In a problem solving session which is attempting to find a set of control rules it may be necessary to reprogram the rules many times as ideas are developed about which factors to take into account, and to what extent each of the factors should influence the decision. Such reprogramming would also be frustrating because of the delay caused to the cycle of 'idea-test-see consequence'. In the case of the particular study in question this was overcome by omitting the control rules from the programmed elements of the model and leaving all control to the manual intervention of the people using the model. (N.B. This strategy had been introduced for a different reason: see section 7.4.3).

Nevertheless, while the need to make delaying alterations to models by the analyst can sometimes be overcome, the open nature of the solution-seeking process is likely to remain a cause of occasions when the process itself has to be interrupted.

The report of the final study (see section 5.8.6) discusses an incident which might indicate how some elements of this difficulty related to model changes can be overcome. It was observed that when two 'analysts' were present at the modelling sessions they could perform different roles. If only one analyst is present this person must spend much of their time discussing the problem and potential solutions with the client. If a structural change is required to the model (and especially if this requires some thinking time to reformulate part of the model) then the analyst must withdraw from the discussions with the client. This can emphasise the interruption to the solution finding process. With a pair of analysts working as a team, one of them can continue to 'facilitate' the discussions while the other reformulates and modifies the model.

7.4.8 Requirement for Written Reports

Given that the VIM literature argues (cf section 3.4.2) that VIM communicates a better understanding of solutions to clients (than is possible without VIM) it might be expected that a more traditional method of communication (a written report at the end of a study) would be supplanted. The VIM and the traditional written report could, however, be complementary. Some evidence for this suggestion was observed in some of the Action Research studies. However there may be an effect here which is related to the nature of the organisation.

Sections 5.6.5 and 5.5.7 both noted that the individuals involved in the study, although content with the findings of the study, were concerned about the new responsibility that VIM placed upon them. In traditional studies they had simply provided information to O.R. analysts for them to use in their analysis. Further consultation would take place and, through an iterative process, a conclusion would be reached by the O.R. analyst and 'reported' to the client. The O.R. analyst was seen as the 'finder' of the solution and the writer of the report. If anything went wrong, the O.R. analyst could take the blame. It is possible that in a large organisation, where, perhaps a large part of each manager's day is taken up by operating in the 'political' environment of the organisation, the correctness of the solution is less important than the infrastructure which protects the manager from any consequences of the solution. The previous statement is conjecture, based on no positive evidence, but it is consistent with the requests in two of the studies for written reports stating the outcomes of the study. The outcomes had been found by the client but the report was to be written by the O.R. analyst.

Section 5.5.7 noted some potential further roles for such a written report in the context of that particular study. This model (of a complex set of interconnecting conveyors) was used many times over a period of some 18 months. The written reports which were produced after each period of use served to 'fix' the outcomes of the modelling sessions in the minds of the participants. It was reported that the, sometimes subtle, conclusions were reinforced by the report and the report could be referred to on subsequent use of the model to establish starting positions for further analysis.

In summary, a written report (while not always requested by clients) can potentially be important in the wider process within which the VIM study is operating.

7.4.9 Are Results of a Model Always Important?

It might be assumed that the purpose of a VIM modelling session with a client cannot be achieved without the model being used to conduct carefully controlled experiments and without a statistically valid analysis of the results. There are probably occasions when this is true, however, the study which assisted with the move of the Rover SD1 to Cowley appeared to aid clients in a different manner too. Section 5.7.4 discusses how the model, simply by being a record of the current plan of how the plant was expected to operate after the move, assisted the client group. The different people involved in the SD1 introduction to Cowley were drawn together by the model and could use the model as a common communication medium. They (it was observed) all appeared to understand the model and could use it as a discussion vehicle when considering aspects of the move.

7.4.10 Summary of Body of Experience

The following is a summary of the key contributions to knowledge in this section (7.4). Most of these contributions are directly from the data chapters, except where synthesis from the literature is also a contribution to understanding the process of Visual Interactive Modelling. While some of these points will be part of existing knowledge and skills built up in an ad hoc fashion by experienced consultants in the VIM (and wider O.R.) field, the significant progress reported in this thesis is that this body of experience has been derived from a deliberate series of experiments designed to bring together such experience in a consistent manner.

* There are a number of different roles within a client group. Some of the roles appear to cause their actors to have a positive desire to be involved in VIM studies.

* The implementation of a study's results is easier when the people who are *responsible* for implementation are involved in the study. Studies can proceed without the involvement of key actors (and that this may be regretted later, in the sense that outcomes may be difficult to implement).

* It is possible to distinguish six types of learning by clients which occur when they are involved in a VIM study. (See table 5.8.5.A)

* One of these categories relates to the notion of a VIM giving examples of potential options to a client which are then compared (judgementally) by the client, thus enabling the O.R. study to achieve more than it could without VIM.

* VIMs enable unstructured shop-floor decisions to be included in the modelling process.

* A number of different types of unstructured shop-floor decisions were delineated.

* VIMs allow some of the subconscious rules used in making decisions to be externalised.

* Further, VIMs allow good control rules to be *designed*.

* Some users of VIMs appear not to fully search the options available to them.

* Clients can be misled by certain aspects of the screen display used with VIMs.

* Client involvement in the model building phase of a study appears to help attain an appropriate level of detail in the programmed model.

* Delays necessitated by making structural changes to models can be frustrating and can be partly avoided by enabling control of a model to be handled manually.

* Working in pairs (of analysts) appears to avoid some of the frustration caused by the delay introduced when making structural changes to models.

* Written reports are required by some clients as 'evidence' from the O.R. analyst.

* VIMs can be used as an easily understood record of current plans, in addition to being a tool for modelling and prediction.

7.4.11 Conclusion

This section has attempted to draw together the experiences gained by conducting the Action Research Studies and the experimental modelling sessions. The purpose of this has not been to be prescriptive about how VIM studies should take place but rather to summarize a 'body-of-experience' (which is descriptive) of what appears to happen in these types of studies. It is this 'body-of-experience' (along with further direct reference to the experimental data) which can be used to attempt some prescription related to how such studies might perhaps be improved.

7.5 Results - Guidelines

To be too specific in suggesting guidelines would suggest that this thesis had a level of scientific accuracy beyond that which is possible in research in its field. The discussions in Chapter Four (Research Methodology) described the expectations of such research and Chapter Nine will further discuss the tentative nature of these findings. However, to restrict the thesis to describing a 'body-of-experience' which has emerged from the data and literature chapters could be criticised for doing little more than synthesizing. The data that has been collected is probably sufficiently strong (in the context of management research) to do more than synthesize. This section thus suggests a number of tentative guidelines.

These guidelines are suggested as means by which the process and outcomes of an Operational Research study (which is making use of VIM) can be enhanced in a manner which better aids the clients of such a study.

7.5.1 Coping with Learning

In the context of the type of study treated in this thesis a number of categories of learning have been distinguished (table 5.8.5.A). If it is assumed that this is a relevant set of categories it is then perhaps worth considering how models and modelling sessions should be designed to best aid some of these categories.

B,D,F (Something is highlighted by the model which needs further investigation). Advice on this appears to be contradictory when considered along side one item in section 7.5.2. To enable learning about anything for which the model was not intended it is almost certainly necessary to display information which is not directly relevant to the originally intended purpose. However, as in practice it is not possible to determine in advance what information is and is not relevant to any open-ended decision, it is likely that category **B** learning will take place (in the region of the original intended purpose) without any special action by the model builder. However recognition of the possibility that the model may indicate findings related to an issue which was not being investigated is important because it may influence progress of modelling sessions (see section 7.5.4).

D,E,F (Model may require amendment before a solution can be discovered). Section 7.4.7 has discussed some of the issues related to making changes to models. A number of observations from the data chapters seem to make potential contributions to this issue.

Section 5.8.6 (Photocopier study) indicated that analysts working in pairs can ease difficulties associated with interruptions in modelling sessions while structural changes are made to models. This method has also been shown to work with some other decision aiding techniques. For example the 'Strategic Options Development and Analysis' approach is said to benefit from use of both a facilitator and a separate person to operate the technology (Eden and Ackermann, forthcoming).

Where possible models should be built in a parameterised form. (An example of such is the conveyor system modelled in section 5.5). While this is both obvious and simple for many aspects of a model it is more difficult (but also useful) when the parameterisation can be applied to structural aspects of the problem. With each model some design effort should be put into considering how major changes could be made to the model in a small amount of time, should the modelling sessions require this.

A further issue which relates to helping the client learn about the problem but one which is relevant to all the categories A-F is associated with transient effects in stochastic models. Section 6.5.6 showed that users of VI models might have to wait for a long time to be sure that a strategy they had formulated would be appropriate at different stages during a model run. If a strategy must cope with both rare events as well as normal steady-state running conditions then to facilitate testing against rare events the model should be able to create those rare events on request. One way to do this is for the user to be able to bias the random numbers temporarily to create the desired effect in the model.

7.5.2 Design of Screen Displays and Interactive Facilities

The data chapters of this thesis have contributed to some guidelines presented here on the design of displays. In addition, there is a considerable literature on interactive computing which can make some contribution to this section. As this literature discusses display issues along side interactive issues the two are treated together here in one section.

7.5.2.1 From the Literature

Shneiderman (1987, page 60) suggests some guidelines for dialogue design. (We can consider 'dialogue' in this context to refer to both communicating with, and receiving feedback from, the model). Some of these are not relevant to VIM. (They, for example, consider lower level tasks such as interactive processing of customer transactions.) Those which are relevant are discussed here.

Consistency:

> To ease use of any computer based system the many different facilities in one system should be usable in broadly the same manner. This applies at several different levels. For example, the same keyboard operation should be used to leave a menu, for all menus in a system. However, at a different level, if a particular set of data can both be displayed and changed, then use the same screen layout for both facilities. (Walker and Woolven, 1991, referring specifically to guidelines for VIM, suggest from their experiences that consistency between different parts of the VIM is important.)

Allow shortcuts:

It is important that systems should both be self explanatory for new users and be quick to use for more experienced users.

Avoid mistakes:

Shneiderman suggests 'error handling' should be as simple as possible. Model builders should take responsibility for ensuring users cannot make mistakes where this is possible. For example, if an answer to a question must be input by the user and there are a limited number of answers with which the system can cope, then the system should present a menu of such options.

Easy reversal:

Models should remember the stages though which they have evolved and allow the user to easily return to one of these previous stages.

Reduce short term memory load:

Remember that the computer has a much better short term memory for detail than the human mind. Make use of this by not forcing entry of information the computer already holds and allowing any information held to be presented and summarized at any time. This allows it to be considered while the user is engaged in deciding what next to input to the computer.

Foley and Van Dam (1982) also suggest a number of "design principles" (which cover similar ground to those of Shneiderman). However they also suggest controlling 'response time'. While this is more relevant to systems on multi-user computers (which VIMs tend not to use for reasons of portability) their comments are perhaps relevant to VI simulation. VI simulation models can run at a speed which is much faster than the 'real' time which they are simulating. For example, a model of a factory might simulate one day's production in only 2 minutes. However, this speed may be highly variable if the processing power required during the simulation run is not smoothly spread throughout the day. If, on three occasions during the day, an important process in the factory changes to a different batch of work, there may be a complex set of rules to be executed by the computer to determine the next batch to process. This additional workload on the computer will slow progress of the model, making the simulated time progress unevenly. It may be less confusing for the user if the model is deliberately slowed during other periods so that the computer can maintain a steady flow of time on the screen.

Foley and Van Dam (1982) regard feedback as an important element of usability of any system. They classify feedback as being at four different levels and it is useful to review these here as having cognisance to each will perhaps improve the usability of VIMs.

Conceptual:

In the context of a VIM this level of feedback can be regarded as the 'results' of a model run (if the VIM is a simulation). This feedback is the user's purpose for using the model.

Semantic:

This is feedback at the operational level. For example at the level where the user is changing the number of lathes in a simulation of a factory. The system should provide feedback which makes it clear that the interaction with the computer has been successful (eg new layout of factory appears on the screen).

Syntactical:

This type of feedback gives a response to each instruction input by the user. (In the example in the previous paragraph there may be several instructions to give to specify the type, speed and location of the new machine).

Lexical:

> This is at the keystroke by keystroke level. For example, users would normally expect to see a character on the screen for every character typed on the keyboard. It is unlikely that VIM model builders would need to consider this level of feedback because this would be handled by their VIM building software. However, it may be relevant when considering issues related to the pressing of special keys such as 'function' keys or related to how a mouse should be used.

Shneiderman (1987) recommends what he calls "direct manipulation" as a means of users interacting with computers. For example, if some data is displayed in a particular manner, then changes to this data should be made directly on the display of that data on the computer's screen. For example, if the data is shown in numerical, tabular form, then changes should be made by moving a cursor to that data and changing the numbers or text where they appear in the table. If the data is displayed graphically, for example in the form of a bar chart, then the data should be changed by moving the cursor to the bar and dragging the bar up or down.

Shneiderman (1987) further suggests a number of guidelines on the use of colour (see page 338). In particular: Colour coding should support the user's task rather than clutter the screen. Showing different aspects of the screen in different colours simply to enhance the distinction between them when they can be distinguished by context may reduce the readability of the information. Use colour to code where this is important, for example, to indicate when some figure is beyond an important limit. He regards a well designed layout and the user's ability to sort and select the layout as more important than colour coding.

Shneiderman (1987) (as a secondary source) reviews many authors' guidelines for interactive systems. While few of these are relevant to the level of task which VIM involves and while some of his review has been quickly outdated by changes in technology, builders of VIMs should be aware of this review. (see, especially, page 327).

7.5.2.2 From Data Chapters

The first contribution to these guidelines on display design comes from the observations taken during the experimental sessions and relates to comments by some of the literature on screen design. Section 6.5.4 noted that a piece of displayed information, although stated to be irrelevant, was used by the subjects of the experiments in selecting a solution to the experimental problem. While this is very tentative evidence, it does suggest that displays should not be filled with any information available but should perhaps be designed to just contain the information necessary for a given task. This suggestion is also made in the literature. Shneiderman states:

"The wrong information, or a too cluttered presentation, can lead to greater confusion"

(page 200)

Keen and Scott Morton (1978) distinguish between Management Information Systems (which simply provide information) and systems which actually support decision making by the way in which the latter selectively display information in a way which is appropriate for the task. Walker and Woolven (1991) state that in designing a VIM one of their most important rules is simplicity of display.

However, this conflicts with the view that it is not possible to predetermine the information which is required to solve open ended problems and that one type of learning which has been useful to decision makers is with regard to aspects of a problem which had not been seen as important until a VIM was used to investigate some related issue.

Perhaps a reasonable guideline to offer on this issue is to make as much information available as possible, but leave this information hidden but easily accessed by the user.

A guideline on screen display design which is suggested by the Action Research Studies is that clients should be encouraged to design the displays for their models. The study into the 'Bolt-on-Items' for the Metro car (section 5.4) indicated that designing the display had perhaps enhanced the client's feeling of 'ownership' of the model. They felt that they had undertaken an important part of the model building process and were thus perhaps more committed towards accepting results which the model might produce. (That the screen display is the only tangible element of the computer model is possibly an important contributory aspect to this - see section 5.4.6).

Furthermore this section (5.4.6) also suggested that the clients are possibly better qualified to design the screen than the analyst because they probably have a better understanding of the problem they are trying to solve and (in particular) those variables within the problem which they most want access to as part of their solution finding process.

This has two (distinguishable) important effects.

1 The display will be designed to enhance the solution finding process (it will display useful data in a way which shows the relevant relationships)

2 The model builder will discover features of the problem which had not come out during the previous discussions about the problem with the decision makers.

The appearance of a variable on the screen designed by the client is an indication that it is perhaps relevant to the problem. The ensuing discussion will lead to clarification, possible redesign of the screen and possible redesign of the underlying model which is hidden from the client.

This second effect is important if the level of detail which is programmed into the model is to be right for the particular problem. Section 5.5.3 (discussing the Cowley conveyor system) noted that the clients' designing of the screen had perhaps contributed to the model being seen as usable by the clients for an ongoing series of studies over an 18 month period.

7.5.3 Handling Different Cognitive Styles

In the chapter on the experimental model, the possibility that the subject's cognitive style may be a relevant issue in determining how best to use VIMs was discussed (section 6.5.1). The literature on VIM (section 3.3.3) has also considered this issue although it has not produced any firm evidence. Different individuals do have different cognitive styles and this leads to them preferring different strategies for solving problems. The conclusion from the discussions in section 6.5.1 lead to the next suggested guideline: That models should be designed to be used flexibly with respect to cognitive style. The experimental model was an example of such a model. The task was to find a good set of rules for controlling the modelled plant. The modelled plant could either be controlled manually or automatically by a set of rules defined by the experimental subject. This allowed subjects to spend most of their time manually adjusting the control rules until they were satisfied they had found a good set or, to postulate a set of automated rules at an early stage which they could then program, test and modify. It was conjectured that these two different methods were used as a result of differing cognitive styles. (For details of the model design see section 6.4). If *cognitive* style is not the driving issue here, it would, nevertheless, seem good practice to build models so that they can be used flexibly with respect to *problem solving* style.

7.5.4 Role of the Analyst

This section discusses some guidelines which are not related to model construction but rather relate to the process of managing the solution finding process.

The first of these relates to maintaining the client's faith in the service which is being provided while the model is under construction. Section 5.8.8 noted that, as part of attempting to ensure that the best solution is achieved, the O.R. analyst may attempt to encourage the client to be involved in the analysis of the model. In addition the analyst may encourage the client to design the model's screen display (cf section 7.5.2). Section 5.4.6 has noted how the client sees the screen display as the model. As part of the process of ensuring the level of detail in the model is correct (cf section 7.4.6) the analyst is likely to create the screen display aspects of the model first (with the client). Unfortunately the screen display design usually takes only a small part of the analyst's time to build the model.

Thus the client possibly thinks the model is almost ready for use and is keen to use the model at a stage which is much too early for the analyst. The client should be set realistic expectations for when the model might actually be ready and given an understanding that the display is only a representation of something more complex which underlies the display. The client should also be made aware of the need to validate and test the model and how experimentation cannot start until this stage is over. Setting this expectation may reduce the degree of lost faith which will occur when the model does not behave correctly.

Two guidelines emerge from the data collected during the experimental modelling sessions. Firstly, section 6.5.2 reported the use of a questionnaire during the experimental sessions and the effect that this appeared to have in enabling the subjects to consolidate their experience of the model to date. That section conjectured that the forced interruption in the analysis that the subjects were performing, and the asking of a series of structured questions about the problem, had the following effect. It appeared to require the subjects to structure some of the thoughts which were as yet unstructured in their minds. A useful guideline may, therefore, be to force a reflection break in the modelling sessions and during this period to ask the clients for the current state of their views of particular aspects of the problem.

Another aspect of the role which these guidelines suggest the analyst should take during the modelling sessions emerged during the experimental sessions. Section 6.5.7 reported how some subjects appeared to search for a solution by first finding an initial set of parameters which produced a reasonably good solution and then carefully refined these parameters without ever returning to consider if there might be completely different parameter settings which would be a much better starting set to then carefully refine. Once they started on the fine tuning they stopped considering wider aspects. An artificial experimental situation may not be representative of real situations, however, until further evidence can be assembled it might be worth considering a further guideline: To encourage the clients to consider radically different alternatives from those which they have at first settled on and started to fine-tune. This can often be easier than it might appear because modelling sessions may take place over a period of several days, giving the analyst time for exploring the model in private and making suggestions for alternatives worth considering (if found).

7.5.5 Written Reports

Referring back to the evidence collated in section 7.4.8 it would seem sensible to recommend a guideline that when any conclusions are reached using a VIM a report should be written (as if the modelling had been conducted in absence from the client). This should enhance the client's confidence (removing some of the client's new found responsibility which comes from modelling - see 5.6.5) and act as a reminder of current stage of thinking of any group involved in the modelling process. (This last point is especially important with regard to subtle distinctions or conclusions reached at the end of a long day's negotiation between multi-interest groups - see section 5.5.7).

7.5.6 Summary of Guidelines

In a similar form to section 7.4.10, the following is a summary of the key contributions to knowledge in the current section (7.5). Most of these contributions are directly from the data chapters, except where synthesis from the literature contributes to a coherent set of guidelines for Visual Interactive Modellers. While some of these suggested guidelines will be part of existing 'standard practice' for experienced consultants in the VIM (and wider O.R.) field, the significant progress reported in this thesis is that this set of guidelines has been derived from a deliberate series of experiments designed to bring together, in a consistent manner, sufficient knowledge to validly suggest some guidelines.

* Recognise, and be prepared for the likelihood, that analyst and client may learn about issues which were not the original purpose of the study while using a VIM.

* Work in pairs during model building and analysis sessions with clients.

* Put design effort into parameterising models.

* VI simulation models should allow users to create events which would otherwise occur rarely.

* Dialogues and screens should be consistent across a model.

* Do not frustrate the users by allowing them to make detectable 'mistakes' during interactive input.

