A SYSTEMS APPROACH TO CONSTRUCTION PRODUCTIVITY

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TO MY PARENTS,

MY WIFE

AND ALL MY CHILDREN

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All the thanks are due to Allah who without his mercy this work has not been achieved.

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ABSTRACT

This thesis describes research undertaken to investigate the possibility of using systems to model productivity in construction. In particular it concentrates on the use of systems dynamics and project level productivity.

Early chapters review writing in the main areas of interest. In particular they describe work in construction productivity: how it is defined and measured and what, in the opinions of researchers, are the factors that affect it. They also describe systems theory and systems modelling, concentrating on systems dynamics but including an explanation of soft systems methodologies and how they might be applied to improve productivity.

The literature identified 34 factors affecting productivity and the thesis describes work carried out to quantify the importance of these and the interactions between them. It was demonstrated that realistic modelling could be achieved using only 5 factors with the rest being combined into a sixth general factor.

The factors recognised as important form the basis of a systems model whose development is described. In this the relative effects of the factors on productivity are taken from the data collected and used cumulatively to demonstrate an overall effect.

A description of how the system model can be used by management on construction projects to develop strategies that can help in improving productivity is provided. It suggests that investment in planning and control have most benefit on project productivity and that investments in safety, motivation and reduction of disruptions are beneficial.

The model includes coefficients produced from analysis of subjective and qualitative views. The results are therefore relative and it would be necessary to validate and calibrate the model for quantitative use in practice. Suggestions for doing this are included.

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO THE RESEARCH

1.1.1 Productivity in Construction

Construction is the world's largest and most challenging industry (Tucker, 1986). In different forms, it holds the key to the prosperity of emerging and industrialised countries. It is also a large user of national resources. Typically in a developed country, construction might account for 10% of the GDP (Daily Telegraph, 1996) and in a developing one as much as 35% (Tinbergen, 1967). The provision of an infrastructure is an essential part of development; the maintenance and change of the infrastructure to cater for the changing demands of the rapidly changing world are essential to maintain developed status.

Construction, however, is expensive. It is complex, dangerous and affected by many factors both within and outside the control of the parties involved. It must be remembered that construction is but one phase in the overall development; it exists or is carried out in order to allow clients to perform their main business. If the client is a country, construction is necessary to allow the economy to function, the population to be educated, health to improve and movement to occur; if the client is a company, construction is required to provide factories and sales facilities to make and sell its products; if the client is an individual, construction will be necessary to provide shelter. No client of construction has infinite money or time available for the construction

process. At all levels, the client will need to balance the cost and time of construction with the benefits which will accrue as a result of the work. The greater the capital investment in construction, the less the amount of money remaining to operate and maintain the facilities and to spend on other things. The lower the amount spent on construction, the slower the development, the lower the quality of the facilities provided, the smaller the benefits and the smaller the opportunity for improvement.

The one opportunity to break the cycle is to improve the productivity of the total construction process. By doing this, clients at all levels will benefit including the economy of the countries and the world as a whole.

It is not surprising then that construction productivity has formed a major research area for a considerable time. In addition to research and studies of productivity itself, the whole of construction and project management might be considered to be aimed at the improvement of productivity from some aspect. For example, legal studies and research into forms of contract are aimed at providing the lowest cost of a facility for the client; project planning and its research is aimed at making the best use of the correct resources and reducing the problems likely to be encountered during the execution of the project thereby increasing productivity for the contractor and client alike; robotics is aimed at reducing the cost of construction; and quality studies are attempting to ensure that the desired quality is achieved with a maximum of time and resources.

Despite all this research effort, there appears to be a broad consensus that there has been a decline in productivity in the construction industry. It is also generally accepted that there is a great deal of improvement in productivity to be achieved.

Improvement in productivity will not be achieved without bearing in mind that there is an enormous number of factors affecting productivity and that there is a necessity to locate the most influential ones among them. Doing so will enable the researchers to pinpoint the areas where efforts are to be directed in order to reach the optimum productivity of the studied project.

1.1.2 Systems Theory and Construction Productivity

Nothing in this world acts on its own. All things are interconnected in such a way that ignoring the outside effects on any entity leads to a deficiency in understanding its behaviour. Any situation needs to be seen as a whole.

'System' is a word applied to any complex thing which is organised in some way, but which is difficult to specify precisely. As can be seen from the outline above, construction productivity is certainly complex and difficult to specify precisely and its components interact with each other. Labour, project, company and industry comprise one body and they interact with each other; if any part of this body suffers from a deficiency then, as a result, the whole body will suffer. Therefore construction productivity would appear eminently suited to systems treatment.

Productivity in construction can be studied through a systems approach. This approach covers number of issues, such as:

- Description of the system to be studied
- Characteristics of that system:
    - The goals and objectives the system is trying to achieve
    - The components of the system
    - The boundaries which exist for the system
    - The interactions existing between the components
- The internal and external factors which affect the system
- The solutions which can be implemented to overcome the problems which hinder the success of the system.

1.2 OBJECTIVES

The research described in this thesis is concerned with the modeling of construction productivity. A hypothesis used for the research is that:

'Productivity in construction can be modeled through the use of 'system theory''

The hypothesis is investigated through the following research objectives:

- To identify factors that are important to construction productivity.
- To investigate the possibility of using system theory to show how factors affecting productivity interact with each other
- To investigate the possibility of developing a model that can be used to build strategies to improve productivity in construction projects.
- To test and evaluate the developed model in order to see if it is suitable for use.

1.3 METHODOLOGY

To achieve the research objectives, the following tasks were undertaken:

1. A comprehensive literature review was conducted to cover the following:

- To determine the current situation of construction productivity.
- To identify the important factors that influence construction productivity.
- To identify the attempts carried out by researchers in the field to quantify construction productivity.
- To explore the idea of *'systems theory'* and find what attempts are being made by researchers to apply this theory.
- To identify the survey methods used by researchers to gather information needed for any research.

2. Using the factors identified to be important in the literature, the following were constructed:

- A *'Factors Matrix'* which shows how factors interact with each other.
- A 'Factors-Productivity' form which shows how factors affect the productivity of the project. This form will complement the *'Factors Matrix'* as there is no indication in the first form of how factors are related to the productivity.

3. These two forms were given to a number of engineers in the field to give their opinions about the relations of the system. These relations are the basis of all the later work.

4. The returned forms were analysed in order to identify factors which have a major influence on other related factors and on the construction productivity as a whole.

5. A theoretical model was developed to simulate a real construction project using the group of factors considered to be the most influential factors mentioned in 4 above.

6. The model developed was tested to see if there was any sensitivity to errors in the technique used.

7. The benefits of the developed model were demonstrated by discussing some of the strategies that management might adopt in order to improve productivity in construction.

1.4 LAYOUT OF THE THESIS

The layout of the thesis and how chapters are connected is shown in Figure 1.1. The figure also shows a very brief summary of the contents of each chapter. However, a more detailed description of the contents of the chapters is required and is given in the following paragraphs.

Chapter 1 has presented a brief introduction to the research topic followed by an outline of the objectives of the research, and the methodology used to achieve these objectives. Finally, a brief summary of each chapter is detailed below.

Chapter 2 reviews the literature in construction productivity. It shows how productivity has been defined and measured by researchers in the field. It also shows how researchers attributed the decline in construction productivity to the effect of numerous factors. Furthermore, it reviews some of the attempts of researchers to categorise these factors. In the light of these views, an adopted method of categorisation is highlighted and a review of some of the factors in each category is given. This review includes a discussion of attempts by researchers to quantify the effects of some of the factors on productivity.

The third chapter reviews the systems theory and how it can be related to the construction industry. It achieves this by explaining the definition of a system, the characteristics a system has and the types of systems. It also shows how a number of researchers have attempted to utilise the system approach in their work. The chapter is

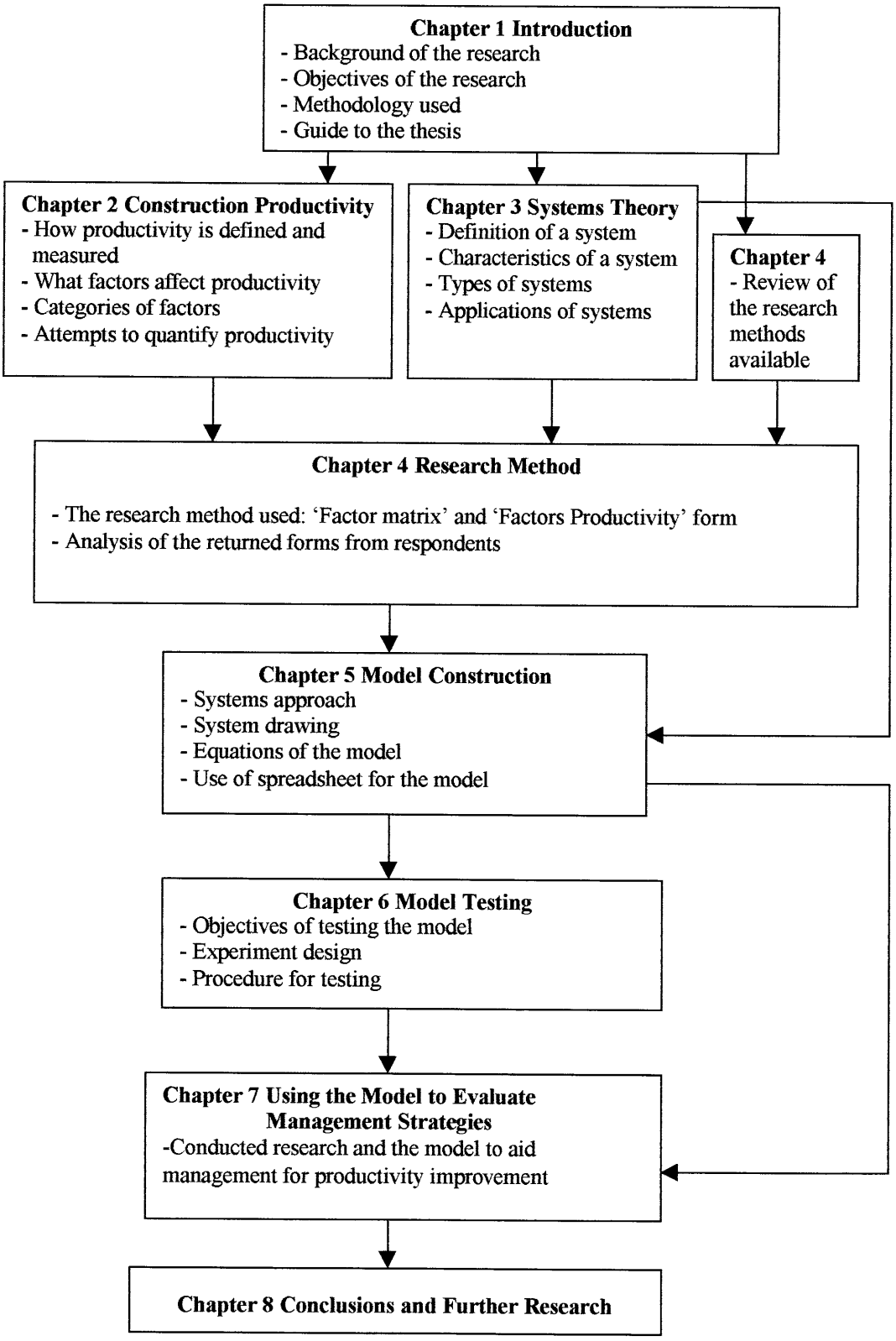


Figure 1.1 Guide to the thesis

concluded with a discussion of the possibility of using the systems approach to tackle the problem of productivity in construction.

Chapter 4 starts by reviewing the research methods available for researchers. It was felt necessary to include such a review in the chapter to reach a conclusion of what the most suitable method for the research project might be. The chapter then discusses the method used to acquire knowledge from engineers in the field. It also discusses the results obtained from the survey and offers some conclusions which form the basis of the following chapters.

The fifth chapter considers the development of the *'productivity model'*. It discusses in detail the system approach which was followed to build the model, highlights the 'system diagram' and shows how elements of the system are related. The results obtained from Chapter 4 are used in this chapter to produce the equations needed for the model. Once these equations were produced, they were then entered into an Excel spreadsheet for the model to be tested and used. The testing and use of the model are the topics of Chapters 6 and 7.

Chapter 6 is concerned with the testing of the model which was developed in Chapter 5. The tests are discussed, together with the relevant results. It gives a brief explanation of how the experiments are designed for testing. It shows in some detail the procedure which was followed for testing the model.

Chapter 7 shows how the conducted research, and specifically the model developed, could be employed to help the management of construction projects to adopt strategies to improve the productivity of a project.

The conclusions drawn from the research, together with recommendations for further work, are outlined in Chapter 8.

The thesis is complemented by appendices which contain a number of tables related to the testing and use of the model.

CHAPTER 2

PRODUCTIVITY IN CONSTRUCTION

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PRODUCTIVITY IN CONSTRUCTION

2.1 INTRODUCTION

This chapter starts with a review of how productivity is defined and measured. There is an enormous number of factors that affect productivity in construction projects and considerable efforts have been made to try to identify and classify these factors. Section 2.3 discusses what these factors are and what attempts have been made by researchers to identify them.

Section 2.4 is an explanation of ways of classifying factors that researchers have suggested and the proposed levels at which they should be considered. This section also discusses a possible way of classifying factors in the light of the classifications which have been reviewed. It is suggested that productivity factors should be viewed at different levels. A brief review of some of the factors in each level and the attempts by researchers in the field to quantify the effects of these factors on productivity is also considered in Section 2.4. The chapter finishes with a summary and some conclusions on the previous work on productivity.

2.2 DEFINITION AND MEASUREMENT OF PRODUCTIVITY

Defining, measuring and comparing productivity of construction is considerably more difficult than might be imagined. At national level, the construction industry is different from country to country as are the construction methods, the resource availability, the

laws which govern it and the requirements made of it. These factors also change over time as expectations change. It is therefore not sufficient, or indeed reasonable, to measure productivity in such terms as the cost of erecting a house or the cost per kilometer of road. Nor is it reasonable to remove the resource costs by defining productivity in terms of labour hours per house or kilometer of road since the expectations of the users of facilities under construction affect their cost and the amount of work included in them.

Reduction of the size of the unit under consideration from the finished article (the house, road etc.) to the component elements is an obvious method to overcome some of these problems. The productivity might therefore be considered in terms of the cost of pouring a cubic metre of concrete or the number of hours taken to lay 1000 bricks. Whilst these measures might be useful to a contractor working in a specific market, they are not helpful to a government wishing to ensure that they achieve value for money for their overall construction. For example, bricks come in different sizes; methods of pouring concrete are more or less mechanised, relying on more or less capital expenditure. These latter measures also take no account of the effectiveness of management of the project and the wastage, which occurs because of inefficient deployment of resources on a project or across projects, or the design of the works.

In addition, each project is, to a great extent, a prototype and the construction is, to a greater or lesser degree, affected by factors which are outside the control of the people directly involved. A project in China or even in the Middle East, where cheap labour is

available, is different from a project in the west where labour charges are high. The laws on safety in the workplace, the requirements to provide facilities for the workers and the laws on employment differ widely even within apparently similar countries. Take, for example, the European Union countries. Whilst they might appear to the outsider to be at least becoming a homogeneous consortium of states, the conditions of employment vary considerably giving rise to significant variations on the actions which contracting companies can take to improve productivity. The simple example of the notice required to sack or lay-off a worker can be used to illustrate this. In the United Kingdom, it is customary to operate on a month's notice for site operatives with payment in lieu of this often enforced. In other member states, the notification of redundancy can be several months with the consequent increase in costs to the employer and apparent reduction in productivity.

Studying the productivity of a project, a company or an industry therefore requires an understanding of how this productivity is defined. The most commonly used definition of productivity is that of the Business Roundtable (BRT) which is:

"Output divided by input"

(Olomolaiye et al., 1998; Ireland, 1994; Dieterle and DeStephanis, 1992; Chang, 1991; Neil, 1987; Brown, 1986; Stubbs and Sikorsky, 1989; Rau, 1988; Russel and Chang, 1987).

The Construction Industry Institute (CII), on the other hand, defines productivity as:

> *"Input divided by the output, calculated for a finite time interval"*

(Chang, 1991; Thomas et al., 1990).

Both definitions only consider productivity related to the people actually carrying out the work. However, there are other definitions which relate productivity to other aspects of the project. At the International Productivity Conference at Kuala Lumpur in 1986 it was suggested that productivity is a management and engineering problem and Rau A. N. (1988) proposed that:

> *"Construction productivity is the analysis or enquiry into productivity over a whole range of functions which include design, plans, specifications, standards, standardisation, quality, economy, regulation, inspection as well as actual building or construction functions at site ".*

It can be seen therefore that there is no common definition to be used for the construction industry. The definition will depend mainly on the type of the work and the party benefiting from the evaluation. An owner of a project is interested in knowing how many units can be finished in a certain time, whereas a contractor's main interest is the time required to finish a particular unit.

Productivity measurement gains its importance through its role in providing a tool to plan for the project, control the costs, motivate the work force, and evaluate the performance inside the organisation or country.

To measure productivity, most people tend to use the ratio suggested by BRT which is (BRT, 1982):

$$\text{Productivity} = \frac{\text{Output (Units of products)}}{\text{Input (Resources)}} \qquad \textbf{Equation 2.1}$$

Inputs and outputs to any productivity equation are difficult to identify and specify exactly. There are some inputs which are tangible, such as labour and material, and some are intangible, such as education and training.

Outputs for a construction project are also difficult to measure. This is mainly because they are non-homogeneous and many trades are included (Talhooni, 1990). A simple building project may, for example, include an air-conditioning system, a heating system and landscaping, and each one of these will have its own method of measurement. In addition, a single output may be the result of a number of trades. Columns in a building, for example, include different trades such as steel reinforcement, formwork and concreting.

If equation 2.1 is to be used to evaluate the productivity of a single input, labour for example, then the productivity evaluated is called a *single factor productivity (SFP)* (Olomolaiye et al., 1998, Talhooni, 1990). This might be, for example, how many hours the labour spends to produce a unit or units of output. This measure is true only in cases where the labour is doing a single job and no other resources are utilised. Such an assumption is not applicable as any work conducted by labour is supported either directly or indirectly by a number of things. For example, some researchers tend to measure the productivity of building a brick-wall by counting how many bricks a bricklayer lays in one hour; this is not valid. There should be an account for the input of management in supervising and motivating the worker, for the plant used to bring bricks and cement to the site, and for the plant used to mix the cement mortar. This limits the use of single factor productivity as a construction project is a complex one where a number of resources are usually utilised for any single activity in the project.

The limitations of the SFP approach are, to some extent, overcome by the idea of *total factor productivity (TFP)* (Olomolaiye et al., 1998; Thomas et al., 1990; Chau and Walker, 1988; Kellog et al., 1981; Lowe, 1987). This approach takes account of all major inputs to the process.

In equation form the Total Factor Productivity TFP can be written as follows:

$$TFP = \frac{\text{Total Output}}{\text{Labour} + \text{Materials} + \text{Equipment} + \text{Energy} + \text{Capital}} \qquad \textbf{Equation 2.2}$$

If output and inputs are expressed in a monetary basis then the ratio becomes:

$$TFP = \frac{\text{money value of output}}{\text{money value of input}} \qquad \textbf{Equation 2.3}$$

This form is an effective way of overcoming the problem of how to consider inputs and outputs in equation 2.2 when the equation refers everything to the same benchmark, in this case monetary. In countries where the labour charge is very low and projects tend to be of a labour intensive type, this form may not reflect the actual image of the situation as the money value of the output is much higher than the input. This may limit the use of the TFP index in the monetary form to be used as a comparison tool for the productivity between countries.

At national and industry levels, the use of the TFP index is a useful tool. It is used for policy making and evaluation of the state of the economy. At lower levels, such as site and labour, the use of this index tends to be difficult as it requires the availability of a tremendous amount of data (Thomas et al., 1990). Talhooni (1990), for example, discounted the use of such an approach as an effective productivity measurement at site level for a number of reasons. Of these, the most important are:

- Difficulty in measuring the inputs and outputs since construction projects are complicated.

- Difficulty in identifying the major source of decline in the TFP index since a number of inputs and outputs are considered.

In view of these reasons he went further to conclude that labour productivity is the proper measurement of project productivity since it comprises the major resource in construction projects.

Kellogg et al. (1981) proposed the use of a hierarchical model for the study of productivity in the construction industry. It is a conceptual model and no attempt has been made to implement such thoughts in practice.

Researchers tend in most published work to measure labour productivity, which is a SFP. They then consider this to represent total project productivity. This may be attributed to the fact that labour may constitute anything between 10 and 90 percent of a project's costs, depending on the type of project and area of the world (Brown, 1986). A second reason may be the difficulty or sometimes impossibility of obtaining numerical values for other determinants of productivity (Rendall and Wolf, 1983). However, this is a narrow view and several types of productivity and the factors which affect them should be considered.

2.3 FACTORS AFFECTING PRODUCTIVITY

When discussing the improvement of construction productivity it should not be ignored that construction projects are complex and there are numerous factors affecting them.

Low or high productivity in a construction project is not the effect of a single variable but a set of variables interacting with each other to produce the final result. Such complexity demands a thorough study of these factors in order to improve the productivity of the construction project. The first step towards this is to find a way of classifying the enormous number of factors to identify which factors have the most influence on the productivity of a construction project.

Reviewing the literature on the classification of factors showed that there is no standard procedure to refer to but rather diverse approaches have evolved which seem to serve a multitude of purposes. For instance, Olomolaiye et al., 1998; Herbsman and Ellis (1990); Thomas et al. (1990); Neil (1987); Naoum and Hackman (1996); and Shaddad and Pilcher (1984) suggested several ways of classifying these factors. It seems useful to discuss how the researchers classify these factors, in order to clarify the factors which are considered in this thesis.

Olomolaiye et al. (1998) stated that there are large numbers of factors influencing productivity. They divided the important factors affecting productivity into two categories:

1. **External factors**: such as the nature of the industry, the construction client, weather, level of economic development, health and safety legislation, procurement policies and code of practice.

2. **Internal factors**: such as management, technology, labour and unions.

Herbsman and Ellis (1990) divided factors into two groups: technological and administrative. The first includes factors related to design, specification, material and location, and the second includes factors related to production, labour and social issues. Specifically they categorise these factors into either the pre-construction stage or the construction stage.

Thomas et al. (1990) proposed a 'factor model' and an 'expectancy model' for labour productivity. In this model they attempted to analyse the nature of factors affecting labour productivity, while at the same time, having a quantifying dimension of such factors. They classified these factors into:

1. manpower
2. design features
3. environmental conditions
4. management practices
5. construction methods, and
6. project organisational structure

Such classification is considered to be of importance to productivity research as it covers all the different aspects of a construction project. On the one hand it directs attention to

the importance of the labour force, while on the other, it emphasises the role of management.

Neil (1987) catalogued the factors influencing labour productivity in terms of a contractor's capability of controlling them as shown in Table 2.1. The first list is of those over which the contractor has little or no control, the second is of those over which the contractor may have some control , and the final list is of those over which the contractor has significant control.

Naoum and Hackman (1996) conducted a study to investigate first, how site management and head office personnel perceive factors affecting site productivity and whether there are similarities in their opinions. Secondly, they attempted to determine what group of factors have more influence on site productivity. Based on a critical discussion of the literature, they selected 29 factors to use. They divided these factors into four groups, namely:

1. Head office factors
2. Resource management effectiveness
3. Motivational factors
4. Education and training

These groups were then included in a survey where the opinions of experts in the field were obtained. Their analysis of the survey showed that the "resources management

Table 2.1 Categories of factors affecting productivity as seen by Neil (1987)

Contractor has little or no control	Contractor may have some control	Contractor has significant control
1) Project location	1) Worker skills	1) Worker attitude
2) Workforce sociological characteristics	2) Relationship to other work	2) Technology employed
3) Weather	3) Job layout	3) Supervisor competence
4) Design engineer competence	4) Holds for quality checks	4) Use of crash scheduling
5) Contracting method	5) Learning curve	5) Materials availability
6) Project demographics	6) Work rules	6) Tool availability
	7) Constructability of design	7) First level quality control
	8) Work area environment	8) Crew stability
		9) Conditions of tools and equipment
		10) Management competence
		11) Crew balance
		12) Support equipment availability
		13) Job safety

effectiveness" group was the most influential.

Shaddad and Pilcher (1984) proposed that a construction project should be thought of as a function of a complex system of inter-related variables: psychological, technical, structural, environmental, personal and managerial. In addition, they classified factors under seven broad categories. These are:

1. external
2. utilisation of resources
3. application of scientific techniques
4. information
5. structural
6. training and selection
7. motivational

Their contribution to productivity studies is significant in that they based their view on the idea of 'systems' (discussed in Chapter 3). Unfortunately, this view has been largely neglected by researchers and no real work has been done to employ such theory in practice.

Another important view is that of Chau and Walker (1988). They stated that:

"Productivity analysis can be applied to any production system which transforms resources (inputs) into goods and services (outputs)"

The purpose of investigation is to decide what is the boundary of the production system. They gave examples of production system which are defined at different levels. These are:

1. national economy
2. region
3. industry
4. firm/site/project
5. plant
6. worker/operative

It can be seen that, although researchers agree that some classification of factors is beneficial, if not essential, there is no agreement as to what classification system to employ. They vary between three and seven categories and use completely different divisions.

Not all literature on productivity recognises the need for a classification as much of the work concentrates on single factors. In this work, where understanding the interactions of factors was of primary importance, it was necessary to employ a classification system into which all factors could be usefully grouped.

The next section outlines the chosen system and uses it as a basis to describe previous published work on construction productivity. The selected system is based on the level of detail at which productivity is being considered.

2.4 PRODUCTIVITY LEVELS

Factors can have effects on productivity at different levels of detail. For example, the type of contract affects productivity at project level while design codes will affect it at national level. Considering the classification described in Section 2.3 and the literature on construction productivity, it is suggested that a useful classification based on the level of detail should consist of four categories:

1. Labour
2. Project
3. Company (management)
4. National

This is similar to the proposal of Chau and Walker (1988) but differs in that the number of levels, or boundaries as they are termed, are four instead of six.

Table 2.2 shows a summary of factors which affect productivity that have been suggested by researchers. These have been grouped into the proposed categories and the references to the original work considered.

When reading this table, it is important to remember:

- The list of factors is derived for an extended study of the literature. It contains therefore only those factors which researchers have studied and published. It may not be comprehensive. Indeed, at the national level, for example, the laws of a country, including health and safety legislation, will affect productivity, but no published work related directly to productivity was found on this and it therefore does not appear in the table.

- Factors affect productivity in different ways. Some, such as 'weather' and 'construction methods' will have direct effects on detailed productivity. Others such as 'safety' and 'site layout' will have rather less direct effects. It might also be possible for some factors to have a direct effect at one level of detail and an indirect effect at another level. For example, "change orders" may have a direct effect at project level and an indirect effect at labour level.

- Some of the factors may fit into more than one level.

The following section reviews the work done on some of the productivity factors at various levels.

2.4.1. Labour

Labour has a tangible effect on the productivity of construction projects. Because of the reasons described in Section 2.2, most of the researchers attributed the decline in project productivity to a deficiency in the productivity of labour.

Table 2.2 Factors affecting construction productivity

Detailed Level **Labour (L)**	
Productivity Factors	**References**
L.1 Absenteeism	Thomas, 1992; Mendel, 1991; Rau,1988; Kohen and Brown, 1986; Shaddad and Pilcher, 1984; Smith, 1987
L.2 Labour Turnover	Mendel, 1991; Kohen and Brown, 1986; Arditi 1985; Shaddad and Pilcher, 1984; Choromokos, 1981; Smith, 1987
L.3 Delays, disruptions and interruptions	Dieterle and DeStephanis, 1992; Horner and Talhooni, 1990; Kohen and Brown, 1986; Logcher and Collins, 1978; Hadavi & Krizek, 1993; Thomas, 1989; Thomas et al., 1990; Summanth, 1984
L.4 Skills of labour	Thomas, 1991; Neil, 1986; Kohen & Brown, 1986; Shaddad & Pilcher, 1984
L.5 Use of Equipment	Rau, 1988; Neil, 1986; Kohen & Brown, 1986; Arditi, 1985; Lucas & Barstad, 1983
L.6 Number of foremen on site	Horner and Talhooni, 1990
L.7 Motivation	ECI, 1994; Hadavi & Krizek, 1993; Olomolaiye and Price, 1989-a; Olomolaiye and Price, 1989-b; Rau, 1988; Smith, 1987; Mansfield and Odeh, 1986; Revay, 1984; Shaddad and Pilcher, 1984; Maloney, 1981; Borcherding, 1980
L.8 Learning curves	Smith, 1987; Dieterle and DeStephanis, 1992; Neil, 1986; Brown, 1986; Galloway & Neilson, 1983; Thomas & Yiakoumis, 1987
L.9 Unions	Olomolaiye et al., 1998; Kohen and Brown, 1986
L.10 Safety	ECI, 1994; Mendel, 1991; Rau, 1988
L.11 Stacking of trades	Dieterle and DeStephanis, 1992; Galloway & Neilson, 1983

Table 2.2 (cont.)

Productivity Factors	References
L.12 Size of project	Peltier, 1978; Boyce, 1991; Shaddad and Pilcher, 1984
L.13 Overtime	Borcherding & Garner, 1981; Galloway & Neilson, 1983; Neil and Nack, 1984; Thomas, 1992; Thomas, 1997
L.14 Weather	Olomolaiye et al., 1998; Dieterle & DeStephanis, 1992; Horner & Talhooni, 1990; Benjamin et al., 1990; Thomas et al., 1989; Smith, 1987; Mendel, 1991; Thomas, 1991; Rau, 1988; Thomas & Yiakoumis, 1987; Brown, 1986; Neil & Nack, 1984; Galloway & Neilson, 1983; Clapp, 1966; NEC, 1974; Talhooni, 1990; Thomas et al., 1990.
L.15 Use of tools	Rau, 1988; Neil, 1986; Clark, 1985; Lucas and Barstad, 1983; Borcherding & Garner, 1981
L.16 Unemployment	Peltier, 1987; Brown, 1986; Clark, 1985; Shaddad & Pilcher, 1984
L.17 Management inefficiency	Olomolaiye et al., 1998; Borcherding, 1991
L.18 Crew size	Shaddad & Pilcher, 1984; Galloway & Neilson, 1983; Dieterle and DeStephanis, 1992; Lucas & Barstad, 1983
L.19 Site access	Galloway & Neilson, 1983
L.20 Buildability of design	Rau, 1988; Lucas and Barstad, 1983
L.21 Change orders	Dieterle and DeStephanis, 1992; Moselhi et al., 1991; Rau, 1988; Lucas and Barstad, 1983; Kappaz, 1977
L.22 Constructability	Neil, 1986; Boyce, 1991
L.23 Design standards	Arditi, 1985
PROJECT (P)	
P.1 Interference by owner	Dieterle and DeStephanis, 1992; Galloway & Neilson, 1983; Kohen and Brown, 1986

Table 2.2 (cont.)

Productivity Factors	References
P.2 Specifications	Lucas & Barstad, 1983
P.3 Restricted access	Dieterle and DeStephanis, 1992
P.4 Change orders	Dieterle and DeStephanis, 1992; Moselhi et. al., 1991; Rau, 1988; Lucas and Barstad, 1983; Kappaz, 1977
P.5 Differing site conditions	Dieterle and DeStephanis, 1992
P.6 Safety	ECI, 1994; Mendel, 1991; Rau, 1988
P.7 Weather	Olomolaiye et al., 1998; Dieterle & DeStephanis, 1992; Horner & Talhooni, 1990; Benjamin et al, 1990; Thomas et. al, 1989; Smith, 1987; Mendel, 1991; Thomas, 1991; Rau, 1988; Thomas & Yiakoumis, 1987; Brown, 1986; Neil & Nack, 1984; Galloway & Neilson, 1983; Clapp, 1966; NEC, 1974; Talhooni, 1990; Thomas et al., 1990
P.8 Material management	Olomolaiye and Harris, 1995; Dieterle and DeStephanis, 1992; Thomas et al., 1990; Thomas, 1989; Rau, 1988; Neil, 1986; Arditi, 1985; Neil and Nack, 1984
P.9 Construction methods	ECI, 1994; Thomas, 1989; Thomas, 1991; Brown, 1986
P.10 Project type	Thomas, 1991; Brown, 1986
P.11 Site layout	Shaddad and Pilcher, 1984; Neil and Nack, 1984
P.12 Project location	Neil, 1986; Brown, 1986; Shaddad and Pilcher, 1984; Arditi, 1985
P.13 Contract method	Thomas, 1991; Neil, 1986; Kohen and Brown, 1986; Shaddad and Pilcher, 1984
P.14 Work inspection	Neil, 1986
P.15 Number of subcontractors	Shaddad and Pilcher, 1984

Table 2.2 (cont.)