* VI simulation models should be deliberately slowed so that time flows at a consistent rate.

* Use colour to highlight only where necessary.

* Hide as much data as possible while allowing it to be easily accessed and reviewed if required.

* Ask clients to design their own screen displays. Alternatively, ask what information they would like to be displayed on the screen.

* Design models to work flexibly with respect to user learning style by, for example, allowing manual and automated operation of parts of the model.

* Clients should be given realistic estimates of the expected time between designing the screen and having the model ready to use.

* Explain to the clients the need to validate models.

* Interrupt modelling sessions with 'reflection breaks', perhaps with the excuse of documenting progress towards a solution.

* Encourage clients to consider radically different alternatives.

* Produce written reports for the clients at stages during a study to consolidate learning and to conform to expectations of the consultancy role.

7.6 Conclusions

The aim of this chapter has been to set out some statements which attempt to answer the first of the research questions posed in Chapter One. It offers two forms of statements. First the chapter has brought together a 'body-of-experience' which can be used (or refuted) by other researchers. Secondly it has used this body-of-experience and the data and literature chapters to argue for a set of guidelines to be used by those who undertake Visual Interactive Modelling.

Discussion of important weaknesses in argument in this chapter and in areas not covered will appear in Chapter Nine.

CHAPTER EIGHT

SOME CONTRIBUTIONS BY VISUAL INTERACTIVE MODELLING TO THE OPERATIONAL RESEARCH PARADIGM SHIFT

8.1 Introduction

This is the second of two results chapters which attempt to provide some answers to the two research questions posed in Chapter One. This chapter concentrates on the question:

> Are there any important ways in which Visual Interactive Modelling benefits Operational Research studies beyond those benefits previously suggested in the literature?

The discussion in Chapter Two about the existence of a debate regarding an appropriate paradigm for O.R. is used along with some evidence from the Action Research and Experimental studies and a synthesis of existing literature on Visual Interactive Modelling to examine the possibility of an omission from this literature.

8.2 The Focus of the Existing VIM Literature

As part of the argument in this chapter it is important to discuss the focus of the literature reviewed in Chapter Three. This review showed that the authors in the field have established a number of benefits (section 3.4) which appear to accrue from using VIM.

A list of these is reproduced here to aid the discussion:

1 Better Client Understanding of Model
2 Better Client and Analyst Understanding of Problem
3 Increased Client Participation in Solution Finding
4 Use of Decision Maker Knowledge and Experience
5 Faster Location of Problem Areas/Better solutions found
6 Improved Model Verification
7 Increased Client Confidence
8 Inclusion of Human Rules
9 Improved Communication
10 Training
11 New Types of Problem
12 Increased Implementation
13 Hidden Agenda 'Benefits'

While the discussion in Chapter Three was not simply a reproduction of the statements made by the writers on VIM, the headings chosen were designed to be a fair reflection of the character of the debates in the existing literature. The discussion in that chapter was not intended to go beyond what the existing authors were saying.

Of some significance to the argument here is that all these benefits are tactical in their nature. They relate to individual aspects of O.R. studies. (For example: Improving the client understanding of the model, better verification, finding better solutions). The current VIM literature appears to focus on specific improvements to the problem-solving process. Perhaps it is possible to make a statement which is more strategic about VIM's benefit.

8.3 The Operational Research Paradigm Debate

In Chapter Two it was argued that, while O.R. had served its clients well during its early life (by looking at management problems from a scientific perspective), this is perhaps no longer an appropriate means for addressing issues which concern our potential clients nowadays. A number of problems were cited with what could be termed the 'traditional O.R. paradigm'. It was also seen in Chapter Two that a number of authors had proposed alternative paradigms, and that (within at least one of these potential paradigms) much successful work is now being conducted.

In summary, approaches have been developed which consider the human, political, social/group pressure, judgemental and unstructured aspects of problems. These approaches have collectively been labelled 'Soft O.R.' in contrast to the techniques of the traditional O.R. paradigm which have been labelled 'Hard O.R.' (cf section 2.5).

These phrases are perhaps not always useful because they tend to group together a number of techniques which their protagonists see as being quite different. Nevertheless, these phrases will be used in this chapter because the important contrasts here are not within the 'Soft O.R.' grouping of approaches but rather are with respect to the 'Hard O.R.' grouping of techniques.

The people who have developed, and those who make use of, these approaches regard them as mainly impinging on the 'problem structuring' aspects of any problem which they are tackling (See, for example, the discussion in Chapman, 1992). When in use these approaches may sometimes indicate the need for a detailed technical investigation of, say, alternative layouts for a factory design. In this case more traditional O.R. techniques may be employed as part of the solution finding process. Thus, when using these approaches their practitioners are not limited to purely considering the non-technical aspects of a problem because their methods do not preclude them breaking away from their 'soft' approach and using a 'hard' technique when appropriate. Nevertheless the approaches themselves are limited to the 'soft' aspects of the problem.

8.4 Broadening Visual Interactive Modelling

The discussion in this section is aimed at showing that the answer to the research question repeated in section 8.1 should be in the affirmative and to indicate the nature of that important omission from the existing VIM literature.

The previous two sections have reminded us of the documented benefits of VIM and the difficulties with the traditional O.R. paradigm and some of the proposed means of handling these difficulties. It is perhaps worthwhile discussing some of these shortcomings against the indicated benefits of VIM to see if VIM is able to help O.R. overcome some of the shortcomings.

One of the first criticisms discussed of the traditional O.R. paradigm was that it is based on the notion of 'optimising' to find the best solution when we do not necessarily know what objectives to optimise and the relative importance of each objective. (Sections 2.3.7.1-3) Sections 3.4.1-3 discussed how, when using VIM, clients can have a better understanding of O.R. models, of their own problem situation, and can participate more fully in the process which is attempting to find a solution. If this is the case, then VIM can enable 'optimisation' to take place via the client. The client can make judgements about which combinations of solution variable values are better than others while the model provides information on which combinations are feasible.

In the context of this discussion it is important to remember the discussion in section 2.3.7.1 which indicated that while writers who criticize the old O.R. paradigm often cite 'optimisation' as one of its main problems, there is probably little intrinsically wrong with the notion of finding the 'best' solution. The difficulties relate to the consequences of trying to optimise using the techniques which were available at the time the old O.R. paradigm was popular. Most of these techniques required mathematically precise input of information such as the relative importance of each of the objectives and a clear definition of those objectives. If clients do not have to state (or even know) these items of 'data' but instead can make their own judgements when they see options presented by a model, then 'optimisation' (in terms of finding a good solution) is perhaps still worthwhile.

The remaining discussion in this section is not dependent on an acceptance that 'optimisation' is worthwhile.

Section 2.3.7.13 discussed the need to reduce opaqueness of O.R. techniques for the reason indicated above; that it would allow increased use of decision maker 'judgement' in solution finding. Reducing opaqueness is also cited (Section 2.3.7.12) for another purpose: Increasing client confidence in the solution. VIM appears to be a means of reducing the opaqueness of O.R.'s methods and increasing client confidence (cf section 3.4.7).

Sections 2.3.7.11, 14, 15 and 22 all suggest a need to involve others, in addition to the decision maker, in the modelling process. They suggest that there is often a need to involve multiple interest groups in solution finding and that practical decision making is not a scientific process but more a social process of negotiation and that this also applies to implementing a solution. It appears that VIM can aid communication between clients (see section 3.4.9 and 7.4.1). This would perhaps indicate that VIM might help with aiding the social process of negotiation towards an agreed decision.

Section 3.4.12, reports evidence from the literature on VIM supporting the view that 'implementation' of solutions is aided by using VIM. Section 2.3.7.22 suggests there is a requirement to improve the way some O.R. solutions are implemented.

Section 2.3.7.20 discussed the difficulty with the traditional O.R. paradigm that simple 'optimisation' does not account for the 'greyness' of some constraints. Techniques which operate while isolated from the decision maker need a priori information on the boundaries within which a solution would be judged acceptable. However, there are cases where the importance of a constraint is dependent on many factors and the relationships which determine the importance of a constraint will be difficult (or impossible) for a decision maker to state clearly (in a mathematically usable manner). Even where constraints are pre-specified, the decision maker may be interested to discover the effect of a constraint and might want to modify constraints in the light of information which might only be obtained during the modelling process. Again, it would seem feasible that, if the decision maker can be involved in the modelling process, then it may become possible to remove the need to pre-specify constraints and for the decision maker to impose constraints on the solution interactively via a VIM.

None of the benefits cited in the VIM literature actually mention that VIM appears to aid 'iterative' solution finding. However, the reduction in opaqueness which allows the clients to be involved in the solution finding and the ability to interactively adjust aspects of models would perhaps both enable some movement towards 'iterative' solution finding. Sections 2.3.7.17 and 19 both discuss the difficulties in attempting to find a solution in one step. The desirability of being able to iteratively find a solution, explore it, and reject it, in favour of an improved solution is related to the complex nature of the types of problems which O.R. people help to solve. It is perhaps only when seeing some potential solutions that it is possible to see the consequences of constraints and the possible relative importance of objectives. Ackoff's (1979b) suggested alternative paradigm had as, one of its themes, "...designing a desirable future and inventing ways of bringing it about..." (page 189) (as an alternate to predicting the future and preparing for it). This, he suggested, required means which would aid creativity and iterative planning. VIM possibly also aids creativity (cf sections 5.4.7 and 7.4.2).

Section 8.3 above noted that a number of approaches have emerged which address some of the needs of a new O.R. paradigm but it is interesting to note that the approaches mentioned in that section do not themselves facilitate the handling of the numerical ('hard') aspects of client problems along side the 'soft' issues. VIM appears to have been used to take techniques more associated with 'hard' O.R. and the traditional O.R. paradigm and enhance them so that they can be harnessed for use at the 'messy' front end of problem solving where the client should be handling judgemental issues. (Examples of techniques which have been enhanced by VIM are given in section 3.3.2).

Thus it is possible to consider that VIM, in achieving some of the benefits claimed for it in the VIM literature (such as increasing communication and allowing clients and others to become involved in the modelling process), has enabled some of the difficulties inherent in the old O.R. paradigm to be handled, while also retaining an ability to utilise what is good about the old O.R. paradigm techniques. The model handles the technical issues and the client handles the subjective issues (which may themselves be more understandable to the client than previously because the modelling process can aid the thinking process).

Figure 8.4.A is offered as a framework by which to consider this new, broader view of VIM.

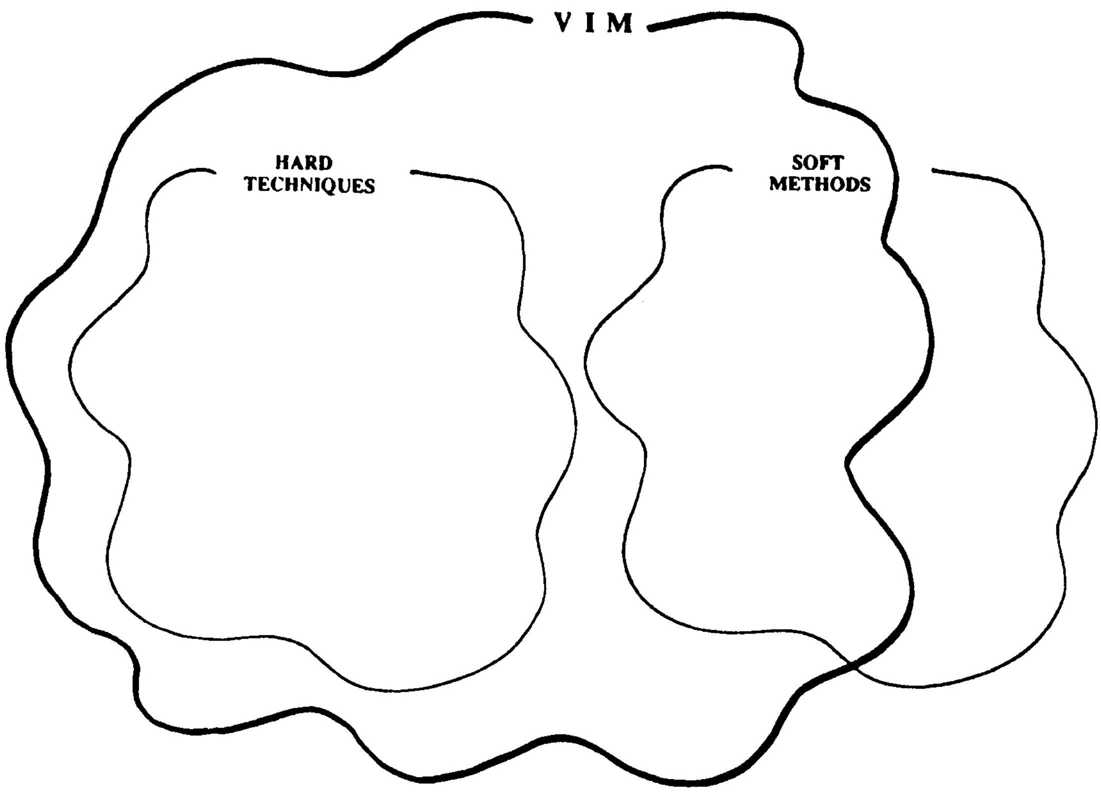

Figure 8.4.A - A Framework for Considering the Breadth of VIM

Figure 8.4.A illustrates, then, that a benefit (which is of some importance) of Visual Interactive Modelling, beyond those evident in the VIM literature, is that VIM is an approach which encompasses both the hard aspects of O.R. and considerations of a new O.R. paradigm which can enable O.R. people to provide a service which is better aligned to the way clients want help with their problems than previously had been possible.

8.5 Related Literature

This section discusses additional literature which relates to the notion proposed in section 8.4.

Bryant's (1988) account of the 'process' issues which were part of an O.R. activity which used a traditional O.R. technique (Linear Programming) is interesting in that most papers about the application of such a technique stress the mathematical and technical issues rather than the process issues. It is usually the papers by the authors of the 'soft O.R.' approaches which stress the process issues because these approaches were developed to enable better treatment of process issues. However, Bryant's thesis is that the use of a traditional technique does not preclude treatment of process issues. He states that O.R. people are normally aware of the importance of matching their services to the needs of their clients (including process issues) and often treat these naturally as part of their professional manner of handling their consultancy intervention. In the case of the particular study he reports the consultant spends considerable time and effort facilitating discussion amongst the client actors within a framework partly based on the constraints / resources / control variables structure used within mathematical programming and partly based on the consultant's wider experience of how to manage and enhance the social processes within the client group. Linear Programming (L.P.) models, in this case, were not analyzed in absence from the clients, but were used interactively with the clients. (In this case an analogue computer with knobs and meters was used but the concept is similar to that reported in Elder and Belton, forthcoming).

> "The L.P. model...allowed the possibility of varying more than one limiting resource at a time. From this facility came the development of 'collective insight' into the structure [of the problem], and although the managers had little confidence in the notion of optimisation as such, they developed an enhanced understanding of the setting in which they were operating and the 'room for manoeuvre' available to them."
>
> (Bryant, 1988 page 425)

Bryant is confirming that essentially 'hard' techniques from the traditional paradigm can be used (when accessible to clients) in a soft manner and are being used in this way by consultants who have had to adapt to keep their services up to date with the wishes of their clients. (It is interesting to note here that, as reported by Bell (1985a), the development of VIM has been practitioner driven in response to their need to serve clients).

In a paper which reviews some of the problems with the traditional O.R. paradigm, Pruzan (1988) argues that:

> "...O.R. methodology should place much greater emphasis upon integration of *analysis* and *policy formulation*"
>
> (page 36, my italics)

Further he suggests that

> "...O.R. will have to *complement* both its schema and its bag of tools with interactive approaches to structuring, investigating and learning about the systems we plan for and within."
>
> (page 38, my italics)

He notes that simulation (in the form of 'consequence analysis' as opposed to 'discrete event') has been seen to overcome some problems associated with optimisation by emphasizing the experimental and inquiring aspects of decision making. However, he does not pursue this argument because he *believes* this mode of simulation is limited by the number of alternatives which would need to be presented to the client. VIM might help to overcome this perceived limitation by enabling the client to drive the search through the alternatives.

Nevertheless the thrust of Pruzan's argument is related to *complementing*, rather than *abandoning* traditional O.R.

Symbiotic Systems (cf section 3.7.1), as discussed by Scriabin et al (1988), have much in common with VIM. This field recognises as an objective the notion of combining together the power of a computer to handle mathematical (and rule based) issues with the power of the human mind to handle judgemental issues.

The only work in the VIM literature which explicitly mentions 'soft' O.R. directly is that of Parker (1985), (published as Bell and Parker, 1985). While Parker does this partly because he finds Checkland's (see Checkland and Scholes, 1990) 'Soft Systems Methodology' a useful starting point for suggesting a step-by-step methodology for *building* Visual Interactive Models, it is more interesting here to note the reason for using this as such a basis. He recognises that

> "While the O.R. literature of cash management emphasizes ... optimizable models, an alternative view is that cash management in a major corporation is a 'human activity system'..."
>
> (Bell and Parker, 1985, page 780)

and thus in his cash management system he is able to handle the 'hard' aspects of the problem using mathematical models embedded in the VIM while the VI interface to the user enables soft issues to be handled by the experienced manager.

This subsection has examined literature which is in sympathy with the notion that a combination of 'hard' O.R. and 'soft' O.R. is possible, and desirable.

8.6 Conclusion

This chapter has attempted to answer the second of the two research questions posed in Chapter One.

In particular this chapter finds that, taking a retrospective view of the achievements of VIM (as cited in the existing literature) it is possible to synthesize these achievements and conjecture that VIM does rather more than has been discussed in the individual pieces of literature. In particular, it would seem to answer some of the difficulties which authors have noted with the 'traditional O.R. paradigm' while maintaining an ability to treat the mathematical and 'hard' aspects of the problems which O.R. people tackle. It would appear to enable O.R. people to handle 'soft' and 'hard' aspects of problems simultaneously.

CHAPTER NINE

CONCLUSIONS

9.1 Introduction

The aim of this chapter is to discuss what is new as a result of the research reported, and arguments discussed, in this thesis. What contribution has been made by this research programme? However, perhaps more importantly, this chapter also discusses the limitations of this research. Where are its weaknesses? Where does it lack generality? Finally the chapter uses this discussion to make suggestions for further research which might either strengthen the arguments in this thesis, or refute its theories.

9.2 Summary of Contribution to Knowledge

This section summarises the nature of the main contributions to knowledge which the research programme has made. This section must be considered in the context of the weaknesses in both the research and the argument which are discussed in section 9.3.

Two research questions were posed in Chapter One. The answers to these will be discussed separately.

9.2.1 What guidelines might be appropriate for Operational Researchers to follow when making use of Visual Interactive Modelling in aiding clients?

Chapter Four determined that it would be over-ambitious to attempt to produce a set of scientifically tested guidelines prescribing precisely what a Visual Interactive Modeller should, and should not, do. Nevertheless, it has been possible to contribute some guidelines which are based on evidence from both some Action Research studies and some laboratory experimental work. This evidence is not of the kind expected of 'positive science' but rather comes from the insights which it has been possible to gain from the Action Research and from further lessons learned from the series of studies designed to contribute in ways which the Action Research could perhaps not.

A further contribution to knowledge from this research programme has been in the form of a 'body-of-experience' related to the practice of Visual Interactive Modelling. This was created as an intermediate step between the raw data collected from the experimental work, and the suggested guidelines. However, this body-of-experience is, in itself, a contribution to knowledge, because it can be used as a basis for further work by later researchers.

9.2.2 Are there any important ways in which Visual Interactive Modelling benefits Operational Research studies beyond those benefits previously suggested in the literature?

Chapter Eight has argued from the evidence in the literature and with some reference to the body-of-experience and data chapters that Visual Interactive Modelling can aid the O.R. profession in overcoming certain problems with what it termed the 'traditional O.R. paradigm' *while* maintaining an ability to handle hard numerical issues. This would appear to be a contribution to knowledge of some significance because (a) it has not previously been argued by the researchers in the VIM field and (b) it would appear that the other approaches which have been developed to cope with the problems of the traditional O.R. paradigm have not at the same time maintained an ability to fully embrace the traditional 'hard' aspects of O.R.

9.3 Weaknesses in this Thesis

This section discusses weaknesses in this research programme which are recognised by the researcher.

9.3.1 The value of the contribution to knowledge presented here is very dependent on the acceptability of the type of research evidence which has been used to create this knowledge. Chapter Four has argued that Action Research is the only way of gaining much of the evidence which would be of benefit to research in a field which is dependent on activity in a decision making context. It is recognised that some researchers might find Action Research an unacceptable means of gaining research data, in which case the output of this research programme would be of very limited value.

9.3.2 In addition to the Action Research studies a series of laboratory based experiments were set up to explore some aspects of VIM which could not be explored using Action Research. With the time and resources available to conduct these experiments, it is not possible do more than conjecture the possibility of certain findings. Too many variables were uncontrolled and too few trials were run of these experiments to be able to claim that they have any 'scientific validity'. However, as was argued in Chapter Six, at this early stage in the development of knowledge about Visual Interactive Modelling, it is inappropriate to conduct a series of studies which examine very closely some individual aspects of the approach. We first require a broader understanding before we can start to fine-tune. Nevertheless, with more time, the tentative findings reported in Chapter Six could have been examined further.

9.3.3 Five of the six Action Research studies were based within the same client organisation investigating problems which related to the manufacturing of the same type of product. As a results, all these studies were within a particular type of organisational political environment, with people who worked with similar customs and practice. It is possible that the conclusions which have been drawn relate only to that environment. While it was possible to conduct one of the Action Research studies in a different environment a better set of Action Research studies might have used a 50/50 split between different organisations.

9.3.4 Creating a similar problem to that raised in the previous sub-section, all the studies used discrete event simulation as the underlying technique which formed the model within each Visual Interactive Model. Thus every model was a Visual Interactive *Simulation* while much of the discussion in this thesis relates to the wider concept of Visual Interactive *Modelling*. The discussion was broadened where it appeared to the researcher not to be dependent on the underlying technique. However, it is recognised that such assumptions could be invalid.

9.3.5 Some of the argument for Chapter Eight being a contribution to knowledge is based on there being no other approaches which combine an ability to assist with both 'hard' and 'soft' issues simultaneously. This assertion goes too far because there is both published work (such as Walton's work cited in Bryant, 1988) and probably much other work (as also suggested by Bryant and illustrated by Hollocks, 1983) occurring in practical settings where O.R. professionals have used their considerable human skills to ensure that 'soft' and 'hard' issues are managed. It is also recognised that there may be other published approaches which are capable of encompassing both hard and soft issues but which have been beyond the limited extent of the research programme reported here.

9.3.6 The Visual Interactive Modelling approach of providing an interface between essentially 'hard' techniques and the client could be criticised by the protagonists of 'soft' O.R. approaches for providing no help with 'problem structuring'. This criticism is accepted, to a limited extent. As suggested by the discussion and guidelines in Chapter Seven, the VIM approach is more than making use of a VI interface. It, for example, includes the notion of using the client to design the screen display and that multiple clients can use the 'common representation' of the display as a communication device between themselves. The VIM acts as an exploration tool for examining areas of the potential decision space, and thus as a problem structuring tool. However, there are certainly approaches designed specifically with 'problem structuring' in mind which tackle this aspect of O.R. problem solving much more directly than VIM. Figure 8.4.A shows VIM as only partly covering the soft issues in recognition of this limitation.

9.3.7 The discussion in Chapter Seven made no reference to Chapter Eight's extension to the possible benefits of VIM. Thus a further weakness of the argument in this thesis is that the guidelines in Chapter Seven were based on attempting to achieve a limited set of benefits which might not be the complete set of objectives of an O.R. worker.

The next section explores methods by which some of these weaknesses can be overcome.

9.4 Further Work

All the areas mentioned in the previous section on weaknesses would be interesting to pursue further, however, some are more likely to lead to immediate useful results than others. There, for example, appears to be little hope of finding a research methodology which *both* collects research data which conforms to the norms of positive science *and* does not disturb the management process in such a way as to render its data irrelevant.

There are specific aspects of the laboratory based experimental work which could be investigated more thoroughly with a rather larger study. Issues related to the over-reaction of subjects (cf section 6.5.5), display design (in relation to unstructured problem solving), work with groups, rather than individuals (cf section 6.5.3) and enforced breaks during the modelling sessions, all could be investigated further. While such investigation must be cautious because of its isolation from the practical aspects of management decision making, it could lead to important insights into how to extend the guidelines.

While six Action Research studies have produced much which could be used to postulate an initial set of guidelines, these are restricted to one industry, one technique, and a limited number of trials. It would be fascinating to extend this series by rigorously applying the tentative set of guidelines postulated in Chapter Seven in a wider and larger study with the hope of learning by either refuting or refining them.

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APPENDIX A

Problem description given to subjects of Experimental Modelling Sessions (cf Chapter Six).

MISSING

PRINT

The Visual Interactive Learning Process Experiments.

When one interactively explores a visual computer model one learns about the behaviour of the modelled system.

As part of my research programme I am attempting to analyse this learning process. To help me in this I am conducting a series of experiments. Your assistance in these experiments would be very welcome.

The role you would play is that of a car factory director. You have to decide on some control rules for a crucial part of your factory. The idea is that these rules will form part of a contract that is to be given to a computer company. The computer company is being commissioned to supply an automated system which will control this part of your factory.

A description of the actual problem is given later in the section headed "The Problem". However first it is best to describe the method of trying to solve the problem.

The Method

As you will all know we can use computers to simulate some real life situations. The computer is programmed with the significant aspects of the problem area and can then be experimented upon. However the problem with the usual form of computer simulation is that you put all the data in at the beginning, run the program, and get a statistical summary at the end. Unfortunately this type of reporting does not give an insight into how the model is behaving with respect to time.

Visual Interactive Simulation displays a moving picture of the modelled system on a colour computer screen. The picture shows the current state of the simulation. It changes as the state of the simulation changes with time.

This makes it possible to watch for bottlenecks in the system (and to see what events preceeded them). It is possible to see control rules in action; to watch individual instances of them operating and to decide how they might be improved. It is possible to get an overall understanding of how a (proposed) system will flow.

In addition to the visual display, Visual Interactive Simulation also makes it possible to interact with the program as it runs. There are many advantages of this but they divide into two categories.

The first is that the interactive facility allows the user to explore the model in terms of ascertaining which parameters have most affect on the objectives and which values of these parameters optimise the operation of the system. The model can, for example, be run with one set of control values from a starting point where certain conditions occur and then again from the same starting point but with a different set of control values. The conditions that occur during the runs can then be compared. Breakdowns can be introduced and the effects observed. Methods of recovering after a breakdown can be tryed out. Product volumes or ratios can be changed and the capacity of the process evaluated.

All these things can be explored interactively via the keyboard, as ideas come to mind. The results can be clearly and understandably seen: It is often the display itself which generates the ideas, which can then be tryed out.

The second category of advantage given by the facility for interaction between man and computer is particularly important for the analysis of the problem used in this series of experiments.

It is often difficult to find control rules which will satisfactorily take decisions at key points in a simulated system. Using Visual Interactive Simulation it is possible for such decisions to actually be taken by the person who is exploring the model. These decisions can be taken in the light of the understanding the human mind has for the current status of the whole system. One can quickly learn what factors are important in the decision and can then formulate automatable decision rules. This is your task in the problem outlined below.

The next section describes the particular problem situation. It was taken from a real study which was undertaken in BL Cars Ltd by their operational research unit. In fact it was "solved" in the same way as you will be "solving" the experimental version; that is by sitting down at the screen and "playng" with the model.

The problem

One of the most difficult parts of the process of making a car is that of painting the body shell. In many car factories more than half the cars painted may fail the quality inspection after the paint process. These rejected cars have to be partially resprayed.

The new paint shop in Cowley, Oxford (built to paint the Triumph Acclaim) uses advanced technology. This is designed to considerably reduce the number of cars that are imperfectly painted the first time around.

This simulation concerns the transport of these poorly painted body shells to the "repair" paint shop, as it is known.

The body shells are carried by a conveyor. It consists of a guide in the roof of the factory. Hanging from the guide are slings which hold the body shells. The slings are pulled along by a chain. They can be automatically detatched from the chain at certain points in the conveyor system. This allows them to stop moving (to queue up) while others continue to move around.

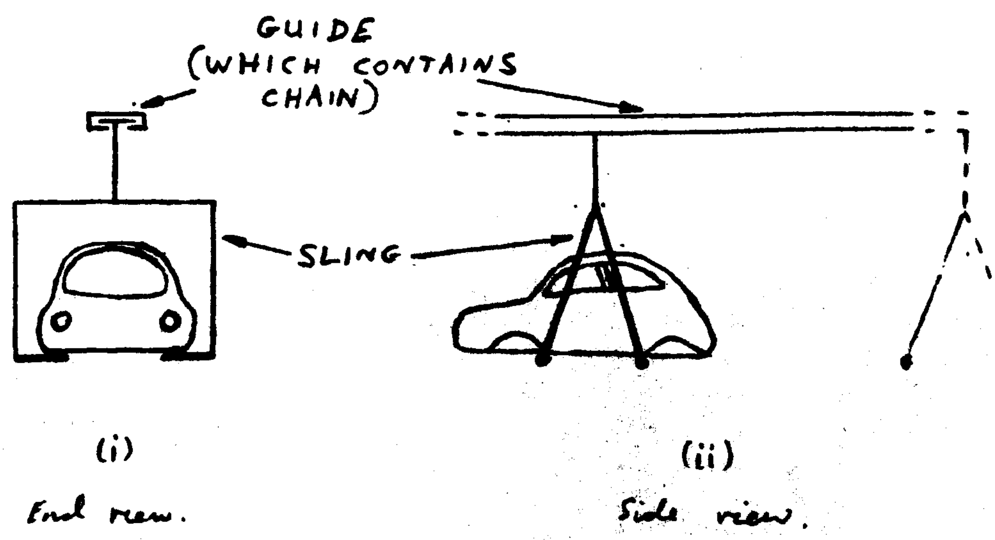


FIGURE 1

The guide is not simply a length to transport the body shells plus a length to return the empty slings for their next load. It also has a siding to a store and two bypass loops.

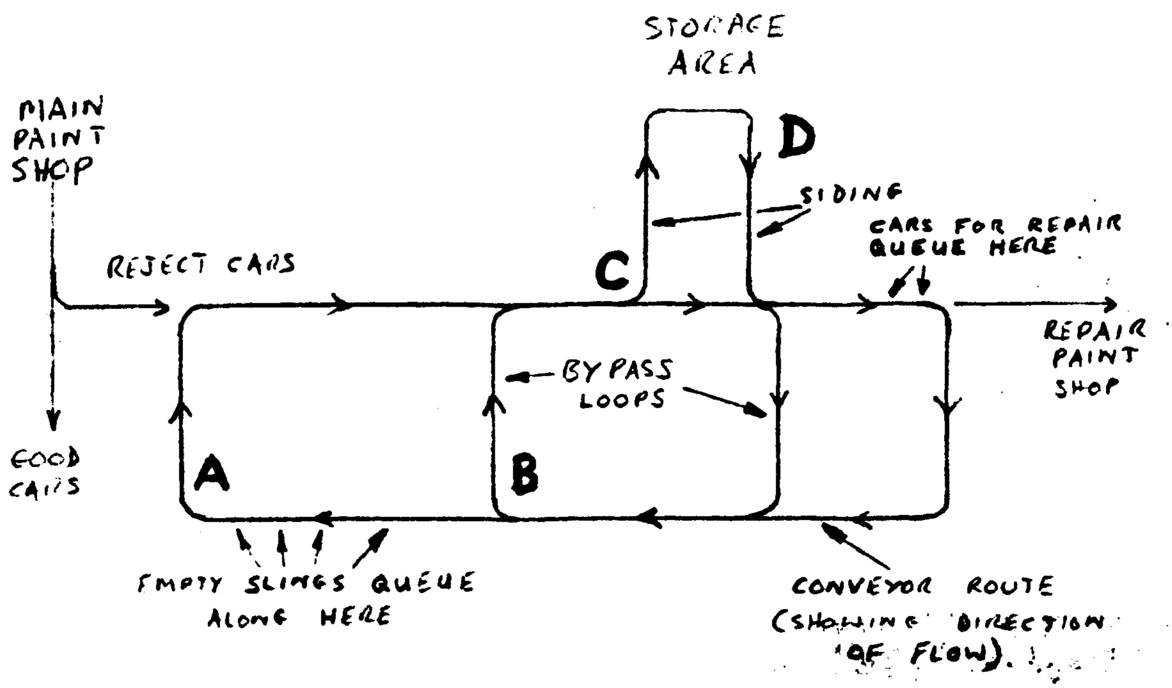


FIGURE 2

The body shells arrive at the inspection point at the end of the new paint shop. They only enter this conveyor system if they are rejected. They are picked up by a sling that has been queuing at point A (figure 2). This will then transport the car to the repair paint shop. It will queue until the repair paint shop is ready to take it and the sling will then return to queue at A. Unfortunately this ideal is not always possible.

The demand on this transport system is highly variable. A 25% paint reject rate does not, unfortunately, mean 1 in 4 cars. It means more like every body shell for 45 minutes will be perfect and then all the body shells in the next 15 minutes will be rejected. Colours are painted in batches and some colours are more difficult to paint than others. So at times we can expect this transport system to be working flat out and at other times it could be lying idle. However the transport system is also designed as a buffer between the main paint shop and the repair paint shop. i.e. Although the supply of reject body shells is highly variable, it is required that the repair shop should work at a smooth rate.

To help achieve this there is a store which can be used to buffer body shells awaiting 'repair' during periods of high demand on the transport system.

When a car body shell is taken to the buffer store it is released from its sling. The sling returns to the queue at A, via a bypass loop.

When a car body shell is to be removed from the store an empty sling must be brought from the queue at A to collect it. The sling can either come from the head of the queue, (via A), or from part way along the queue (via B; a shorter journey). A car cannot leave the store without a sling to carry it.

The bypass loops are used to speed the transit of slings.

There are two conflicting objectives in this problem. We need to maintain a continuous flow of car body shells to the repair paint shop. We also need to maintain a supply of empty slings queuing at A. This is to ensure that there will be sufficient slings to pick up body shells from the main paint shop should there be a sudden rush of cars requiring repair.

If a car fails the inspection and there is no sling to pick it up the whole of the main paint shop will have to stop production until a sling arrives. If there is no car waiting at the entrance to the repair paint shop and that process is ready to take another car, then a gap will be left in the line of cars moving through that shop.

Before describing the computer model and the commands availible, there are some facts and figures which may be of use to you in 'solving' the problem.

There are 25 slings availible in the system.

The storage area (used as a buffer) has no effective limit to its size. In practice, if the storage area is full (about 200 cars) then the body shells are 'vacuum packed' in plastic film and stored in a car park.

The main paint shop runs at a rate of 120 cars per hour. So if a rejected car has to wait 2 minutes for a sling the paint shop will loose 4 cars worth of production!

The repair paint shop runs at a rate of 30 cars per hour. Therefore if there is no car availible to be taken into this shop for a period of 2 minutes then 1 car worth of production will be lost!

The average probability of a failed inspection is 1 in 4.

The store can unload and/or load a sling in 1.5 minutes.

Travel times (assuming the journey is unhindered, for example by queuing) are as follows:

Main paint shop to repair paint shop	15 mins.
Repair paint shop to A (figure 2)	15 mins.
B (figure 2) to store	7 mins.
Store to repair paint shop	6 mins.
Store to A (figure 2)	16 mins.

This section has described the problem area. The task of the factory director is to find a set of control rules which will minimise losses.

The next section describes the model and the commands availible.

The Model

If you are willing to be one of the subjects in this series of experiments then you will be given a 10 minute introduction to the model at the beginning of your session. The whole session is designed to last about an hour.

For this reason only a superficial description of the model will be given here.

The screen shows a plan view of the conveyor system rather like figure 2. The position of each sling and sling/car combination can be seen. The inspection area in the paint shop can also be seen, along with the start of the repair paint shop. The current simulation time is shown (in hours and minutes) as well as the number of losses that have been inccured at the main paint shop and at the repair paint shop.

The commands controlling the decisions in the model are entered while the simulation is running. However pressing the "H" key will temporarily halt the foreward progression of the model to allow time to think (if required). Pressing the "H" key a second time restarts the foreward progression of the simulation.

There are four decision points in the model. These are labelled A,B,C, and D in figure 2. There are four model decision commands which relate to the four decision points.

The decision at A is whether to release slings or keep them queuing up. They are automatically released when a reject car is ready to enter the conveyor system. Your decision is whether extra slings should be allowed to travel around to the store.

To avoid the need to instruct the computer every time a sling reaches point A the decision is set to either:

CURRENTLY RELEASING SLINGS AT D.P.A

or

NOT RELEASING SLINGS AT D.P.A

The current state of the set decision is reversed by pressing the "A" key.

A similar arrangement is used for decision points B,C and D.

Decision point B relates to the release of slings through the bypass labelled B in figure 2. If this decision is negative the slings will continue to point A.

Decision point C relates to whether cars are taken along the siding leading to the store.

Decision point D relates to whether slings at this point should be loaded with cars from the store. It should be noted that control of both decisions C and D is necessary in order to control the store.

This section has described the model and the commands availible.

The Modelling Session and Conclusion

If you would like to help me with these experiments this section will describe to you how the session will be conducted.

The session will take up only an hour of your time and should be of benefit to you as well as my research. You will get first hand experience of a visual interactive model and understand better why they are becoming so popular in the O.R. profession.

The purpose of the session for the factory director is for him to develop a set of control rules that satisfy him. The control rules need to be automatable. e.g. You need to find out what factors it is that makes you decide when to allow slings through point A (figure 2) etc.

The best way to approach the task is to start 'playing' with the model. You will find that you quickly get a 'feel' for how the system behaves. There are some automatic rules already in the simulation program. So if a rule you think would be good is in the program it will be possible to interactively activate it. Thus testing out your idea without the need for you to make each decision. You will then be able to concentrate on other control points. Alternatively, seeing the automation in practice may give you an idea for an ammendment to it. Obviously I cannot tell you what automatable rules are availible! If I did there would be no learning to do!

The simulation program will move the slings and cars around the screen. All you have to do is apply controls at the decision points (A, B, C, & D).

The aims of this series of experiments are (1) to discover what particular aspects of a model aid the learning process and (2) to discover through what stages one's mental model of the problem passes during the learning.

May I thank you in advance for your participation.

APPENDIX B

Description of automatic control rule structure given to subjects of Experimental Modelling Sessions (cf Chapter Six).

Rule Structure

The rules availible are of the following form:

Each control point has a standard setting. This is only "disobeyed" if the condition applied to the decision point is currently true.

A "condition" is of the following form:

```
         { A }    {        }    {   } {   } { 0 }
         {   }    {        }    { 1 } {   } { . }
         { B }    { HEAD   }    {   } { > } { . }
Decision {   } IF {        } Leg { 2 } {   } { . }
         { C }    { TOTAL  }    {   } { < } { . }
         {   }    {        }    { 3 } {   } { . }
         { D }    {        }    {   } {   } {100}
```

For example:

Decision A IF HEAD Leg 2 < 3

In finding out if this condition is true the computer will, in the above case, count the number of slings on leg 2. If this is less than 3 it will release a sling at decision point A.

The standard settings of decsions are:

Decision Point	Standard Setting
A	NOT RELEASING
B	STRAIGHT ON
C	STRAIGHT ON
D	UNLOAD

The computer counts:

Cars only on leg 1
Slings only on leg 2
Cars only on leg 3

There is room for a maximum of:

22 slings or cars on leg 1
30 sling on leg 2
8 slings or cars on leg 3

If a decision point is not to be used it should be left under manual control.

Your task is to find automatic rules for each of the decision points you wish to use.

To assist you the decision points are manually controlled initially. Just play with the controls at first to find out how they work and then how you can use them to influence the behaviour of the system.

When you have a rule of the above form for a decision point you can ask for it to be automated. The rules you have automated can be changed at any time; just ask. My role in these sessions is to implement and change rules as you require.

APPENDIX C

Mid-session Questionnaire used with subjects of Experimental Modelling Sessions (cf Chapter Six).

Mid Session Questionnaire.

I am going to ask you the following three questions in turn, please try to answer them as separately as possible.

What conditions do you think it is useful to maintain or prevent in order to avoid losses?

Which control points can be used to maintain or prevent the above conditions?

What factors make you decide when to change the flow at a control point?

APPENDIX D

Graphical Logs of subjects trial control rules during Experimental Modelling Sessions (cf Chapter Six).

The following pages contain summaries of some of the raw data collected during the experimental modelling sessions (cf Chapter Six). Each page refers to one subject's attempt to 'solve' the problem.

The control rules which the subjects were attempting to find could use, as an input parameter, the number of items (cars or empty slings) on one of three conveyors legs. Each of the graphs (there are three on each page) refer to one of these conveyor legs.

The coloured lines on each graph refer to each of the control points (junctions in the conveyor system) for which the subjects were attempting to find control rules.

Control Point	Colour
A	Black
B	Blue
C	Red
D	Green

Solid lines represent automatic (computer controlled) rules. Dotted lines represent reasonably fixed, but manually controlled rules, where the subject stated these were being used.