COMPANY (MANAGEMENT) – M	
Productivity Factors	**References**
P.16 Construction technology	Olomolaiye et al., 1998
M.1 Planning	Olomolaiye et al., 1998; ECI, 1994; Kohen & Brown, 1986; Clark, 1985; Shaddad and Pilcher, 1984; Rau, 1988
M.2 Control	Olomolaiye et al., 1998; Thomas et al., 1990; Rau, 1988; Kohen and Brown, 1986; Lucas and Barstad, 1983
M.3 Good communications	Rau, 1988
M.4 Material management	Olomolaiye and Harris, 1995; Dieterle and DeStephanis, 1992; Thomas, 1989; Thomas et al., 1990; Arditi, 1985; Neil, 1986; Neil and Nack, 1984; Rau, 1988
M.5 Material movement	Thomas et al., 1990; Neil, 1986
M.6 Crew interference	Thomas et al., 1990; Maloney, 1981
COUNTRY (C)	
C.1 Contract conditions	Rau, 1988; Lucas and Barstad, 1983
C.2 Education	Rau, 1988; Hutcheson, 1985; Klotz, 1978
C.3 Training	Rau, 1988; Brown, 1986; Clark, 1985; Shaddad and Pilcher, 1984
C.4 Design codes	Arditi, 1985

Absenteeism

Absenteeism represents one of the problems leading to low productivity at labour level. Mendel (1991) sees that reasons for absenteeism must be considered when analysing productivity trends. Kohen and Brown (1986), and Neil (1984) agreed that absenteeism is one of the main factors impairing productivity. Rau (1988) partially attributed the increase in absenteeism among workers to the management's insistence on overtime.

Absenteeism results in the loss of productivity due to the time lost in replacing the absent worker with another one. The influence of the absenteeism will be greater if the work required by the absent worker is of the type which requires high skills. This means more time is required to find a worker possessing the required skills to replace the absentee. Report C6 of the Business Roundtable entitled "Absenteeism and Turnover" discusses the problems associated with absenteeism and tries to set some guidelines for the estimation of the costs of absenteeism (BRT, 1982).

Thomas (1992) referred to absenteeism, amongst other factors, as affecting overtime. For example, an increase in absenteeism will force the management to think about introducing overtime to finish the job as scheduled. Thomas made it clear that absenteeism is not the only factor leading to overtime . He concluded that in reality the need for overtime working is the result of numerous factors interacting with each other.

Overtime

Productivity is affected by overtime working. This is the conclusion of some studies in

the literature on overtime working. For example, Neil and Nack (1984), quoting investigations by BRT and others, suggested that workers tend to slow down throughout the working day as a direct result of increasing the time worked. This leads to a decrease in their productivity throughout the work period. In addition, management inefficiency is another reason for decreased productivity as the mental attitude decreases with increased time of work (Borcherding, 1991).

Borcherding and Alarcon (1991) mentioned the concept of "the point of no return". This concept is used to describe the productivity loss due to overtime. The point of no return as described by them is:

> *"that point when the overtime schedule no longer produces more than a standard fourty-hour week"*

They used results of a study carried out by the Associated General Contractors of America to explain this concept. According to this study, productivity is improved in the first few weeks of overtime. Near the seventh week the productivity is the same as that of normal working hours; the point of no return is reached at approximately fifteen weeks of overtime. Although the results of the study fit in with the concept of the 'point of no return', the results were entirely based on the effect of overtime while the effects of other factors on productivity were ignored.

Thomas (1992) has reviewed the literature on the effects on labour productivity of

scheduled overtime and reached a conclusion that the results of some of the published studies seemed unbelievable and hence, unreliable. He based this judgement on the view that these studies do not designate the reasons that lead to losses of efficiency.

Overtime reduces productivity, but concerning the reverse, that is shortening the length of the workday, Thomas (1991) stated that :

> *"Shorter workdays will be likely to lead to reduced productivity because the length of the gearing-up and winding-down periods will remain about the same".*

Motivation

The effect of motivation on labour productivity should not be ignored. The duty of project management is to make sure that the project team is motivated to do the work to an extent that will lead to high productivity. Since motivation is a factor highly related to management it will be discussed later under the management factors in Section 2.4.3.

Weather

It is very important when analysing productivity trends to include the impact of weather. Adverse weather has a great effect on productivity. In hot countries, where the temperature in the summer is very high, the productivity of the worker is reduced. If this is coupled with high humidity, then the situation is even worse. In cold countries the situation is obviously different. Heavy snow and low temperature can cause a large fall in productivity. In both cases, the non-productive time is increased due to the frequent

trips to the water cooler in hot weather or by standing around a fire in very cold weather (Borcherding, 1991).

What is considered to be adverse weather in one place may not be considered so in others. Kohen and Brown (1985) studied the effects of climate on productivity and found that humidity significantly affects the productivity at both high and low temperatures. They suggested that craftsmen should cease working if the temperature is below -10°F and above 110°F. The high limits of temperature suggested by Kohen and Brown (1985) might not apply to countries such as Kuwait and Bahrain where the temperature is high for most of the year. In such countries construction work continues even though the temperature and humidity are very high. The productivity will be highly reduced but with cheap labour this does not represent a major problem to the contractor.

Talhooni (1990) stated that operatives in the U.S. continue production with adverse weather, while if similar conditions are encountered in the U.K., then operatives stop working. He also added that Smith investigated 92 contracts in the U.K. and found that interruptions due to excessive rainfall are almost the same in summer and winter.

Grimm and Wagner (1974) studied the productivity of 51 masons during the construction of 283 test wall panels over a 9 month period. They found that productivity declined as the temperature or humidity deviated from 24°C (75°F) and 60%.

Clapp in 1966 studied the effect of weather on labour productivity in five housing

projects. In this study she identified five categories of man-hour loss due to bad weather. These categories are:

1) Time lost when the work is stopped completely because of bad weather
2) Decreased productivity if the work continues
3) Rework due to damage resulting from bad weather
4) Stood-off time
5) Reduced working week.

This categorisation of Clapp's is good practice which should be considered by researchers when dealing with the effects of adverse weather on labour productivity.

The National Contractors' Association (NECA, 1974) conducted an experiment to measure the effect of high temperature and humidity on the productivity of two journeyman electricians. The experiment involved varying the temperature and humidity at the working place to mimic reality. Unfortunately, this does not give a real picture as it only considers one category which was considered by Clapp, that is, decreased productivity if the work continues.

Thomas and Yiakoumis (1987) summarised some of the studies on the effects of weather and highlighted their limitations. They developed a factor model of construction productivity considering weather as one of the important factors together with site, management, and design factors.

Harris (1979) studied the effects of weather on construction projects. By examining detailed historical data for twenty separate locations around the British Isles, which had hourly records of each day's weather over a sixteen year period, he constructed a computer program named PROWESS (PROject Weather Simulation System). By noting the effects on construction projects of temperature, rainfall, windchill and windspeed, it was possible to measure these effects in terms of loss of production time. The system was then able to simulate the likely influence of these weather conditions on a variety of projects in a range of locations. Harris studied the duration, start dates (January, April, July or October), the types and sequence of activities involved in the project, as well as their geographical locations.

He found that short projects were more likely to be sensitive to adverse weather conditions and that for such projects start dates were not important. Start dates in October or January on short projects were likely to result in delays in excess of 20% of the duration of the project, while a start date of April was likely to result in a delay of less than 5%. There was no significant difference in delay with long projects whatever the start date.

Projects that included a high proportion of processes involving concrete were very susceptible to delays caused by temperature while those using tower cranes were affected by windspeed. All projects were similarly affected by rainfall.

Using this simulation technique, Harris attempted to forecast the likely effect of the

weather for any particular project at any particular location in the British Isles for up to one year.

Skills of the work force

The level of skill of the labour is considered to be one of the major factors that has an impact on productivity. This is the opinion of many researchers. Among these are Thomas (1991), Neil (1984, 1986), Kohen and Brown (1986), and Shaddad and Pilcher (1984). Thomas stated that the productivity of a skilled work force is higher than that of a less skilled one , but it does not necessarily follow that the relationship between skill and productivity is linear. More time may be spent in support work and less time in direct work by a skilled labour force than its less skilled counterpart.

If the economy of a country is strong and many projects of the same type are being constructed in the same area and at the same time, then there is pressure on contractors to employ marginally qualified and unskilled workers. This, in turn, will lead to lower productivity of the project. According to Neil (1984), this pressure is eased if the number of qualified workers seeking jobs is more than the required number. If the ratio of the workers seeking work to the number required is 2:1 or higher, then the conditions are optimum because the contractor will be selective in hiring. As the ratio reaches 1:1, the average quality of the group is decreased and consequently there exists the possibility of decreased productivity.

Worker skills as a factor is coupled with the proper use of tools and equipment. Workers

with good skills know how to utilise fully the tools which will improve the quality of work done. On the other hand, availability of the required tools and equipment on time will help to reduce the 'waiting time', as Lucas and Barstad (1983) emphasised. They felt the need to answer five questions when dealing with equipment and tools. These questions are:

1. Who is responsible for ensuring that the men have the required tools and equipment?
2. What type of equipment and tools are required for the project?
3. When are particular tools and equipment required?
4. Where is the equipment or special tool needed?
5. How are the equipment and tools to be used ?

Designers and the management of the project share the responsibility of finding the answers to these questions, designers by not forgetting ease of construction when creating the design, and management by proper planning of work before and during construction.

Disruptions

Delays represent a major factor in labour productivity. Delays may be classified as 'short delays' and 'extended delays'. Short delays are delays occurring during the working day while extended delays are delays lasting several weeks (Talhooni, 1990).

As is the case in many factors, delay is a factor which is dependent on many others. Take, for example, 'materials management'. A lack of availability of materials on time will disrupt the work, leading to more delay. Other events, such as strikes, work inspection by engineers, and interference from other trades, all are examples of disruptions to labour.

Interruptions are circumstances which cause a temporary halt to the production process and the progress of the activity (Talhooni, 1990). By comparing average productivity at standard conditions with the average daily productivity on interrupted days, Talhooni (1990) found that the average daily productivity is reduced by 35% when interruptions occur.

Change Orders

It is unusual to have a construction project without any changes occurring during its life. Most of these changes are due to the poor design produced by the designers at the design stage. Project delay is to be expected if errors in design occur. Therefore, great care must be taken to ensure that the design has the least number of errors.

In an attempt to quantify the effects of change orders on productivity, Moselhi et al. (1991) studied 90 cases drawn from 57 different construction projects in Canada and the USA. They presented models that show the relationship between change orders and productivity losses under various conditions. These conditions are: changes only, changes plus one major cause, and changes plus two major causes. They concluded that

one additional cause is expected to increase productivity losses by between 11% and 14% on electrical and mechanical work and 8% in civil and architectural work. In the case of two additional causes losses are 20% and 24% on electrical and mechanical work and 14% on civil and architectural work. One of the drawbacks of this work is that it does not reflect the real image as it only considered one or two causes of productivity loss while ignoring other effects.

Another significant attempt in this respect is by Thomas and Napolitan (1995) who tried to quantify the effects of changes and change orders on labour productivity. For this purpose they used historical data from three industrial projects constructed between 1989 and 1992. These projects are:

1. A process plant employing mechanical and electrical trades
2. A paper mill employing electrical trades
3. A refinery employing mechanical trades

In total, 522 workdays of data were collected. Applying data analysis techniques they reached the conclusion that it is possible to perform changes without a negative impact on the labour productivity and that the time of the change is the key variable affecting productivity. However, the average effect of all changes was found to result in a 30% loss in labour productivity.

Disruptions occurring as a result of changes to the work was found to be the reason for

the loss in productivity. Thomas and Napolitan found that these disruptions resulted in a daily loss of something in the range of 25-50% of labour productivity. The most significant types of disruption suggested by the study are the lack of materials and information, and out-of-sequence rework. Based on the data studied, the most important factor is the lack of material. This is because the types of changes that have a significant effect on the work are mostly of the type that requires new orders for materials. The procedures of ordering and purchasing new materials will result in a delay to the project.

Although the study comes up with some respected conclusions, these conclusions cannot be generalised to cover construction projects. This is because only the electrical and piping crafts were studied. Furthermore, the work performed by these crafts was narrowed to crews performing production-related work.

The best way of reducing the effect of change orders on the project is by reducing the number of these changes. Ehrenreich (1994) recommended that a detailed plan should be prepared before the commencement of the project in order to achieve such a solution. This plan should include: project objective, scope of work, time plan, risk plan, cost plan, management plan and control plan for change orders. Coffman (1997) agreed with Ehrenreich as he acknowledges the importance of the collaboration between owners and contractors from the start of the project. Such collaboration may lead to the setting up of a system which will handle the problem of change orders effectively (Hanna, 1998).

2.4.2 Project

Many factors affect productivity at the project level. Among these are materials management and site layout.

Material Management

The contribution of materials management to productivity is a considerable one since materials often represent a major part of any project. This is illustrated in a study carried out by Thomas et al. (1989) for a five-storey, steel-frame building with brick façade and adjacent two storey parking structure. The objective of the study was to quantify the adverse impacts of ineffective material management practices. Typical examples given by the researchers for adverse material management conditions identified on some commercial construction projects include the following:

- Organisation of storage area: extensive multiple handling of materials and materials improperly sorted or marked
- Housekeeping: difficulty of movement of materials as trash and debris obscure access to the store
- Planning of material delivery: erection sequence of material is not co-ordinated with material arrivals to the site
- Material availability: running short of material, crew slowdowns in anticipation of material shortages and rework when material arrives
- Material handling and disruption: inappropriate materials supplied and inefficient methods used to distribute materials.

The data used for the study was collected on a daily basis where disruptions were reported and the productivity measured. The calculations of the researchers showed that an investment of $1,570 would have saved $8,942 in quantified disruptions. This means a benefit/cost ratio of 5.7.

In order to verify the cost impacts, the researchers compared the cumulative productivity of the studied project with the cumulative productivity of another similar project where materials are properly managed. The results of the comparison showed that the productivity in the second project was better than that in the first project for the following reasons:

- The effective planning of material deliveries where the steel could be erected directly from the truck.
- The efficient organisation of the storage area where the materials were stored in a neat and orderly manner.

These two issues are to be considered thoroughly by any contractor wishing to minimise the disruptions on the site and especially in cases where the storage area for materials is very limited.

Neil (1986) and Muehlhausen (1991) both agreed with Thomas et al. (1989) about the importance of planning for the delivery of materials to the site and their proper storage. Neil (1986) however, stated that the greatest variable in the cost of materials and

installed equipment is the effectiveness of the materials management system. He suggested a number of elements that can reduce the cost of materials. These are

- Bar-coding of materials: applying this to warehousing at the project site will cut down warehousing personnel requirements, reduce material mix-up and waste, and speed the inventory and issue processes.
- Controlled access to the store
- Employing an off-shift warehousing crew who will help to preposition materials in each shift.

These recommendations are mainly for large projects where spending on such programmes will result in a considerable reduction in disruptions. They are not applicable for small projects where the costs of adopting such programmes is greater than the benefits acquired.

Muehlhausen (1991) mentioned that material handling costs something in the range of 30 to 80% of the total construction costs, depending on the type of construction. Based on this figure, he strongly emphasised the role of management in controlling the movement of materials to and from the site. If management is successful in this duty then a considerable cut in project costs could be achieved.

A study by Olomolaiye and Harris (1995) considered the impact of an economic recession on project management processes. They examined the materials management

and wastage at eleven sites of a medium-sized contractor and measured the wastage levels of six construction materials prior to and during the recession.

They found that, although the recession appeared to have no direct effect, a decline in motivation and productivity during the period of recession indirectly affected waste levels. They concluded that if motivation could be kept constant, then wastage would probably stay much the same. They therefore recommended that during periods of poor productivity and declining motivation the employment of a materials manager to improve working practices and reduce wastage would actually be cost effective.

Site Layout

One of construction management's main goals must be to have a good 'site layout' for all phases of the work. It actually has manifold benefits to the overall cost of the project. These are (Muehlhausen, 1991):

- less storage of materials
- elimination of duplicate handling of materials
- fewer moves from storage to the working point.

Site layout motivates workers to do a better job. If the site is organised in such a way that it meets the needs of the workers it would be of great benefit to the project as a whole (Neil and Nack, 1984).

2.4.3 Management

There is general agreement that management plays a major role in the success of construction projects. Among these are the European Construction Institute (ECI, 1994), Shaddad and Pilcher (1984), Thomas et al. (1990), Rau (1988), Kohen and Brown (1986), Lucas and Barstad (1986) and Clark (1985). Failure of the management to plan for the project and to take action at the proper time will adversely affect the productivity of labour in particular, and the productivity of the project as a whole.

Management through all its levels must work together to achieve the best productivity. Management at head office should be aware of what is going on at the site; the site manager should have the required talents to control the project most effectively; and foremen need to know how to deal with workers in the required manner.

Lack of communication between different levels of management reduces the morale of workers and sometimes affects lower levels of management. For this reason, Bresnen et al. (1987) suggested that site management should be involved in planning for the project. Such involvement will develop their understanding of their job.

Gunning (1984) also favours the idea of site managers' involvement in the planning stage. He suggested that site management should have a major say in setting the targets and organising the resources. In reality, such a suggestion might not be practical.

The degree of the success of any project is a reflection of the strength of management of

that project. In this respect, Sanvido (1992) has demonstrated that jobs, where planning and control were practiced well, showed more profit and finished sooner than those where planning and control were poorly performed.

Thomas et al. (1990) quoted from Handa and Thomas that a study by CIB showed that the principal causes of productivity loss were: lack of training, inadequate supervision and the inability of management to provide adequate direction and resources.

Motivation

One should not underestimate the role of management in motivating workers. Good planning, goal setting, social activities, incentives, work environment and workers' participation could be tried by management in order to raise the efficiency of the labour (Hadavi and Krizek, 1993).

Revay (1984) suggested that motivation governs the rate at which the worker is going to do his job. He went further to conclude in his study that motivation is ranked as the highest of those factors affecting productivity. This philosophical view is correct in the sense that labour constitutes the basis for productivity success and any management effort to improve productivity which neglects this will have no effect.

Maloney (1981) further suggested that motivation governs the expenditure of labour's effort. However, since people differ in their values, needs, expectations, attitudes, past

experience, and personality, it is essential that any programme designed to improve motivation should recognise these differences.

Olomolaiye and Price (1989-b) conducted a study to evaluate the motivation variables in construction operatives in the UK. They used for this study two lists of variables: one for motivators including 15 variables and the other for demotivators including 14 variables as shown in Table 2.3. The two lists were presented to construction operatives on twelve building sites; they were asked to evaluate the same variables twice. The first evaluation was a general one and not related to any site while the second was related directly to their present sites.

The researchers analysed the responses received from the workers and found the following:

- In the motivators' list 'good relations with mates', 'good wages' and 'good supervision' were found to be the most important factors.
- In the demotivators' list 'disrespect', 'cold weather' and 'unsafe conditions' were highly ranked.

These findings support the idea of the hierarchy of needs suggested by Abraham Maslow (Olomolaiye et al., 1998; Baguley, 1995). Maslow said that a human being has five basic types of needs and these needs are arranged in a hierarchical order as shown in Figure

2.1. Feeling warm is considered by Maslow to be the most basic need and this was ranked by the researchers to be the first in the demotivator variables.

Table 2.3 List of motivators and demotivators used by Olomolaiye and Price (1989-b) in their survey

Motivators	Demotivators
Good relations with mates	Disrespect
Good safety programme	Little accomplishment
The work itself	Discontinuity of work
Overtime	Non-recognition
Fairness of pay	Under-utilisation of skill
Recognition on the job	Incompetent work mate
Accurate description of work	Mates not co-operating
Participation in decisions	Poor inspection programme
Good supervision	Unsafe conditions
Promotion	Urging but no one caring
More responsibility	Hot weather
Challenging task	Cold weather
Job security	Too much work
Choosing work mates	Not enough work
Bonus	

Concerning the motivator which management should consider first is the desire of workers for good supervision or the respect of management towards them.

The researchers concluded that there is great interdependency between motivation variables and that management should bear this in mind when devising any motivation

policy. In other words, management should not consider the high ranking motivators and ignore the less important ones as every thing is related.

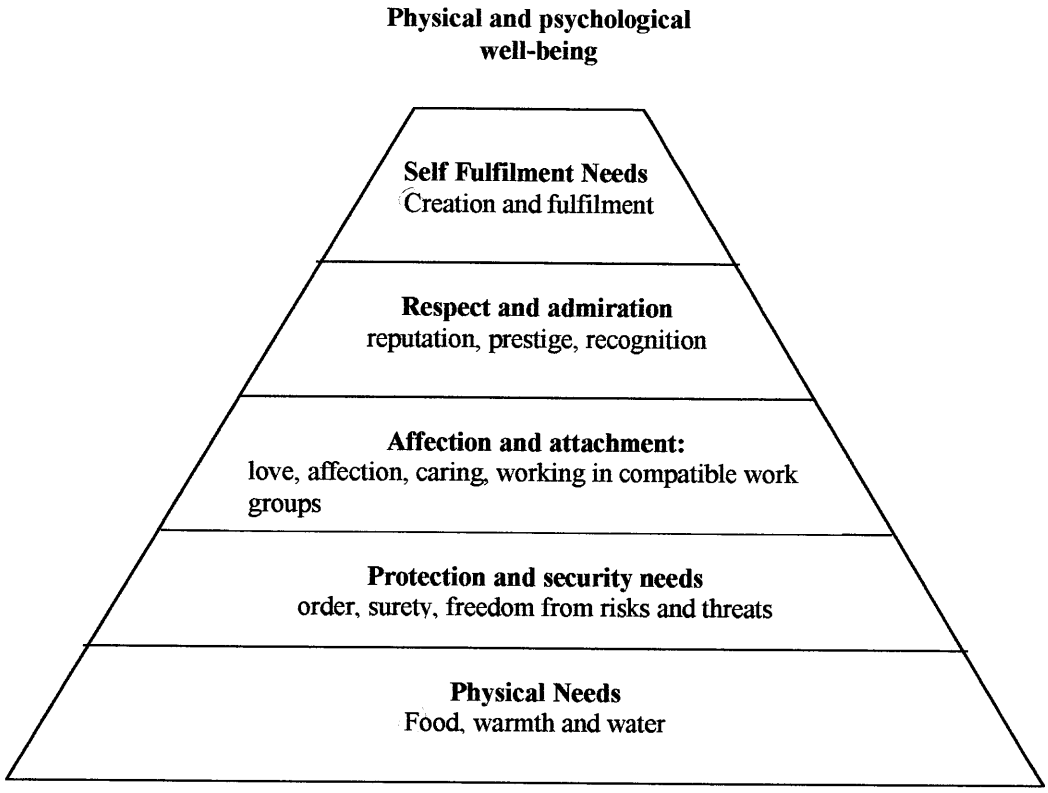


Figure 2.1 The hierarchy of needs as suggested by Maslow

In a similar manner to that of Olomlaiye and Price, Parker (1980) listed some of the variables in the field of motivation where he divided them into motivators and demotivators. Among motivators he listed the following:

- Good working relationship among the trades.
- Adequate orientation programme.

- Recognition.
- Goals defined.
- Open house and project tour.
- Wages.
- Suggestion solicitation.

And amongst demotivators were:

- Disrespectful treatment.
- Productivity urged but no one cares.
- Lack of co-ordination.
- Communications breakdown.
- No participative decision-making.

It can be seen that the demotivators list is centred around how management treats workers and whether these workers are respected or not.

The main idea behind listing demotivators is to demonstrate to management, when they are introducing motivation programs, that it is advisable first to eliminate the demotivators.

Crew interference

Crew interference is a factor which management can prevent by good planning. A

foreman on a site can easily prevent members of the crew from interfering with each other by properly directing each one to suitable places and suitable jobs (Maloney, 1981).

2.4.4 National Level

A number of factors which are of vital concern to the construction industry are those which are really only controllable by government and hence should be of interest to government. Government responsibilities are to ensure that the environment is such that the productivity of labour, projects and companies can be at a maximum. For this to be achieved it is necessary for the government to know which factors within its control have most effect. Some of these are: contract conditions, education, training of engineers, vocational training and design codes.

Contract Conditions

Government should ensure, wherever possible, the use of contract forms which are known to be clear, simple, and fair to all parties of the contract. One of the fundamentals of contract conditions is that it should be fair to all parties. In most cases it is the contractor who will suffer from unjust conditions (Rau,1988). Failing to fulfil the fairness of the conditions will result in delays, stoppages and claims which in turn lead to lower productivity.

A well-written contract will help to prevent disputes and attendant losses of productivity since each party knows what are its responsibilities and what benefits are to be gained

from meeting those responsibilities.

Education

Education systems tend to produce engineers who are ignorant in areas related to construction (Klotz, 1978). The government needs to prevent such situations by urging academic agencies (i.e. universities and colleges) to implement curricula which offer management courses in order to qualify engineers as good managers (Rau, 1988).

Klotz (1978) summarised some observations and discussions presented in a session of the ASCE conference in the late seventies. This session was about the "Civil Engineer's Role in Productivity in the Construction Industry" and was devoted mainly to the discussion of education and communication.

Several interesting points were raised in this session. Among these was the need to include practical courses on organisational behaviour, effective public speaking, and report writing as part of the required curriculum for an engineering degree. Furthermore, the session suggested the need to improve the relationship between industry and education and the periodical review and examination of engineering educational programmes .

The construction industry's contribution to the educational process is insufficient. It should have considerable input into the curriculum of the educational bodies. This

should come through the effective support of academic research and training and real involvement in developing the curricula of academic bodies (Klotz, 1978).

Engineers, through their academic studies, should gain knowledge of how to lead people (workers) (Hutcheson, 1985). Although some people are born to be leaders, most leadership traits come through education, training and experience.

Hutcheson (1985) insisted on the necessity of educating engineers to be good leaders. He suggested four variables to be considered by leaders and to be recognised by teachers

- personality and style of the leader
- situational requirements , goals or objectives
- needs, values and attitudes of the led
- organisational setting.

Training

In order to produce engineers who can achieve high productivity in all situations, training has to go side by side with education (Rau, 1988). Training is an activity which will help engineers and managers to implement theories in the real world.

The government's strategies to improve productivity should consider carefully the existence of training programmes for every individual in the construction industry. The labour force, which plays a crucial part in the productivity process, should have its own

share of training schemes, while foreman, supervisors and site managers should all be well trained (Clark, 1985).

2.5 SUMMARY

This chapter has presented a literature review of the work done in construction productivity. It showed how people define and measure productivity in construction. The long list of factors affecting productivity, agreed by the researchers, gives an indication of how complex the construction industry is, how difficult it is to study this industry and, most important of all, is the fact that conducting research on productivity by examining single factors will be of limited benefit to the industry as a whole.

It has reviewed the attempts of researchers in the field to categorise factors affecting productivity. In view of these attempts, a suggested classification is discussed in which factors were classified according to the level of their effect on productivity. A sample of factors from each level was then discussed to show how these factors affect productivity and whether there are any attempts by researchers to quantify such effects.

One of the major conclusions of this chapter is that it is not enough to study the effect of one factor on productivity but the situation should be studied as a whole. This is the idea of 'system theory' which is discussed in Chapter 3.

CHAPTER 3

SYSTEMS THEORY

CHAPTER 3

SYSTEM THEORY

3.1 INTRODUCTION

This chapter explains the theory of systems. It starts by discussing the meaning of the word 'system' and how it is defined in the literature. It then gives an overview of what types of systems are of importance to the research. Section 3.4 highlights some of the areas where the idea of systems is applied, both in general and in the construction field.

3.2 WHAT IS A SYSTEM ?

One may hear a discussion among a group of people where the word 'system' is repeated many times and one may read in a book or newspaper about systems. This does not mean that the word 'system' is easy to explain. It is rather vague and needs considerable explanation as Dandy (1989) describes:

> *"In everyday language, 'system" is a vague word, applied to any complex thing which is organised in some way, but which is difficult to specify precisely".*

In order to give a useful explanation of what a 'system' is in this section, the following areas will be covered:

3.2.1 Definition of a system

3.2.2 Characteristics of systems

3.2.1 Definition of a System

If a group of scientists were asked to define a system, then the definition of each one would be based on the discipline in which he or she was involved. A mechanical engineer, for example, would define it in terms of cooling systems and engines while an architect would define it in terms of foundations, columns and beams.

According to the Oxford Dictionary, a system is defined as:

> *"Group of things or parts working together in a regular relation: the nervous system , the digestive system ..."*

The word 'system' is not new. It has its origins in the Greek word 'systema' (Jenkins,1969). This has two parts:

'syn' meaning together , and

'histemi' meaning to set .

The Oxford dictionary's definition and the meaning of the word in Greek have a similar basis:

> *'the idea of a system is to work together'.*

Mawdesley (1994) listed a number of definitions mentioned in systems texts to be as follows:

1. An assembly of parts connected in an organised way that has been identified by someone as being of special interest and that behaves in some way
2. Any purposeful organisation of resources or elements
3. A set of instructions and rules for conducting an activity to some pre-determined end event
4. An assembly of components united by some form of regulated interaction to form an organised whole.

The last definition is the simplest one of all but it is the one which explains in simple terms the meaning of systems. This is the definition which will be adopted for the work discussed in the coming chapters.

It can be seen from all the definitions above that a system does something which means it is dynamic (Mawdesley, 1994).

3.2.2 Characteristics of Systems

A review of the definitions mentioned in Section 3.2.1 above reveals that there are certain characteristics of systems. These are:

- a system must have an objective

- a system does something
- a system must be designed in such a way that it is capable of achieving its overall objective in the best way possible
- a system consists of components; any addition or removal of such components changes the system
- there is a boundary for the system; outside the boundary is the system environment
- a system may be broken down into sub-systems
- within each subsystem there are interactions which produce the output of that subsystem
- these sub-systems interact with each other; outputs from a sub-system provide the inputs for other sub-systems
- any system usually forms part of a hierarchy of systems

These characteristics support what Churchman (1979) mentioned in his book about systems thinking. He outlined five basic considerations that should be kept in mind when thinking about the meaning of a system. These are:

1. The system objectives
2. The system's environment
3. The resources of the system
4. The elements of the system, their activities, goals and measure of performance
5. The management of the system

Figure 3.1 shows the concept of a system. It shows that there is an input to the system where there is a process. This process is represented by the interaction of the elements. The elements utilise the resources available in order to convert the inputs to outputs. Outside the boundary of the system there exists the environment which influences the system.

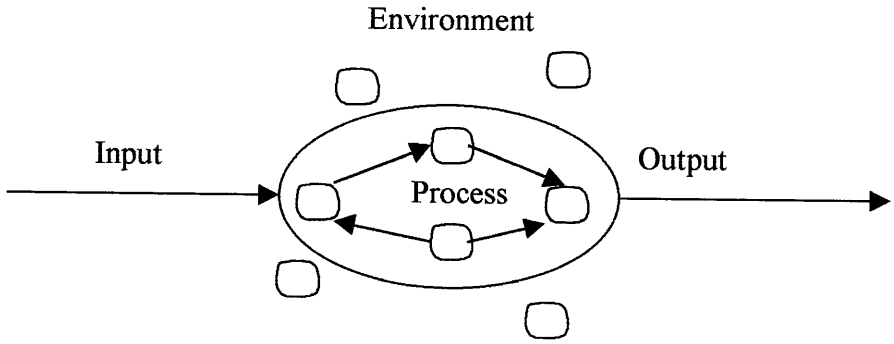


Figure 3.1 Concept of a system

Any system has an objective. Absence of a clear objective for an organisation leads to a conflict between its members. In contrast, a clear objective is the path to good planning and better efficiency of any organisation.

The environment is defined to be all the external conditions (i.e. situations, events, people) that will influence the system (Longman Dictionary, 1995) or as defined by Kendall and Kendall (1995):

"Anything external to an organisation's boundary is considered to be an environment"

The system has no control over the forces of the environment. In a construction project, for example, the project has nothing to do with severe weather that may halt it completely or with fluctuating prices of materials that may result, in some cases, in a great loss to the contractor.

Resources of the system can be represented by all means available to the system to accomplish its objectives. Unlike the environment, the resources can be controlled by the system. In the construction industry, for example, management can ask for overtime or for more labourers to be employed in order to meet the objectives. Similarly, money, information, equipment and tools are all resources which could be utilised.

The efficiency of the system is the result of the efficiency of the components and how these components interact with each other. This emphasises the importance of studying each component separately and to explore how it will affect other components within the system.

3.3 TYPES OF SYSTEMS

Systems may be classified under four types (Carter et. al, 1984; Waring, 1989; Wilson, 1990):

- Natural systems (e.g. biological systems, forests)
- Abstract systems (e.g. computer programs, a set of linked mathematical equations)
- Engineered or designed systems (e.g. telephone hardware, computer hardware, central heating)
- Human activity systems (e.g. a company, a department, a committee)

These can contain either 'hard' or 'soft' systems.

Construction comprises both types. The use of PERT or CPM and other planning techniques are examples of the use of hard systems (Yeo, 1993). Other functions of the management, such as motivating and co-ordinating, are examples of soft systems. Therefore it is necessary to discuss briefly both these approaches.