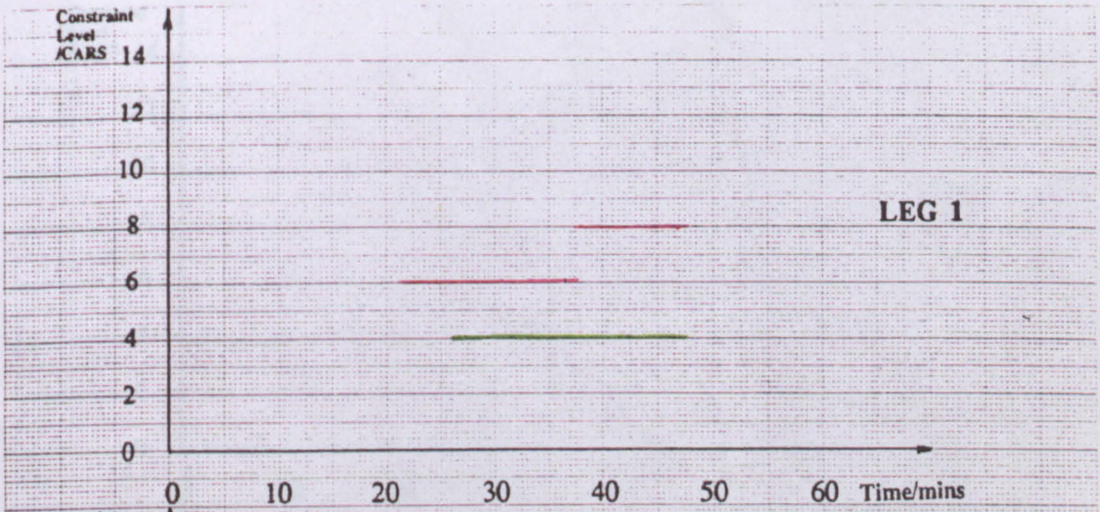
The x-axis represents time in minutes from the start of the modelling session.

The y-axis represents the number of items (cars or empty slings) on the conveyor leg when the particular control point (represented by the coloured line) is triggered to operate in the opposite mode from its default.

Referring to the page for the first session (overleaf), the red line (control point C) shows that the subject (user) set control point C to be dependent on the number of items in leg 3, ten minutes after the start of the session. Until 21 minutes into the session control point C would allow items to travel 'straight on' (cf figure 6.5.5.2.A) unless there were more than 4 items in conveyor leg 3.

At this point in time (21 minutes into the session) the subject changed the trial so that control point C was controlled by leg 1 rather than leg 3. (At a level where more than 6 items in leg 1 were required before the items would be diverted to the storage area).

Session 1



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Time/mins
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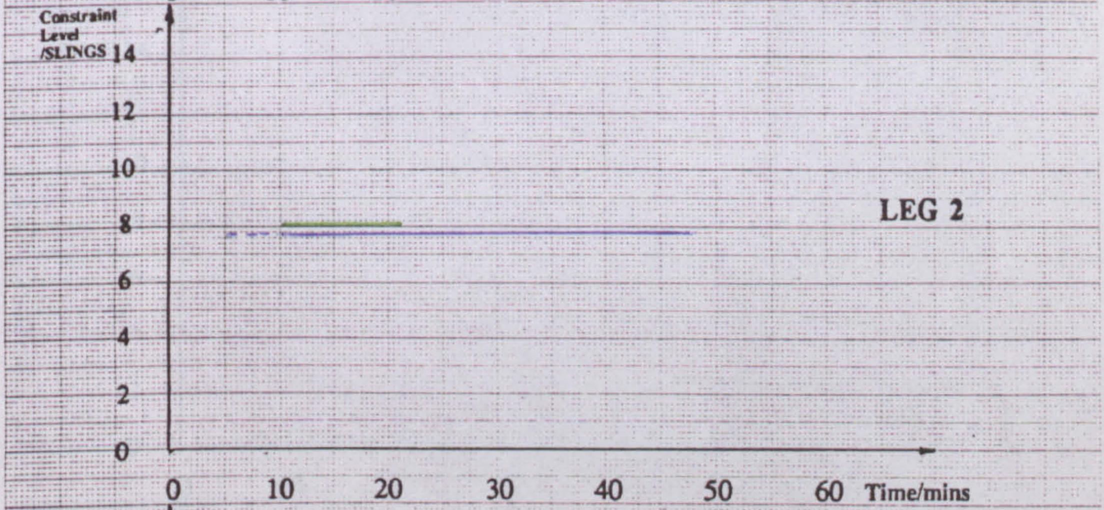

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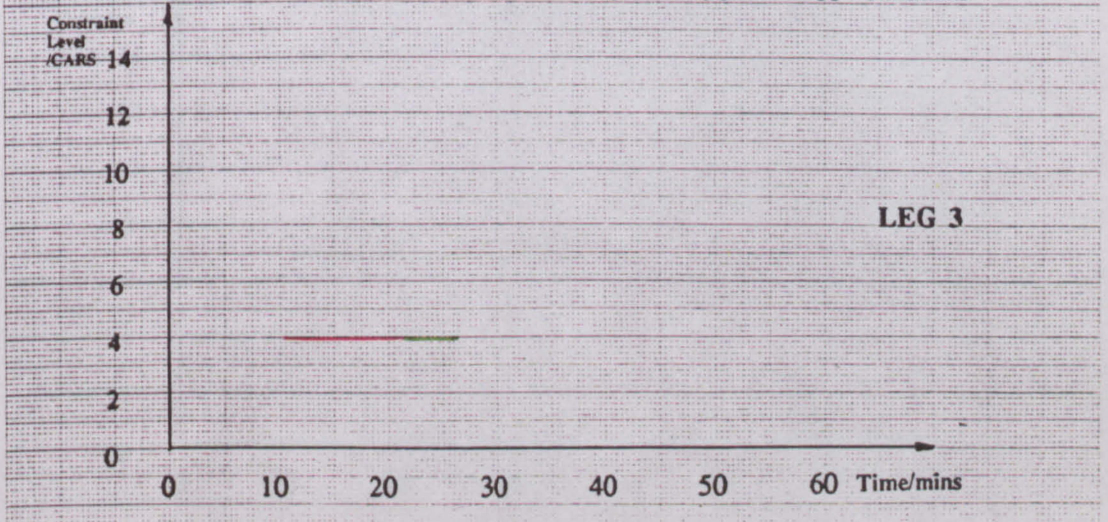

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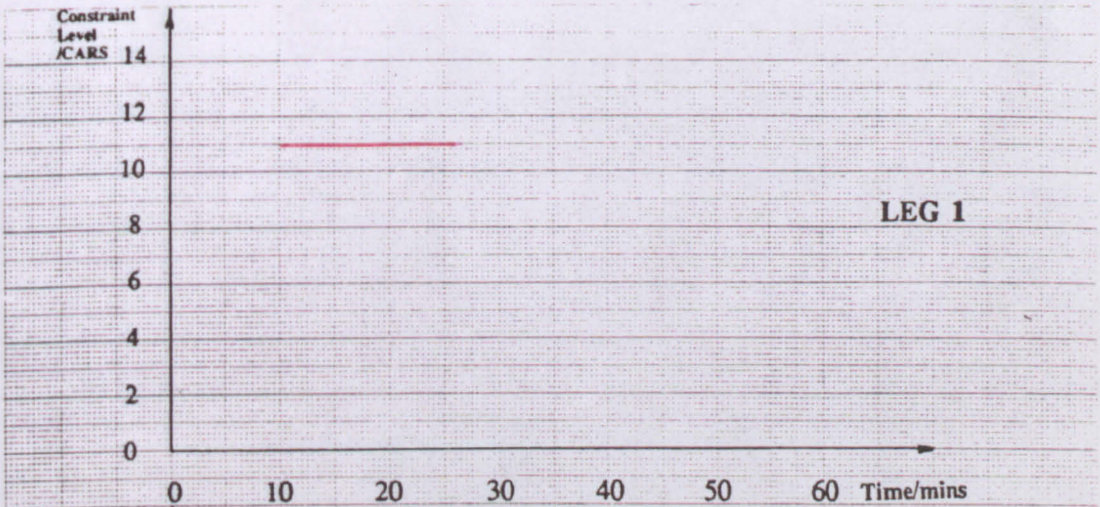
Session 2



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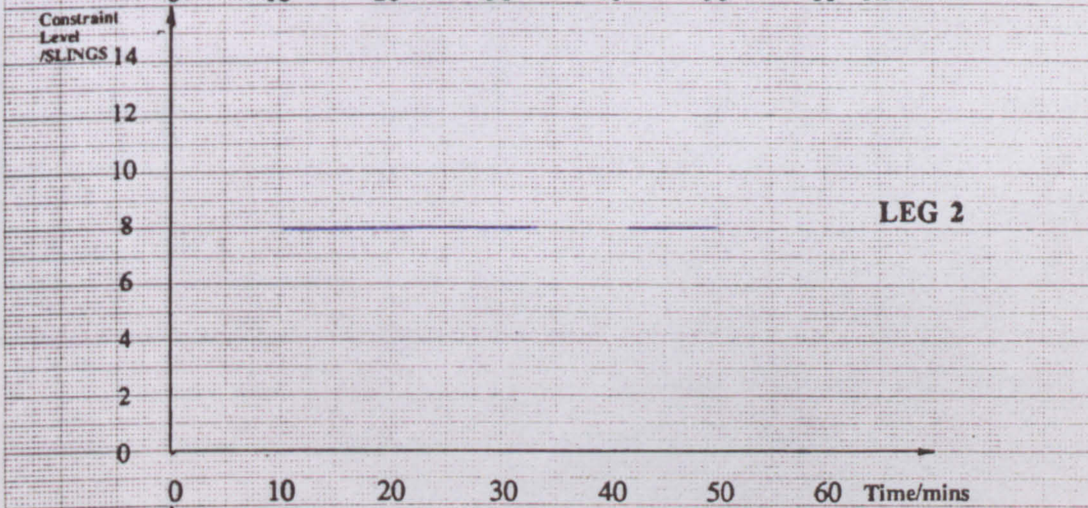
LEG 1



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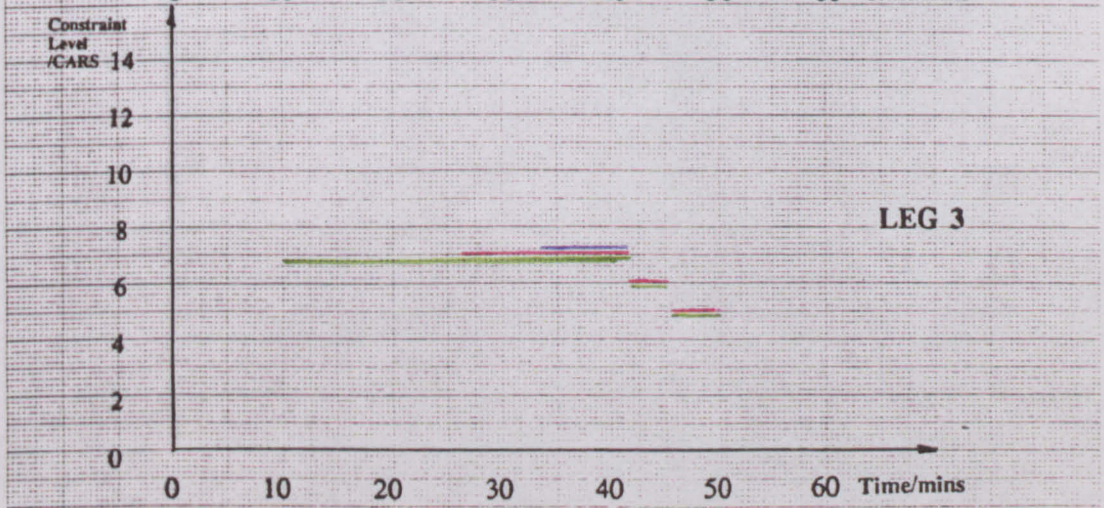

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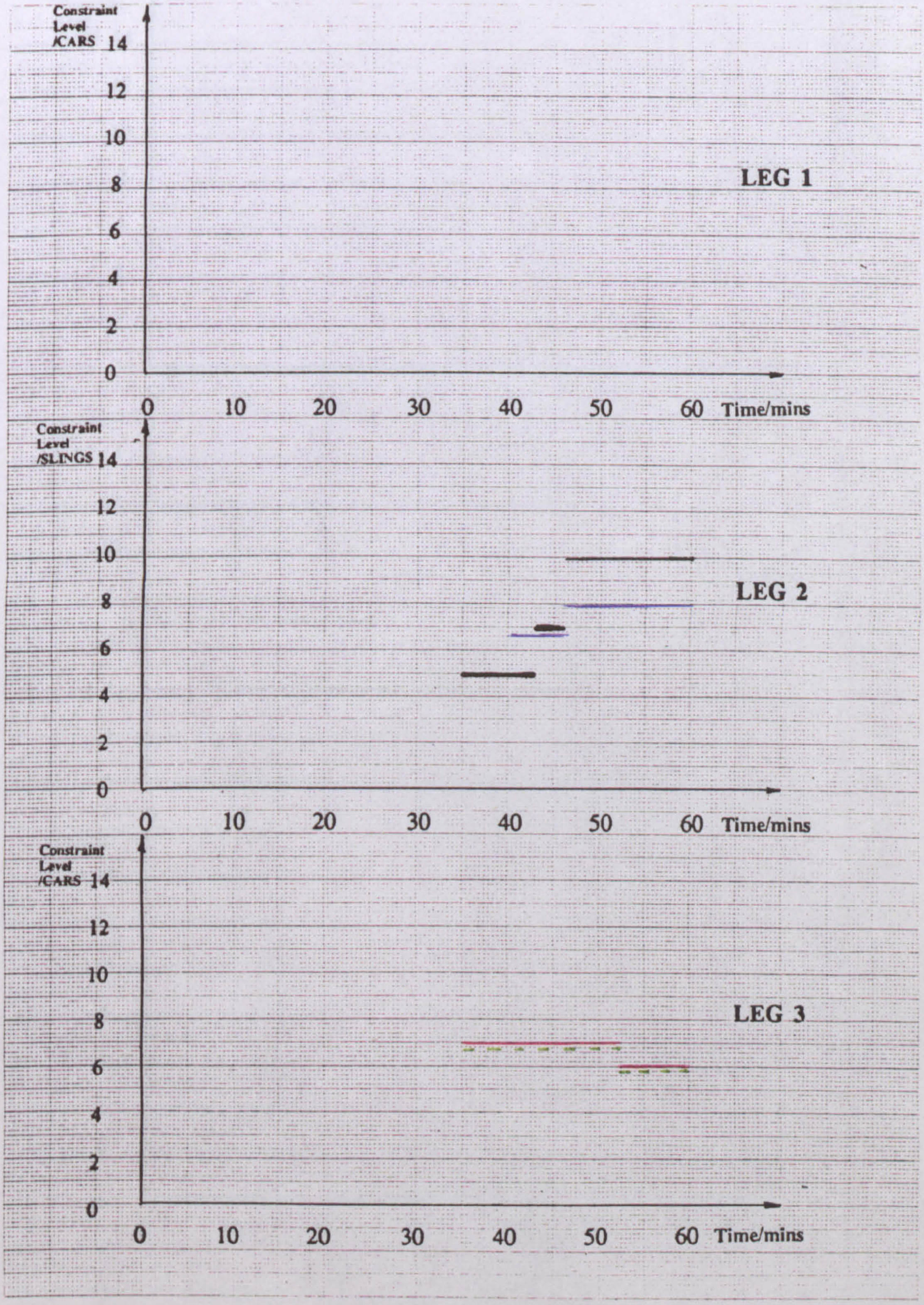
Session 3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LEG 2
Constraint Level /CARS
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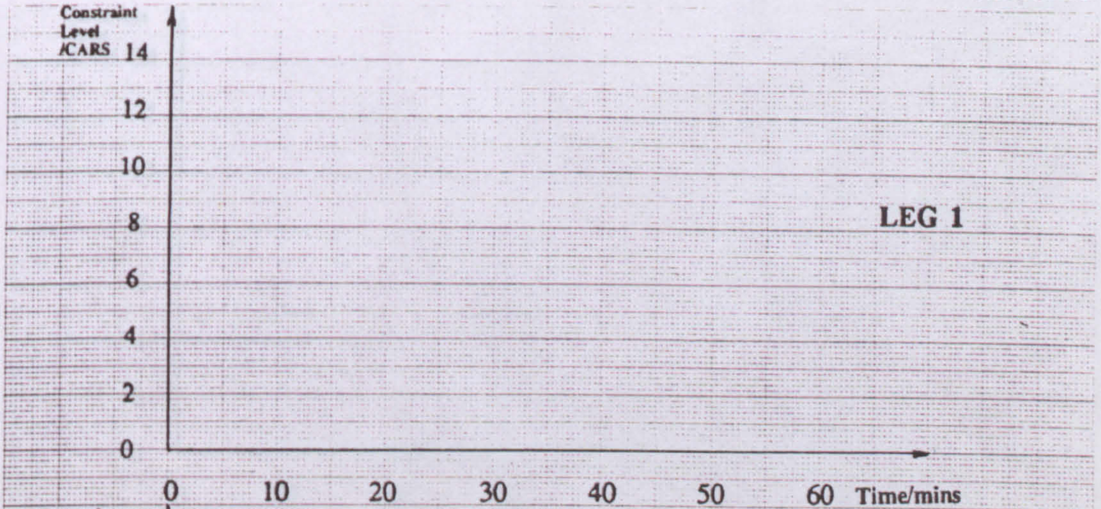
LEG 3

Session 4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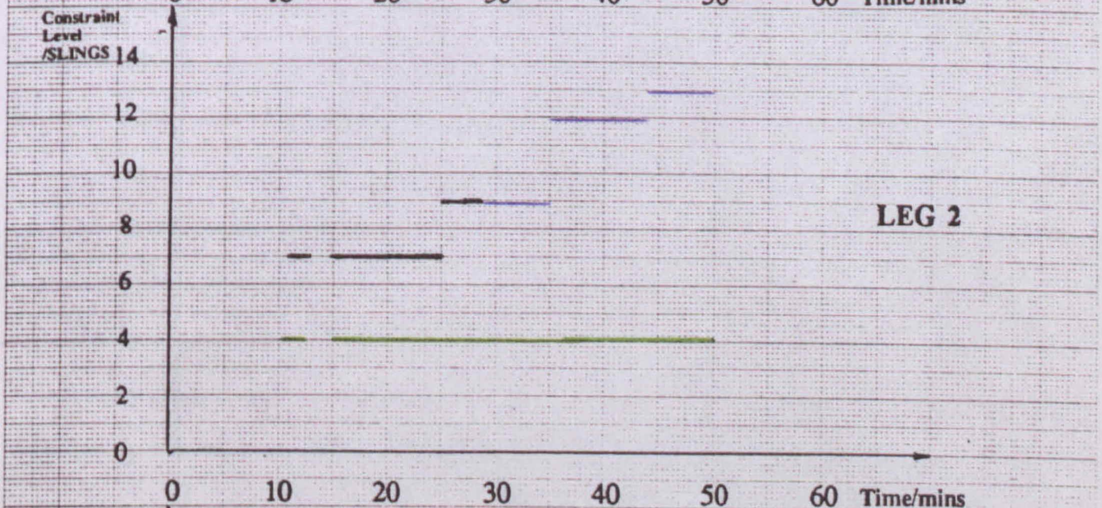
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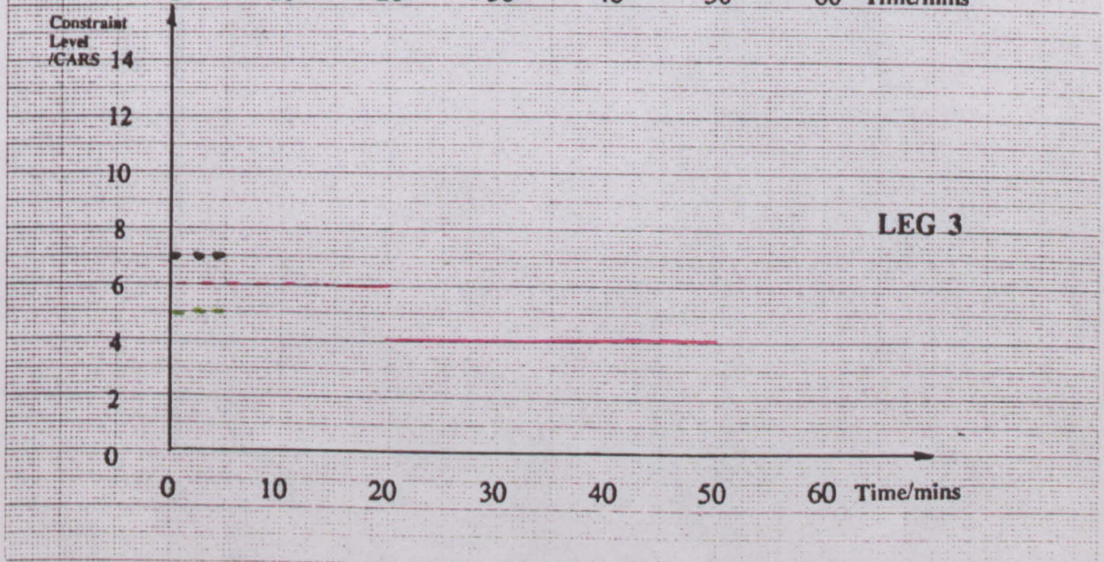
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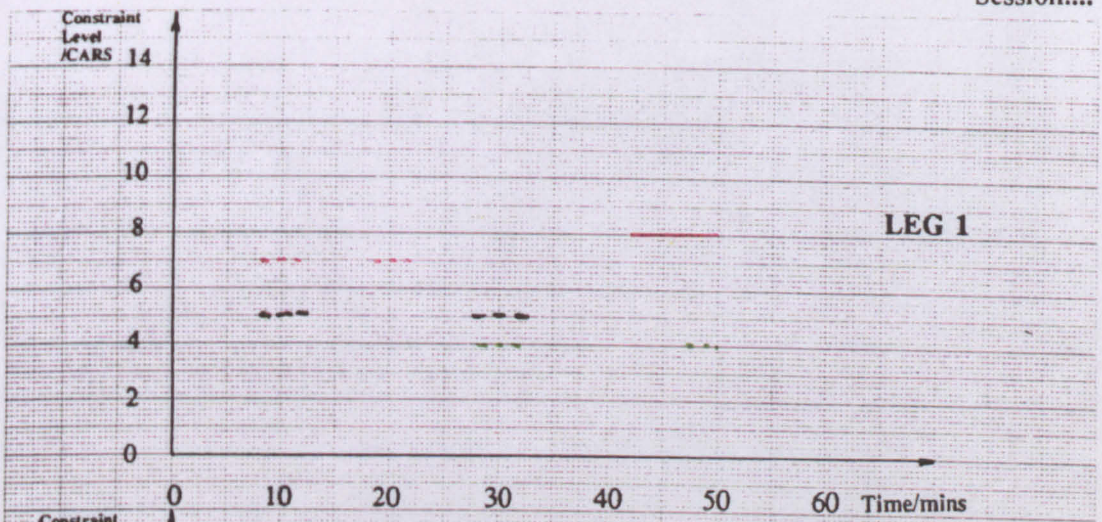
Session 5