3.3.1 Hard Systems

Hard systems as defined by Waring (1989) are:

> *"..... those in which human behaviour is perceived to play a minor role, even though many people may in fact be involved in the system".*

These systems rely on a 'solid' or 'hard' base of facts which could be quantified and predicted. Hard systems are used in situations where it makes sense to measure them,

make models of them, and expect them to behave with a predictable degree of regularity (Carter, 1984).

A number of hard system analyses are suggested by researchers. Hall (1962) sees the hard systems approach to consist of five stages. These are:

1. Program planning
2. Exploratory planning
3. Development planning
4. System development
5. System improvement

However, the first three of the above stages involve iteration of the following steps (Wilson, 1990):

1. Problem definition: define needs, search environment, list system's inputs, outputs and how they are related; define the boundary of the system
2. Choosing objectives
3. System synthesis: collect alternatives, list system functions and delineate subsystems
4. Systems analysis: decide what to analyse, select analytical tools, deduce uncertain consequences, and compare system performance with objectives
5. Selecting the optimum system: define decision criteria, evaluate consequences, and compare system

6. Planning for action: write reports, and promote system plan.

Jenkins (1969) suggested a methodology which consisted of the following four stages:

1. Systems analysis: what is going on and why, whether it might be done better, objectives of the system, and information and data collection.
2. Systems design (or system synthesis): forecasting, model building, and simulation and optimisation.
3. Implementation: documentation and sanction approval, construction, and performance and reliability check.
4. Operation.

In a similar manner to the above mentioned approaches, Waring (1989) suggested the following stages:

1. Groundwork
2. System description
3. Goals and objectives
4. Strategies: finding ways to reach objectives
5. Assessment measures
6. Modeling
7. Evaluation
8. Making a choice

9. Implementation

It can be seen from all the approaches above that even though there are slight differences in these approaches the thought is always the same: that at the start of the study it is essential to know what objectives are to be achieved and how they are to be achieved (Checkland, 1978).

3.3.2 Soft Systems

The 1970's witnessed the emergence of a way of system thinking as a result of the failure of established methods of 'System Engineering' when faced with messy, complex problem situations. This method is the 'Soft Systems Methodology' (SSM). The pioneer of this method is Professor Peter Checkland from Lancaster University.

Everyday life, as Checkland (Checkland, 1981) describes, is a:

> *'flux of interacting events and ideas which unroll through time'.*

To manage anything is to try to cope with this flux. The manager is a person who tries to "improve situations which are seen as problematical". 'Soft Systems Methodology' (SSM) is a tool which helps such managers in their task. Soft Systems Methodology (SSM) is an organised way of tackling messy situations in the real world. It is based on systems thinking, which enables it to be highly defined and described, but is flexible in use and broad in scope (Checkland, 1981).

Soft Systems Methodology (SSM) is a method capable of being used in situations where a hard systems approach would be inappropriate.

In the hard systems approach, the analyst sets goals and finds solutions. The case in soft systems is different. Soft systems thinking does not focus on finding a solution to a predefined, structured problem. It is not the purpose of the approach to advise ways of reaching objectives, but it is an approach which tries to locate problems and solve them.

Because soft systems methods model people's attitudes' and behaviour, they are known to have a high degree of unpredictability. Furthermore, they have properties such as viewpoints and conflicts that are difficult to quantify and measure.

Checkland suggested that there are seven stages to the implementation of SSM. These are:

1. The problem situation unstructured
2. The problem situation expressed (rich pictures)
3. Naming relevant systems and developing root definitions
4. Developing conceptual models of the systems named in the root definitions
5. Comparison of models and the real world
6. Consideration of changes : systemically desirable and culturally feasible
7. Action to improve the problem situation.

Stages one and two are steps toward structuring the problem where data is collected and expressed in pictures mode.

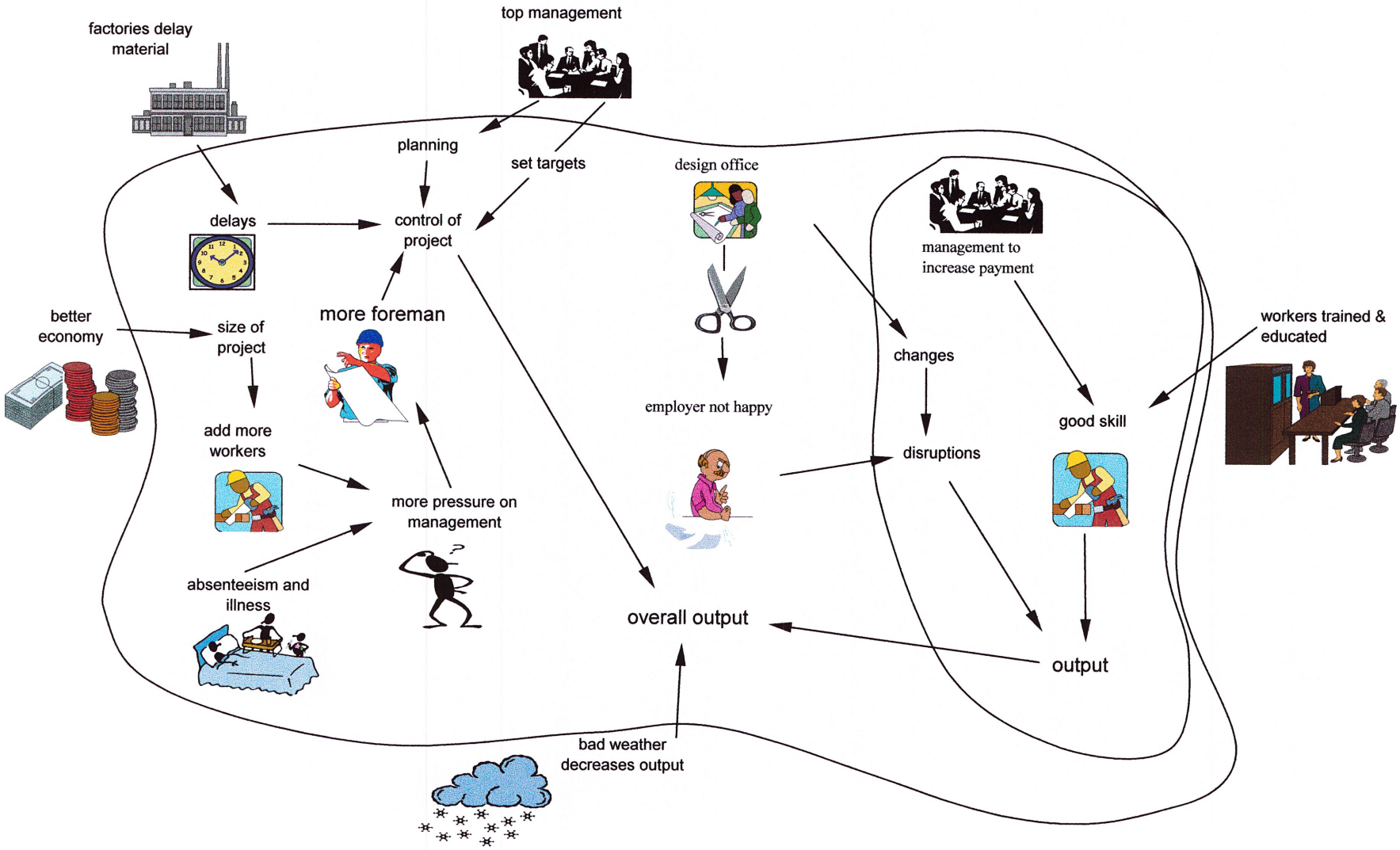
Rich pictures, one of the most common methods used to express the problem, is a technique which holds particular promise for the study of construction productivity (Waring, 1989).

Rich pictures are summaries of the situation to be studied. This means that great care should be taken when developing these pictures. There are no specific rules of how to construct rich pictures. It is up to the analyst to decide what to include and how his thought of the situation is expressed clearly in these pictures (Patching, 1987).

Figure 3.2 illustrates the properties of rich pictures as a means of describing complex and ill-defined systems. Take, for example, the size of project; as this increases, the number of workers will tend to increase and consequently the pressure on the managers will also increase. The situation is represented although the actual relationships between the elements are not considered. The relationships are qualitative more than quantitative.

Stage 3 is the first stage that moves from the real world to the system thinking. In order to model a situation, the problem is to be defined and the relevant system to be named. How to decide if a certain system is relevant or not is itself a problem (Skidmore, 1994).

Figure 3.2 Rich picture of the construction productivity



Rich pictures serve as a base for developing the root definition. From rich pictures the analyst should identify a number of issues and perhaps one or two primary task areas that seem important to the situation. In doing so, the analyst will be able to construct the root definition which is a statement of what the system shown in the rich picture is designed to achieve (Waring, 1989).

Checkland defines root definition to be (Patching, 1987):

> *" A concise, tightly constructed description of a human activity system which states what the system is; what it does is then elaborated in a conceptual model which is built on the basis of the definition. Every element in the definition must be reflected in the model derived from it. A well-formulated root definition will make explicit each of CATWOE elements".*

The CATWOE elements mentioned in Checkland's definition above is a sort of a test to check whether the root definition is well-formulated or not . This mnemonic stands for (Checkland, 1985;Checkland, 1981; Waring, 1989; Skidmore, 1994) :

Customers	Who are the system's victims or beneficiaries ?
Actors	Who would carry out these activities ?
Transformation process	What input is transformed into what output ?
Waltanschauung	The world-view which makes this definition meaningful (world views of actors)

Owners	Who could abolish this system ? (power figures who control the system)
Environment	What are the constraints on the system ?

The root definition, if not adequately structured, may create difficulties later in the cycle. For this reason the aim of the analyst is not to draft a brilliant definition, but a definition which is considered to be 'comfortable' or useful (Checkland, 1981; Patching, 1987). This could be done through testing some possible definitions or by iteration to end with a less ambiguous definition.

From the root definition constructed in Stage 3, a model is drawn in Stage 4. This model does not follow the conventional modeling techniques; instead, it will utilise a Checkland-style 'Conceptual' model which employs verbs to describe each component. When dealing with conceptual modeling of SSM the analyst has to remember that he/she is still dealing with hypothetical systems and not solutions.

The main purpose of this stage is to enhance understanding of the problem situation through the stimulation of debate. This purpose will be served by developing more than one conceptual model (Davies, 1988).

Stage 5 is considered to be the most important part of the method where both conceptuality and reality meet. The conceptual model developed in Stage 4 is compared with the real model considered in Stage 2. This comparison will lead to the final stages

(Stages 6 and 7) where the implementation of 'feasible and desirable' changes is considered.

Structural changes, procedural changes, and change in policies are different forms of change to be implemented. Structural changes are those changes made to those parts of reality which in the short term do not change i.e. organisational groupings, and reporting structures. Changes in the process of reporting and informing are examples of procedural changes where changes in overall objectives and strategies are changes in the policy of the organisation.

3.4 Systems Diagrams

The importance of system diagramming is generally accepted (Britton and Doake, 1996; Waring, 1989). It is a technique, which helps to describe and visualise systems. The system description, if clear, will in turn lead to a better understanding of the nature of the system and the problems that need to be tackled.

System diagramming is an art to be considered at the initial stages of systems thinking problems (Waring, 1989). It is the art of knowing how to convey the message to the reader in a simple manner. It is a tool that will enable the analyst to communicate easily with the others. (Britton and Doake, 1996).

There are number of diagramming techniques used in systems work. These are (Avison and Shah, 1997; Britton and Doake, 1996; Waring, 1989):

1) Organisation charts
2) System maps
3) Spray diagrams
4) Rich pictures
5) Influence and causal diagrams
6) Flow charts
7) Data flow diagrams.

Each of these diagramming techniques is explained below.

1) Organisation Charts

This type shows how a system is structured and how elements in this system are broken down into sub-elements. Organisations and companies find this type of diagramming to be most suitable as it shows how they are structured.

Figure 3.3 shows diagramming types in the form of an organisation chart. Two concepts are introduced in this type. The first is the relationship and the second is the hierarchies in relationships.

2) System Maps

This type is consistent with the theory of sets (Waring, 1989). In this theory, sets of like components are bounded together and boundaries overlap. This overlap is an indication of shared properties between the sets as shown in Figure 3.4.

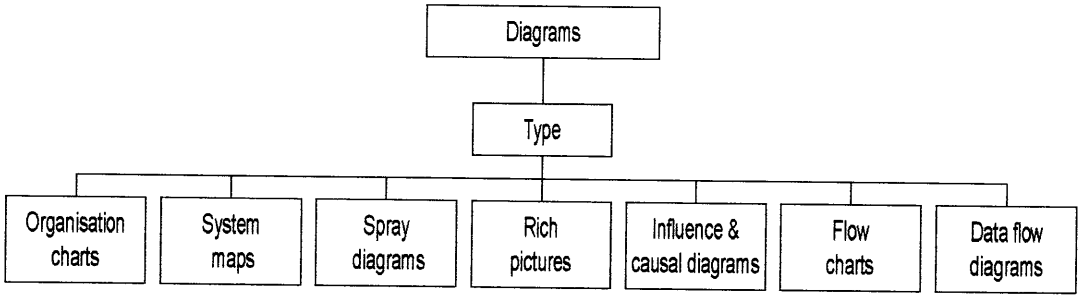


Figure 3.3 Organisation charts

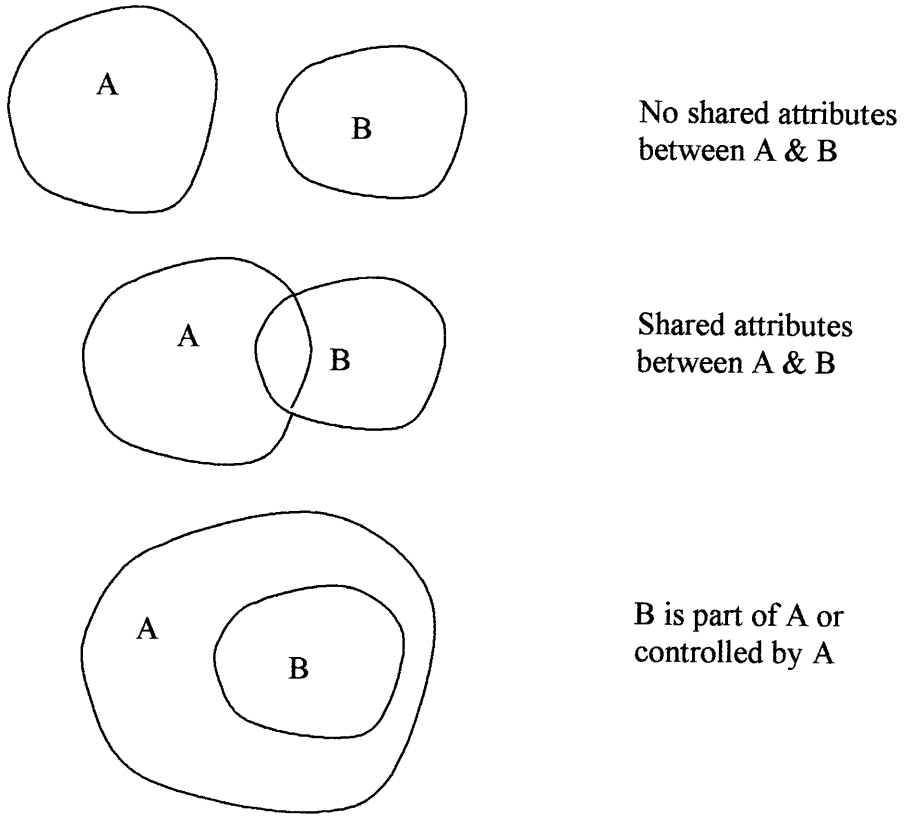


Figure 3.4 System Maps

3) Spray Diagrams

These diagrams are also called 'spider grams' (Waring, 1989). This type, as is the case in all other types, helps to loosen up the thinking of the analyst as his/her thinking at the early stages is limited to partial images of the problem. Figure 3.5 shows an example of this type. It is related to a problem of converting a free car park to a 'pay and display' type.

4) Rich Pictures

This type was discussed in Section 3.3.2 and an example of this is shown in Figure 3.2.

5) Influence and Causal Diagrams

Linked boxes or blobs are employed by this type to show how things are related in the system. In some cases, analysts do not bother to include these components in circles or blobs (Waring, 1989). An example of this type is shown in Figure 3.6.

The lines between components show that a relationship exists. Arrowheads show the direction of influence. In the case of double-headed arrows, it is an indication of mutual influence (Waring, 1989). A plus or minus signs could be used to indicate a causal process between any two components. Figure 3.6 shows how safety and the motivation of workers in construction are related using this technique. The drawing indicates that as safety increases there is a tendency for the worker to do a better job. One might interpret this as being because there is a feeling of security in the work place.

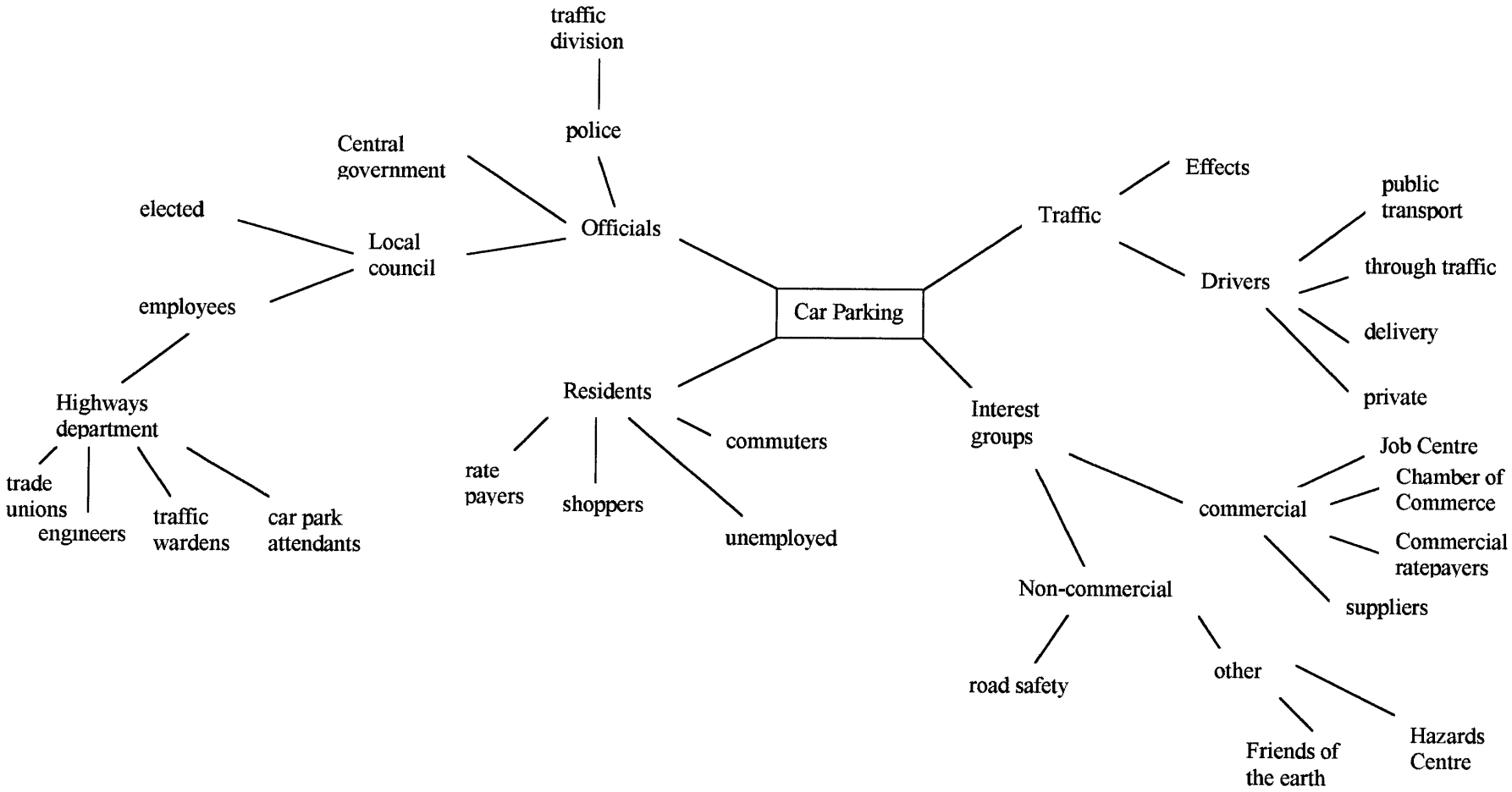


Figure 3.5 Spray diagram of components relating to car parking (after Waring, 1989)



Figure 3.6 Influence and causal diagram

There are cases where a mutual influence exists between two elements. Take, for example, the relationship between disruptions and control in construction projects. Disruptions will have an effect on control and control in turn will have an effect on disruptions. This could be shown in a mutual influence diagram as shown in Figure 3.7. In this figure both control and disruptions are related to each other. The drawing in the figure reads like this: "As disruptions increase, control will decrease and as control is improved then disruptions to the work will be reduced".



Figure 3.7 Influence and causal diagram – mutual influence

6) Flow Charts

A flow chart diagram is a well known type used by many analysts, especially in computer programming. It is used to summarise the set of operations for solving a particular problem.

7) Data Flow Diagrams

Like other types of diagrams, data flow diagrams limit the amount of detail tackled in the problem by decomposition and abstraction (Britton and Doake, 1996).

Data flow diagrams depict the flow of information in an information system (Waring, 1989). They identify the system boundary, the external entities and the flow of information into and out of the system.

Data flow diagrams are process-based. They try to show what the system does to the information and how this information is processed (Britton and Doake, 1996).

There is no standard to be used for notations in data flow diagrams, but it is up to the analyst to decide his/her own set. Figure 3.8 shows some notations used by Avison and Shah (1997). The arrow represents the movement of data into, out of and within the system. A circle is a representation of a process within the system. It shows how data is transformed from certain inputs to an output.

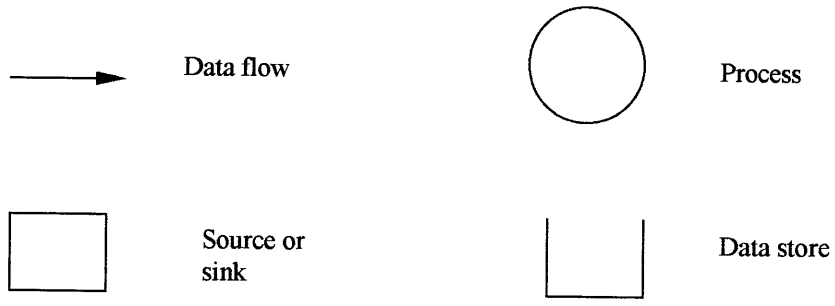


Figure 3.8 Data flow diagram notations

Some analysts may use squares to represent 'source or sink'. A source as described by Skidmore et al. (1992) is

> *"a person or part of an organisation which enters or receives data from the system".*

In some cases, an open square may be used to represent a data source. A data source is the place where the data is held within the system, such as a filing cabinet, or a computer file (Avison and Shah, 1997).

3.5 APPLICATIONS OF SYSTEMS THEORY

The importance of systems theory lies in the overall view to any problem under study. Such views stimulated researchers in different disciplines to approach their problems in a systemic manner. This section discusses some of the attempts by researchers to apply the theory to their work. It is divided into two parts: the first part shows the attempts in general while the second part shows those attempts related to the construction industry.

3.5.1 Applications in General

G. Ragsdell (1994) applied Soft Systems Methodology (SSM) in a community project. She used a group from Hull Council for Voluntary Services (HCVS) in the city of Hull in the UK for this purpose.

The work concentrated on some of the practical considerations involved in the use of Soft System Methodology to examine the development responsibilities of the HCVS's team. It also tries to find the answer to whether SSM is capable of tackling the conceptual issues that people struggle with.

The development team comprised six members of different backgrounds. The average age of the group was the mid-thirties. The team functioned in a non-hierarchical manner and operated in a turbulent environment where it interacted with changing community needs.

The situation studied was an ill-structured one in which there were no obvious starting or finishing points.

Confidential interviews were conducted to help members of the team to structure their thoughts, enabling them to reflect on the role of organisation, the role of the team and of them as individuals. This was the base for the next stage which was the drawing of the rich picture. At this stage the team was able to draw the rich picture on a large sheet. During the compilation of the rich picture, more understanding of the individuals and their current activities was reached.

A system to tackle the themes expressed in the rich picture, such as lack of guidance and ineffective use of time, was defined. This was followed by forming a model for the

analysis of new development projects. This model was based on verbs such as ask, examine, assess, monitor, evaluate and discuss.

The change considered by the team as an outcome of the study was the introduction of a framework for assessing and prioritising development projects. The action of applying such change was not an obstacle since the team proposed the change and they owned the solution to it.

The benefits to the team, as Ragsdell explained, were:

- Increase in confidence of the team
- Tackling the problem together helped to boost the effort of the team
- The team added new knowledge by the use of SSM.

Dyner et al. (1995) proposed a methodology to support an integrated energy policy making the case for a strategy to substitute traditional household electricity appliances with more efficient alternatives. The methodology relies on developing a system dynamics model to analyse energy efficiency and gas penetration policies in the urban residential sector. The model assumes that all decisions are made under the least cost principle. Least cost principle assumes that users base their decisions on cost only.

The authors claimed in their conclusions that system dynamics had been found appropriate to support the integrated planning and management of problems related to

energy efficiency issues. Therefore they suggested that the model could be developed further to suit other needs in other situations. Despite the fact that the model developed is very restricted and limits the user to a small number of alternatives, it demonstrates the strength of system theory and its ability and applicability to model certain real world problems.

Wolstenholme (1993) utilised SD to develop a model to assist in gaining insight into the consequences of the changes that occur at the interface between the health service and personnel social services. The model developed was based on a case study in community care services. It is interesting to see certain models which incorporate knowledge capturing, and which translate qualitative models into quantitative ones.

Even though the author claimed that the model helped in understanding the consequences of changes in their main subject, he does not show how the model helped its users, neither did he extend the model to be computer-based.

3.5.2 Applications in Construction

Anbari (1985) adopted the system approach to study various elements of project evaluation. He viewed a project as a total system which transforms input into output by certain processes, and where there is feedback. This feedback will provide a mechanism that will assure that goals and objectives set for the project are met. His view is shown in Figure 3.9.

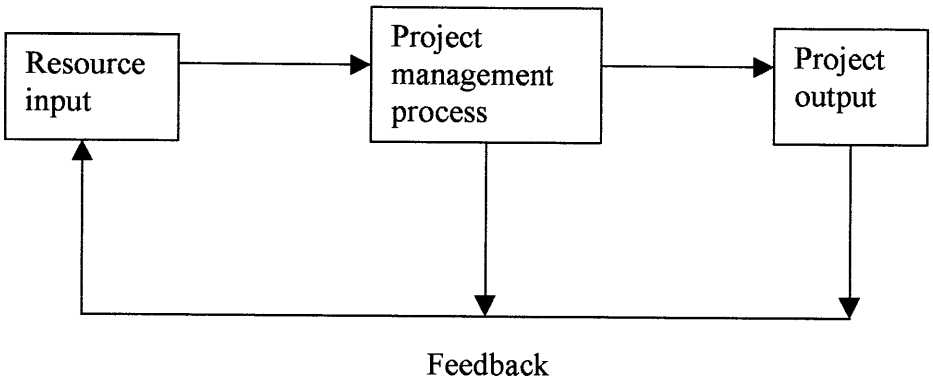


Figure 3.9 A systems approach to project evaluation as seen by Anbari (1985)

The study viewed the process as the management of six subsystems. These subsystems are: scope, time, cost, quality, human resources and communications. Each of these subsystems has its own inputs, process, outputs and feedback. For example, scope management can be considered as a subsystem with inputs such as goal settings and documents.; its process is change control and all necessary supporting documentation. The output includes the final closeout and acceptance of the project while the feedback is a periodic evaluation.

Evaluation of each subsystem of the process will be based on its meeting the objectives of that subsystem, its interaction with other subsystems and whether it is meeting the objectives of the project as a whole.

In order for the project to be successful, Anbari suggested that evaluation needs to be done prior to the beginning of the project, at regular intervals during construction and during its conclusion.

Rodrigues et al. (1998) claimed that existing project management techniques are inadequate for analysing modern complex technology projects especially where there are effects by multiple client actions. They discussed the practical use of 'system dynamics' (SD) models to evaluate the impact of client behaviour in projects. The system dynamics model they developed is focussed on three major roles: estimating, risk analysis, progress monitoring and diagnosis. The models were developed based on studying the interaction of the software design tasks using influence diagrams that lead to the development of a number of cause-effect relationships.

The authors proposed what they refer to as a System Dynamics-based Project Management Integrated Model (SYDPIM). SYDPIM uses SD models to support the planning and monitoring functions; the model is based on continuous calibration of the SD models to replicate past behaviour and to capture the plans. Within the planning function the models are used to estimate the project outcome and to help identify better planning alternatives (ensuring that the plan is based on realistic assumptions). In monitoring, the models are used to uncover several metrics about the project status, and as a diagnosis tool to help identify possible causes for observed deviation. The model developed was validated on a software project mainly to investigate how schedule

adjustments should be managed and negotiated with the client so that the effects of introducing requirement changes during the later design stages can be minimised.

Shaddad and Pilcher (1984) developed what has been referred to as a causal model for project productivity. The model is mainly a schematic descriptive model that shows and tries to explain the inter-relationship between managerial variables and the system performance of projects in the construction industry. Within the model, the construction project management activities are seen as a system that consists of seven sub-systems. The model is concerned with illustrating the influence of the management activities on system productivity at the project level, the main input to the model is the management activities variables and the output is concerned with the end result variable "system productivity variable". The model introduces a number of factors that affect productivity and classify those factors in a reasonable manner.

The model produced by Shaddad and Pilcher can be described as conceptual and no real attempt was made to show it in practice. This was clear from part of their conclusion as they mentioned the complexity of construction projects and the lengthy execution period which resulted in more uncertainties. Despite the fact that the model did not use SD, the factors introduced and classified in this model can be further investigated and provide a useful background to researchers interested in SD.

The above examples demonstrated the application of system theory. However, it is not intended to list all the applications reported in the literature but rather to give a broad picture. In addition to the above examples, Table 3.1 summarises some applications.

3.6 SYSTEMS APPROACH AND CONSTRUCTION PRODUCTIVITY

It is worthwhile examining the relevance of systems theory to construction productivity to see if it can be used to give a better understanding of such productivity. There are a number of characteristics of systems which can be employed in construction productivity.

A systems approach provides a framework for understanding and analysing construction productivity through the internal interactions of factors affecting such productivity and also through certain external effects of the environment on that productivity. For example, the productivity of labour in a project remains important if it is seen within the context of the relationships between the factors affecting labour productivity and the environment.

It is clearly the case that productivity in construction depends to a large extent upon the way in which factors affecting productivity interact with each other. For example, disruption of the work is a factor which may have great effect on the productivity of the project, but this factor does not stand on its own as there are other factors related to it, such as planning and weather.

Table 3.1 Brief examples of the application of systems theory to a real world problem

No	Title	Reference	Purpose of the system
1	Human factors and global problems: A system approach	Vicente. K.J, 1998	It describes how the discipline of human factors can play a unique role in helping to solve global problems such as reducing wastage
2	Research on how to develop R&D strategies using the soft systems approach	Nakano, M. et al 1997	It develops a method allowing the drawing up of strategies that can be shared by all researchers in a project.
3	System approach to building assessment	Harris, S. 1996	It presents an energy model that differentiates between the functional aspects of building assessment and the aesthetic elemental assessment of building.
4	Toward a systems approach to sewer management	Oomens, A. et al 1990.	It develops a systems-based framework for analysis and improvement of sewer management. It also involves a structural model representing various levels of decision- making involved in sewer management.

3.7 SUMMARY

This chapter has reviewed and explained the theory of systems. It began by discussing the meaning of the word 'system' and how it is defined in the literature. It also discussed some of the characteristics of systems and then gave a brief idea of what types of systems there are. These types are: Soft Systems and Hard Systems.

Both types have their applications in real life. Soft systems methodology is an approach to be used in situations where a hard systems approach would be inappropriate and would be unlikely to produce the expected results. Applications of both soft and hard systems in different disciplines, including construction, were discussed.

The main conclusion of the chapter is that a systems approach offers convincing results. Construction productivity is a problem which can be seen as a whole in order to reach a satisfactory result. This is the topic of the next two chapters where the use of a systems approach to model construction productivity is demonstrated.

CHAPTER 4

RESEARCH METHOD

CHAPTER 4

RESEARCH METHOD

4.1 INTRODUCTION

The significant conclusions of Chapter 2 and Chapter 3 are that it is necessary to study productivity in a holistic manner. This chapter aims to fulfil such needs by, first, showing how factors in construction projects interact with each other and, second, by selecting from these interactions the most influential ones to be used later in building the model in Chapter 5.

To achieve such aims a survey method was used. There are a number of survey methods used by researchers in order to collect the required data for similar research. These are described and discussed in Section 4.2. The selected method for the research work is described in Section 4.3.

Numerous factors affect productivity. A selection of these factors is chosen to construct the 'factors matrix' and 'factors-productivity' form, which are both introduced in Section 4.3. The 'factors matrix' is proposed as a good way of collecting information about the interactions between factors while the 'factors-productivity form' is a way of collecting information about the interactions between factors and productivity. The experience of professionals in the field was sought by sending the two forms to a number of them. The final step was then to produce the responses to ascertain the factors

that had a major influence on productivity. This is explained in the results and discussions in Section 4.4 and Section 4.5 respectively.

4.2 SURVEY METHODS

Much of the work on survey methods has been carried out by social scientists and may need to be adapted for use in engineering projects.

A survey, as described by Fink(1995), is:

> *"A system for collecting information to describe, compare, or explain knowledge, attitudes and behaviour".*

McBurney's (1994) view of surveys is that their purpose is:

> *"to determine how people feel about a particular issue".*

Surveys should involve setting objectives for data collection, designing the research method, preparing suitable data collection instruments and analysing the data.

There are a number of survey methods which are used by researchers to elicit information from people. These are (Stone, 1978; Bryman, 1988; Dane, 1990; Fink, 1995; McBurney, 1994; Hartman, 1995; and Khorramshagol, 1988).

- Questionnaires

- Interviews
- Structured record review
- Structured observation, and
- Delphi method.

4.2.1 Questionnaires

Questionnaires rely on obtaining information directly from individuals by raising a number of questions. These questions may be written in a manner that allows the researcher to know about the behaviour of the addressee (and possibly that of others), their attitudes to their work environment and how they perceive things in their organisation (Bryman, 1988).

There are certain steps to be considered when designing a questionnaire. These are (McBurney, 1994):

1. Determine the purpose of the questionnaire.
2. Determine the types of questions: open ended questions or close-ended questions.
3. Write the questions, and
4. Determine how the data will be analysed.

Writing questions is an art in which the surveyor has to excel. The design of an effective questionnaire should generate the most reliable results. When designing a questionnaire it is very important to end up with one which is simple and clear. Greenfield (1996),

Bryman (1988) and McBurney (1994) suggested a number of key factors in the design of questionnaires. Briefly, the main ones are:

1. Use clear and unambiguous questions.
2. Avoid slang and fashionable language.
3. Make questions as short and to the point as possible.
4. Avoid double-barreled questions (two things in one question).
5. Make it easy for the respondent to answer; such as 'tick' and 'yes or no' types.

4.2.2 Interviews

An interview as defined by Frey (1995) is:

> *"A purposeful conversation in which one person asks prepared questions (the interviewer) and another answers them (the respondent)".*

Interviews may be conducted in a structured or unstructured way. A structured interview is itself a questionnaire administrated in a face-to-face setting (Bryman, 1988; Frey, 1995; McBurney, 1994; Hart, 1989). The interviewer prepares a standard set of questions to be presented to the interviewee. In the unstructured interview the case is different. The interviewer raises a certain topic for the interviewee to comment on. In this case it is the interviewee who has complete control over the comments (Stone, 1978).

There may be cases where the interviewer chooses to use both structured and unstructured interviews. These are referred to as semi-structured interviews and may take two shapes. In the first, the interviewer presents the respondent with a set of questions to which he or she responds in any manner. In the second, respondents are asked to respond to open-ended questions in a definite and defined way (Stone, 1978).

Some hints on interviewing techniques are summarised by Waring (1989) as follows:

- make sure to select the right person
- interview on a 1:1 basis wherever possible
- avoid interruptions (telephones, visitors, etc.)
- establish rapport
- clearly state the purpose of the interview however diplomatically it is presented
- ask open-ended questions (Why was that ? Could you tell me more about?)
- avoid superimposing biases on questions and responses
- get the interviewee to do most of the talking
- make notes
- avoid interrupting to clarify (leave till later)
- check through the notes at the end and then clarify points
- make sure not to forget anything at the end of the interview
- thank the interviewee for his/her assistance.

Technological developments have made life easier for researchers. Use of the telephone and computer networks is rapidly increasing. Surveyors may find it easier to carry out the survey over the phone rather than travelling long distances to meet the selected people. Furthermore, the widespread use of electronic mail makes life easier for both the administrator of the survey and respondents.

4.2.2.1 Questionnaires and Interviews

The advantages and disadvantages, together with the purpose of the study itself, are the criteria which will decide what method is to be used. The advantages and disadvantages of questionnaires when compared to interviews are as follows (Greenfield, 1996; Bryman, 1988 and Stone, 1978) :

ADVANTAGES

1. Questionnaires are cheaper than interviews, especially when there is a large number of respondents and if they are geographically dispersed.
2. Questionnaires are quicker than interviews.
3. The characteristics of interviewers, such as their age, appearance, race, gender and social class, may have an effect on interviewees. In the case of questionnaires these may be eliminated.

DISADVANTAGES

1. There are cases where questions are not clear, leading to a misrepresentation by the respondent.
2. Sometimes answers to earlier questions are influenced by the later ones since respondents can read the whole questionnaire before starting to answer.
3. There is no certainty about who answered the questionnaire. Top level management, for example, find it easy to pass the questionnaires to those in lower levels.
4. Posting the questionnaire may deprive the researcher of benefiting from additional documents and information whereas with interviews the case is totally different. The interviewer can ask for whatever information is needed and collate documents from the firm he or she is visiting.
5. Questionnaires are prone to bias, as response rates are lower than in the interview method. This bias is due to the difference in characteristics related to research between respondents and non-respondents.

4.2.3 Structured Record Review

This method is used by some researchers to utilise already existing data. It is sometimes called archival research (McBurney, 1994). Many organisations have records and data in their archive section which can be studied and explored. Analysis of such data may prevent additional effort and expense to the organisation, as some studies are repetitions of past ones.

4.2.4 Structured Observation

Structured observation is a method which visually studies specific actions or the behaviour of individuals or groups without attempting to influence them (Fink, 1995; McBurny, 1994). In construction, this method is called work measurement or time study (Harris and McCaffer, 1995). The British Standards defines work measurement as:

> "*The application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance.*"

An example of this method is to find the productivity of a bricklayer. It is necessary for an observer to record the time the bricklayer needs to finish a certain job. This method needs trained and skilful observers in order to produce accurate studies.

Harris and McCaffer (1995) advised a number of applications of work measurement data. These are as follows:

1. Determining suitable manning levels on construction activities.
2. Setting standards of machine utilisation and labour performance.
3. Providing the basis for sound financial incentive targets.
4. Providing a basis for cost control by fixing standard performance targets.
5. Determining the most economic from alternative methods.

4.2.5 Delphi Method

This method was developed by the Rand Corporation in the 1950s (Pilcher, 1992). As defined by Khorramshagol and Azani (1988) it is:

"A systematic procedure to evoke expert opinion"

The main idea of the method is to solicit expert opinions in an iterative manner (Baguley, 1995). This method uses either questionnaires or brainstorming as a base. In the case of questionnaires, the steps involved are (Hartman and Baldwin, 1995):

1. Questionnaires are distributed to a number of selected experts.
2. A co-ordinator collates and summarises the answers and returns the results to the group members.
3. The process is repeated until a consensus is reached. In most situations three iterations appear to provide a consensus.

The questionnaire method is used whenever it is difficult to gather experts in one place. However, there are situations when it is possible to gather experts together in which case, the brainstorming method may be preferred.

Even though the Delphi method seems reasonable, there is a major drawback associated with its use. This is the limited number of participants which may lead to a bias in their ideas which, in turn will affect the outcome. Extending the panel to a group larger than

the normal size may prevent this. The use of the available technology represented by electronic mail is of great help (Hartman and Baldwin, 1995).

4.2.6 Choice of Method

There is no standard method of deciding which survey method should be used. A researcher may find it easier to use a questionnaire or the Delphi method in cases where information is required from a large number of individuals who are spread over a large geographical area, making it almost impossible to interview each one individually. In contrast, the use of interviews is preferable in cases where the study is limited to a definite area or organisation.

Finally, there are situations where the researcher finds himself/herself needing to combine methods. This may serve as a good tool to optimise the knowledge and expertise gained from respondents.

4.3 METHOD USED

It was decided to survey construction professionals to find out which factors they thought of particular importance and how these factors interact with each other. A questionnaire and unstructured interviews (face-to-face and telephone) were used for this purpose.

Two forms aimed at acquiring knowledge from experts were used. These two forms were:

1. 'Factors Matrix' form
2. 'Factors-Productivity' form

A detail of how these two forms were constructed is shown below in Subsection 4.4.1 and 4.4.2. The two forms were given to twenty experts in the field to elicit their knowledge about how factors interact with each other and with productivity. Out of those twenty, only 12 responses were used as the rest were not completed. This proportion of responses is considered to be acceptable for the type of work considered here, as the idea is to seek the knowledge of a limited number of experts rather than considering a large number.

4.3.1 Factors Matrix

In order to think about construction productivity as a system, it is necessary to think of a way that shows clearly how factors interact with each other. How, for example, weather affects, if it does, the control of the construction project. The idea of a "Factors Matrix", shown in Figure 4.1, emerged as a good tool to serve this purpose.

The first step towards building this matrix was the identification of factors which have an effect on productivity. Studying the literature on construction productivity and the survey of professionals in this field revealed that there are a large number of factors. These factors vary in their effect on productivity. Some have a considerable effect while the effect of others may be considered to be slight. Factors considered for the matrix are those believed to have a considerable effect on productivity.

Figure 4.1 'Factors Matrix'

- Fill in the matrix to show the interactions of the factors. For example if you think the 'weather' has large effect on 'absenteeism' enter H (for high) in the cell in the weather column and absenteeism row.

- Show the effects as H for high, M for medium and L for low. For no effects leave the cell blank.

	ABSENTEEISM	DISRUPTIONS	LEVEL OF SKILLED CRAFTMANS	USE OF EQUIPMENT	OVER TIME	LENGTH OF WORK DAY	NUMBER OF FOREMAN ON SITE	CREW SIZE	MOTIVATION	LEARNING CURVES	COMMUNICATIONS	DESIGN & BUILDABILITY	INTERFERENCE BY OWNER	RESTRICTED ACCESS	CHANGE ORDERS	ACCELERATION OF PERFORMANCE	DIFFERING SITE CONDITIONS	SAFETY	WORK INSPECTION BY ENGINEER	MATERIAL MANAGEMENT	CONTROL OF THE PROJECT	PLANNING	MODERN MANAGEMENT SYSTEMS	CREW INTERFERANCE	WEATHER	SIZE OF PROJECT	PLANS AND SPECIFICATIONS	CONSTRUCTION TECHNOLOGY	CONTRACT CONDITIONS	GOVERNMENT REGULATIONS	EDUCATION	TRAINING (OF ENGINEERS)	VOCATIONAL TRAINING	DESIGN CODES
ABSENTEEISM																																	
DISRUPTIONS																																	
LEVEL OF SKILLED CRAFTMANS																																	
USE OF EQUIPMENT																																	
OVER TIME																																	
LENGTH OF WORK DAY																																	
NUMBER OF FOREMAN ON SITE																																	
CREW SIZE																																	
MOTIVATION																																	
LEARNING CURVES																																	
COMMUNICATIONS																																	
DESIGN & BUILDABILITY																																	
INTERFERENCE BY OWNER																																	
RESTRICTED ACCESS																																	
CHANGE ORDERS																																	
ACCELERATION OF PERFORMANCE																																	
DIFFERING SITE CONDITIONS																																	
SAFETY																																	
WORK INSPECTION BY ENGINEER																																	
MATERIAL MANAGEMENT																																	
CONTROL OF THE PROJECT																																	
PLANNING																																	
MODERN MANAGEMENT SYSTEMS																																	
CREW INTERFERANCE																																	

The matrix is structured in such a way that some of the factors are repeated in rows and columns in order to find how these factors interact. The idea is to show how the factors in rows are influenced by those in the columns. There are a number of factors which are independent and are not affected by others. In this case they are shown only in columns and not repeated in rows. The size of the project, for example, is a factor which is believed to be independent where none of the factors in rows have any effect on it. The same argument is applicable for weather and construction technology.

As mentioned above, the 'factors matrix' forms were given to experts. The respondents were asked to indicate what influence each factor has on each of the others. The scale to be adopted was as follows:

- H if the relation is high
- M if the relation is medium
- L if the relation is low.

There are cases where the respondent feels that no relation exists between any two factors. In such cases he/she is asked to leave the cell blank.

While trying to fill in the matrix, respondents felt that two main difficulties faced them. These were:

1. A large number of responses were required which demanded a good deal of time.

2. Some of the interactions elicited more than one possible response. The types of contract and geographical locations, for example, are two conditions that might alter the views of respondents. The size of a project might be perceived by a respondent to have either a high or low effect on material management depending upon the planning and control of the project.

Figure 4.2 shows how one of the respondents filled in the 'Factors Matrix'. It can be seen, for example, that the respondent thought that absenteeism had a significant effect on the control of a project and its planning, but had a lesser effect on site safety and acceleration of performance. Furthermore, change orders had a considerable effect on a number of factors. The respondent felt that change orders, if increased, would lead to more disruptions to the work; the motivation of workers would be affected where workers might be less motivated as the variations in the work increased.

4.3.2 FACTORS - PRODUCTIVITY FORM

The "factors matrix" shows only the interactions of factors within the system of the construction project and offers no indication of how these factors might affect productivity. In order to show how factors affect productivity, another form, showing the effects of factors on productivity, was needed.

In this form, shown in Fig. 4.3, all the factors considered in the "factors matrix" were listed again. This time the respondents were asked to show the effects of each individual factor on productivity using the scale 0 to ±10 where:

Figure 4.2 'Factors Matrix' filled by one of the respondents

- Fill in the matrix to show the interactions of the factors. For example if you think the 'weather' has large effect on 'absenteeism' enter H (for high) in the cell in the weather column and absenteeism row.

- Show the effects as H for high, M for medium and L for low. For no effects leave the cell blank.

	ABSENTEEISM	DISRUPTIONS	LEVEL OF SKILLED LABOUR	USE OF EQUIPMENT	OVER TIME	LENGTH OF WORK DAY	NUMBER OF FOREMAN ON SITE	CREW SIZE	MOTIVATION	LEARNING CURVES	COMMUNICATIONS	DESIGN & BUILDABILITY	INTERFERENCE BY OWNER	RESTRICTED ACCESS	CHANGE ORDERS	ACCELERATION OF PERFORMANCE	DIFFERING SITE CONDITIONS	SAFETY	WORK INSPECTION BY ENGINEER	MATERIAL MANAGEMENT	CONTROL OF THE PROJECT	PLANNING	MODERN MANAGEMENT SYSTEMS	CREW INTERFERENCE	WEATHER	SIZE OF PROJECT	PLANS AND SPECIFICATIONS	CONSTRUCTION TECHNOLOGY	CONTRACT CONDITIONS	GOVERNMENT REGULATIONS	EDUCATION	TRAINING (OF ENGINEERS)	VOCATIONAL TRAINING	DESIGN CODES
ABSENTEEISM			M				L		M				L		L	L		L			L	L		L							L		L	
DISRUPTIONS			L				L		L		M	M	M	L	M	L	M	L		L	L	M		L			L	L	L	L		L		L
LEVEL OF SKILLED LABOUR							L		L						L	L					L							M			M		L	
USE OF EQUIPMENT							L																				M	M		M				
OVER TIME																																		
LENGTH OF WORK DAY																																		
NUMBER OF FOREMAN ON SITE			L						L						L	L					L	L	L	L			M	L			M	L	M	L
CREW SIZE			L	L					L					L								L	L	L			L	L		L	L	L	L	
MOTIVATION		M	L	L			L				L	L	L		M	L				L	M	M	L	L			M	L			M	L	M	
LEARNING CURVES		M	L						L			L	L		M	L	L	L			L	L		L			M	L			L	L	L	
COMMUNICATIONS		L					L		L			L			L	L								L				L	L	L	L	M	L	
DESIGN & BUILDABILITY		L	L	L																							L	L	L	M	M	M		
INTERFERENCE BY OWNER												L				L					L	L	L					L	L					L
RESTRICTED ACCESS																								L	L				L					
CHANGE ORDERS									L			L	L	L		M	L	L		L	L	M	L	L	L		L	L	L	L		L		L
ACCELERATION OF PERFORMANCE	L	L					L	L	L	L	L	L	L	L	L		L	L	L	L	L	M	L	L	L		L	L	L	L	L	L	L	L
DIFFERING SITE CONDITIONS																									L									
SAFETY	L		L				L	L	L	L		L	L	L		L	L		L		L	L			L		L	L			L	L	L	
WORK INSPECTION BY ENGINEER		L	M				L				L		L		L	L					L	L	L	L			L	L	L	L	L	L	L	
MATERIAL MANAGEMENT																																		
CONTROL OF THE PROJECT	M	L					M	M	L	L	L				M	M		M	M			H	L	L			M	L				L	L	
PLANNING	M	H					M	L	L	L		M		L	M	L	L	L		L	H		L	L	L			L	L	L		L		L
MODERN MANAGEMENT SYSTEMS																																		
CREW INTERFERENCE																																		

Figure 4.3 'Factors-Productivity Form'

Factors	Effects on Productivity
Absenteeism	
Disruptions	
Level of skilled labour	
Use of equipment	
Overtime	
Length of workday	
Number of foremen on site	
Crew size	
Motivation	
Learning curves	
Communications	
Design	
Interference by owner	
Restricted access	
Change orders	
Acceleration of performance	
Differing site conditions	
Safety	
Work inspection by engineer	
Material management	
Control of the project	
Planning	
Modern management systems	
Crew interference	
Weather	
Size of project	
Specifications	
Construction technology	
Contract conditions	
Government regulations	
Education	
Training	
Vocational training	
Design codes	

Show the effects of each factor on productivity using a scale of: -10 to +10

0 for no effect

-10 for very large negative effect

+10 for very large positive effect

For example, absenteeism may have negative medium effect on productivity which may be presented by (say): -5.

- +10 represents high positive effect on productivity
- 0 represents no effect on productivity
- - 10 represents high negative effect on productivity

Figure 4.4 shows the opinion of one of the respondents. It showed that the respondent felt that more disruptions in the work would reduce productivity and that this effect is moderate.

4.4 KNOWLEDGE ELICITATION

This section discusses how the opinions and experience offered by experts was elicited. In the 'Factors Matrix' a qualitative scale was used, hence there is a need to convert this to a quantitative one in order to simplify the process of identifying the most important group of factors to be used to build a model that could be used for productivity in construction projects. Certain procedures were used to attain such an aim and these are discussed in some detail in Subsection 4.4.1.

As for the 'Factors-Productivity' form, the scale used is a quantitative one and the procedure followed is simpler than the one used for the 'Factors Matrix'. The steps used are discussed in Subsection 4.4.2.

4.4.1 'Factors Matrix' Knowledge Elicitation

The procedure used to elicit the experts' knowledge can be summarised in the following steps:

Figure 4.4 'Factors-Productivity Form' as seen by one of the respondents

Factors	Effects on Productivity
Absenteeism	-4
Disruptions	-6
Level of skilled labour	+8
Use of equipment	+5
Overtime	+1
Length of workday	-5
Number of foremen on site	+2
Crew size	-2
Motivation	+8
Learning curves	+5
Communications	+5
Design	+7
Interference by owner	-5
Restricted access	-8
Change orders	-3
Acceleration of performance	-6
Differing site conditions	-6
Safety	+7
Work inspection by engineer	-3
Material management	+4
Control of the project	+8
Planning	+7
Modern management systems	+1
Crew interference	-5
Weather	-7
Size of project	-3
Specifications	-5
Construction technology	+3
Contract conditions	0
Government regulations	-2
Education	+3
Training	+5
Vocational training	+2
Design codes	0

1. Convert the qualitative scale to a quantitative one

2. Normalise the forms received from respondents because every respondent looks at things from a different angle and it is necessary to use one benchmark.

3. Identify the most important group of factors that have a considerable influence on others.

1) Convert the qualitative scale to quantitative one

As described in Section 4.4.1 and as shown in Figure 4.2, the scale used is a four-point scale: high, medium, low and no relation. These were converted to a numbers scale for simplicity. The conversion scores used are:

- High (H) 4 points
- Medium (M) 3 points
- Low (L) 2 points
- No relation (Blank cell) 1 point

The idea of considering a score of one for a blank cell is that even though the cell is left blank, in practice, there exists a relation however small. Here it is represented as a minor effect which is one and not zero.

Figure 4.5 shows the same form as that shown in Figure 4.2 but this time with the letters converted to numbers. The form is shown in colour in order to help the reader locate the most important interactions easily. It can be seen that the respondent thinks that, amongst all the interactions, there are only three which are considered 'high'. These relations are:

1. disruptions are significantly affecting the planning of the project
2. control is significantly affecting planning, and
3. planning is significantly affecting control.

This may lead to the belief that this respondent leans more towards the management side of the project where he feels that the interactions of management factors are the most important of all the interactions.

If the medium relation is considered (cells with 3) in addition to the high ones, the respondent opinion is that the control of the project is the most vulnerable factor amongst all the others. It is affected by 8 factors with medium relations and one with high relation. Motivation comes after control followed by motivation, then by planning and disruptions. However, the case is different if the situation is considered as a whole. The total score of the four mentioned factors are shown in Table 4.1. Planning has the highest score among others which indicates that this factor comes at the top of all other factors that are affected by other factors in the system.

Figure 4.5 'Factors Matrix' where letters are converted to numbers

	ABSENTEEISM	DISRUPTIONS	LEVEL OF SKILLED CRAFTMANS	USE OF EQUIPMENT	OVER TIME	LENGTH OF WORK DAY	NUMBER OF FOREMAN ON SITE	CREW SIZE	MOTIVATION	LEARNING CURVES	COMMUNICATIONS	DESIGN & BUILDABILITY	INTERFERENCE BY OWNER	RESTRICTED ACCESS	CHANGE ORDERS	ACCELERATION OF PERFORMANCE	DIFFERING SITE CONDITIONS	SAFETY	WORK INSPECTION BY ENGINEER	MATERIAL MANAGEMENT	CONTROL OF THE PROJECT	PLANNING	MODERN MANAGEMENT SYSTEMS	CREW INTERFERANCE	WEATHER	SIZE OF PROJECT	PLANS AND SPECIFICATIONS	CONSTRUCTION TECHNOLOGY	CONTRACT CONDITIONS	GOVERNMENT REGULATIONS	EDUCATION	TRAINING (OF ENGINEERS)	VOCATIONAL TRAINING	DESIGN CODES
ABSENTEEISM		1	3	1	1	1	2	1	3	1	1	1	2	1	2	2	1	2	1	1	2	2	1	2	1	1	1	1	1	1	2	1	2	1
DISRUPTIONS	1		2	1	1	1	2	1	2	1	3	3	3	2	3	2	3	2	1	2	2	3	1	2	1	1	2	2	2	2	1	2	1	2
LEVEL OF SKILLED CRAFTMANS	1	1		1	1	1	2	1	2	1	1	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1	1	3	1	1	3	1	2	1
USE OF EQUIPMENT	1	1	1		1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	3	1	1	1	1
OVER TIME	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LENGTH OF WORK DAY	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NUMBER OF FOREMAN ON SITE	1	1	2	1	1	1		1	2	1	1	1	1	1	2	2	1	1	1	1	2	2	2	2	1	1	3	2	1	1	3	2	3	2
CREW SIZE	1	1	2	2	1	1	1		2	1	1	1	1	2	1	1	1	1	1	1	1	2	2	2	1	1	2	2	1	2	2	2	2	2	1
MOTIVATION	1	3	2	2	1	1	2	1		1	2	2	2	1	3	2	1	1	1	2	3	3	2	2	1	1	3	2	1	1	3	2	3	1
LEARNING CURVES	1	3	2	1	1	1	1	1	2		1	2	2	1	3	2	2	2	1	1	2	2	1	2	1	1	3	2	1	1	2	2	2	1
COMMUNICATIONS	1	2	1	1	1	1	2	1	2	1		2	1	1	2	2	1	1	1	1	1	1	1	2	1	1	1	2	2	2	2	3	2	1
DESIGN & BUILDABILITY	1	2	2	2	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	1	1
INTERFERENCE BY OWNER	1	1	1	1	1	1	1	1	1	1	1	2		1	1	2	1	1	1	1	2	2	2	1	1	1	1	2	2	1	1	1	1	2
RESTRICTED ACCESS	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	2	2	1	1	1	2	1	1	1	1	1
CHANGE ORDERS	1	1	1	1	1	1	1	1	2	1	1	2	2	2		3	2	2	1	2	2	3	2	2	2	1	2	2	2	2	1	2	1	2
ACCELERATION OF PERFORMANCE	2	2	1	1	1	1	2	2	2	2	2	2	2	2	2		2	2	2	2	2	3	2	2	2	1	2	2	2	2	2	2	2	2
DIFFERING SITE CONDITIONS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
SAFETY	2	1	2	1	1	1	2	2	2	2	1	2	2	2	1	2	2		2	1	2	2	1	1	2	1	2	2	1	1	2	2	2	1
WORK INSPECTION BY ENGINEER	1	2	3	1	1	1	2	1	1	1	2	1	2	1	2	2	1	1		1	2	2	2	2	1	1	2	2	2	2	2	2	2	1
MATERIAL MANAGEMENT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
CONTROL OF THE PROJECT	3	2	1	1	1	1	3	3	2	2	2	1	1	1	3	3	1	3	3	1		4	2	2	1	1	3	2	1	1	1	2	2	1
PLANNING	3	4	1	1	1	1	3	2	2	2	1	3	1	2	3	2	2	2	1	2	4		2	2	2	1	1	2	2	2	1	2	1	2
MODERN MANAGEMENT SYSTEMS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1
CREW INTERFERANCE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1

Table 4.1 Considering only 'H' and 'M' for one of the respondents

FACTOR	H (4)	M (3)	TOTAL SCORE
Disruptions	-	6	60
Motivation	-	7	59
Control	1	8	61
Planning	2	4	63

2) Normalise the forms

The problem faced when the forms are received from respondents is that each respondent considers his own benchmark when looking at the relations in the form. A 'low' interaction considered by one respondent may equate to 'medium' with another. Therefore, it is important to normalise all the forms in order to judge on an equal basis.

The normalisation to be done here is to find a '*normalisation index*' for each form. The procedure followed to find this index is as follows:

1. Find the total score for each respondent

2. Find the total score for the average 'Factors Matrix' (The average 'Factors Matrix' is the matrix which contains all the interactions of the factors at an average). In this case it is calculated as follows:

   Number of cells of the whole matrix × average of the considered scores

   $$= 792 \times (4+3+2+1)/4 = 1980$$

3. The normalisation index for the form is

$$\frac{\text{total of the average 'Factors Matrix' (from step 2)}}{\text{total score of the form (from step 1)}}$$

Table 4.2 shows the normalisation index for all the forms together with the total sum. The normalisation of each form is achieved by multiplying the index of the form by the score of every cell. Figure 4.6 shows one of the respondent's forms after it has been normalised.

3) Identify the group of factors that has the most important influence on others

The procedure followed for this step is as follows:

1. Find the average of the normalised forms. This will be called the 'average normalised form'. This form is shown in Figure 4.7. It can be seen from Figure 4.7 that there are three major interactions. These interactions are:

   - Planning affecting control. The score is 5.602
   - Change orders influencing disruptions. The score is 5.064
   - Interference by owner influencing disruptions. The score is 5.063

2 Find the sum of rows and columns of the 'average normalised form' (Figure 4.7)

Table 4.2 Normalisation indices for the respondents' forms

Form No.	Total score	Normalisation Index
Sheet 1	1111	1.78
Sheet 2	1102	1.80
Sheet 3	1266	1.56
Sheet 4	1502	1.32
Sheet 5	1172	1.69
Sheet 6	1121	1.77
Sheet 7	1128	1.76
Sheet 8	1118	1.77
Sheet 9	1688	1.17
Sheet 10	928	2.13
Sheet 11	1324	1.50
Sheet 12	1233	1.61

3 Sort rows and columns in descending order, based on the scores obtained in Step 2. Figure 4.8 shows the 'average normalised form' after sorting rows and columns. Sorting rows in descending order gives an opportunity to look at factors in order of importance. For example, control of project comes at the top of factors where the score is approximately 114, indicating that this factor is the most sensitive one compared to others. Size of project, on the other hand, has the highest score amongst those in the columns. This indicates that this factor has the highest influence on other factors.