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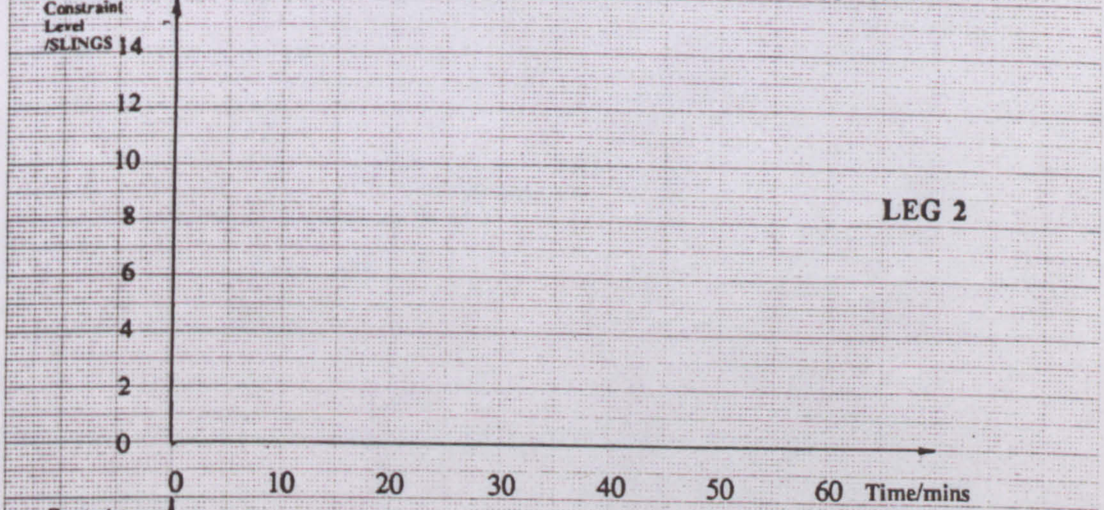

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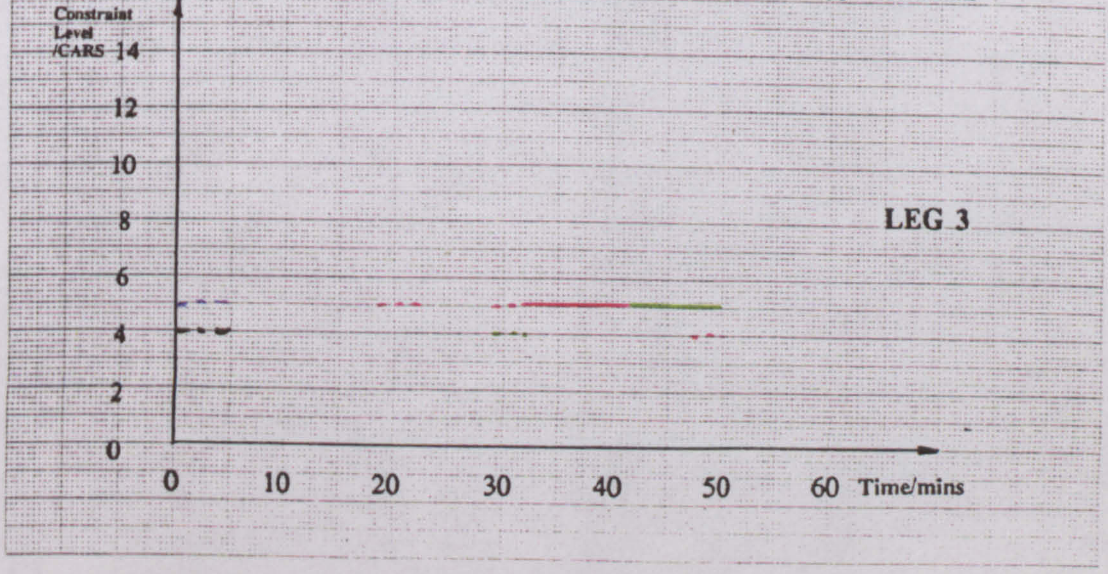

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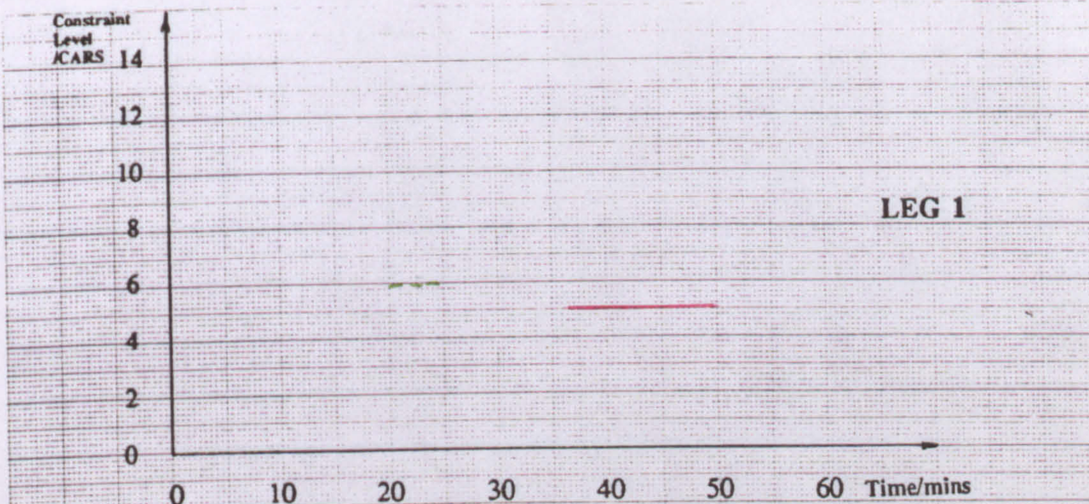
Session 6



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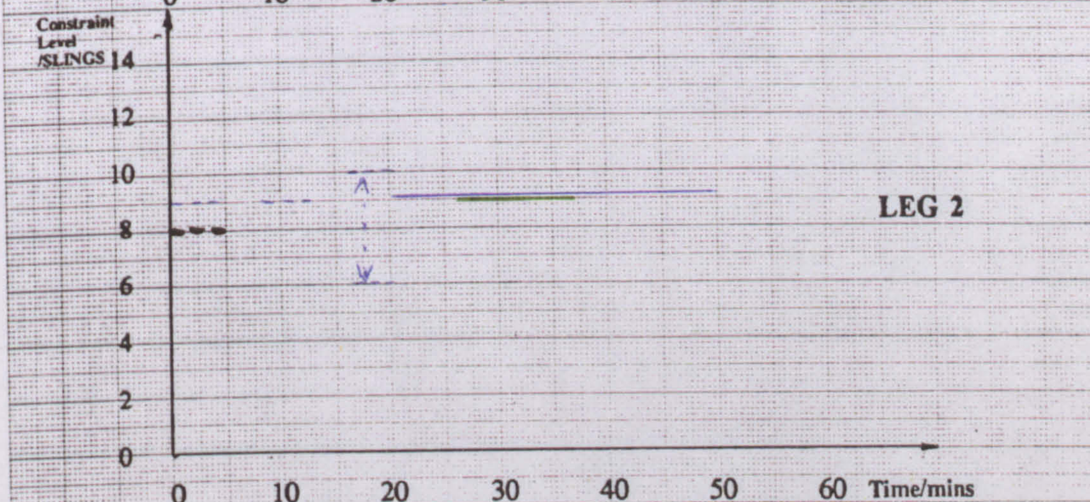

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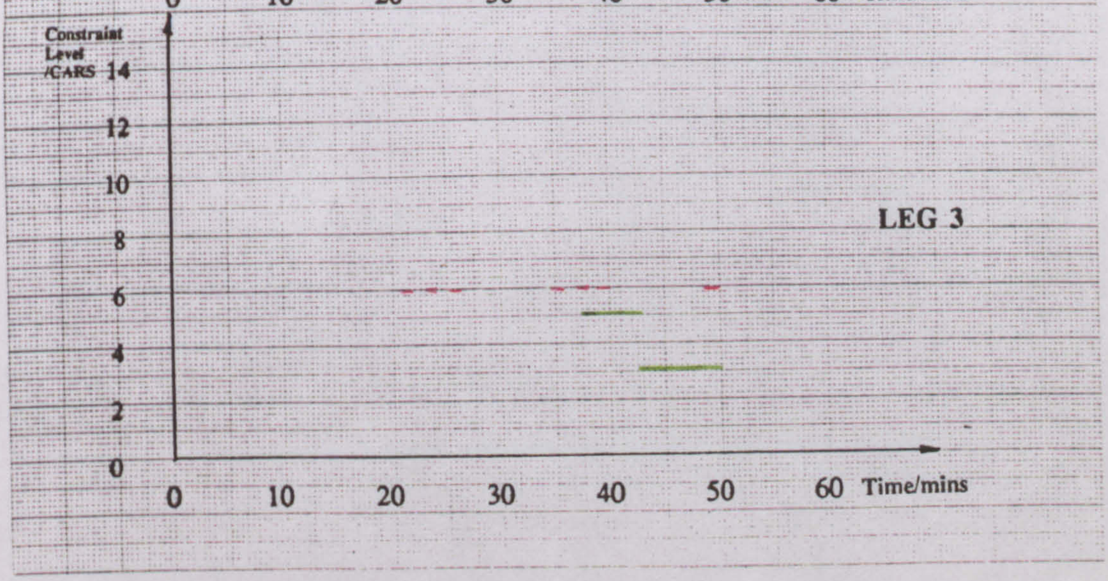

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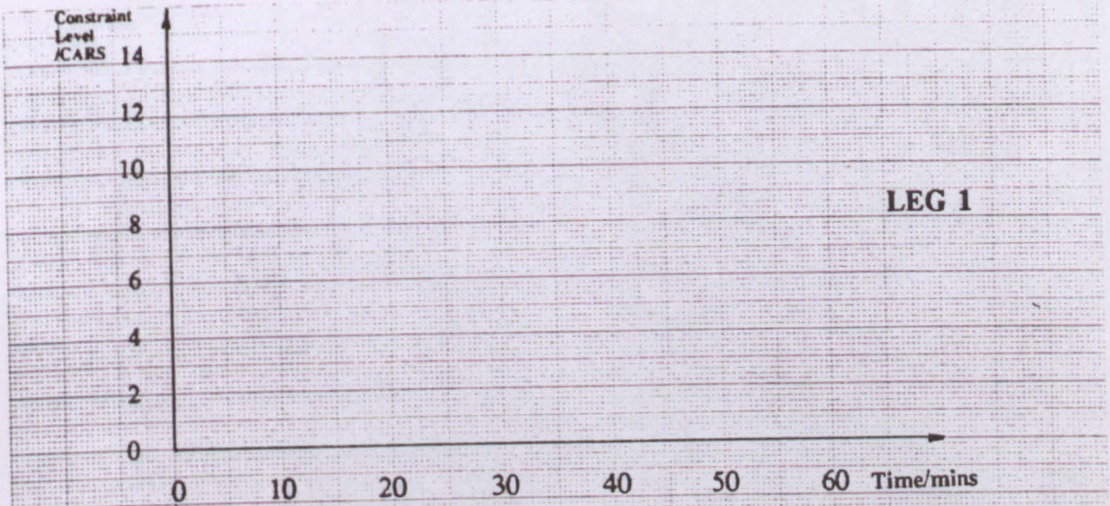
Session 7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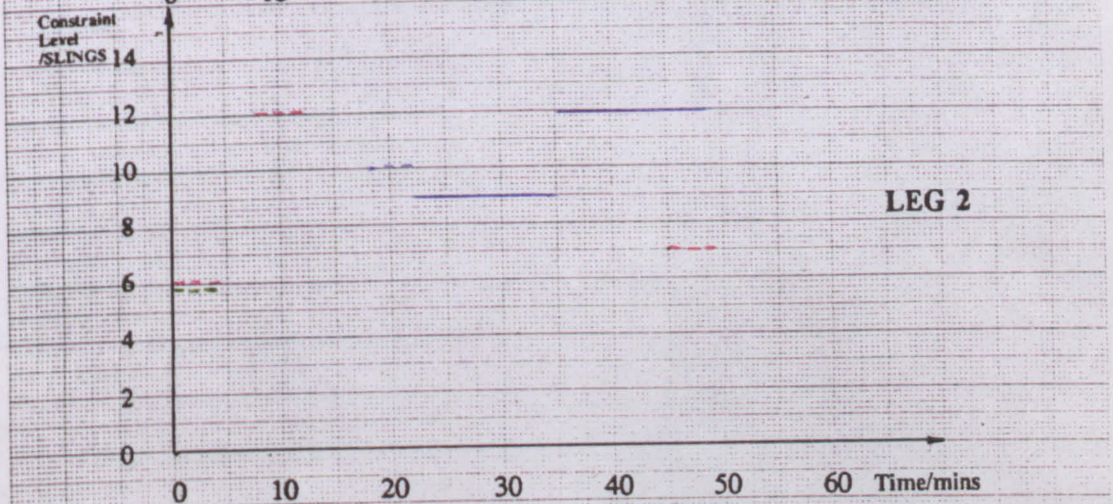
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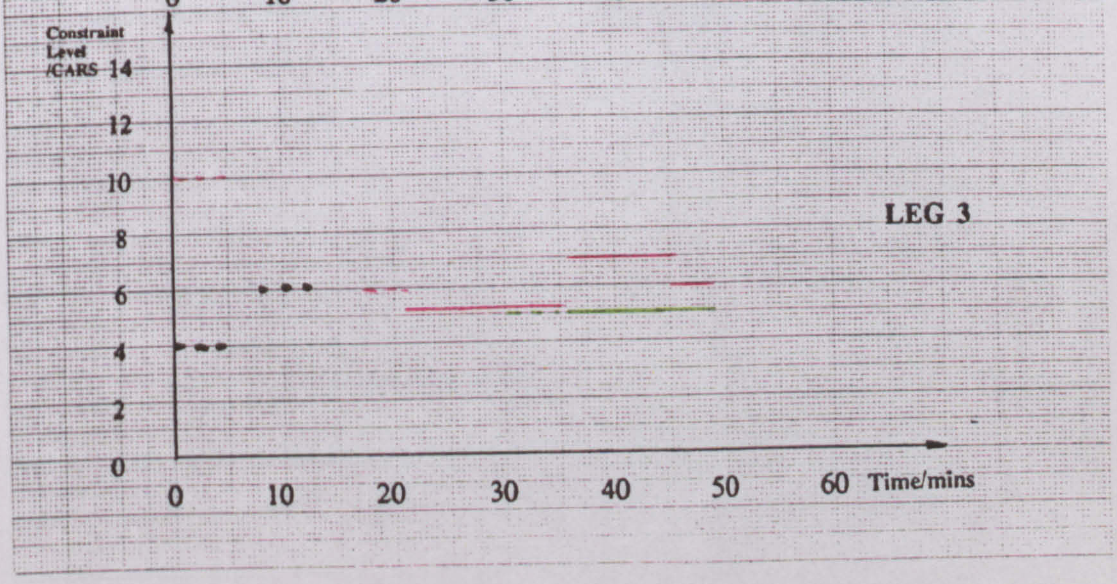
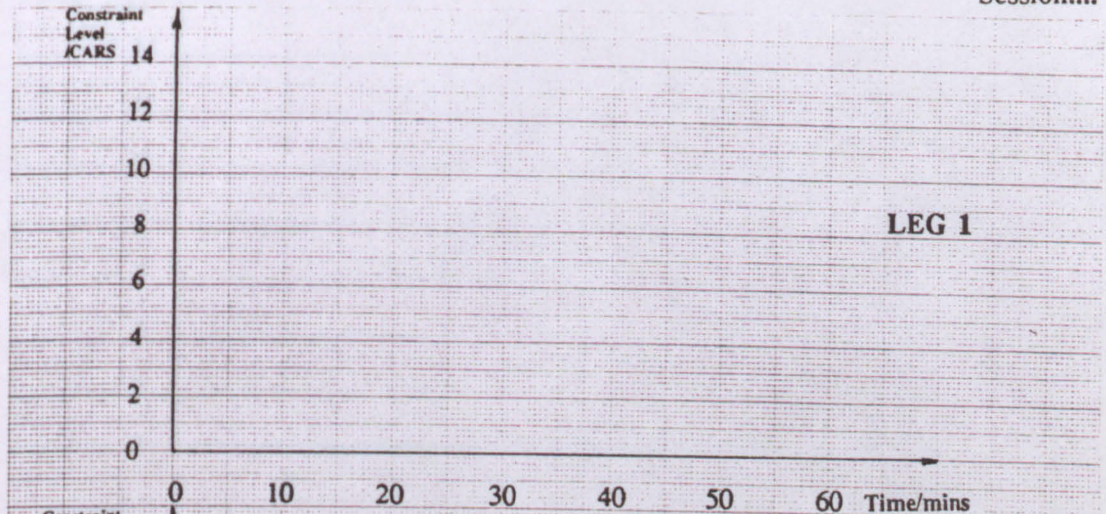
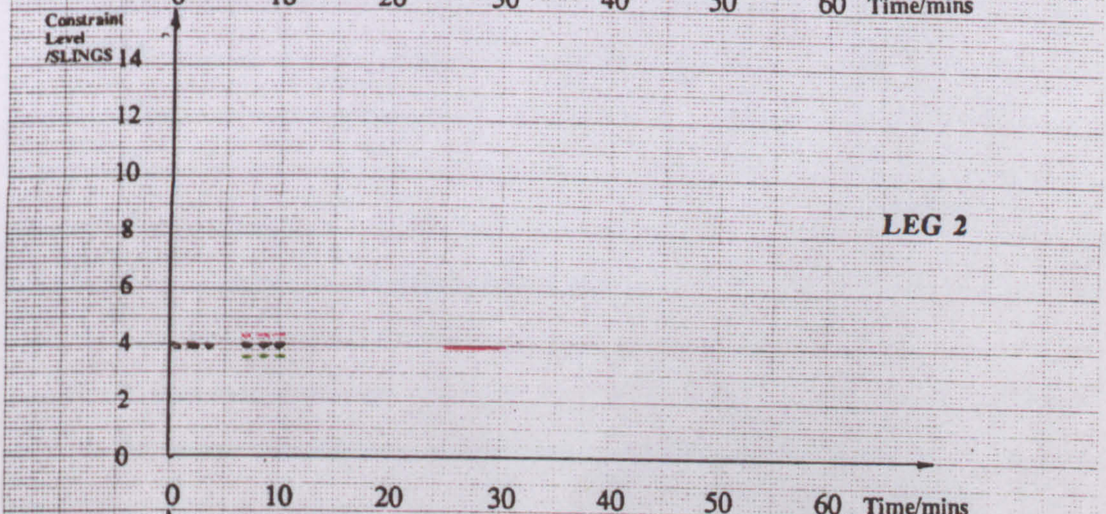
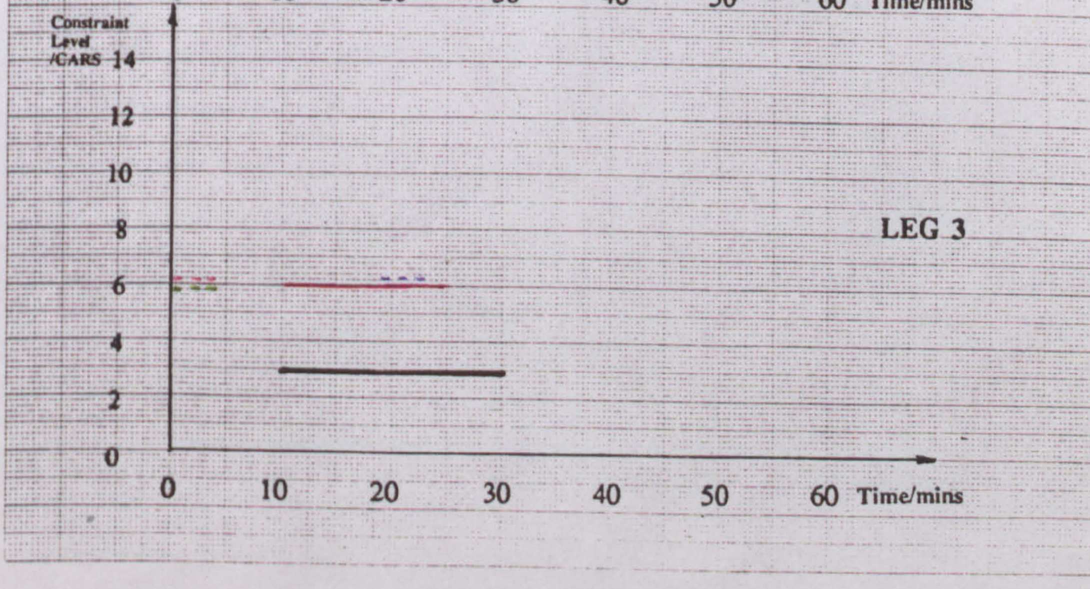
Time/mins
LEG 2