Figure 4.6 Normalised 'Factors Matrix' of one of the respondents

	ABSENTEEISM	DISRUPTIONS	LEVEL OF SKILLED LABOUR	USE OF EQUIPMENT	OVER TIME	LENGTH OF WORK DAY	NUMBER OF FOREMAN ON SITE	CREW SIZE	MOTIVATION	LEARNING CURVES	COMMUNICATIONS	DESIGN & BUILDABILITY	INTERFERENCE BY OWNER	RESTRICTED ACCESS	CHANGE ORDERS	ACCELERATION OF PERFORMANCE	DIFFERING SITE CONDITIONS	SAFETY	WORK INSPECTION BY ENGINEER	MATERIAL MANAGEMENT	CONTROL OF THE PROJECT	PLANNING	MODERN MANAGEMENT SYSTEMS	CREW INTERFERENCE	WEATHER	SIZE OF PROJECT	PLANS AND SPECIFICATIONS	CONSTRUCTION TECHNOLOGY	CONTRACT CONDITIONS	GOVERNMENT REGULATIONS	EDUCATION	TRAINING (OF ENGINEERS)	VOCATIONAL TRAINING	DESIGN CODES
ABSENTEEISM	0	1.782	5.347	1.782	1.782	1.782	3.564	1.782	5.347	1.782	1.782	1.782	3.564	1.782	3.564	3.564	1.782	3.564	1.782	1.782	3.564	3.564	1.782	3.564	1.782	1.782	1.782	1.782	1.782	1.782	3.564	1.782	3.564	1.782
DISRUPTIONS	1.782	0	3.564	1.782	1.782	1.782	3.564	1.782	3.564	1.782	5.347	5.347	5.347	3.564	5.347	3.564	5.347	3.564	1.782	3.564	3.564	5.347	1.782	3.564	1.782	1.782	3.564	3.564	3.564	3.564	1.782	3.564	1.782	3.564
LEVEL OF SKILLED LABOUR	1.782	1.782	0	1.782	1.782	1.782	3.564	1.782	3.564	1.782	1.782	1.782	1.782	1.782	3.564	3.564	1.782	1.782	1.782	1.782	3.564	1.782	1.782	1.782	1.782	1.782	1.782	5.347	1.782	1.782	5.347	1.782	3.564	1.782
USE OF EQUIPMENT	1.782	1.782	1.782	0	1.782	1.782	3.564	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	5.347	5.347	1.782	5.347	1.782	1.782	1.782	1.782
OVER TIME	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
LENGTH OF WORK DAY	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
NUMBER OF FOREMAN ON SITE	1.782	1.782	3.564	1.782	1.782	1.782	0	1.782	3.564	1.782	1.782	1.782	1.782	1.782	3.564	3.564	1.782	1.782	1.782	1.782	3.564	3.564	3.564	3.564	1.782	1.782	5.347	3.564	1.782	1.782	5.347	3.564	5.347	3.564
CREW SIZE	1.782	1.782	3.564	3.564	1.782	1.782	1.782	0	3.564	1.782	1.782	1.782	1.782	3.564	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	3.564	3.564	1.782	1.782	3.564	3.564	1.782	1.782	3.564	3.564	3.564	1.782
MOTIVATION	1.782	5.347	3.564	3.564	1.782	1.782	3.564	1.782	0	1.782	3.564	3.564	3.564	1.782	5.347	3.564	1.782	1.782	1.782	3.564	5.347	5.347	3.564	3.564	1.782	1.782	5.347	3.564	1.782	1.782	5.347	3.564	5.347	1.782
LEARNING CURVES	1.782	5.347	3.564	1.782	1.782	1.782	1.782	1.782	3.564	0	1.782	3.564	3.564	1.782	5.347	3.564	3.564	3.564	1.782	1.782	3.564	3.564	1.782	3.564	1.782	1.782	5.347	3.564	1.782	1.782	3.564	3.564	3.564	1.782
COMMUNICATIONS	1.782	3.564	1.782	1.782	1.782	1.782	3.564	1.782	3.564	1.782	0	3.564	1.782	1.782	3.564	3.564	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	1.782	1.782	1.782	3.564	3.564	3.564	3.564	5.347	3.564	1.782
DESIGN & BUILDABILITY	1.782	3.564	3.564	3.564	1.782	1.782	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	3.564	3.564	3.564	5.347	5.347	5.347	1.782
INTERFERENCE BY OWNER	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	0	1.782	1.782	3.564	1.782	1.782	1.782	1.782	3.564	3.564	3.564	1.782	1.782	1.782	1.782	3.564	3.564	3.564	1.782	1.782	1.782	3.564
RESTRICTED ACCESS	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	3.564	1.782	1.782	1.782	3.564	1.782	1.782	1.782	1.782	1.782
CHANGE ORDERS	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	1.782	1.782	3.564	3.564	3.564	0	5.347	3.564	3.564	1.782	3.564	3.564	5.347	3.564	3.564	3.564	1.782	3.564	3.564	3.564	3.564	1.782	3.564	1.782	3.564
ACCELERATION OF PERFORMANCE	3.564	3.564	1.782	1.782	1.782	1.782	3.564	3.564	3.564	3.564	3.564	3.564	3.564	3.564	3.564	0	3.564	3.564	3.564	3.564	3.564	5.347	3.564	3.564	3.564	1.782	3.564	3.564	3.564	3.564	3.564	3.564	3.564	3.564
DIFFERING SITE CONDITIONS	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	3.564	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
SAFETY	3.564	1.782	3.564	1.782	1.782	1.782	3.564	3.564	3.564	3.564	1.782	3.564	3.564	3.564	1.782	3.564	3.564	0	3.564	1.782	3.564	3.564	1.782	1.782	3.564	1.782	3.564	3.564	1.782	1.782	3.564	3.564	3.564	1.782
WORK INSPECTION BY ENGINEER	1.782	3.564	5.347	1.782	1.782	1.782	3.564	1.782	1.782	1.782	3.564	1.782	3.564	1.782	3.564	3.564	1.782	1.782	0	1.782	3.564	3.564	3.564	3.564	1.782	1.782	3.564	3.564	3.564	3.564	3.564	3.564	3.564	1.782
MATERIAL MANAGEMENT	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
CONTROL OF THE PROJECT	5.347	3.564	1.782	1.782	1.782	1.782	5.347	5.347	3.564	3.564	3.564	1.782	1.782	1.782	5.347	5.347	1.782	5.347	5.347	1.782	0	7.129	3.564	3.564	1.782	1.782	5.347	3.564	1.782	1.782	1.782	3.564	3.564	1.782
PLANNING	5.347	7.129	1.782	1.782	1.782	1.782	5.347	3.564	3.564	3.564	1.782	5.347	1.782	3.564	5.347	3.564	3.564	3.564	1.782	3.564	7.129	0	3.564	3.564	3.564	1.782	1.782	3.564	3.564	3.564	1.782	3.564	1.782	3.564
MODERN MANAGEMENT SYSTEMS	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782
CREW INTERFERENCE	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	0	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782	1.782

Figure 4.7 'Average Normalised Form'

	ABSENTEEISM	DISRUPTIONS	LEVEL OF SKILLED LABOUR	USE OF EQUIPMENT	OVER TIME	LENGTH OF WORK DAY	NUMBER OF FOREMAN ON SITE	CREW SIZE	MOTIVATION	LEARNING CURVES	COMMUNICATIONS	DESIGN & BUILDABILITY	INTERFERENCE BY OWNER	RESTRICTED ACCESS	CHANGE ORDERS	ACCELERATION OF PERFORMANCE	DIFFERING SITE CONDITIONS	SAFETY	WORK INSPECTION BY ENGINEER	MATERIAL MANAGEMENT	CONTROL OF THE PROJECT	PLANNING	MODERN MANAGEMENT SYSTEMS	CREW INTERFERENCE	WEATHER	SIZE OF PROJECT	PLANS AND SPECIFICATIONS	CONSTRUCTION TECHNOLOGY	CONTRACT CONDITIONS	GOVERNMENT REGULATIONS	EDUCATION	TRAINING (OF ENGINEERS)	VOCATIONAL TRAINING	DESIGN CODES	Total score
ABSENTEEISM	0	3.109	2.59	2.145	3.206	2.767	2.547	2.696	4.466	1.984	2.351	1.801	1.95	1.984	1.803	2.586	2.221	3.346	1.654	1.654	2.61	2.36	1.788	2.554	3.702	2.624	1.654	1.654	1.654	1.752	2.041	1.654	1.944	1.654	76.51
DISRUPTIONS	3.724	0	2.494	3.024	2.413	1.785	3.376	2.694	2.494	2.099	4.482	3.273	5.063	4.499	5.064	2.296	4.495	2.89	2.816	3.767	4.105	4.907	3.014	3.623	4.374	2.96	3.05	3.008	2.47	2.811	1.795	2.431	2.256	2.041	105.6
LEVEL OF SKILLED LABOUR	2.451	2.045	0	2.757	1.752	2.051	2.267	2.524	2.347	3.742	2.531	2.91	1.654	1.654	2.395	1.803	1.654	2.479	1.984	1.752	2.474	2.767	1.752	2.201	1.801	2.618	1.752	2.758	1.98	1.85	4.145	2.814	3.638	1.785	77.09
USE OF EQUIPMENT	1.996	3.017	3.25	0	1.752	2.047	2.081	1.764	1.92	2.67	2.222	3	1.654	2.094	2.051	1.98	2.713	3.149	1.752	1.752	2.179	2.775	2.371	1.93	2.905	2.918	2.525	3.846	1.85	2.227	2.262	3.411	2.484	1.984	78.53
OVER TIME	2.57	3.208	2.047	2.433	0	4.183	1.984	2.335	2.867	1.898	1.752	2.177	2.169	1.85	3.489	3.269	2.449	2.248	1.877	1.909	2.379	2.716	1.752	1.785	3.083	2.818	1.654	2.043	1.947	1.752	1.654	1.795	1.654	1.654	75.4
LENGTH OF WORK DAY	2.737	2.609	1.752	2.047	3.372	0	1.752	2.336	3.269	1.886	1.9	1.942	2.142	2.201	2.614	2.376	1.654	2.149	1.954	1.654	2.118	2.648	1.654	1.654	2.352	2.55	1.654	1.654	2.289	2.684	1.654	1.795	1.654	1.654	70.36
NUMBER OF FOREMAN ON SITE	2.162	2.167	2.656	2.215	2.166	1.9	0	2.922	3.157	2.734	2.686	1.949	1.654	2.185	2.022	2.753	1.984	3.052	2.192	2.201	3.88	3.633	3.225	2.2	1.654	3.715	2.422	2.951	1.832	1.654	1.951	2.084	1.951	1.803	79.71
CREW SIZE	3.166	2.536	2.716	2.546	2.701	1.9	2.86	0	2.869	1.886	2.588	2.377	1.882	2.546	2.103	2.756	2.134	2.417	1.752	1.922	2.96	3.644	2.42	2.913	1.654	3.411	2.414	2.521	1.654	1.803	1.803	2.07	2.07	1.654	78.65
MOTIVATION	3.359	4.595	2.694	2.645	3.563	2.769	3.015	2.914	0	3.234	3.617	2.875	3.511	2.043	4.083	2.711	3.379	3.357	2.115	2.058	3.565	3.861	3.242	3.839	3.833	3.617	1.951	2.645	1.886	1.984	2.716	3.782	2.599	1.654	99.71
LEARNING CURVES	2.692	3.078	3.799	2.382	2.406	2.141	2.24	3.025	3.704	0	3.13	3.012	2.025	1.954	3.196	3.058	2.564	2.034	1.752	1.779	2.12	2.794	2.004	2.57	2.193	2.462	2.147	3.912	1.654	1.654	3.147	3.428	3.117	1.785	84.96
COMMUNICATIONS	3	3.489	2.679	1.972	1.752	2.046	3.327	3.392	3.555	1.752	0	2.242	2.196	1.654	2.225	2.129	2.016	1.941	1.795	1.654	3.17	3.581	2.837	2.645	1.788	3.735	2.65	2.359	2.78	1.803	2.204	2.363	1.949	1.795	80.48
DESIGN & BUILDABILITY	1.752	2.091	2.096	2.787	1.752	1.654	1.654	1.752	1.752	2.274	2.689	0	2.531	2.283	3.298	2.479	2.335	3.229	2.133	1.85	2.819	2.531	2.377	2.097	1.801	2.938	4.753	4.404	1.901	3.214	2.407	2.96	1.954	3.965	82.51
INTERFERENCE BY OWNER	1.997	2.858	1.9	1.752	1.85	1.654	1.802	1.752	1.85	1.654	2.743	2.622	0	1.922	2.516	2.505	1.752	1.801	2.248	1.654	2.962	2.868	2.57	1.85	1.801	2.532	2.007	1.998	2.578	1.85	1.654	1.654	1.654	1.803	68.61
RESTRICTED ACCESS	1.948	2.351	1.752	2.474	1.85	2.103	1.752	1.752	1.85	1.654	1.96	2.066	1.948	0	1.832	1.948	1.752	2.714	1.654	2.347	1.98	2.212	1.654	1.998	2.078	2.114	1.785	1.85	1.901	1.85	1.654	1.654	1.654	1.654	63.74
CHANGE ORDERS	1.997	2.874	2.128	2.315	1.948	1.654	1.997	1.752	2.096	2.03	2.655	4.674	2.721	1.933	0	2.704	3.027	1.933	2.455	2.182	2.676	3.371	2.298	1.998	1.933	2.975	3.581	2.408	3.197	2.372	1.654	1.803	1.654	2.307	79.3
ACCELERATION OF PERFORMANCE	2.96	3.469	3.437	2.7	2.846	2.474	2.571	2.897	2.955	3.113	2.822	3.446	2.446	2.692	3.182	0	2.571	1.998	2.226	2.499	3.268	3.77	2.42	2.129	3.158	2.273	1.998	2.832	2.681	1.901	1.901	2.512	1.803	1.803	87.75
DIFFERING SITE CONDITIONS	1.654	2.21	1.85	2.047	1.997	1.795	1.654	1.654	2.149	2.244	1.972	2.37	1.752	1.654	1.98	1.949	0	2.164	1.752	1.949	1.85	2.149	1.752	1.654	3.017	1.882	1.654	1.654	1.654	1.654	1.654	1.654	1.654	1.654	62.34
SAFETY	1.998	1.972	2.788	3.697	2.713	2.564	3.539	3.377	2.547	2.601	2.419	3.262	2.263	2.829	1.984	2.512	3.054	0	2.672	2.504	3.323	4.415	3.825	3.434	2.721	3.699	2.691	4.146	2.209	3.825	2.784	4.369	3.024	2.977	98.74
WORK INSPECTION BY ENGINEER	2.371	2.814	2.792	1.882	1.98	1.785	2.78	2.319	2.41	2.319	2.36	2.506	2.692	2.134	2.695	2.792	2.382	3.31	0	2.229	2.938	3.048	1.933	2.5	1.909	3.188	2.466	2.637	2.669	2.221	1.803	3.272	1.927	2.186	81.25
MATERIAL MANAGEMENT	2.388	3.313	2.282	2.154	1.948	1.654	2.899	2.082	2.027	1.947	2.836	2.255	1.984	2.239	3.033	2.657	2.164	2.763	2.007	0	2.756	3.481	2.414	1.785	2.397	4.777	2.922	2.488	1.98	1.654	1.795	2.414	1.654	1.785	78.93
CONTROL OF THE PROJECT	3.026	3.696	2.764	2.689	2.516	2.305	4.198	2.777	3.262	2.798	4.562	3.749	3.456	2.752	4.718	3.614	3.28	4.288	2.968	3.892	0	5.602	4.499	3.372	3.043	4.896	3.751	3.2	3.686	2.47	2.63	4.231	2.748	2.819	114.3
PLANNING	2.82	3.933	2.992	2.604	2.144	2.177	3.357	1.901	3.284	3.387	4.193	3.731	3.452	2.897	4.425	3.649	3.284	3.411	2.641	3.561	4.747	0	4.057	1.998	2.693	4.981	3.612	3.238	3.354	2.866	3.195	4.077	2.344	2.345	107.3
MODERN MANAGEMENT SYSTEMS	1.654	2.618	1.996	2.082	1.996	1.785	2.1	2.082	2.489	1.85	4.271	2.591	1.915	1.654	1.85	2.179	2.082	1.752	1.85	1.898	2.538	2.208	0	1.752	1.654	2.785	2.654	2.406	2.592	1.85	3.393	3.008	1.801	1.925	73.26
CREW INTERFERENCE	2.577	2.248	2.463	2.311	1.886	2.047	2.974	2.853	2.74	1.752	3.135	1.984	1.654	1.654	3.01	2.229	2.444	2.568	2.132	2.034	2.256	2.843	2.363	0	2.308	2.987	1.654	2.059	1.654	1.654	2.235	2.433	2.168	1.654	74.97
Total score	57	66.3	57.92	55.66	52.51	49.24	58.73	55.55	62.06	53.51	65.88	62.81	54.72	51.31	65.57	58.93	57.39	60.99	48.38	50.7	65.67	74.18	58.22	54.48	59.85	75.45	59.4	64.67	54.05	51.35	54.13	63.67	51.36	48.34	

Figure 4.8 'Average Normalised Form' after columns and rows are sorted in descending order

	SIZE OF PROJECT	PLANNING	DISRUPTIONS	COMMUNICATIONS	CONTROL OF THE PROJECT	CHANGE ORDERS	CONSTRUCTION TECHNOLOGY	TRAINING (OF ENGINEERS)	DESIGN & BUILDABILITY	MOTIVATION	SAFETY	WEATHER	PLANS AND SPECIFICATIONS	ACCELERATION OF PERFORMANCE	NUMBER OF FOREMAN ON SITE	MODERN MANAGEMENT SYSTEMS	LEVEL OF SKILLED CRAFTMANS	DIFFERING SITE CONDITIONS	ABSENTEEISM	USE OF EQUIPMENT	CREW SIZE	INTERFERENCE BY OWNER	CREW INTERFERENCE	EDUCATION	CONTRACT CONDITIONS	LEARNING CURVES	OVER TIME	VOCATIONAL TRAINING	GOVERNMENT REGULATIONS	RESTRICTED ACCESS	MATERIAL MANAGEMENT	LENGTH OF WORK DAY	WORK INSPECTION BY ENGINEER	DESIGN CODES	total score
CONTROL OF THE PROJECT	4.9	5.6	3.7	4.56	0	4.72	3.2	4.23	3.75	3.26	4.29	3.04	3.75	3.61	4.2	4.5	2.76	3.28	3.03	2.69	2.78	3.46	3.37	2.63	3.69	2.8	2.52	2.75	2.47	2.75	3.89	2.3	2.97	2.82	114
PLANNING	4.98	0	3.93	4.19	4.75	4.43	3.24	4.08	3.73	3.28	3.41	2.69	3.61	3.65	3.36	4.06	2.99	3.28	2.82	2.6	1.9	3.45	2	3.19	3.35	3.39	2.14	2.34	2.87	2.9	3.56	2.18	2.64	2.35	107
DISRUPTIONS	2.96	4.91	0	4.48	4.1	5.06	3.01	2.43	3.27	2.49	2.89	4.37	3.05	2.3	3.38	3.01	2.49	4.49	3.72	3.02	2.69	5.06	3.62	1.8	2.47	2.1	2.41	2.26	2.81	4.5	3.77	1.78	2.82	2.04	106
MOTIVATION	3.62	3.86	4.6	3.62	3.57	4.08	2.65	3.78	2.88	0	3.36	3.83	1.95	2.71	3.02	3.24	2.69	3.38	3.36	2.65	2.91	3.51	3.84	2.72	1.89	3.23	3.56	2.6	1.98	2.04	2.06	2.77	2.12	1.65	99.7
SAFETY	3.7	4.41	1.97	2.42	3.32	1.98	4.15	4.37	3.26	2.55	0	2.72	2.69	2.51	3.54	3.83	2.79	3.05	2	3.7	3.38	2.26	3.43	2.78	2.21	2.6	2.71	3.02	3.82	2.83	2.5	2.56	2.67	2.98	98.7
ACCELERATION OF PERFORMANCE	2.27	3.77	3.47	2.82	3.27	3.18	2.83	2.51	3.45	2.95	2	3.16	2	0	2.57	2.42	3.44	2.57	2.96	2.7	2.9	2.45	2.13	1.9	2.68	3.11	2.85	1.8	1.9	2.69	2.5	2.47	2.23	1.8	87.8
LEARNING CURVES	2.46	2.79	3.08	3.13	2.12	3.2	3.91	3.43	3.01	3.7	2.03	2.19	2.15	3.06	2.24	2	3.8	2.56	2.69	2.38	3.03	2.03	2.57	3.15	1.65	0	2.41	3.12	1.65	1.95	1.78	2.14	1.75	1.78	85
DESIGN & BUILDABILITY	2.94	2.53	2.09	2.69	2.82	3.3	4.4	2.96	0	1.75	3.23	1.8	4.75	2.48	1.65	2.38	2.1	2.34	1.75	2.79	1.75	2.53	2.1	2.41	1.9	2.27	1.75	1.95	3.21	2.28	1.85	1.65	2.13	3.97	82.5
WORK INSPECTION BY ENGINEER	3.19	3.05	2.81	2.36	2.94	2.7	2.64	3.27	2.51	2.41	3.31	1.91	2.47	2.79	2.78	1.93	2.79	2.38	2.37	1.88	2.32	2.69	2.5	1.8	2.67	2.32	1.98	1.93	2.22	2.13	2.23	1.78	0	2.19	81.3
COMMUNICATIONS	3.73	3.58	3.49	0	3.17	2.23	2.36	2.36	2.24	3.56	1.94	1.79	2.65	2.13	3.33	2.84	2.68	2.02	3	1.97	3.39	2.2	2.65	2.2	2.78	1.75	1.75	1.95	1.8	1.65	1.65	2.05	1.8	1.8	80.5
CHANGE ORDERS	2.98	3.37	2.87	2.65	3.88	0	2.41	1.8	4.67	2.1	1.93	1.93	3.58	2.7	2	2.3	2.13	3.03	2	2.31	1.75	2.72	2	1.65	3.2	2.03	1.95	1.65	2.37	1.93	2.18	1.65	2.46	2.31	80.5
USE OF EQUIPMENT	2.92	2.77	3.02	2.22	2.68	2.05	3.85	3.41	3	1.92	3.15	2.9	2.52	1.98	2.08	2.37	3.25	2.71	2	0	1.76	1.65	1.93	2.26	1.85	2.67	1.75	2.48	2.23	2.09	1.75	2.05	1.75	1.98	79
MATERIAL MANAGEMENT	4.78	3.48	3.31	2.84	2.76	3.03	2.49	2.41	2.25	2.03	2.76	2.4	2.92	2.66	2.9	2.41	2.28	2.16	2.39	2.15	2.08	1.98	1.78	1.8	1.98	1.95	1.95	1.65	1.65	2.24	0	1.65	2.01	1.78	78.9
NUMBER OF FOREMAN ON SITE	3.71	3.63	2.17	2.69	2.96	2.02	2.95	2.08	1.95	3.16	3.05	1.65	2.42	2.75	0	3.23	2.66	1.98	2.16	2.22	2.92	1.65	2.2	1.95	1.83	2.73	2.17	1.95	1.65	2.19	2.2	1.9	2.19	1.8	78.8
CREW SIZE	3.41	3.64	2.54	2.59	2.18	2.1	2.52	2.07	2.38	2.87	2.42	1.65	2.41	2.76	2.86	2.42	2.72	2.13	3.17	2.55	0	1.88	2.91	1.8	1.65	1.89	2.7	2.07	1.8	2.55	1.92	1.9	1.75	1.65	77.9
LEVEL OF SKILLED LABOUR	2.62	2.77	2.04	2.53	2.47	2.4	2.76	2.81	2.91	2.35	2.48	1.8	1.75	1.8	2.27	1.75	0	1.65	2.45	2.76	2.52	1.65	2.2	4.15	1.98	3.74	1.75	3.64	1.85	1.65	1.75	2.05	1.98	1.78	77.1
ABSENTEEISM	2.62	2.36	3.11	2.35	2.61	1.8	1.65	1.65	1.8	4.47	3.35	3.7	1.65	2.59	2.55	1.79	2.59	2.22	0	2.14	2.7	1.95	2.55	2.04	1.65	1.98	3.21	1.94	1.75	1.98	1.65	2.77	1.65	1.65	76.5
OVER TIME	2.82	2.72	3.21	1.75	2.38	3.49	2.04	1.8	2.18	2.87	2.25	3.08	1.65	3.27	1.98	1.75	2.05	2.45	2.57	2.43	2.33	2.17	1.78	1.65	1.95	1.9	0	1.65	1.75	1.85	1.91	4.18	1.88	1.65	75.4
CREW INTERFERENCE	2.99	2.84	2.25	3.13	2.26	3.01	2.06	2.43	1.98	2.74	2.57	2.31	1.65	2.23	2.97	2.36	2.46	2.44	2.58	2.31	2.85	1.65	0	2.24	1.65	1.75	1.89	2.17	1.65	1.65	2.03	2.05	2.13	1.65	75
MODERN MANAGEMENT SYSTEMS	2.78	2.21	2.62	4.27	2.54	1.85	2.41	3.01	2.59	2.49	1.75	1.65	2.65	2.18	2.1	0	2	2.08	1.65	2.08	2.08	1.91	1.75	3.39	2.59	1.85	2	1.8	1.85	1.65	1.9	1.78	1.85	1.93	73.3
LENGTH OF WORK DAY	2.55	2.65	2.61	1.9	2.12	2.61	1.65	1.8	1.94	3.27	2.15	2.35	1.65	2.38	1.75	1.65	1.75	1.65	2.74	2.05	2.34	2.14	1.65	1.65	2.29	1.89	3.37	1.65	2.68	2.2	1.65	0	1.95	1.65	70.4
INTERFERENCE BY OWNER	2.53	2.87	2.86	2.74	2.96	2.52	2	1.65	2.62	1.85	1.8	1.8	2.01	2.51	1.8	2.57	1.9	1.75	2	1.75	1.75	0	1.85	1.65	2.58	1.65	1.85	1.65	1.85	1.92	1.65	1.65	2.25	1.8	68.6
RESTRICTED ACCESS	2.11	2.21	2.35	1.96	1.98	1.83	1.85	1.65	2.07	1.85	2.71	2.08	1.78	1.95	1.75	1.65	1.75	1.75	1.95	2.47	1.75	1.95	2	1.65	1.9	1.65	1.85	1.65	1.85	0	2.35	2.1	1.65	1.65	63.7
DIFFERING SITE CONDITIONS	1.88	2.15	2.21	1.97	1.85	1.98	1.65	1.65	2.37	2.15	2.16	3.02	1.65	1.95	1.65	1.75	1.85	0	1.65	2.05	1.65	1.75	1.65	1.65	1.65	2.24	2	1.65	1.65	1.65	1.95	1.8	1.75	1.65	62.3
	75.5	74.2	66.3	65.9	65.7	65.6	64.7	63.7	62.8	62.1	61	59.9	59.4	58.9	58.7	58.2	57.9	57.4	57	55.7	55.6	54.7	54.5	54.1	54.1	53.5	52.5	51.4	51.4	51.3	50.7	49.2	48.4	48.3	

4 Figure 4.9 shows that part which represents the most important portion of the matrix. This portion of the matrix will be referred to as the 'reduced matrix'. The 'reduced matrix' is to be used to represent the whole matrix. This was felt necessary for two reasons. The first of these is the difficulty in considering all of the interactions between the factors. The second reason is that selecting the most important interactions can represent the system as a whole since it largely consists of the major interactions in themselves.

5 Select from the interactions, existing in the 'reduced matrix', a group which will be used as a base to build the model in Chapter 5. To achieve this, it is necessary to execute two steps:

- Consider interactions which have a score of more than 3.308 and ignore the rest. This number refers to the value of the 'Low' scale in the 'average normalised matrix', calculated as follows:

$$2 \text{ x average of indices} = 2 \times 1.654 = 3.308$$

- Rearrange the rows in order to have all the important interactions together.

The final outcome is a small matrix (shown in Figure 4.10).

Figure 4.9 The most important part of the 'Average Normalised Form'

	CONTROL OF THE PROJECT	PLANNING	CHANGE ORDERS	SIZE OF PROJECT	COMMUNICATIONS	TRAINING (OF ENGINEERS)	DISRUPTIONS	CONSTRUCTION TECHNOLOGY	DESIGN & BUILDABILITY	MOTIVATION	SAFETY
CONTROL OF THE PROJECT	0	5.602	4.718	4.896	4.562	4.231	3.696	3.2	3.749	3.262	4.288
PROPER PLANNING	4.747	0	4.425	4.981	4.193	4.077	3.933	3.238	3.731	3.284	3.411
DISRUPTIONS	4.105	4.907	5.064	2.96	4.482	2.431	0	3.008	3.273	2.494	2.89
MOTIVATION	3.565	3.861	4.083	3.617	3.617	3.782	4.595	2.645	2.875	0	3.357
SAFETY	3.323	4.415	1.984	3.699	2.419	4.369	1.972	4.146	3.262	2.547	0
ACCELERATION OF PERFORMANCE	3.268	3.77	3.182	2.273	2.822	2.512	3.469	2.832	3.446	2.955	1.998
LEARNING CURVES	2.12	2.794	3.196	2.462	3.13	3.428	3.078	3.912	3.012	3.704	2.034
DESIGN & BUILDABILITY	2.819	2.531	3.298	2.938	2.689	2.96	2.091	4.404	0	1.752	3.229
WORK INSPECTION BY ENGINEER	2.938	3.048	2.695	3.188	2.36	3.272	2.814	2.637	2.506	2.41	3.31
COMMUNICATIONS	3.17	3.581	2.225	3.735	0	2.363	3.489	2.359	2.242	3.555	1.941
CHANGE ORDERS	3.88	3.371	0	2.975	2.655	1.803	2.874	2.408	4.674	2.096	1.933

Figure 4.10 The 'reduced matrix' after ignoring any interaction less than 3.308

	CONTROL OF THE PROJECT	PLANNING	CHANGE ORDERS	SIZE OF PROJECT	COMM BETWEEN PARTIES	TRAINING (OF ENGINEERS)	DISRUPTIONS	CONSTRUCTION TECHNOLOGY	DESIGN & BUILDABILITY	MOTIVATION	SAFETY
CONTROL OF THE PROJECT	0	5.6016	4.7184	4.8955	4.5616	4.2308	3.6964	0	3.7487	0	4.2877
PLANNING	4.7469	0	4.4254	4.9811	4.193	4.0772	3.9335	0	3.7315	0	3.4106
DISRUPTIONS	4.1049	4.907	5.0638	0	4.4821	0	0	0	0	0	0
MOTIVATION	3.5655	3.8615	4.0826	3.617	3.6169	3.7821	4.5953	0	0	0	3.3575
SAFETY	3.3227	4.415	0	3.6986	0	4.369	0	4.1459	0	0	0
ACCELERATION OF PERFORMANCE	0	3.7698	0	0	0	0	3.4689	0	3.4458	0	0
LEARNING CURVES	0	0	0	0	0	3.4283	0	3.9116	0	3.7037	0
DESIGN & BUILDABILITY	0	0	0	0	0	0	0	4.4038	0	0	0
WORK INSPECTION BY ENGINEER	0	0	0	0	0	0	0	0	0	0	3.3095
COMMUNICATIONS	0	3.581	0	3.7348	0	0	3.4892	0	0	3.5553	0
CHANGE ORDERS	3.8796	3.371	0	0	0	0	0	0	4.6739	0	0

4.4.2 'Factors-Productivity Form' Knowledge Elicitation

The procedure followed to make use of the data available in the forms returned is more direct than that of the 'Factors Matrix'. This involves finding the average of the scores of each of the factors. The result of this procedure is shown in Figure 4.11. The factors are arranged in order of the importance of their effect on productivity.

4.5 COMMENTS ON THE RESULTS OF THE SURVEY

A number of important issues can be extracted when looking at the 'average normalised form' in Figure 4.8. This section highlights some of these issues.

It was mentioned in Section 4.4.1 that of all the interactions of the system, only three had been proved to be very important. These interactions are: planning influencing control, change orders influencing disruption, and interference of owner influencing disruption to the work. These results confirm what was mentioned in Chapter 2 about the major role that management could play in the success of the project, and about the effect of change orders and its detrimental effect on the productivity.

Interference by an owner can have a great effect on the progress of the work. If not happy with the progress of the work or its quality, the owner will then interfere. This in turn will lead to more disruptions to the work.

If the 'average normalised form' is to be looked at as a system, then within it there are subsystems. The 'reduced matrix' is considered to be the major subsystem referred to as

Figure 4.11 Results of 'Factors-Productivity Form'

Factors	Effects on Productivity
Planning	+7.24
Level of skilled labour	+6.24
Control	+6.12
Disruptions	-5.53
Motivation	+5.41
Design and buildability	+5.29
Communications	+4.82
Weather	-4.77
Training	+4.65
Use of equipment	+4.59
Material management	+4.53
Absenteeism	-4.41
Restricted access	-4.41
Change orders	-4.29
Acceleration of performance	-4.19
Modern management systems	+4.18
Construction technology	+4.18
Vocational training	+4
Overtime	-3.88
Learning curves	+3.71
Crew interference	-3.59
Length of workday	-3.53
Differing site conditions	-3.47
Crew size	-3.53
Safety	+3
Number of foremen on site	+2.94
Education	+2.88
Interference by owner	-2.77
Specifications	+2.77
Size of project	+2
Contract conditions	+1.88
Work inspection by engineer	+1.71
Design codes	+0.77
Government regulations	-0.71

'MAJ' in Figure 4.12. The existence of this major sub-system does not cancel the effect of other subsystems; they also have their roles in the system but their roles are of less importance.

Based on the idea of the hierarchy of systems, mentioned in Section 3.3, the major subsystem (MAJ) is composed of two sub-systems. As shown in Figure 4.12 these two subsystems are MAJ1 and MAJ2. MAJ1 is the upper part of the reduced matrix containing the most important factors in its rows. These factors are control, planning, disruptions, motivation and safety.

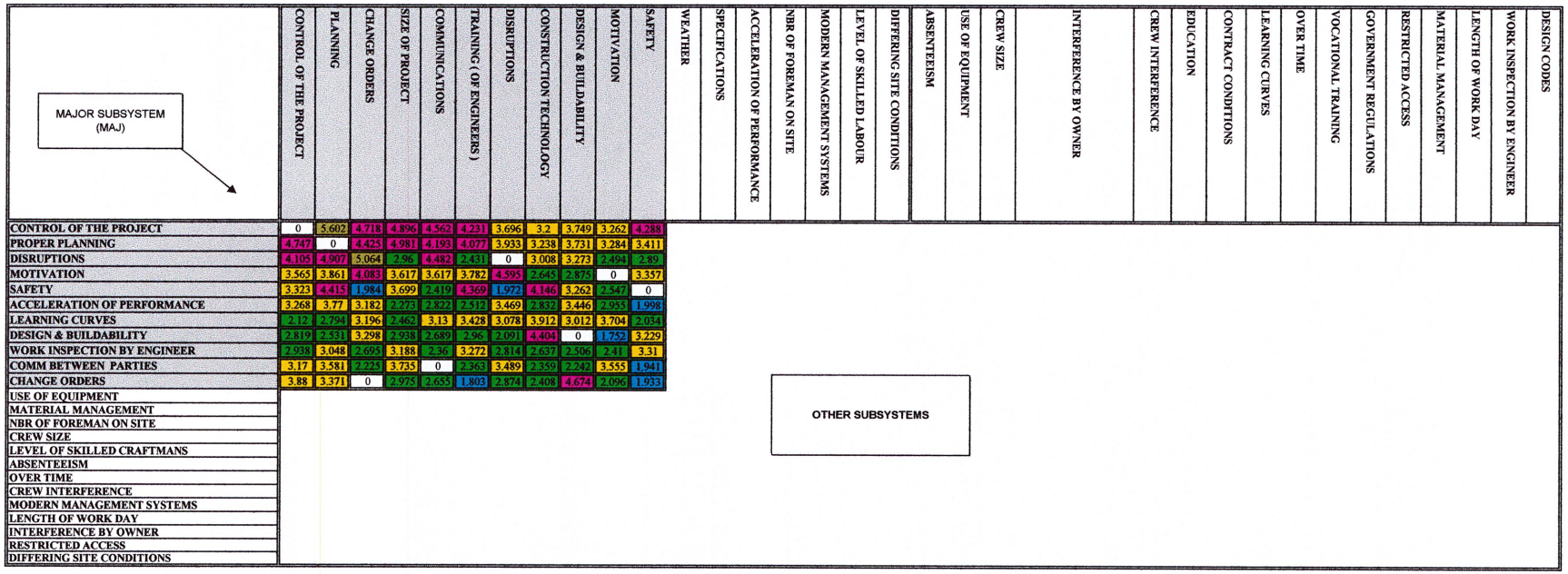
MAJ1 is a subsystem which consists of two subsystems: MAJ1-A and MAJ1-B.

MAJ1-A contains, in its rows and columns, the five important factors mentioned above. The idea of considering such subsystems is to have a clear view of how these important factors interact with each other. The rest of the factors in the columns, other than the important ones, are considered in the other subsystem (MAJ1-B). The two subsystems (MAJ1-A and MAJ1-B) are the core of the model to be considered in Chapter 5.

4.6 SUMMARY

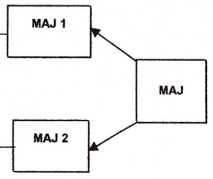
This chapter reviewed some of the survey methods available to researchers to acquire knowledge from experts. Of these methods, two were selected for the research work in this thesis. These are: questionnaires and face-to-face interviews. The results of these are two forms: 'Factors Matrix' and 'Factors-Productivity Form'.

Figure 4.12 The idea of subsystems within the main matrix

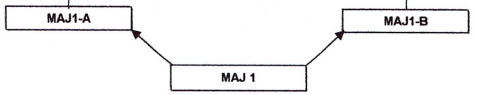


	CONTROL OF THE PROJECT	PLANNING	CHANGE ORDERS	SIZE OF PROJECT	COMMUNICATIONS	TRAINING (OF ENGINEERS)	DISRUPTIONS	CONSTRUCTION TECHNOLOGY	DESIGN & BUILDABILITY	MOTIVATION	SAFETY
CONTROL OF THE PROJECT	0	5.602	4.718	4.896	4.562	4.231	3.696	3.2	3.749	3.262	4.288
PROPER PLANNING	4.747	0	4.425	4.981	4.193	4.077	3.933	3.238	3.731	3.284	3.411
DISRUPTIONS	4.105	4.907	5.064	2.96	4.482	2.431	0	3.008	3.273	2.494	2.89
MOTIVATION	3.565	3.861	4.083	3.617	3.617	3.782	4.595	2.645	2.875	0	3.357
SAFETY	3.323	4.415	1.984	3.699	2.419	4.369	1.972	4.146	3.262	2.547	0
ACCELERATION OF PERFORMANCE	3.268	3.77	3.182	2.273	2.822	2.512	3.469	2.832	3.446	2.955	1.998
LEARNING CURVES	2.12	2.794	3.196	2.462	3.13	3.428	3.078	3.912	3.012	3.704	2.034
DESIGN & BUILDABILITY	2.819	2.531	3.298	2.938	2.689	2.96	2.091	4.404	0	1.752	3.229
WORK INSPECTION BY ENGINEER	2.938	3.048	2.695	3.188	2.36	3.272	2.814	2.637	2.506	2.41	3.31
COMM BETWEEN PARTIES	3.17	3.581	2.225	3.735	0	2.363	3.489	2.359	2.242	3.555	1.941
CHANGE ORDERS	3.88	3.371	0	2.975	2.655	1.803	2.874	2.408	4.674	2.096	1.933
USE OF EQUIPMENT											
MATERIAL MANAGEMENT											
NBR OF FOREMAN ON SITE											
CREW SIZE											
LEVEL OF SKILLED CRAFTMANS											
ABSENTEEISM											
OVER TIME											
CREW INTERFERENCE											
MODERN MANAGEMENT SYSTEMS											
LENGTH OF WORK DAY											
INTERFERENCE BY OWNER											
RESTRICTED ACCESS											
DIFFERING SITE CONDITIONS											

	CONTROL	PLANNING	CHANGE ORDERS	SIZE OF PROJECT	COMMUNICATIONS	TRAINING (OF ENGINEERS)	DISRUPTIONS	CONSTRUCTION TECHNOLOGY	DESIGN & BUILDABILITY	MOTIVATION	SAFETY
CONTROL	0	5.602	4.718	4.896	4.562	4.231	3.696	3.2	3.749	3.262	4.288
PLANNING	4.747	0	4.425	4.981	4.193	4.077	3.933	3.238	3.731	3.284	3.411
DISRUPTIONS	4.105	4.907	5.064	2.96	4.482	2.431	0	3.008	3.273	2.494	2.89
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SAFETY	3.323	4.415	1.984	3.699	2.419	4.369	1.972	4.146	3.262	2.547	0
ACCELERATION OF PERFORMANCE	3.268	3.77	3.182	2.273	2.822	2.512	3.469	2.832	3.446	2.955	1.998
LEARNING CURVES	2.12	2.794	3.196	2.462	3.13	3.428	3.078	3.912	3.012	3.704	2.034
DESIGN & BUILDABILITY	2.819	2.531	3.298	2.938	2.689	2.96	2.091	4.404	0	1.752	3.229
WORK INSPECTION BY ENGINEER	2.938	3.048	2.695	3.188	2.36	3.272	2.814	2.637	2.506	2.41	3.31
COMM BETWEEN PARTIES	3.17	3.581	2.225	3.735	0	2.363	3.489	2.359	2.242	3.555	1.941



	CONTROL	PLANNING	DISRUPTIONS	MOTIVATION	SAFETY		TRAINING (OF ENGINEERS)	CHANGE ORDERS	CONSTRUCTION TECHNOLOGY	DESIGN & BUILDABILITY	SIZE OF PROJECT	COMMUNICATIONS
CONTROL	0	5.602	3.6964	3.262	4.288		4.231	4.718	3.2	3.749	4.896	4.562
PLANNING	4.7469	0	3.9335	3.284	3.411		4.077	4.425	3.238	3.731	4.981	4.193
DISRUPTIONS	4.1049	4.907	0	2.494	2.89		2.431	5.064	3.008	3.273	2.96	4.482
MOTIVATION	3.5655	3.861	4.5953	0	3.357		3.782	4.083	2.645	2.875	3.617	3.617
SAFETY	3.3227	4.415	1.9717	2.547	0		4.369	1.984	4.146	3.262	3.699	2.419



The two forms were constructed based on 'systems theory' discussed in Chapter 3. These two forms were given to experts in the field to give their opinion about the interaction of factors in the 'Factors Matrix' and about the interactions of factors with productivity in the 'Factors-Productivity' form. The knowledge given by experts was then used to locate the most important subsystems. A major subsystem called MAJ is found to be the most important portion of all the interactions. This subsystem is largely the one which will form the base of the model in the next chapter.

In the data collection, respondents were asked to provide information about productivity in relative terms rather than absolute ones. For this reason all the productivities, that the factors affect, are relative.

Having identified the most influential factors and the interactions between them, these will be used in the following chapter as a basis for a system model of relative productivity.

The fact that only the major factors have been selected may give rise to concern but this selection was based on the idea that the interactions between these factors represent the system as a whole with sufficient accuracy. If, in any particular situation, it was felt necessary to include other factors, this would not significantly alter the form of the model.

All references to productivity in Chapters 5, 6 and 7 should be considered to be relative productivity.

CHAPTER 5

MODEL CONSTRUCTION

CHAPTER 5

MODEL CONSTRUCTION

5.1 INTRODUCTION

The raw data collected and analysed in Chapter 4 is translated into a mathematical model in this chapter. This mathematical model provides a quantitative study that simulates the construction productivity. It shows the relationships between the factors affecting productivity and between the factors and the productivity itself.

In Section 5.2 the steps involved in the modelling process are briefly described; Section 5.3 discusses the reasons behind the selection of certain groups of factors to be modelled.

System diagramming is a good tool to explain complex problems. For this reason a system diagram is used to provide a pictorial and qualitative representation of the relationships between the system components. This is the topic of Sections 5.4 and 5.5 which lay the foundation for Section 5.6 where transition equations for the model are constructed. In order to validate the model and investigate the possible uses of it, an Excel spreadsheet was used and this is discussed in section 5.7.

5.2 MODELING PROCEDURE

One of the main objectives of the research is to build a model that could be used to adopt strategies that help to improve productivity in construction projects.

Figure 5.1 shows a schematic diagram of the approach followed to build the model in this research. A summary of this approach is given below:

1. *'Determine the elements involved in the system'*

This step has already been covered in Chapter 4 where the major subsystem (MAJ) has been identified as the most important portion of the system. Factors in this subsystem (MAJ) constitute the elements of the model.

2. *Determine the relationships which exist between the elements*

The major subsystem (MAJ) is used as a tool to build the relationships between the elements in the model.

3. *Determine or define the limits to the system (the system boundary)*

The elements identified in the first step are of two types: internal factors and external factors. Weather, for example, determined as one of the important factors in the major subsystem 'MAJ', can be considered as a factor external to the system. This is because weather is a factor over which the management of the project has no control and hence it is included in the environment of the system. Planning, on the other hand, is considered to be an internal element. The reason for such consideration is that the management of the project has considerable control over this element. Categorising factors as either external or internal helps to define the boundary of the system.

4. *Draw a diagram for the system*

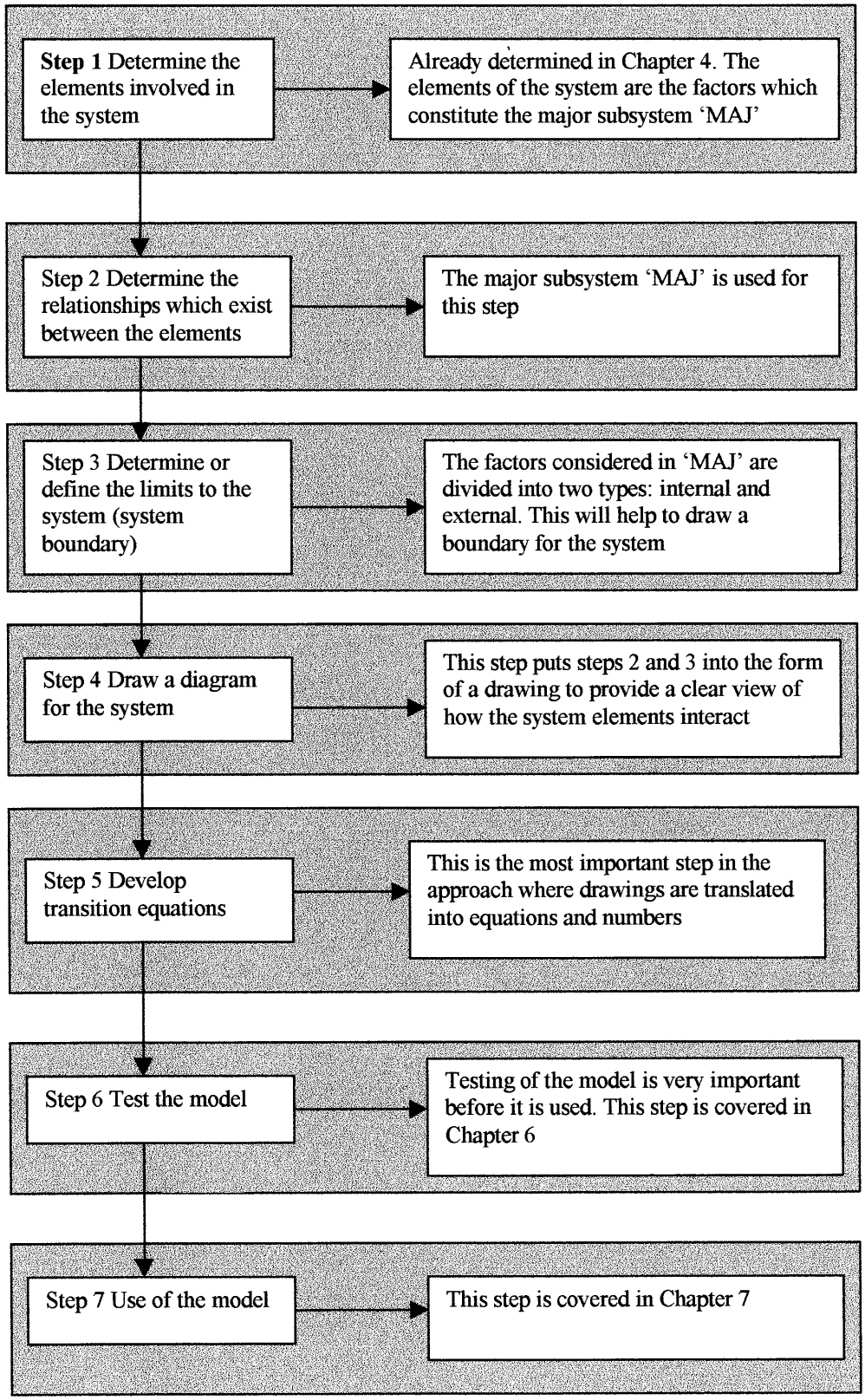


Figure 5.1 The 'Systems Approach' to the problem of the research work

This is a step which gives the analyst and the reader the ability to visualise the problem and understand it better. Therefore, this diagram should be simple and easy to understand as it models reality and it should show the relations existing between the elements in a very simple manner.

5. *Develop transition equations*

The major subsystem 'MAJ', in conjunction with the 'Factors Productivity Form', is used here to develop the equations required for the model.

6. *Test the model*

Coefficients considered in the transition equations of the model are prone to errors as these are derived from the qualitative opinions of experts. Therefore, a sensitivity analysis of these coefficients is necessary in order for the model to be valid for use. This step will not be tackled in this chapter but it is the topic of Chapter 6.

7. *Use of the model for prediction and/or control*

This step will be covered in Chapter 7.

The first four steps in this are very important, leading to the production of a system diagram which in turn will be used as a basis for all the analysis.

5.3 ELEMENTS INVOLVED IN THE SYSTEM

At the end of Chapter 4 it was concluded that there exists a group of interactions

between factors affecting the productivity of a construction project which is considered to be the most important of all the interactions. This group was called the 'major subsystem' and was abbreviated as 'MAJ'. Furthermore, this subsystem was divided into two subsystems: MAJ1 and MAJ2. The factors in these two subsystems are the elements of the model which is here called the 'general model'. The term 'elements', whenever it is used in this chapter, will mean the factors which affect productivity and which are included in the major subsystem (MAJ).

The 'general model' considered above contains 14 elements interacting with each other. The number of interactions produced by these elements is huge (48 in total), making it difficult to consider them all. Therefore, a 'reduced model' is to be considered. The elements of this model are the factors existing in MAJ1 and are shown in Figure 5.2.

Figure 5.2 shows also how MAJ1 is divided into two subsystems: MAJ1-A and MAJ1-B.

5.4 SYSTEM DIAGRAM

This section includes steps 2,3 and 4 of the systems approach discussed in Section 5.2. The factors in the major subsystem (MAJ) are included in the system diagram.

The interactions available in the major subsystem (MAJ) can be used to show part of the relationships existing between the elements; this is step 2 of the approach. Table 5.1 is produced for this purpose where it shows how factors are related. Three of the factors in

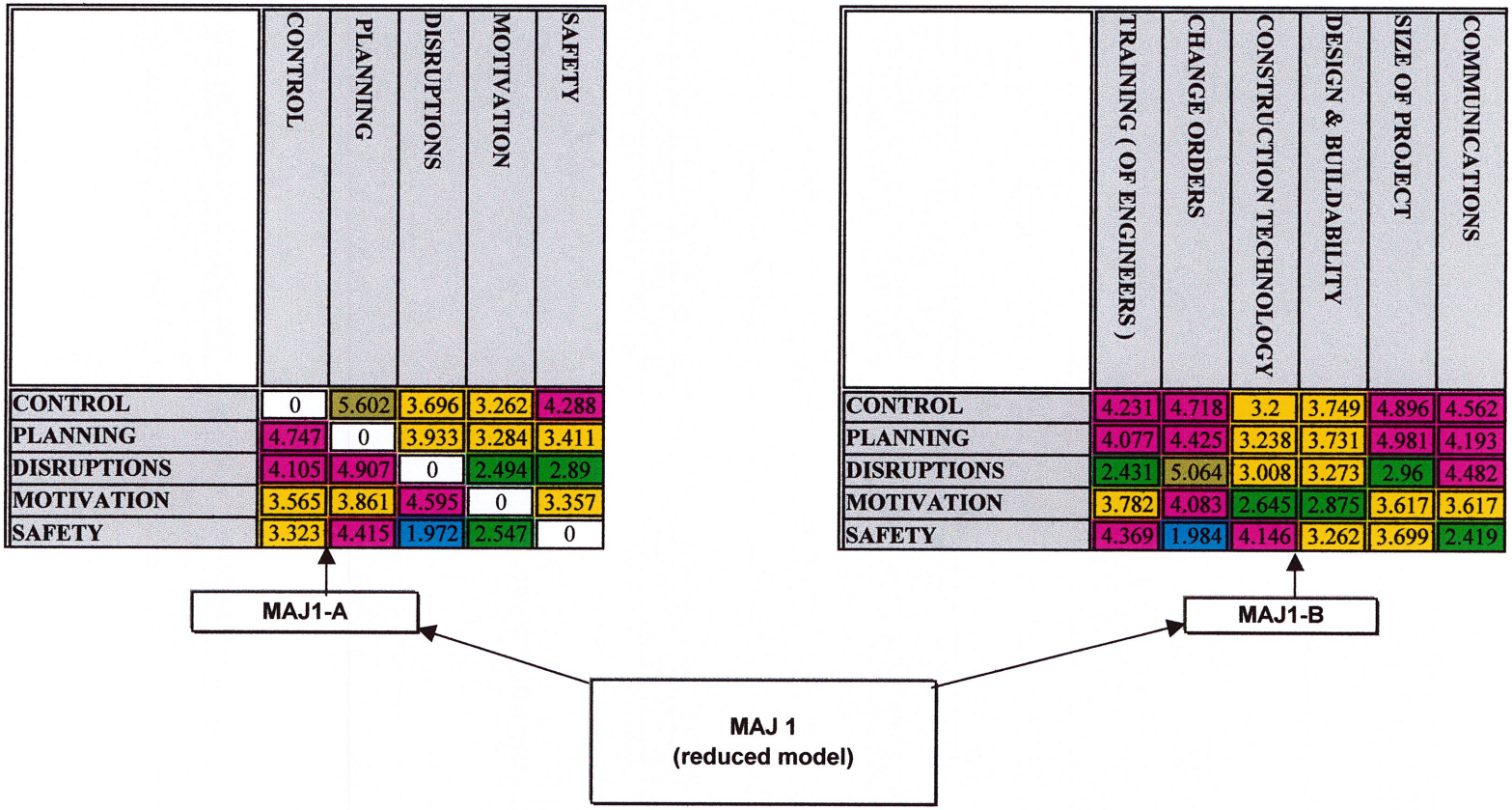
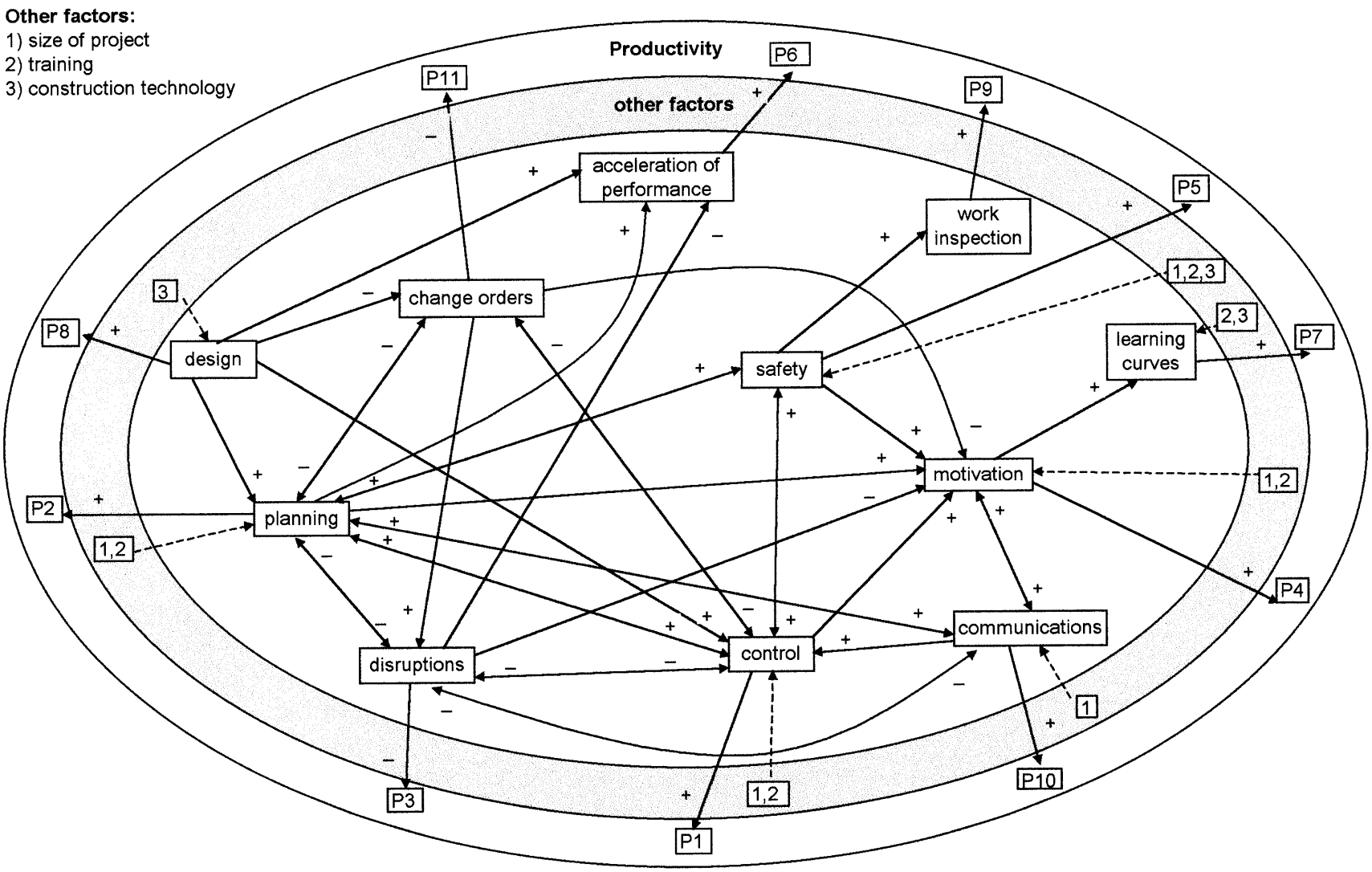


Figure 5.2 Subsystems with their elements used in the model

Table 5.1 Type of relationships between factors in the major subsystem (MAJ)

Relation	Type
Control - planning	+ ve
Control – motivation	+ ve
Control – safety	+ ve
Control – disruptions	- ve
Control – change orders	- ve
Planning – control	+ ve
Planning – motivation	+ ve
Planning – safety	+ ve
Planning – disruptions	- ve
Planning – communications	+ ve
Planning – change orders	- ve
Planning – acceleration of performance	- ve
Disruptions – control	- ve
Disruptions – planning	- ve
Disruptions – motivation	- ve
Disruptions – communications	- ve
Disruptions – acceleration of performance	+ ve
Motivation – communication	+ ve
Motivation – Learning curve	+ ve
Safety – control	+ ve
Safety – planning	+ ve
Safety – motivation	+ ve
Safety – work inspection by engineer	+ ve
Change orders – control	- ve
Change orders – planning	- ve
Change orders – motivation	- ve
Change orders – disruptions	+ ve

Figure 5.3 Major subsystem diagram



affected by motivation internally and by external factors number 2 and 3. Factor 2 is training while 3 is construction technology.

The system works as a loop where there is no specific start. Depending on what scenarios are considered, a start may be made at any point. Take, for example, 'design' as a starting point. In this case a number of routes could be envisaged. It is worthwhile explaining one of these routes to give a clear picture of how the system works. This route is as follows:

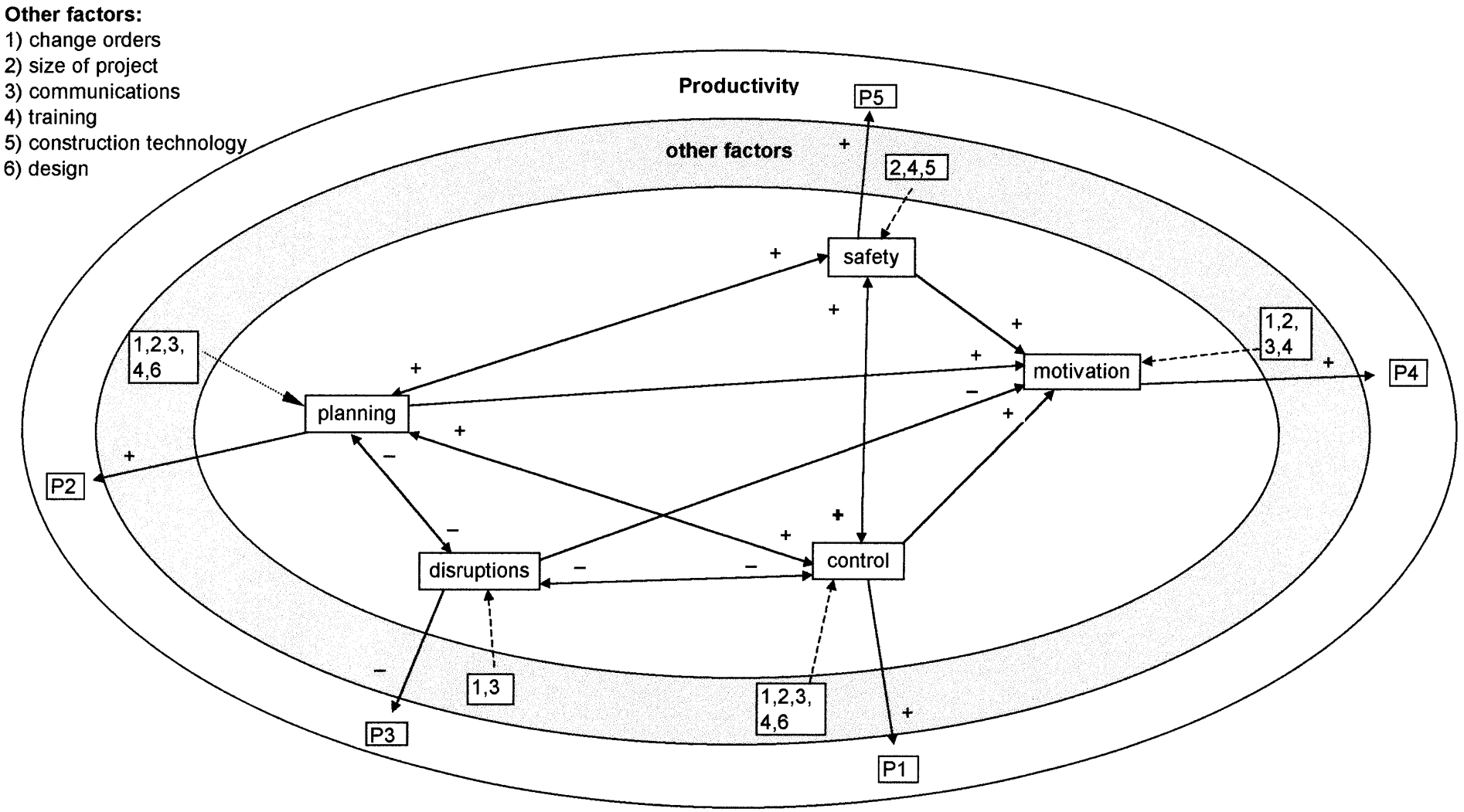
Design $\xrightarrow{+}$ planning $\xrightarrow{+}$ control $\xrightarrow{+}$ motivation $\xrightarrow{+}$ learning curves

This route implies that if design drawings are ready and perfect before the project starts, then this will help the management of the project to plan and proceed with the plan as required. Consequently, the quality of control of the project will indirectly be improved. Labourers witnessing better management of the project through good quality planning and control will be motivated to produce better work. As the project progress, the motivation of workers will increase.

5.5 MODEL DIAGRAM

From the major subsystem diagram shown in Figure 5.3 a simplified diagram, representing MAJ1 is drawn and is called the "Model diagram". This diagram is shown in Figure 5.4.

Figure 5.4 Model system diagram



In this diagram, only the elements of MAJ1-A: control, planning, motivation, safety and disruptions are considered within the inner ellipse, indicating their importance to the model. Elements of MAJ1-B are located outside the boundary of the inner ellipse and are treated as external.

In addition to the small loops existing between every two factors in the model diagram, there exist three main loops. Table 5.2 shows all the small loops while Figure 5.5 shows the three main loops.

The main loops will help to understand the behaviour of the model when considering certain scenarios. Consider, for example, loop 1. If the disruption to the work at any time is reduced then planning will be improved through completing activities on time. Improvement in planning will lead to better safety at work. Feeling safe at the site will motivate workers to do a better job. This is because, as the worker feels safe in his work, his work-rate will be improved which means a reduction in time needed for activities. This indicates effective control of the project.

Part of the argument considered for loop 1 could be applied to loops 2 and 3 as these loops are mainly part of loop 1. Loop 2, for example, is composed of three factors: planning, control and safety. Planning and control in construction projects are two functions which are strongly related to each other. Any improvement in one of them leads to improvement in the other. Safety precautions taken at work lead to better control of the project and better planning.

Table 5.2 Relations between elements of the reduced model (MAJ1-A)

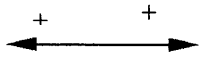
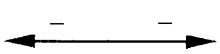
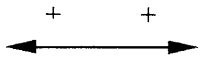
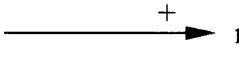
Relation	Type of relation	Comments
1) Control-Planning	Mutual influence	As control increases planning will increase and as planning increases the control will increase control  planning
2) Control-Disruptions	Mutual influence	As control is improved there will be fewer disruptions to the work. On the other hand if disruptions are reduced, then better control will be achieved. If disruption is increased, then it will reduce control of the project. control  disruptions
3) Control-Safety	Mutual influence	Improvement of control of the project requires an improvement to safety. If safety measures are taken, then this will help to control the project by minimising the number of accidents in the work which, in turn means less disruption to the work. control  safety
4) Control-Motivation	Single influence	Better management of the project through good control will motivate workers to do a better job. control  motivation

Table 5.2 (cont.)

Relation	Type of relation	Comments
5) Planning-Safety	Mutual influence	Good planning of a project means improvements in safety levels. At the same time good safety programmes will reduce the risk of accidents on the site, enabling the plan to proceed accordingly. planning $\overset{+}{\longleftrightarrow}$ safety
6) Planning-Disruptions	Mutual influence	Good planning for the project will prevent a lot of disruptions to the work. Work in the project will run smoothly unless there is an unpredicted cause of disruption, such as bad weather. The more disruptions occurring in the work, the more the planning is negatively affected and hence the schedule of the project is delayed. planning $\overset{-}{\longleftrightarrow}$ disruptions
7) Planning-Motivation	Single influence	Workers will be more motivated if they find that the management of the project has produced effective plans for the work. planning $\overset{+}{\longrightarrow}$ motivation

Table 5.2 (cont.)

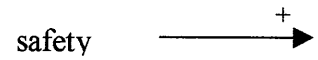
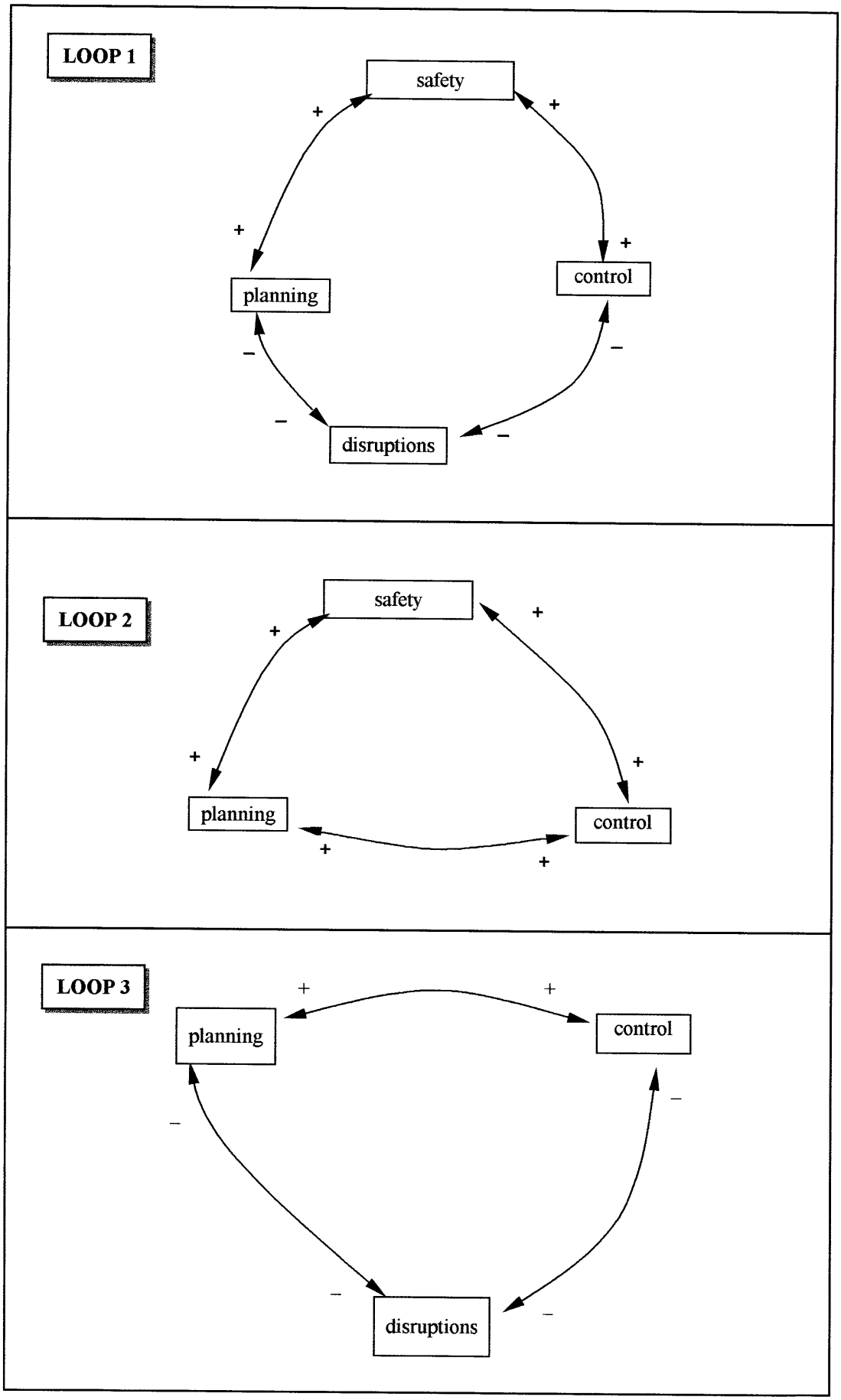
Relation	Type of relation	Comments
8) Disruptions-Motivation	Single influence	It is a psychological phenomenon that if a human being who is engrossed in his work is interrupted, then his motivation to do the work will be decreased. The more his work is disrupted the more reluctant he is to finish the job as required. Although he will undoubtedly finish the required job his rate will be influenced by the extent of his motivation. 
9) Safety-Motivation	Single influence	One of the necessities of life for any human is to feel safe. If the worker performs his job in a place where he feels there is no risk of his life then this will motivate him more. 