Constraint Level /CARS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 3

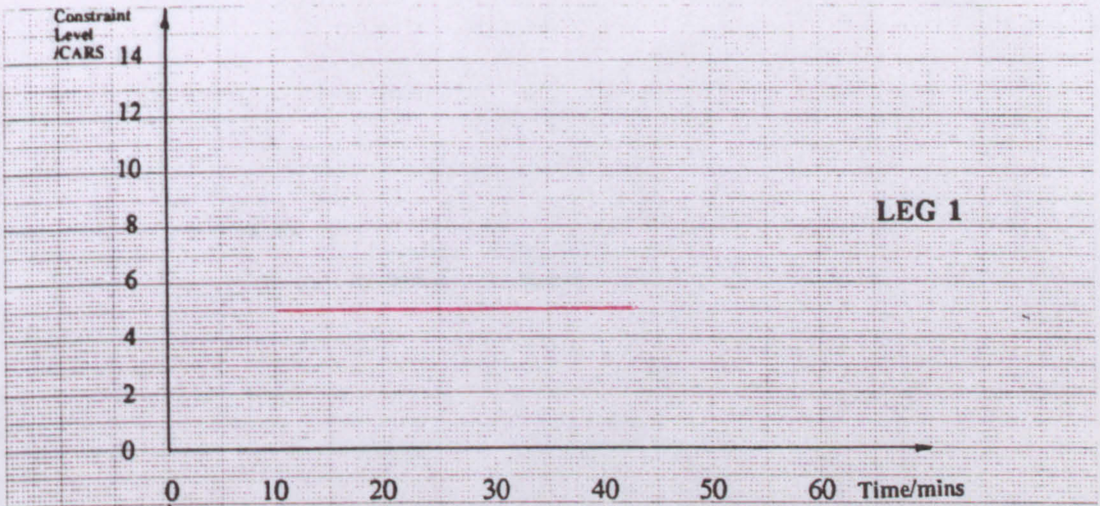
Session..8


Constraint Level /CARS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 1


Constraint Level /SLINGS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 2


Constraint Level /CARS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 3

Session...9



Constraint Level /CARS
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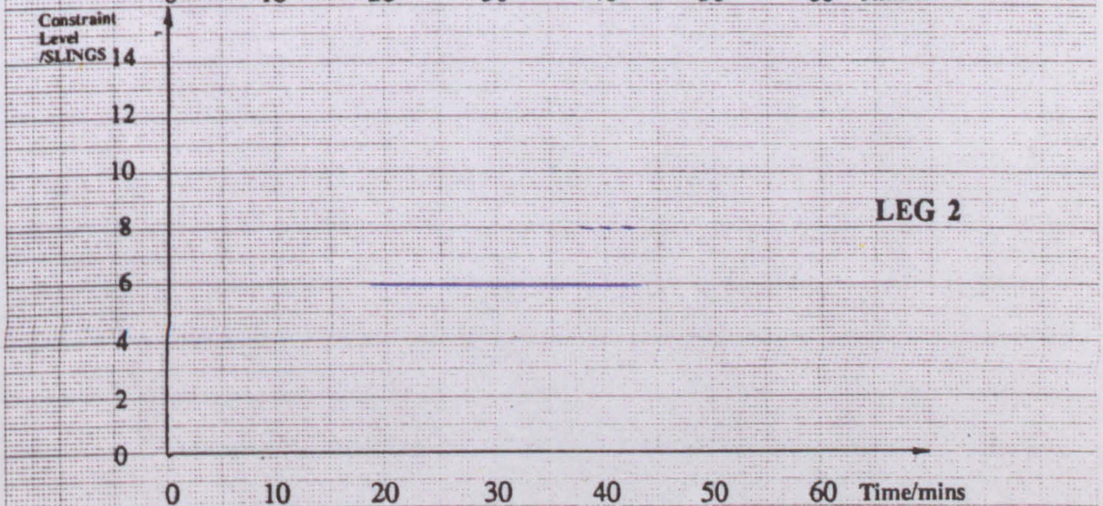
10
8
6
4
2
0
LEG 1
0
10
20
30
40
50
60
Time/mins



Constraint Level /SLINGS
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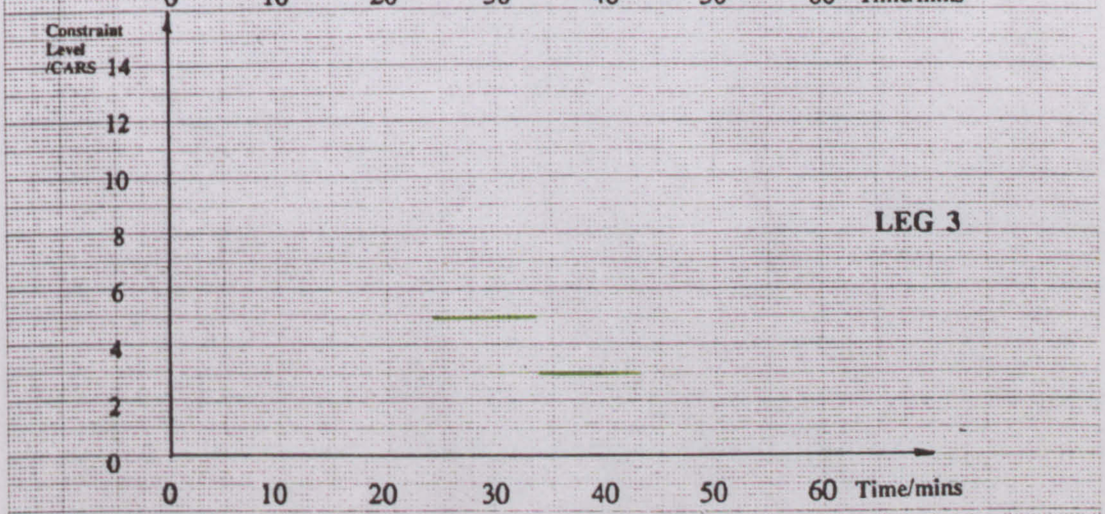
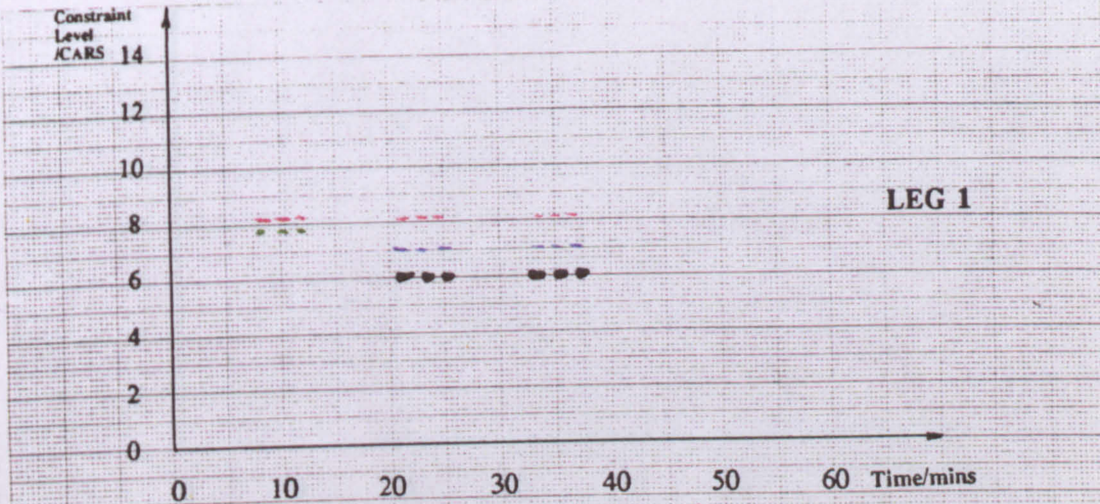
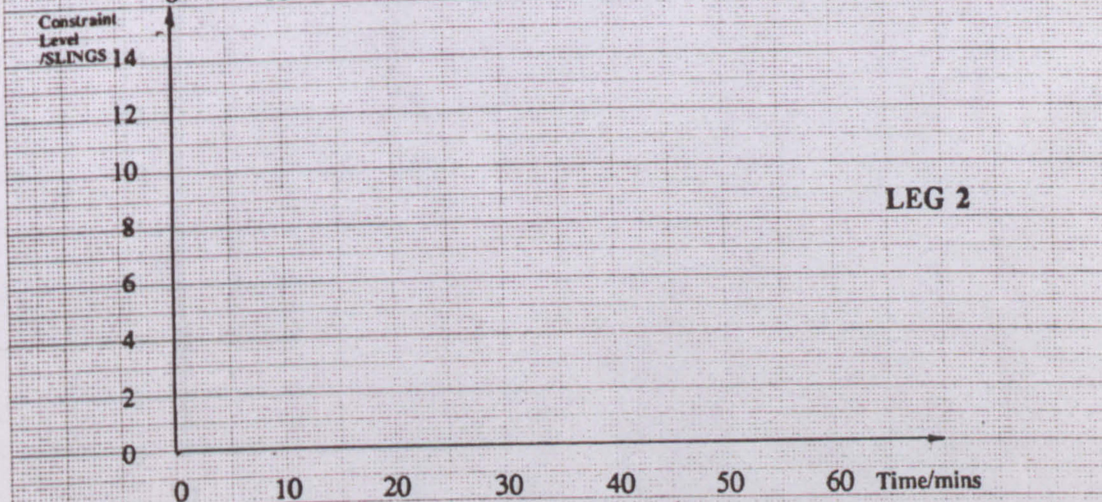
10
8
6
4
2
0
LEG 2
0
10
20
30
40
50
60
Time/mins

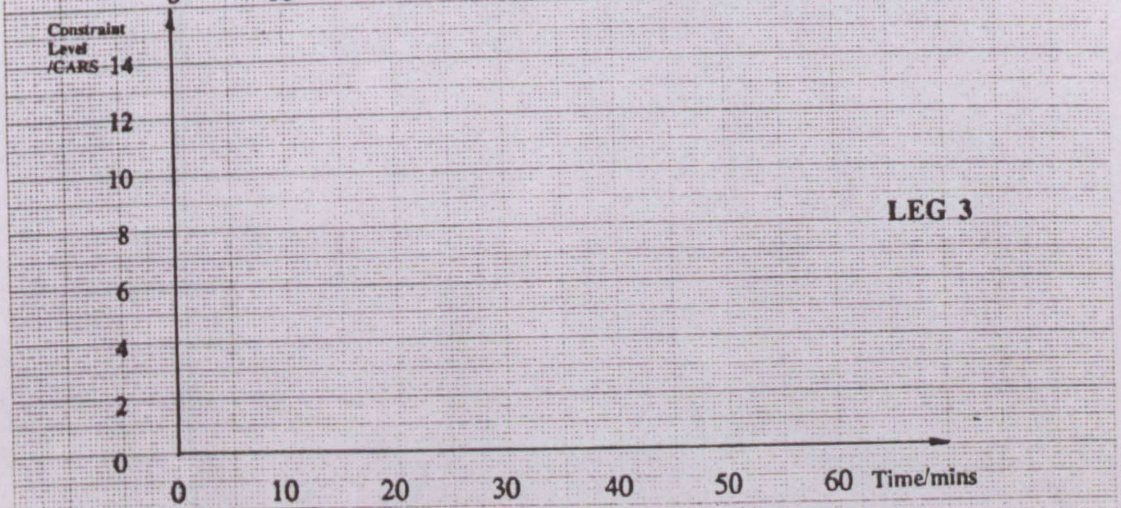


Constraint Level /CARS
14
12
10
8
6
4
2
0
LEG 3
0
10
20
30
40
50
60
Time/mins

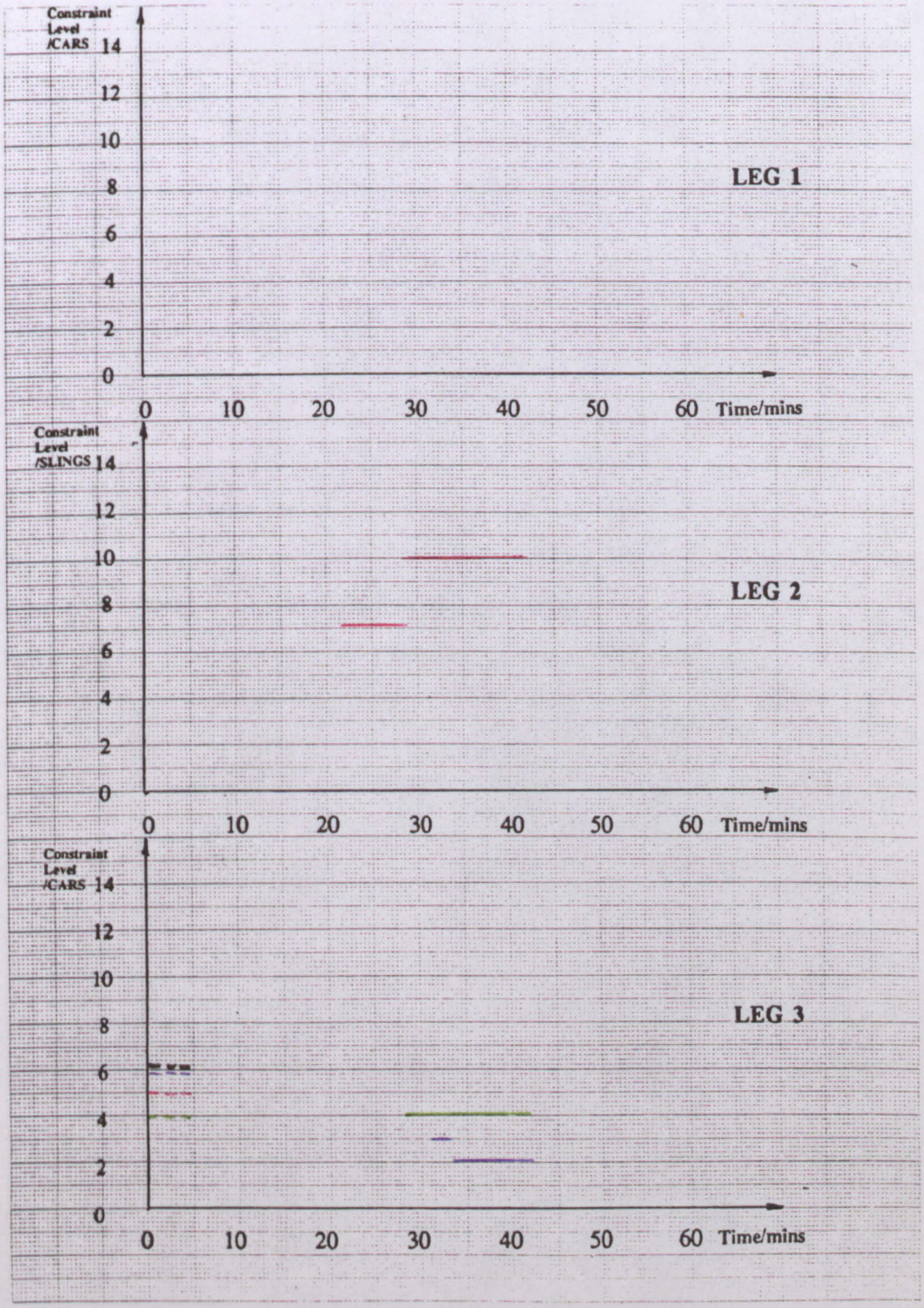
Session 10


Constraint
Level
/CARS
14
12
10
8
6
4
2
0
LEG 1
0
10
20
30
40
50
60
Time/mins


Constraint
Level
/SLINGS
14
12
10
8
6
4
2
0
LEG 2
0
10
20
30
40
50
60
Time/mins

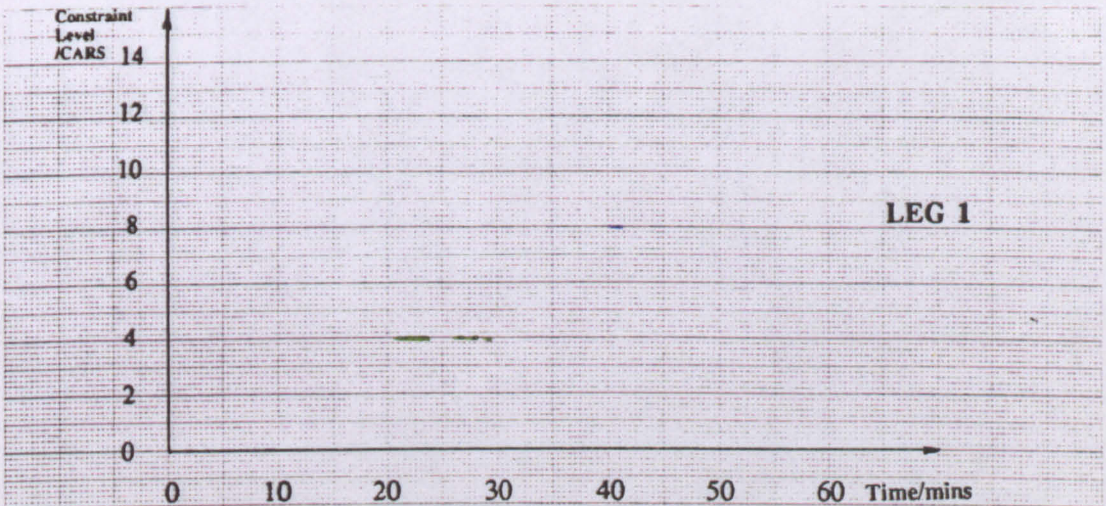

Constraint
Level
/CARS
14
12
10
8
6
4
2
0
LEG 3
0
10
20
30
40
50
60
Time/mins

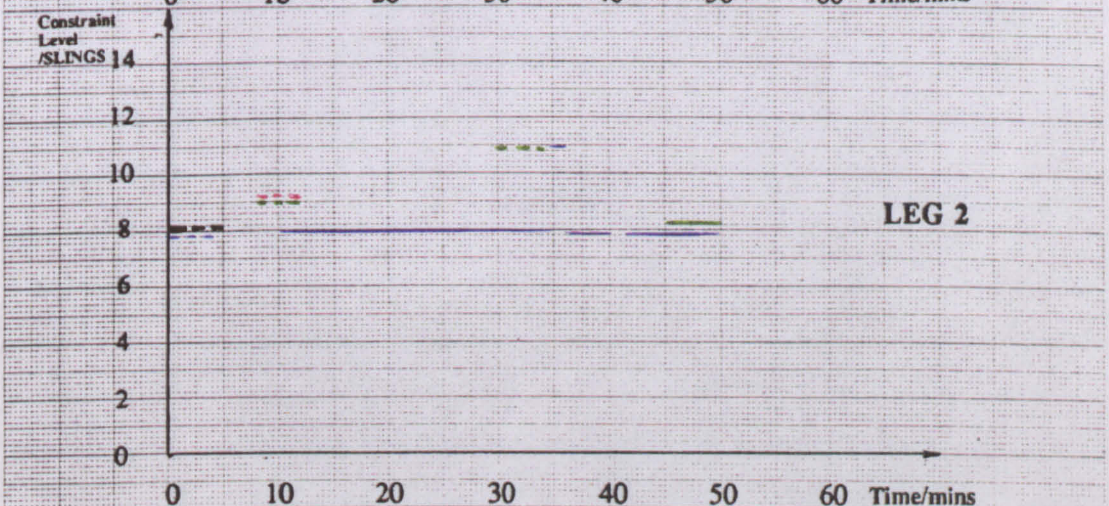
Session 11



Constraint Level /CARS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 1
Constraint Level /SLINGS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 2
Constraint Level /CARS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 3

Session..12


Constraint Level /CARS
14
12
10
8
6
4
2
0
LEG 1
0 10 20 30 40 50 60 Time/mins


Constraint Level /SLINGS
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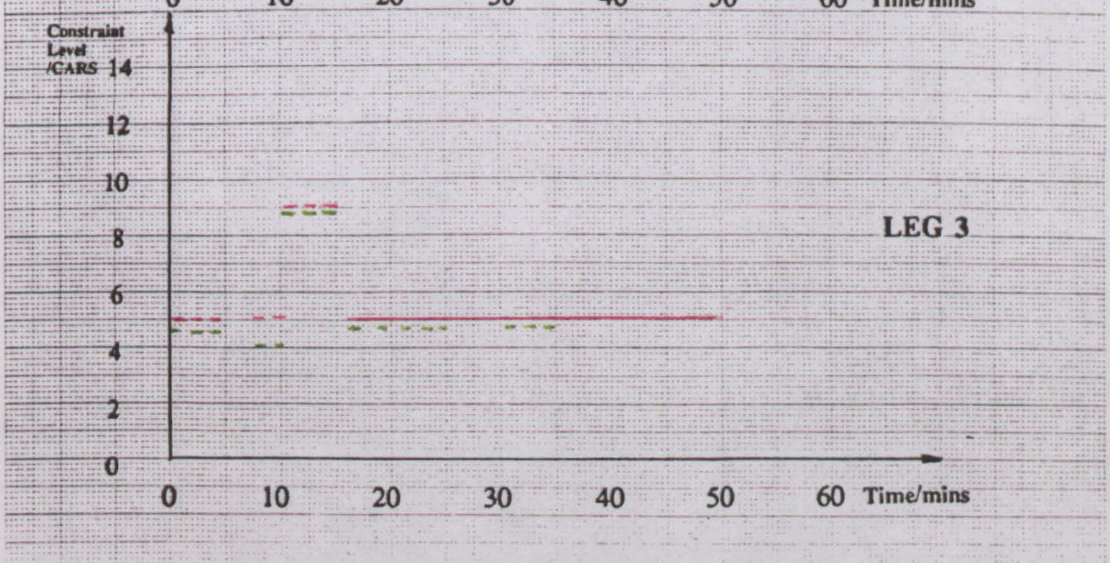
12
10
8
6
4
2
0
LEG 2
0 10 20 30 40 50 60 Time/mins


Constraint Level /CARS
14
12
10
8
6
4
2
0
LEG 3
0 10 20 30 40 50 60 Time/mins

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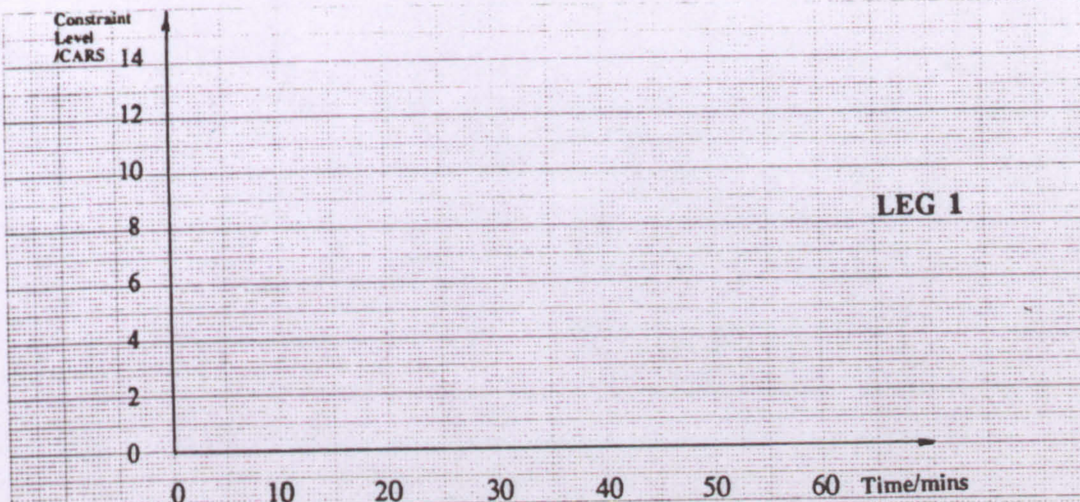
Session 14


Constraint Level /CARS
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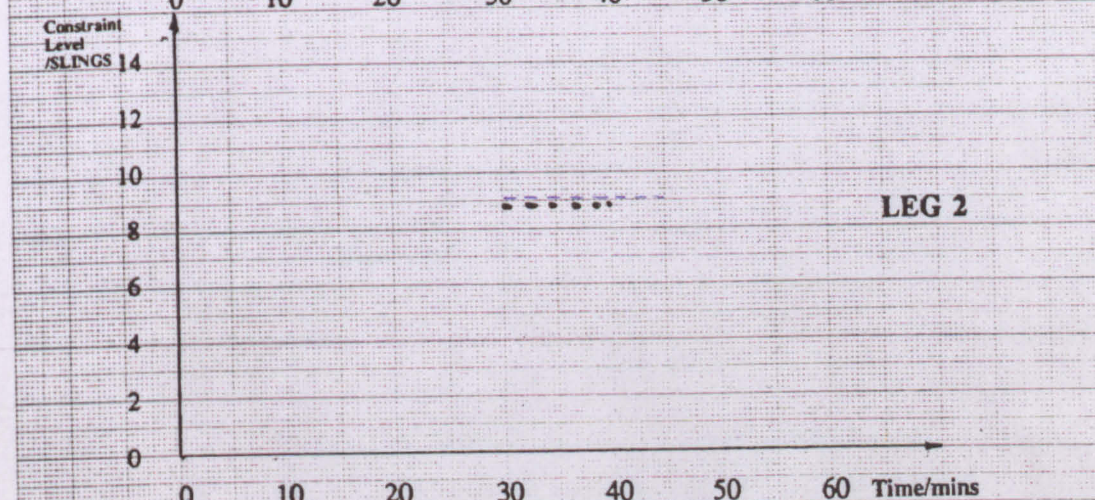
10
8
6
4
2
0
LEG 1
0
10
20
30
40
50
60
Time/mins


Constraint Level /SLINGS
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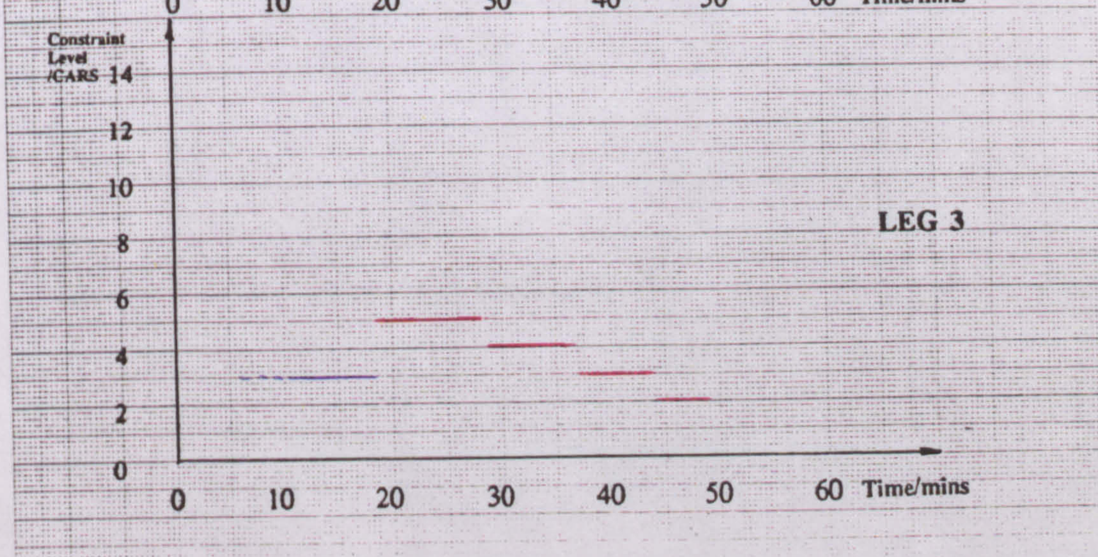
12
10
8
6
4
2
0
LEG 2
0
10
20
30
40
50
60
Time/mins


Constraint Level /CARS
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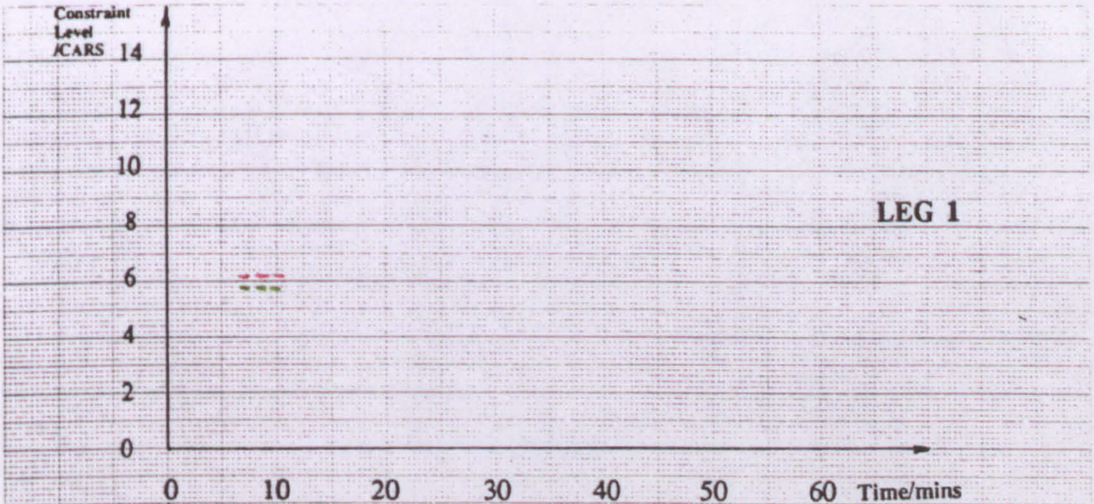
12
10
8
6
4
2
0
LEG 3
0
10
20
30
40
50
60
Time/mins

Session 15



Constraint Level /CARS
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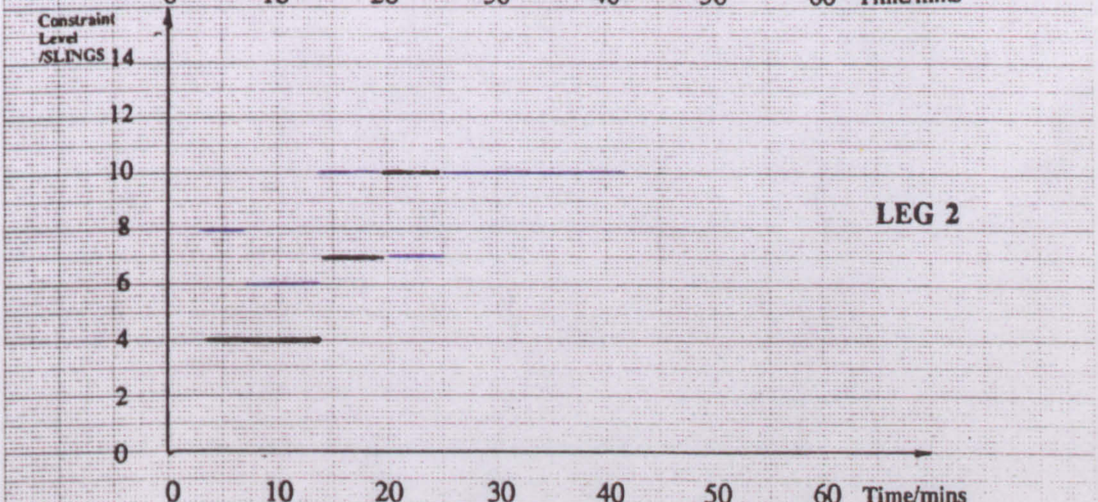
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 1



Constraint Level /SLINGS
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8
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4
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0
10
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40
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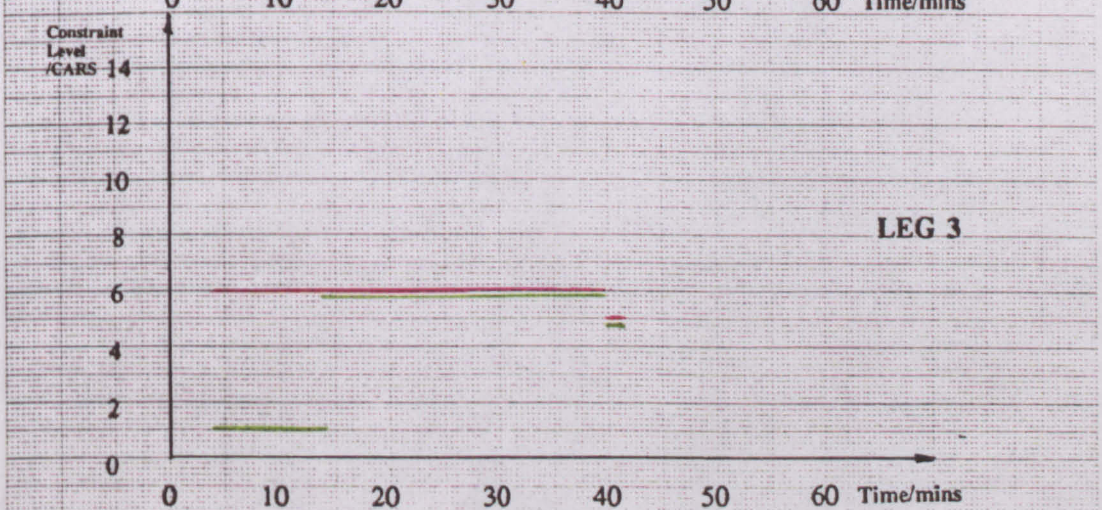
60
Time/mins
LEG 2



Constraint Level /CARS
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8
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4
2
0
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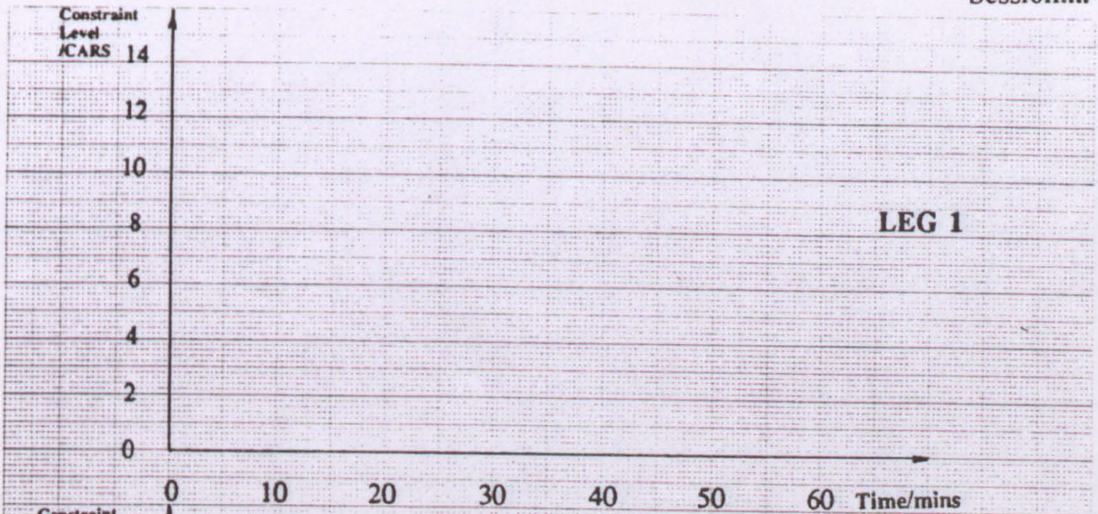
10
20
30
40
50
60
Time/mins
LEG 3

Session 16


Constraint
Level
/CARS
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4
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30
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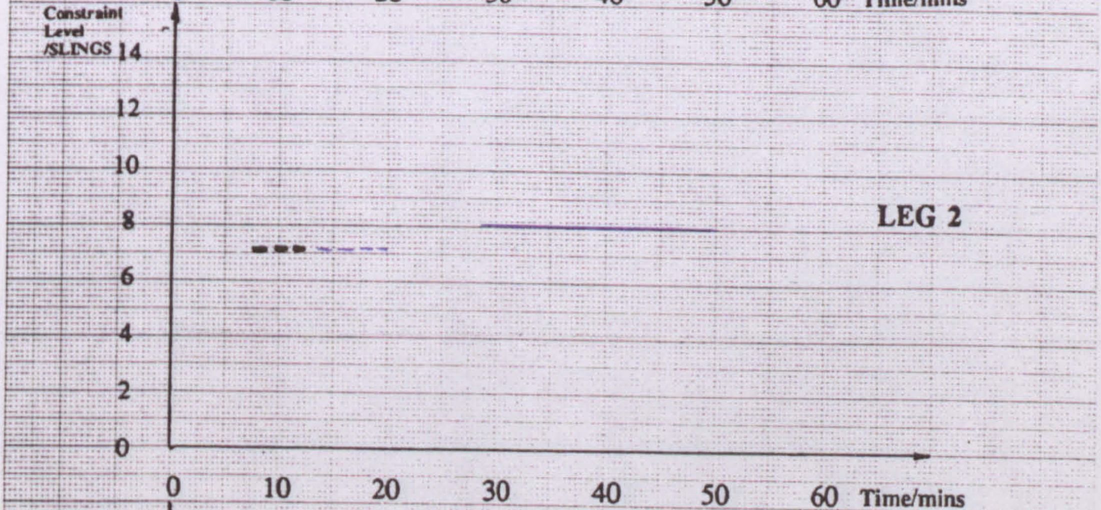
60
Time/mins
LEG 1


Constraint
Level
/SLINGS
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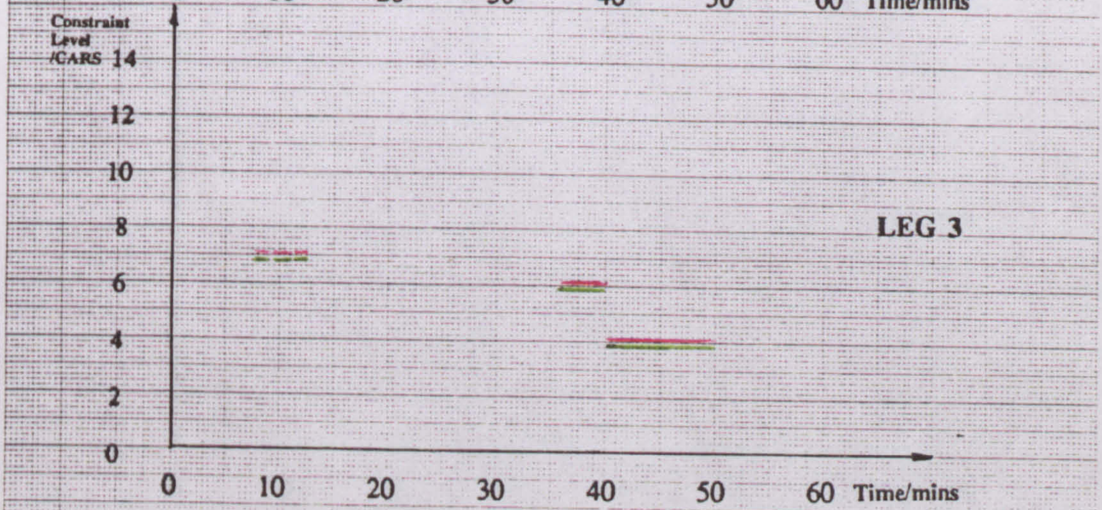
60
Time/mins
LEG 2