Figure 5.5 Causal Loops of the Model



Loop 3 is composed of three factors: planning, control and disruptions. Minimising disruptions will lead to better control and planning of the work and the reverse is also correct. Increased disruption to the work is one of the signs of poor planning and poor control of the project.

5.6 MODEL EQUATIONS

This section is the fifth step in the system approach discussed in Section 5.2. It shows how to relate elements and put them in equation form, but first it is a necessary to discuss two assumptions considered for building the model:

- The value of any factor at any period of time is the sum of two things as Figure 5.6 shows:

  1 a percentage from the previous period of that factor, and
  2 the influence of other factors on that factor from the previous period.

Translating this into equation form gives the following equation

$$factor_R(t) = e \times factor(t-1) + (1-e) \times factor(t) \qquad \textbf{Equation 5.2}$$

Where: $factor_R(t)$ = resultant value of the factor at period (t)

e = percentage of the considered factor from a preceding period

factor (t-1) = value of the factor from a preceding period

factor (t) = value of the factor at the present period influenced by other factors from a preceding period.

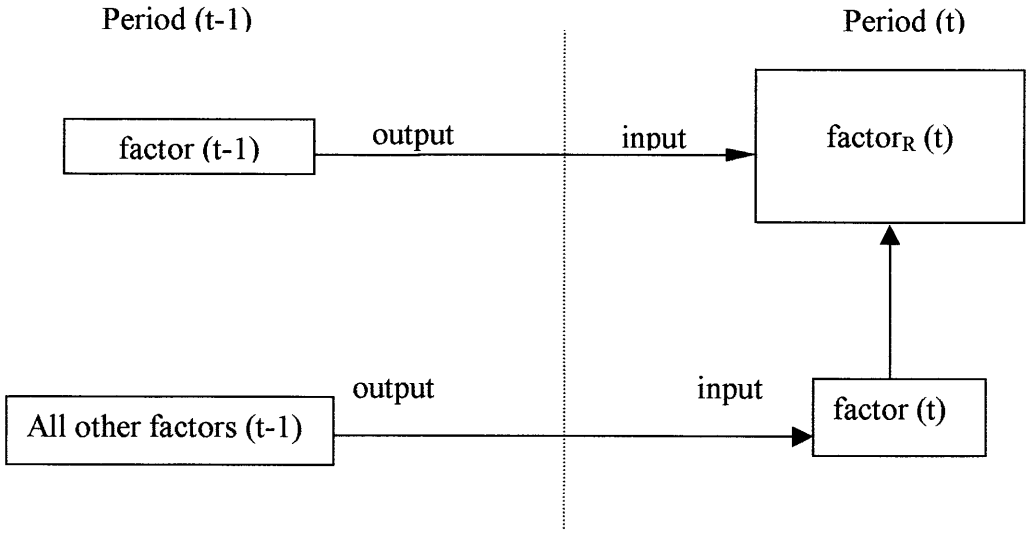


Figure 5.6 The idea of the resultant value of factors

At any period of time, the value of any factor is a commutative effect of previous periods. Planning at period 't', for example, is not separated from the previous effects and therefore, whatever value is obtained from a period, part of that value is a contribution of a previous effect.

There is no standard for how great a percentage is to be considered but it is a matter of judgement. Therefore, this percentage is to be assumed for Equation 5.2. For the purpose of the developed model, the assumed percentage is 80 percent for all the factors.

- Productivity is the result of:

  1 a percentage from the preceding period (t-1)

2 the influence of factors on productivity from the same period (t).

Figure 5.7 illustrates the above point. In equation form it could be written as follows:

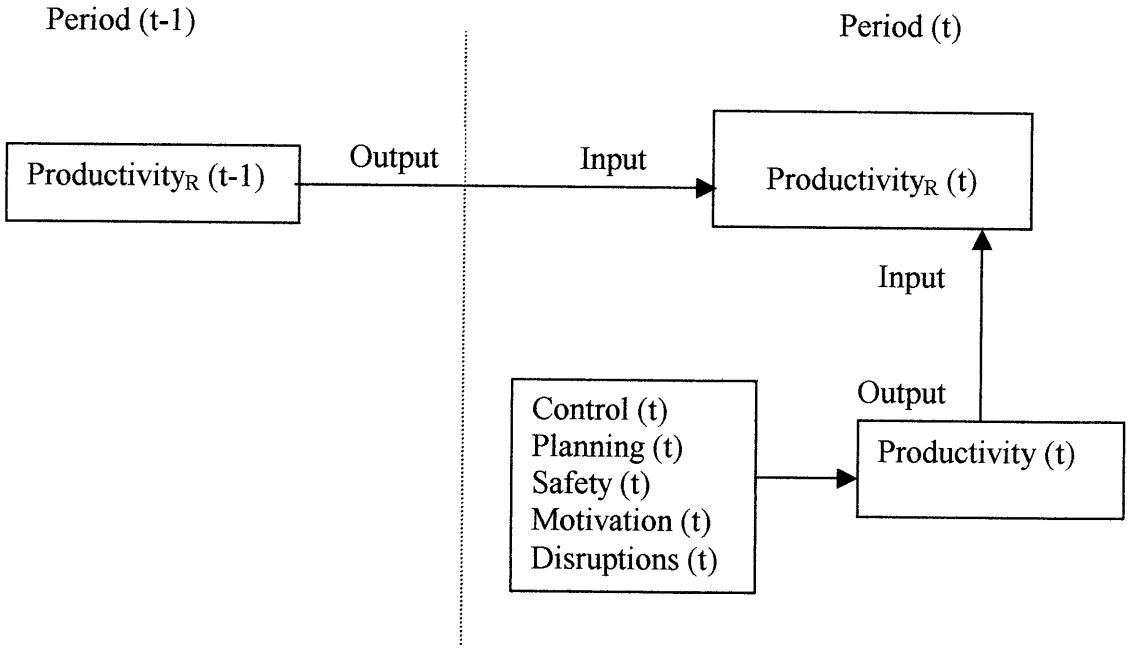


Figure 5.7 The idea of inputs for productivity from a preceding period

$$\text{Productivity}_R\,(t) = c \times \text{Productivity}\,(t\text{-}1) + (1\text{-}c) \times \text{Productivity}\,(t) \qquad \textbf{Equation 5.3}$$

Where: Productivity$_R$ (t) = resultant productivity at period (t)

Productivity (t) = productivity at period 't' as a result of the effects of factors in that period

c = percentage

Productivity (t-1) = productivity from the preceding period.

The same argument of the cumulative effect of factors is applied here for productivity. The productivity of an activity at any time is the result of a cumulative effect from previous periods.

5.6.1 CONSTRUCTION OF EQUATIONS

Each factor that affects productivity is itself affected by a number of factors. This viewpoint was mentioned in Chapter 4 and is emphasised here to form the base of the model equations. This viewpoint gives an indication that each factor is a function of a number of factors. For example, control is a function of planning, safety, disruptions and other factors from the previous period (Figure 5.6). Based on this, equations for the model are written as follows (the productivity equation will be considered later as it differs slightly):

$$Control_R(t) = e_c \times Control(t-1) + (1-e_c) \times Control(t) \qquad \textbf{Equation 5.4}$$

Where $Control_R$ = the resultant Control at period (t)

e_c = a percentage of Control from the preceding period, and

Control (t) = the Control value at period t as a result of other factors from the previous period. It can be calculated by the following equation:

$$Control(t) = b_c \times [a_{1,2} \times Planning(t-1) + a_{1,4} \times Safety(t-1) - a_{1,5} \times Disruptions(t-1)] + (1-b_c) \times other\ factors(t-1) \qquad \textbf{Equation 5.5}$$

Where: b_1 is a coefficient which relates 'significant factors' with the 'other factors' in MAJ1-B. Values of these coefficients are shown in Section 5.6.1.1.b.

$a_{1,2}$, $a_{1,4}$ and $a_{1,5}$ = coefficients which relate the significant factors with each other.

Substituting the value of Control (t) in equation 5.4 gives the following equation:

$$Control_R(t) = e_c \times Control(t-1) + (1- e_c) \times [b_c \times [a_{1,2} \times Planning(t-1) + a_{1,4} \times Safety(t-1) - a_{1,5} \times Disruptions(t-1)] + (1-b_c) \times other\ factors(t-1)]$$

Equation 5.6

Equation 5.4 applied for Control can be used for other significant factors and hence the following equations are obtained:

$$Planning_R(t) = e_p \times Planning(t-1) + (1- e_p) \times [b_p \times [a_{2,1} \times Control(t-1) + a_{2,4} \times Safety(t-1) - a_{2,5} \times Disruptions(t-1)] + (1-b_p) \times other\ factors(t-1)]$$

Equation 5.7

$$Motivation_R(t) = e_m \times Motivation(t-1) + (1- e_m) \times [b_m \times [a_{3,1} \times Control(t-1) + a_{3,2} \times Planning(t-1) + a_{3,4} \times Safety(t-1)] - a_{3,5} \times Disruptions(t-1)]+ (1-b_m) \times other\ factors(t-1)$$

Equation 5.8

$$Safety_R(t) = e_s \times Safety(t-1) + (1- e_s)\,[\,b_s \times [a_{4,1} \times Control(t-1) + a_{4,2} * Planning(t-1)] + (1-b_s) * other\ factors(t-1)] \quad \textbf{Equation 5.9}$$

$$Disruptions(t) = e_d \times Disruption(t-1) + (1- e_d) \times [b_d \times [a_{5,1} \times Control(t-1) + a_{5,2} \times Planning(t-1)] + (1-b_d) \times other\ factors(t-1) \quad \textbf{Equation 5.10}$$

Where: b_1, b_2, b_3, b_4 and b_5 are coefficients which denote how much effect significant factors have on the calculated factor. Coefficient b_m , for example, relates the effect of significant factors such as control, planning, safety and disruption on motivation.

Productivity Equation

Productivity is a function of the significant factors considered in MAJ1-A and the equation can be written as follows:

$$Productivity(t) = p_c \times Control(t) + p_p \times Planning(t) - p_d \times Disruptions(t) + p_m \times Motivation(t) + p_s \times Safety(t) \quad \textbf{Equation 5.11}$$

Where: p_c , p_p , p_d , p_m and p_s are coefficients which relate significant factors with productivity.

Substituting the value of Productivity (t) from Equation 5.9 in Equation 5.3 gives the following equation:

$$\text{Productivity}_R(t) = c \times \text{Productivity}(t-1) + (1-c) \times [p_1 \times \text{Control}(t) + p_2 \times \text{Planning}(t) - p_3 \times \text{Disruptions}(t) + p_4 \times \text{Motivation}(t) + p_5 \times \text{Safety}(t)]$$

Equation 5.12

There is no consideration in the productivity equation for other factors other than the significant ones. These factors have only an indirect effect which manifests itself throughout the five significant factors.

As can be noticed from the transition equations, there are three sets of coefficients: 'a', '*b*' and '*p*' coefficients. The procedure for producing these factors is discussed in the following section.

5.6.1.1 Coefficients of the Equations

The transition equations developed for the model include three sets of coefficients. These coefficients are:

- Type '*a*' coefficients: these coefficients are the coefficients produced for the equations of the 'significant factors' (factors in the MAJ1-A)

- Type '*b*' coefficients: these are coefficients produced for the equations of 'total factors' (all the factors in MAJ1)

- Type '*p*' coefficients: these are the coefficients produced for the productivity equation. The data available from respondents in the 'Factors-Productivity Form', discussed in Section 4.4.2, has been used for this purpose.

The results of the 'factors matrix', discussed in Chapter 4 and specifically the results of the MAJ subsystem, and the data obtained in the 'Factors Productivity Form' can be used to produce these coefficients. The procedure followed for each type of coefficient is discussed separately in the following sections.

5.6.1.1-a Procedure to Produce *'a'* Coefficients

The procedure followed to obtain this type of coefficient consists of two steps. These are as follows:

Step 1

The total effect of the five significant factors on productivity is found using Equation 5.1. The number of elements 'i' considered here is 5, as can be seen from Figure 5.4. Hence the total effect on productivity of the five elements is

$$= P_1 + P_2 + P_3 + P_4 + P_5$$

Values of P can be obtained from the 'Factors-Productivity Form', shown in Figure 4.11 and shown again here in Table 5.3. The total effect of factors on productivity is therefore:

$$= 6.12 + 7.24 + 5.53 + 5.41 + 3 = 27.3$$

Table 5.3 Part of the 'Factors-Productivity Form' showing the effect of the significant factors on productivity

Factors	Effects on Productivity
Control (P_1)	+6.12
Planning (P_2)	+7.24
Disruptions (P_3)	-5.53
Motivation (P_4)	+5.41
Safety (P_5)	+3
Absolute total effect	27.3

The total effect considered here is the sum of absolute values and no consideration is given to the minus sign shown for disruptions in Table 5.3 as this effect is already considered in the transition equations (equations 5.6-10).

Step 2

In this step the effect of each interaction between any two factors is related to the total effect on productivity calculated in step 1. To demonstrate how the coefficients are calculated, part of the system diagram in Figure 5.4 is shown in Figure 5.8. This part shows four elements: planning, control, safety and disruptions. It shows planning affected by control, safety and disruptions. For the sake of simplicity in referring to coefficients, numbers are allocated to elements as can be seen in both Figure 5.8 and Figure 5.9. For example, for the diagram shown in Figure 5.8, the coefficients related are:

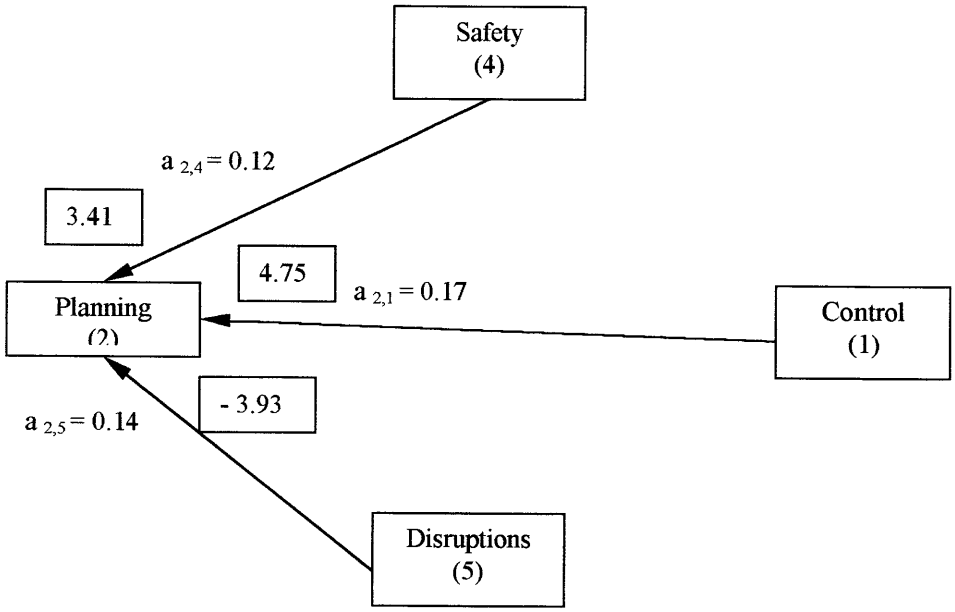


Figure 5.8 Part of the model system diagram

- $a_{2,1}$: this coefficient relates to the interaction between planning, shown in the drawing as number 2, with control which is number 1
- $a_{2,5}$: this coefficient relates to the interaction between planning (number 2) and disruptions (number 5)
- $a_{2,4}$: this coefficient relates to the interaction between planning (number 2) and safety (number 4).

To calculate the coefficient $a_{2,4}$,for example, the quantity of interaction between safety and planning, which is 3.41 (refer to MAJ1-A) shown in the small box above the arrow, is divided by the total effect on productivity:

$$a_{2,4} = 3.41 / 27.3 = 0.125$$

Similarly, all the coefficients are calculated in the same manner and are shown in Figure 5.9.

Figure 5.9 Type 'a' coefficients

		1 CONTROL	2 PLANNING	3 MOTIVATION	4 SAFETY	5 DISRUPTIONS
1	CONTROL	0	$a_{1,2} = 0.21$	$a_{1,3} = 0$	$a_{1,4} = 0.16$	$a_{1,5} = 0.14$
2	PLANNING	$a_{2,1} = 0.17$	0	$a_{2,3} = 0$	$a_{2,4} = 0.12$	$a_{2,5} = 0.14$
3	MOTIVATION	$a_{3,1} = 0.13$	$a_{3,2} = 0.14$	0	$a_{3,4} = 0.12$	$a_{3,5} = 0.17$
4	SAFETY	$a_{4,1} = 0.12$	$a_{4,2} = 0.16$	$a_{4,3} = 0$	0	$a_{4,5} = 0$
5	DISRUPTIONS	$a_{5,1} = 0.15$	$a_{5,2}$ 0.18	$a_{5,3} = 0$	$a_{5,4} = 0$	0

5.6.1.1-b Procedure to Produce 'b' Coefficients

Type '*a*' coefficients are concerned with the relations existing between the factors control, planning, motivation, safety and disruptions which are in subsystem MAJ1-A. In MAJ1-B there are other interactions between factors which are also of importance and should not be ignored when building the model. Type *'b'* coefficients take this into

consideration. These coefficients relate the effects of factors in MAJ1-B to the significant factors in MAJ1-A.

The procedure followed for these calculations is as follows:

- Subsystem MAJ1-A in Figure 5.4 constitutes the main part of this process as it includes the interactions between the five important elements selected for the model. The total score of each significant factor in MAJ1-A is found and is called $Factor_{significant}$. Factor here relates to any of the five significant factors. Thus, if safety is to be considered then it is $Safety_{significant}$.

- The overall sum of all interactions between the significant factors and all other factors in MAJ1 is found and is called $Factor_{total}$.

- The coefficients are found by dividing the total sum of significant variables $Factor_{significant}$ by the overall sum $Factor_{total}$. For example, the coefficient relating to motivation is

$$\text{Motivation coefficient} = \frac{Motivation_{significant}}{Motivation_{total} \times 100} = \frac{15.4}{30.5 \times 100} = 0.5$$

Figure 5.10 shows $Factor_{significant}$, $Factor_{total}$ and 'b' coefficients for the five significant factors.

Figure 5.10 calculation of '*b*' coefficients

	$Factor_{significant}$	$Factor_{total}$	Coefficient
Control	13.6	35.7	b_c=0.38
Planning	12.1	33.5	b_p=0.36
Motivation	15.4	30.5	b_m=0.50
Safety	7.74	20	b_s=0.39
Disruptions	9.01	18.6	b_d=0.48

5.6.1.1-c Procedure to Produce '*p*' Coefficients

These coefficients relate significant factors to productivity. They could be obtained by dividing the effect of each significant factor on productivity by the total effect of all significant factors on productivity. In equation form this could be written as:

$$\frac{P}{P_{significant}}$$

Where: P = the effect of the considered significant factor on productivity

$P_{significant}$ = the overall effect of significant factors on productivity. This could be obtained by using Equation 5.1 where i is equal to 5.

For example, p_c coefficient for control can be calculated as 6.12/27.3 = 0.22. In a similar manner other coefficients are calculated and shown in Table 5.4.

5.7 USE OF SPREADSHEET FOR THE MODEL

In order to validate the model and investigate the possible uses of it, an Excel spreadsheet was used. A number of important issues are to be raised regarding the

Table 5.4 The coefficients of relations between significant factors and productivity '*p*' coefficients

Factors	Effects on Productivity	'p' Coefficients
Control	+6.12	0.22
Planning	+7.24	0.27
Disruptions	-5.53	0.20
Motivation	+5.41	0.20
Safety	+3	0.11
Absolute total effect	27.3	

model in the spreadsheet. These are:

- equations entered in the spreadsheet are the equations of significant factors (Equations 5.6-10) and productivity (Equation 5.11).

- the scale used for significant factors and productivity is as follows:

Control: the scale used in this case is 0 to 10.

If the management of the project is not taking sufficient measures to control the project and does not allocate enough money for this purpose, then this means poor control. Therefore, control will be very low (say 3 or 4). On the contrary, more effort spent by management will improve control. In this case a score of 8 or even 9 out of ten will be achieved.

Planning: the scale used in this case is 0 to 10.

Good planning by management and increased spending of time, effort and money will increase the level of planning. A score below 5 means that management should improve things.

Motivation: the scale used is 0 to 10

A level of 2 in motivation means that workers at work are not motivated well to do their work and more attention is to be directed towards them. If a level of, say 8, is achieved, then the motivation of the labour force is high.

Safety: the scale used is 0 to 10

No safety at work means it is 0. Poor safety at work means something near to zero. If safety is high then it is near to 10.

Disruptions: the scale used is 0 to 10

The scale used for disruptions measures how much the work is disrupted. If the level of disruption is 1 then this means about 10% of the work is disrupted.

Productivity: the scale used is 0 to 10

The scale indicates the level of productivity of the project. If the level is, say 2, then this means that the productivity of the project is low and things are to be improved.

- Initial values for significant factors and for productivity should start in some cases at zero level and in other cases at five or nine in order to assess how the model behaves at very low level, at average and at high levels.

- Effects of other factors considered in equations of factors are assumed to be random, as there are various effects. These effects could be either negative or positive. Such an assumption is due to the fact that this value is the result of the effect of a number of factors. These factors may vary in their effect on the factor which is considered significant. This effect may add up to a positive value in cases where factors which have a positive effect dominate the situation, or to a negative one where negative factors are in the majority.

- The disruptions equation is not to be considered for the model. This is to test the model for ideal cases where there are no disruptions.

5.8 SUMMARY

This chapter has described the construction of a model for relative productivity for construction projects. It has shown how the information collected from engineers is used to produce system diagrams and transition equations.

The model assumes that there is a group of factors which has a major role in controlling the output of the project. This group was used to build a model which gives a representation of the reality.

Within the system diagram of the model there exists a number of causal loops, which were briefly explained to gain a conceptual view of how the model behaves. However, the actual behaviour needs to be tested by running some experiments. This is described in Chapter 6.

CHAPTER 6

MODEL EXPERIMENTATION

CHAPTER 6

MODEL EXPERIMENTATION

6.1 INTRODUCTION

This chapter describes a series of experiments which were conducted on the system model described in Chapter 5.

The chapter starts with specifying the objectives of performing tests on the model. It then explains how these experiments are designed to meet those objectives. Sections 6.3 to 6.5 describe experiments to determine the behaviour of the model; to assess the effects of any errors in it, and to modify it if and where necessary.

6.2 MODEL TESTING

There are two basic types of testing to a model. The first is testing carried out to ensure that there are no unforeseen differences between the model being used and the theory on which the model is based. These differences usually occur because of errors in the model construction but may also happen when a computer package behaves in an unpredicted manner.

The second type of testing is that designed to determine the behaviour of the model when aspects, which are not known with certainty, are changed. Here, for example, the model developed in Chapter 5 contains coefficients which were developed from answers to questionnaires and cannot therefore be known with certainty. This type of testing is

required in order to predict the sensitivity of the model to changes in these uncertain variables. By comparing the behaviour of the model with different values of coefficients it is possible to determine whether or not the model can be applied with confidence.

With these two types of testing in mind, the following objectives for testing have been recognised:

- To ensure that no differences exist between the model and the basic theory- *'error removal'*
- To determine the sensitivity of the model to variations in coefficients

The second objective must be applied to all the model coefficients described in Chapter 5 and therefore can be stated in detail as:

1. To test the sensitivity of the model to variations in *Significant Factors (SF)* coefficients (*'a'* coefficients). This is necessary because as described above about the development of the model, values of the coefficients cannot be known exactly.

2. To test the sensitivity of the model to variations in *Total Factors (TF)* coefficients (*'b'* coefficients)

3. To test the sensitivity of the model to variations in *Productivity Equation* coefficients (*'p'* coefficients)

4. To test the sensitivity of the model to variations in *Significant Factors - Productivity (SF-P)* coefficients (*'a'* and *'p'* coefficients).

These objectives form the foundations for the design of the testing regime described in the following section.

6.3 ERROR REMOVAL

Errors can occur at several stages in the development of a model. In particular in this work they could have happened:

1. When the coefficients were being developed
2. When the equations were being entered into the computer

Errors at stage 1 are very difficult to find and, indeed, may only come to light as the rest of the testing proceeds. This point had to be borne in mind when interpreting results for the tests described in Section 6.4.

Errors at stage 2 are remarkably common (Reason, 1990) and can have significant effects. In this work the process of 'debugging' the equations was carried out in a systematic manner to ensure that errors were minimised.

6.4 SENSITIVITY TESTING

6.4.1 Design of Experiments

Model parameters were developed through transferring qualitative opinions of construction experts to quantitative ones. This was done in the analysis of the questionnaire as described in Section 4.5. As was discussed there, the interpretation of opinions is very difficult and the actual values obtained could vary depending on the set of experts used and the analysis methods employed. It is apparent therefore that such an operation will result in some uncertainties in the model. In particular, the values of the coefficients associated with the factors in the system equations are not known with certainty. Indeed the factors classed as significant in Chapter 5 may, under different circumstances, not be significant. The importance of the relative contribution therefore of each factor to the overall productivity must be examined.

The values used in the model may be 'wrong' in that they might not be the exact values which should be used in any situation. This is despite being the best estimate of the values which could be made from the available information. However, despite being in error, they may collectively model the actual system satisfactorily. If the model is to be used for forecasting the behaviour of the real system, it is essential to know what the effects of errors in the coefficients on it are.

Since the estimates of the coefficients have been derived in a rational way from the data available (see Section 5.6.1) the errors in their values is likely to be small. Thus testing has concentrated on the range value ± 40%.

All the tests in this section take the form of evaluating the equations over a number of periods with different values of the coefficients. Since some of the coefficients in each test will be changed randomly, it is a Monte Carlo simulation of the project. The process of this simulation is repeated for hundreds or even thousands to produce a distribution that will represent the project outcome (Mawdesley, 1997). Tests have been conducted to decide what is the best number of iterations to be used.

The design of the testing regime requires decisions to be made concerning the length of the operation and the analysis requirements. It must also recognise the classification of the coefficients. Classification of coefficients is already stated in Section 6.2 while other aspects are described below and following this, the procedure to be adopted is developed.

6.4.2 Length of Operation

To decide how many periods to run the model for and when to assess the output from the model, a number of options were considered.

1. **Model reality (1):** a construction project will operate for, say, 2 years with planning/control decisions made monthly. In this case the number of periods for which the model should be tested is 20 to 25.

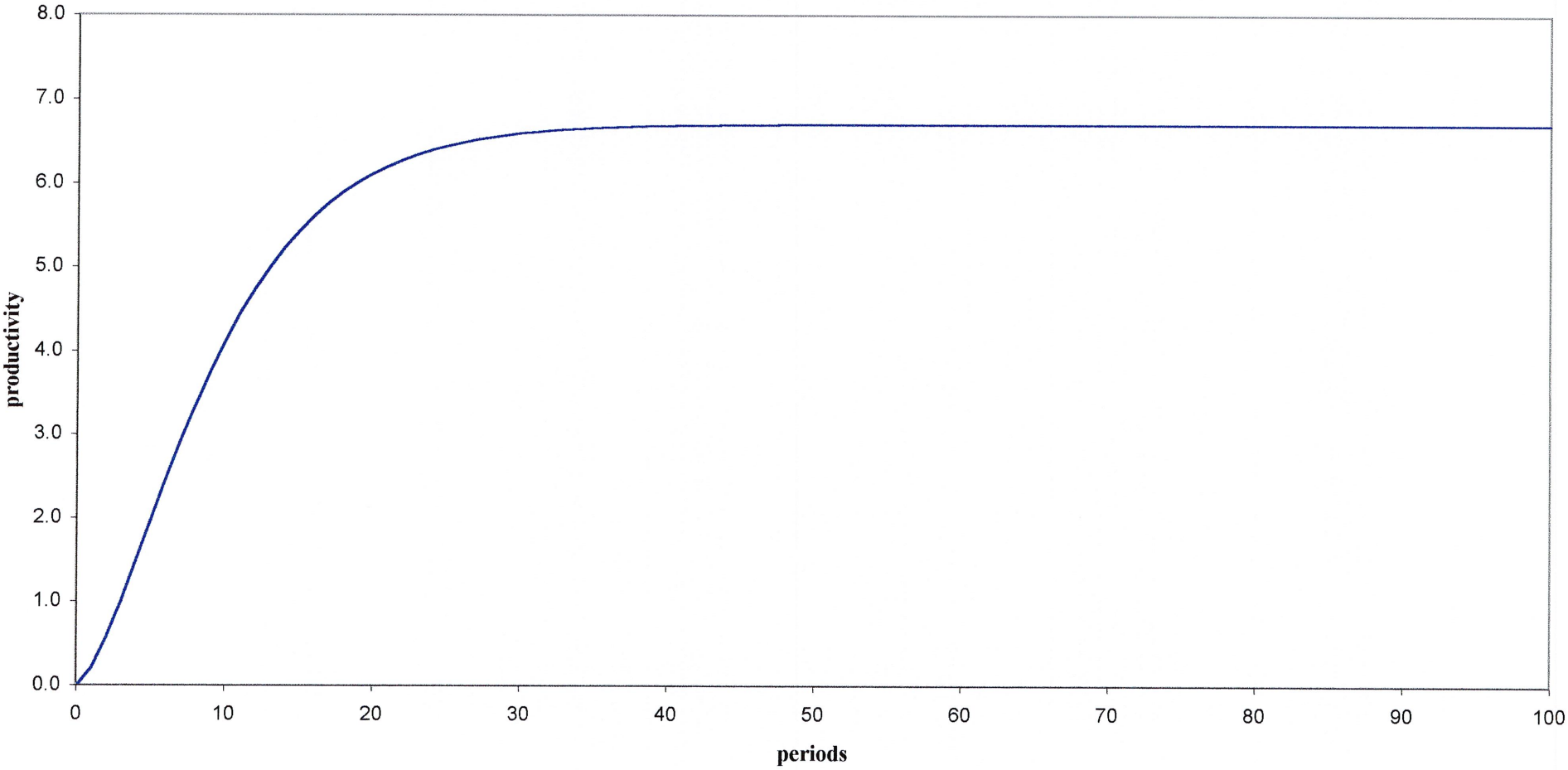
2. **Model reality (2):** a construction project operating with weekly planning/control decisions. If it is assumed that the project is to operate for about one year then the suggested duration for the testing of the model is between 50 and 60 periods.

3. **Stability of the model:** look at when the model becomes stable (if ever) and consider this to happen on a construction project after the learning curve has been passed.

The amount of time taken to run the model depends on the number of periods over which it is operated. Typically, 100 periods run through the full Monte Carlo simulation takes approximately 20 hours where 40 periods takes 5 hours and 20 periods approximately 2.5 hours in a Pentium with 16 MB Ram. With so many tests to run it was important from a practical point of view to limit the number of periods whilst still ensuring the validity of the results.

To this end, a test of the model with all initial values at zero was carried out over 100 periods. This enabled a decision to be made as to when stability occurred. Figure 6.1 shows the average productivity against time for the model with 100 periods and all initial values of the factors and productivity at zero. As can be seen from this graph, productivity increases in the early stages of the project until it reaches a constant level somewhere between 35 and 40 periods. Therefore a decision was taken to use the 40 period duration for the model.

Figure 6.1 Average productivity over time for the model



6.4.3 Analysis Requirements

To reach a conclusion as to whether the model is sensitive to variations of coefficients or not, certain parameters have to be examined and/or compared. These are:

1. Average productivity outcome for the model with no variations. This represents the benchmark for all comparisons.

2. Frequency distribution of the productivity outcome for the model with no variations at different periods. This again is to be used as a benchmark for comparisons.