Constraint
Level
/CARS
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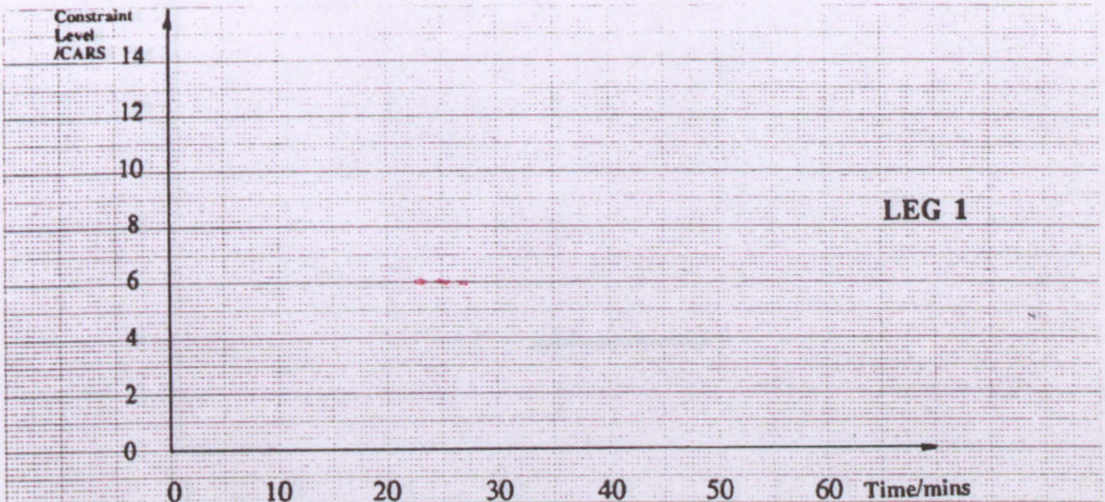
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 3


Constraint Level /CARS
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8
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4
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0
0
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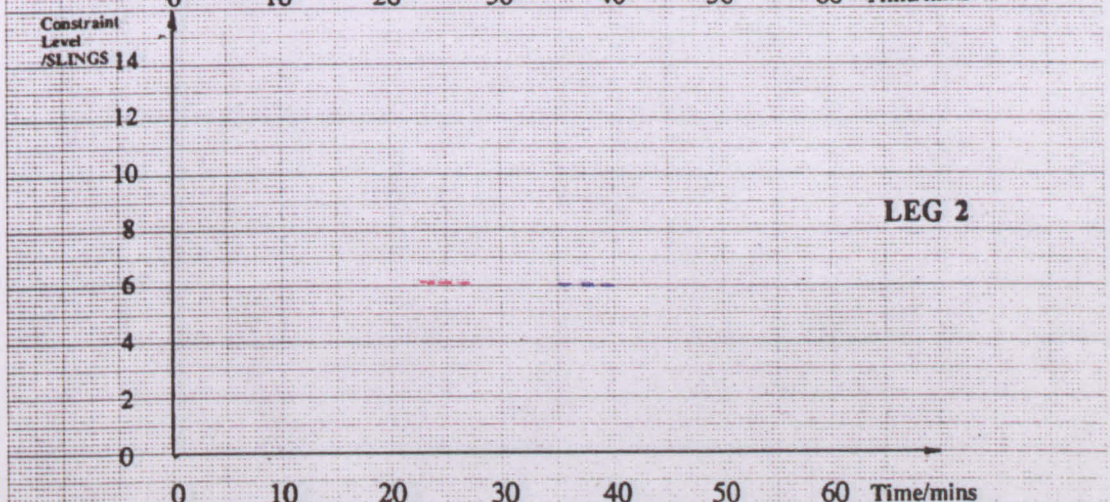
20
30
40
50
60
Time/mins
LEG 1


Constraint Level /SLINGS
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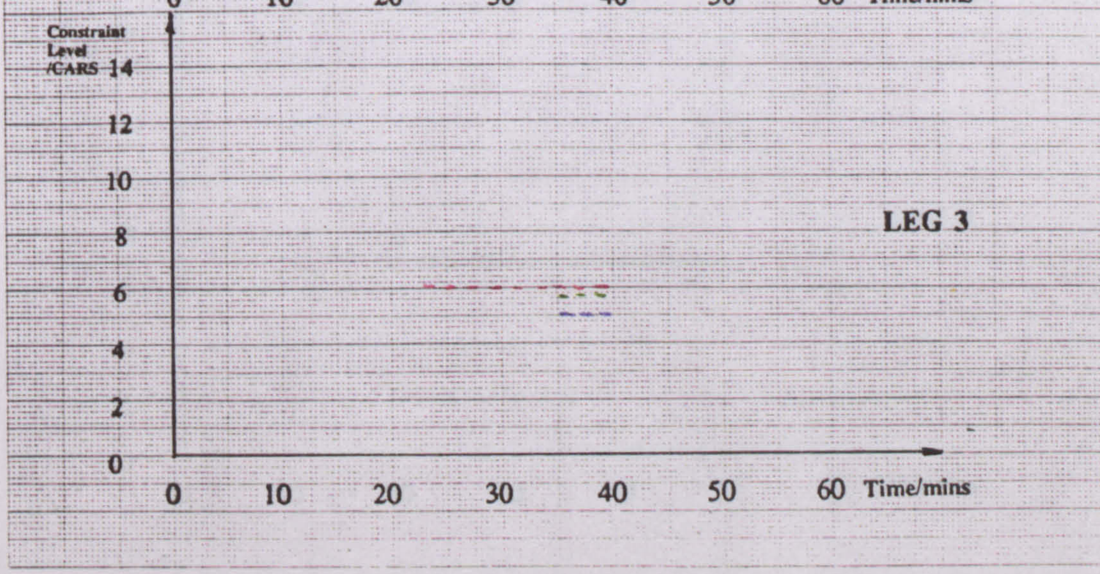
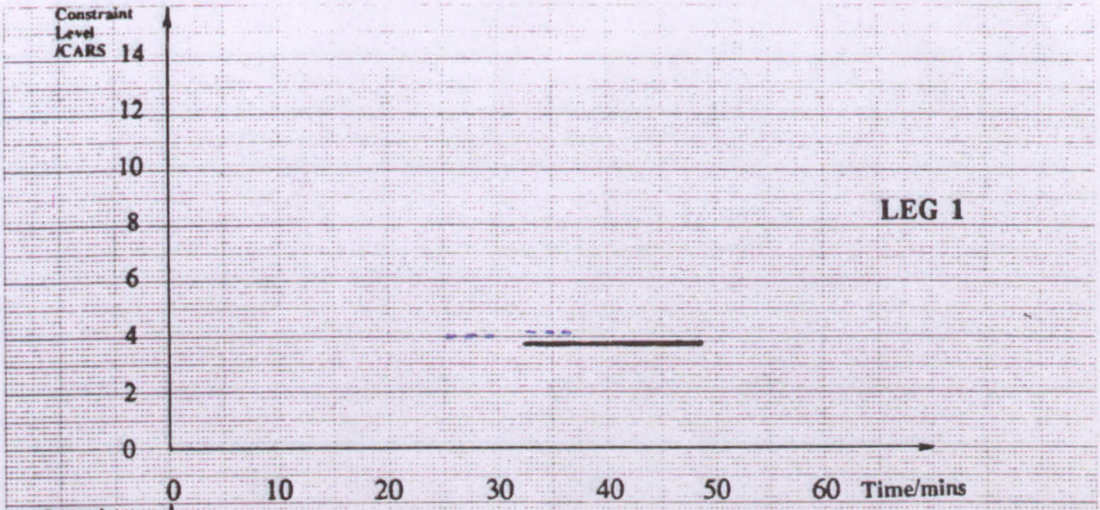
50
60
Time/mins
LEG 2


Constraint Level /CARS
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Time/mins
LEG 3

Session....18



Constraint Level /CARS
14
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10
8
6
4
2
0
LEG 1
0
10
20
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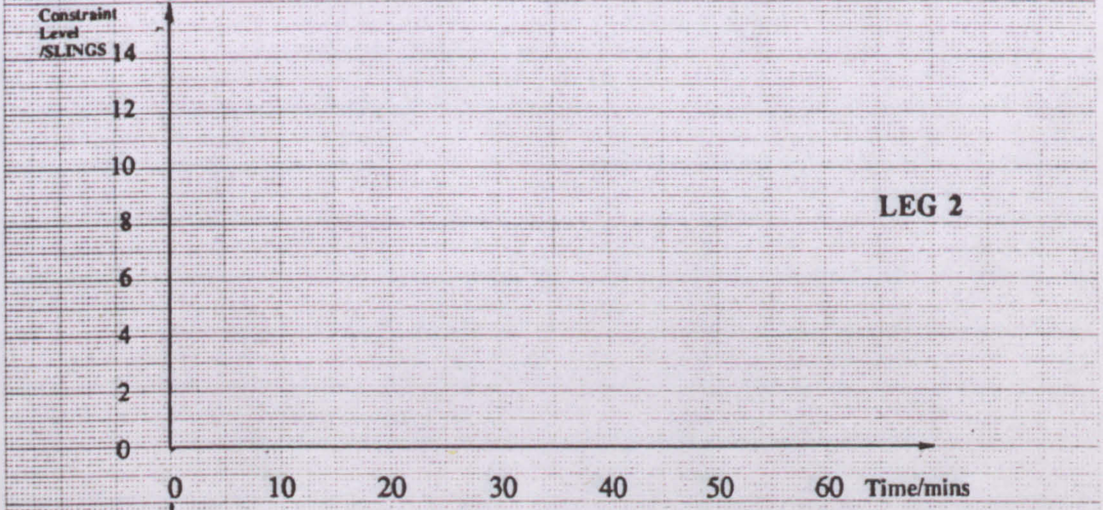
50
60
Time/mins



Constraint Level /SLINGS
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8
6
4
2
0
LEG 2
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10
20
30
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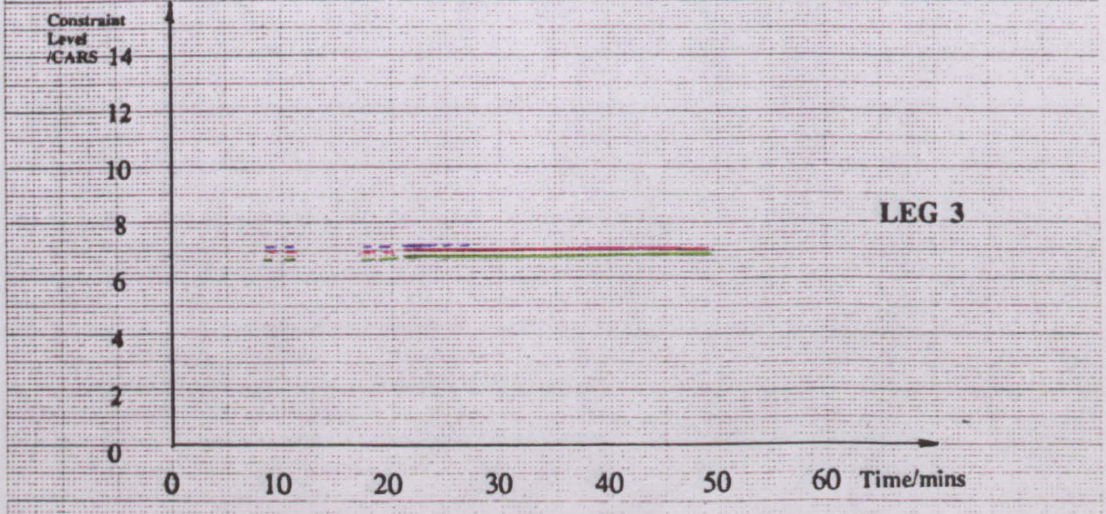
50
60
Time/mins



Constraint Level /CARS
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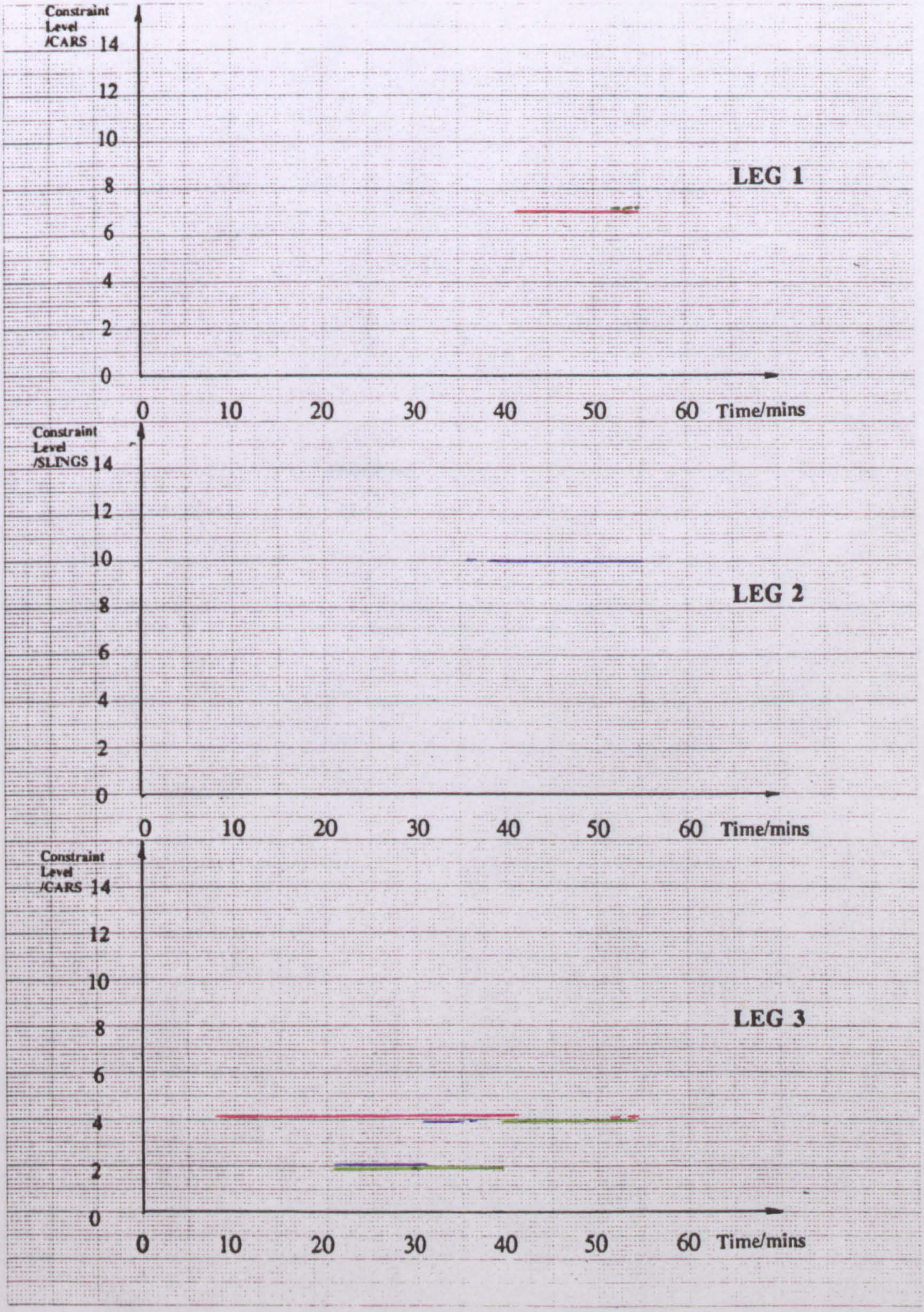
12
10
8
6
4
2
0
LEG 3
0
10
20
30
40
50
60
Time/mins

Session..19


Constraint Level /CARS
14
12
10
8
6
4
2
0
LEG 1
0 10 20 30 40 50 60 Time/mins
Constraint Level /SLINGS
14
12
10
8
6
4
2
0
LEG 2
0 10 20 30 40 50 60 Time/mins
Constraint Level /CARS
14
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10
8
6
4
2
0
LEG 3
0 10 20 30 40 50 60 Time/mins

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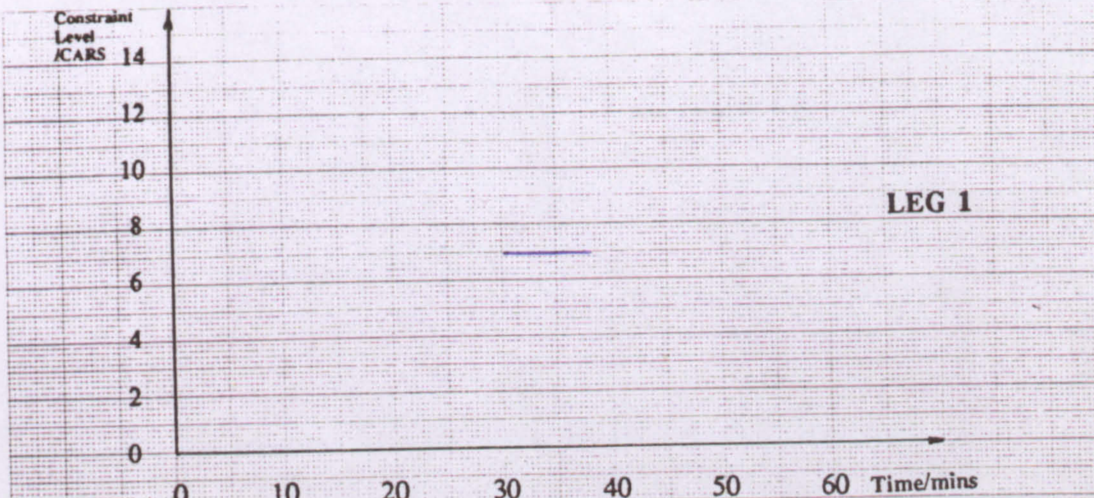
Session 21


Constraint
Level
/CARS
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4
2
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LEG 1
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20
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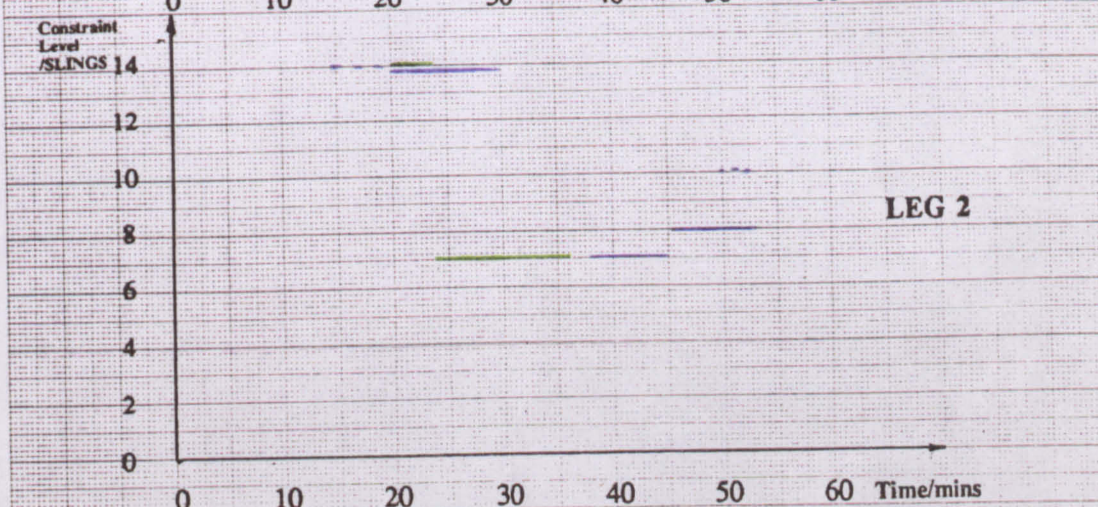
40
50
60
Time/mins


Constraint
Level
/SLINGS
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10
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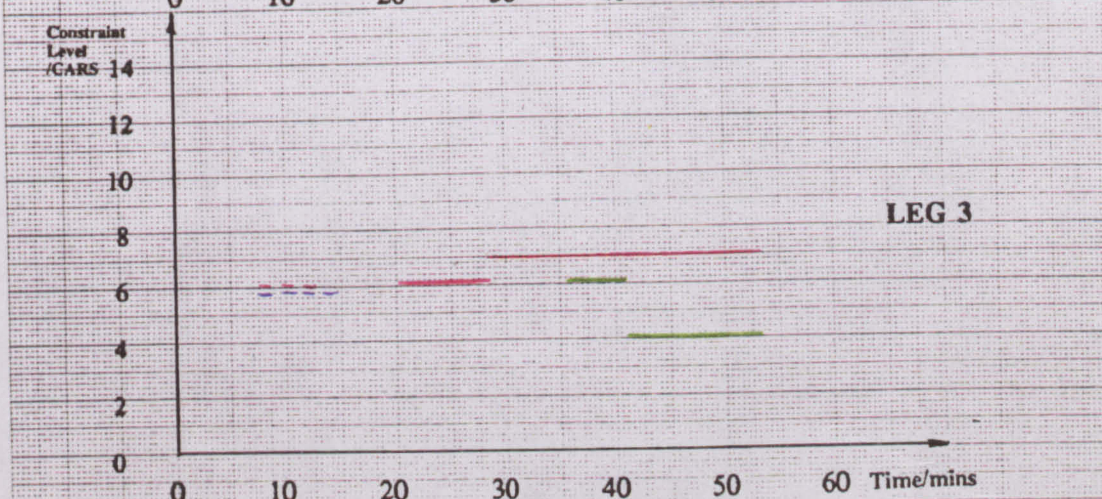
6
4
2
0
LEG 2
0
10
20
30
40
50
60
Time/mins


Constraint
Level
/CARS
14
12
10
8
6
4
2
0
LEG 3
0
10
20
30
40
50
60
Time/mins