3. Average outcome of the significant factors and productivity with different percentages of variations in the *'Significant Factors'('a') coefficients'*, *'Total Factors' ('b') coefficients*, *'productivity' ('p') coefficients* and the combination of *'Significant Factors'('a') and productivity' ('p')* coefficients

4. Frequency distributions of productivity and significant factors outcome for different periods in the model with variations in the coefficients mentioned in 3 above to compare them with the distributions of the benchmark model.

6.4.4 Procedure of Testing

The procedure followed to obtain the above requirements is shown in flowchart form in Figure 6.2. The following paragraphs are an elaboration of particular aspects of that procedure.

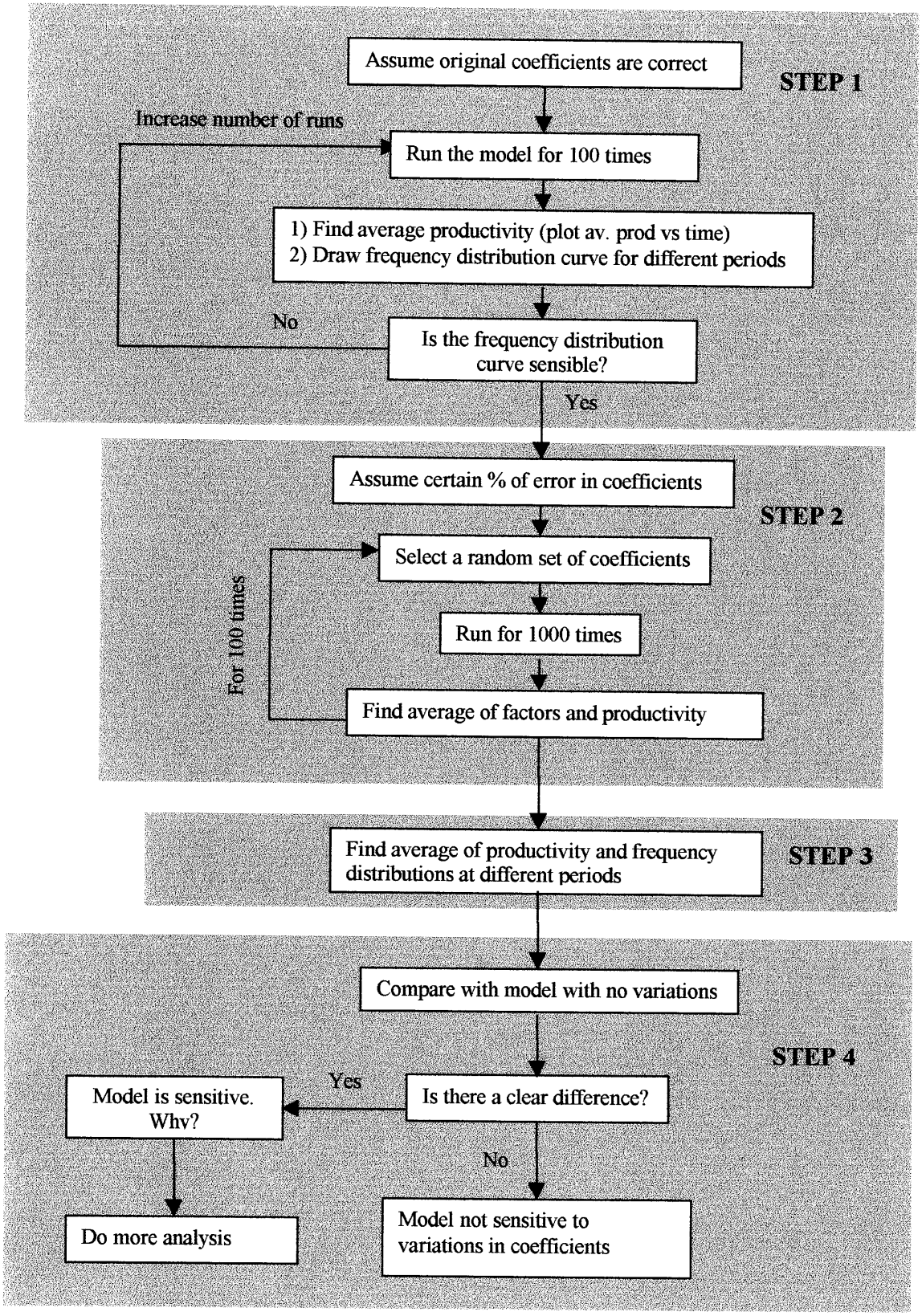


Figure 6.2 Procedure for testing the model

Step 1

It is necessary to have a reference or a benchmark where any comparison is to be performed. In this case, this is the model without any variations. The main aim here is to obtain the average productivity together with the frequency distribution of the productivity outcome at different periods. The average productivity will be obtained by iteration of the model for 1000 runs and by taking the average for all these runs. The idea here is to ensure a fair representation of the reality as one run of the model does not reflect the real picture.

The simulation was run for 1000 iterations. This number was chosen after several trials with different numbers of iterations.

Step2

The percentage variation in the model coefficients has to be assumed. There is no knowledge as to how accurately they were determined. However, it is considered likely that they will be within ±10% and very unlikely that they will be outside ±40%.

It would be a lengthy procedure to test each coefficient individually. Therefore, these coefficients are to be treated as a group where all of them are to be tested for variations. At this stage a random set of coefficients is chosen and simulated for 1000 runs to find the average of productivity. Selection of random sets of coefficients is simulated for 100 runs.

Each model was tested with variations of 5, 10, 15, 20, 25, 30, 35 and 40% on the coefficients. Thus for example, the equation:

$$\text{Control (t)} = b_1 * [a_{1,2} \times \text{Planning (t-1)} + a_{1,4} \times \text{Safety (t-1)} + a_{1,5} \times \text{Disruptions (t-1)}] + (1-b_1) \times \text{other factors (t-1)}$$

contains the coefficients: $a_{1,2}$, $a_{1,4}$ and $a_{1,5}$. If a 15% variation is considered for all the set, which in this case consists of three coefficients for the control equation, then the new values of coefficients will be within the following ranges:

$a_{1,2}$ between 0.1785 and 0.2415

$a_{1,4}$ between 0.136 and 0.184

$a_{1,5}$ between 0.119 and 0.161

Step 3

The average result of factors and productivity after 100 runs is calculated together with the frequency distribution of different periods.

Step4

This is the stage where it is decided whether the model is sensitive to errors in the coefficients or not. A comparison of the average of factors and productivity and a comparison in the frequency distribution of the model without variations and the model

with variations will determine if the model is sensitive or not. If there is no difference between the two comparisons, then the model is not sensitive.

There is a possibility that there is a difference between the model without variations and the one with variations. In this case more analysis is needed to locate where this sensitivity comes from. It may be needed to test each coefficient individually to find if this coefficient is the one which causes the problem.

6.5 RESULTS ANALYSIS

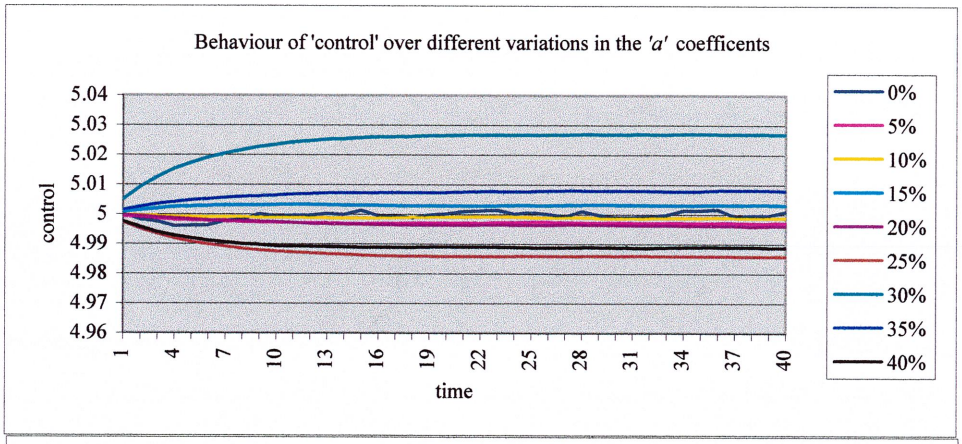
The results of all the experiments have been analysed and presented in graphical form in Figures 6.3 to 6.10. Tabulated values for the main figures are presented in Appendix A. For Clarity, the interpretation of information is described here in a separate section.

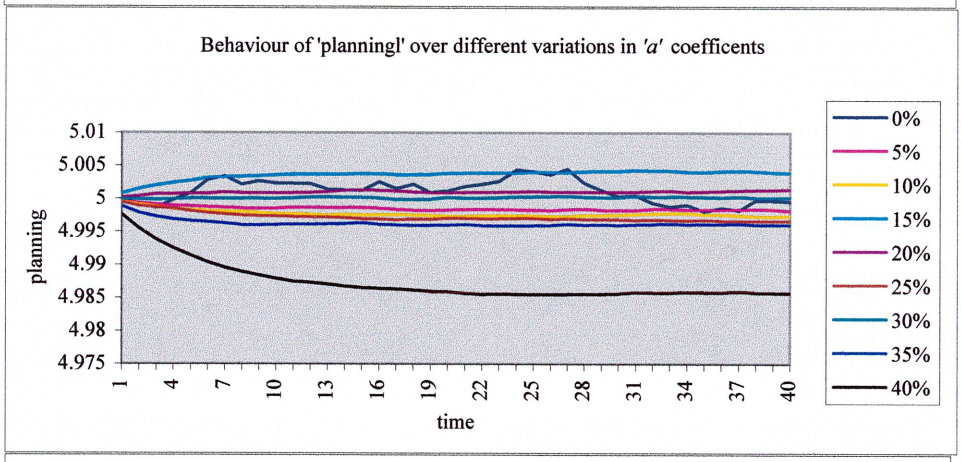
6.5.1 Significant Factors Coefficients (*'a'* coefficients)

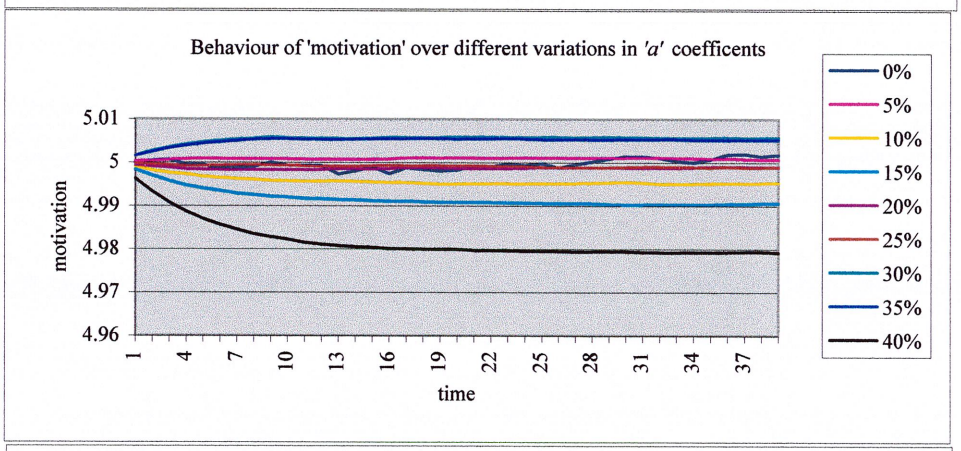
The average outcome for the significant factors against time is shown in Figure 6.3. It is important to note here that for all factors the outcome fluctuates around the average value, whatever the variation in the coefficient. This may suggest that although a high variation of coefficients is considered, there is almost no effect noticed on the outcome of the factors. It is hence concluded that the model is not sensitive to variations in coefficients of significant factors.

The above conclusion is confirmed by the results presented in Figure 6.4. The figure shows the frequency distribution at different periods of one of the significant factors,

Figure 6.3 Behaviour of significant factors with different percentages of variations in 'a' coefficients







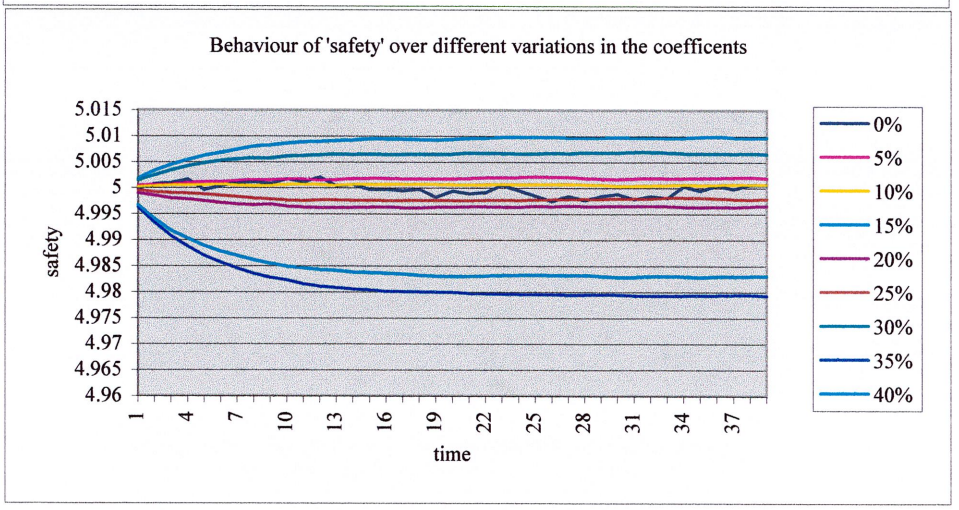
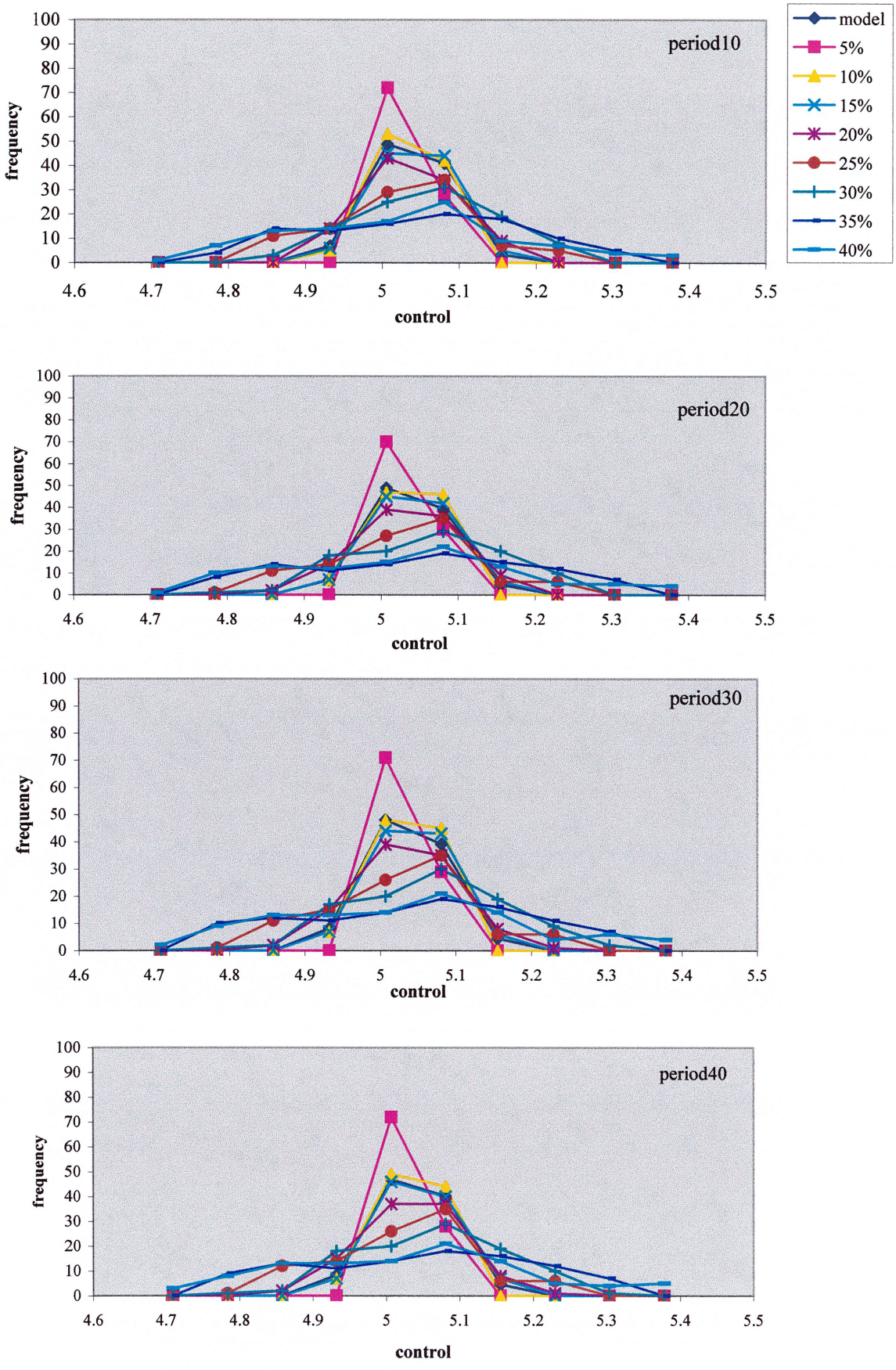


Figure 6.4 Frequency distribution for 'control' outcome with different percentages of variations in 'a' coefficients at different periods



which is, in this case, control. The graphs of other factors are shown in Appendix A, Figure A-1, A-2 and A-3. The reason for showing the frequency distribution at different periods is to observe the behaviour of the model throughout the life of the construction project. Intervals of 10 periods of time are used for this purpose. In order to simplify the comparison of the frequency distribution of the model, all periods are drawn to the same scale.

Two important points can be derived from studying the frequency distribution curves of the model:

1. The distribution curves may be classified into two groups. The first one is the 0% (original model), 5, 10 and 15% curves while the rest constitute the other group.

2. The first group of curves has a narrow spread while the other has a wide spread. This confirms the logic that increasing the variation in the coefficients will have more influence on the results of the model, but this disturbance is relatively small. Take, for example, the standard deviation of control with 40% variation and at period 40 (see Table A.1-Appendix A and Figure 6.4) the value is 0.167. Compared to the mean, which is 4.989, this value is around 3.36% of the mean which is considered to be trivial.

Among all the values of standard deviations shown for factors in Table A.1 (Appendix A), the values of 40% variation at period 40 of motivation, and the value of safety at

35% variation at period 40, are noticed to be the highest. This value is 0.185, which is about 3.72% of the mean. Again, this value is considered to be unimportant and has no great effect on the model. Such a small figure reflects the robustness of the model and is considered as further evidence of the insensitivity of the model to any variation.

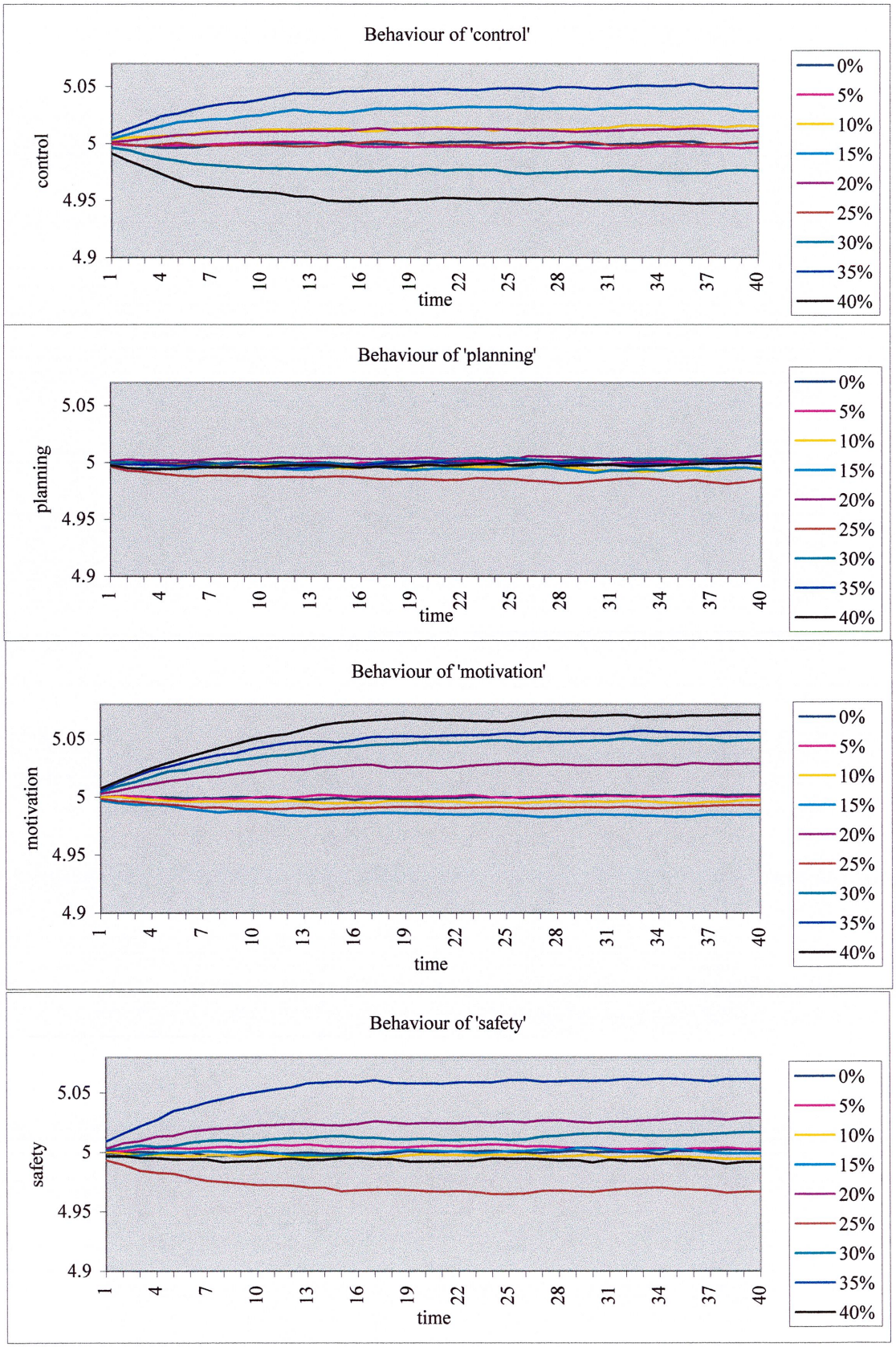
6.5.2 Total Factors Coefficients (*'b'* coefficients)

The coefficients considered for variation in this case are the *'b'* coefficients. Again different percentages of variations were applied to the coefficients in order to be able to judge whether the model is sensitive to variations or not.

The graphs of the average outcome of significant factors shown in Figure 6.5 show that even though a high percentage of variation is considered, the model still behaves sensibly. For example, in the safety graph Figure 6.5, 25% variation in the 'total factors coefficients' (*'b'* coefficients) is the one that gives the minimum value, which is 4.967, while the maximum value is 5.061, observed at 35%. The reason for the maximum values to be at different percentages other than the maximum variation is the randomness applied to the variations.

When comparing standard deviation of the model with variation in the *'total factors'* (*'b'*) coefficients with the model with variations in 'significant factors' (*'a'*) coefficients, then it can be seen that the model is sensitive at a high percentage of variation (i.e. at ±40%). This sensitivity cannot be considered as a serious problem as it exists only at high levels of variation.

Figure 6.5 Behaviour of significant factors with variations in '*b*' coefficients



For example, a value of 0.181 of standard deviation (3.6% of the mean) at 40% variation is reported at period one. The values tend to grow bigger with time where a maximum value of 1.221 is reached at period 40. This value is about 24% of the mean which may reflect some sort of sensitivity of the model at such a level of variation.

As discussed earlier in Section 6.5.1, frequency distribution curves drawn for the model can be seen to be two groups (see Fig 6.6). One group has a narrow spread and the other a wide spread, but the degree of spread is greater in this instance. A maximum value of 7.859 and a minimum of 2.643 are reported at 40% variation and period 40 of motivation. Such a wide spread in the values may be related to the sensitivity of the model to high variations but not to small variations in the *'total factors'* (*'b'*) coefficients. Graphs for other factors are shown in Figure A.4, A.5 and A.6 in Appendix A.

6.5.3 Productivity Coefficients (*'p'* coefficients)

As with the other coefficients, these coefficients have been tested with different percentages of variations. This time it is the productivity outcome which is of main concern to the discussion and hence to the conclusion as to whether these coefficients play a role in the sensitivity of the model.

Figure 6.7 shows the graph of the average productivity for the model with different percentages of variations over 40 periods of time. The graph shows that there is no noticeable difference between the values of the model with variations in the coefficients

Figure 6.6 Frequency distribution for motivation outcome with different variations in '*b*' coefficients

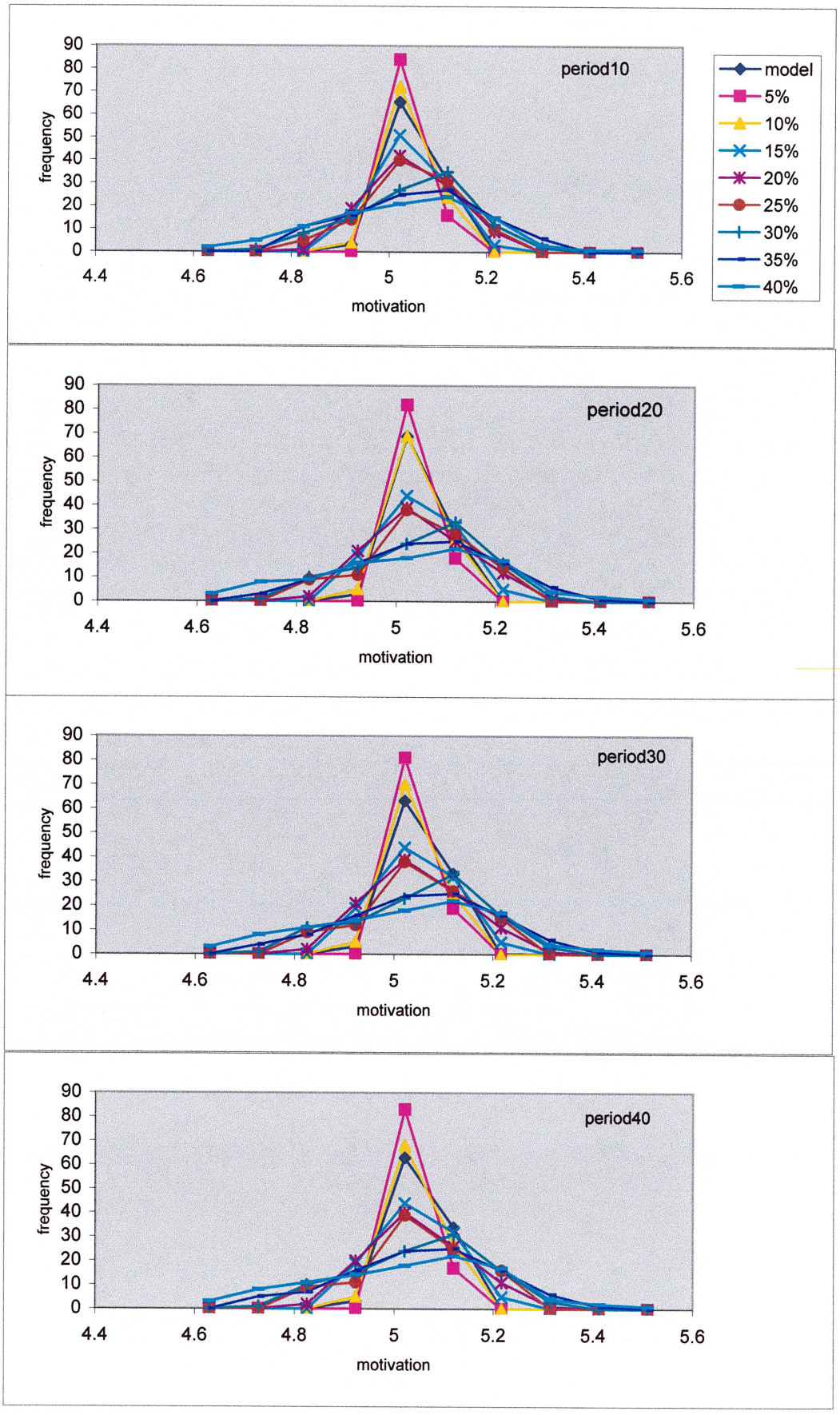
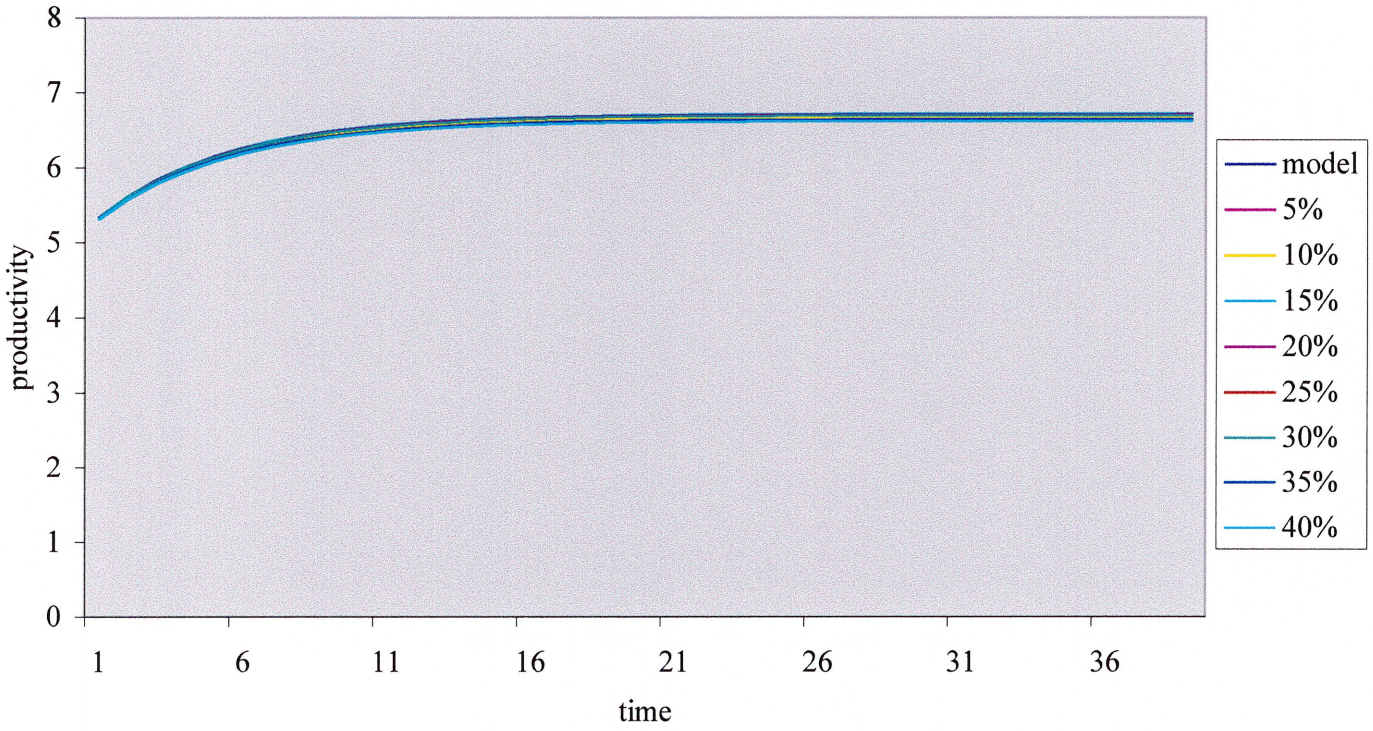


Figure 6.7 Average productivity of the model with different variations in '*p*' coefficients



compared to that with no variation. Based on that view it could be said that the model behaves in a sensible way even with the amount of variations considered.

The frequency distribution for productivity with different percentages of variation is shown in Figure 6.8. As is the case with significant factors coefficients, frequency distribution curves show how the curves become widely spread with the increase in the variation in coefficients.

6.5.4 Significant Factors Productivity Coefficients ('*a*' and '*p*' coefficients)

Varying the coefficients of *'significant factors coefficients'* (*'a'*) together with the *'productivity coefficients'* (*'p'*) is a scenario that has been considered when testing the validity of the model relations. Testing of type '*a*' coefficients only was considered in Section 6.5.1.while testing of type '*p*' coefficients only was considered in Section 6.5.3. The discussion in these sections covered the outcome of the testing of significant factors and of productivity separately. The aim in this section is to look at productivity outcome of the original model and compare it to the productivity with variations in the coefficients.

Figure 6.9 shows the average productivity over 40 periods for all the conditions considered in previous sections. Figure 6.9(a) illustrates the average productivity for variations in *'significant factors coefficients'* ('*a*') Figure 6.9(b) for the *'total factors coefficients'* ('*b*') and Figure 6.9(c) for *'significant factors-productivity coefficients'*.

Figure 6.8 Frequency distribution for productivity with different variations in the '*p*' coefficients

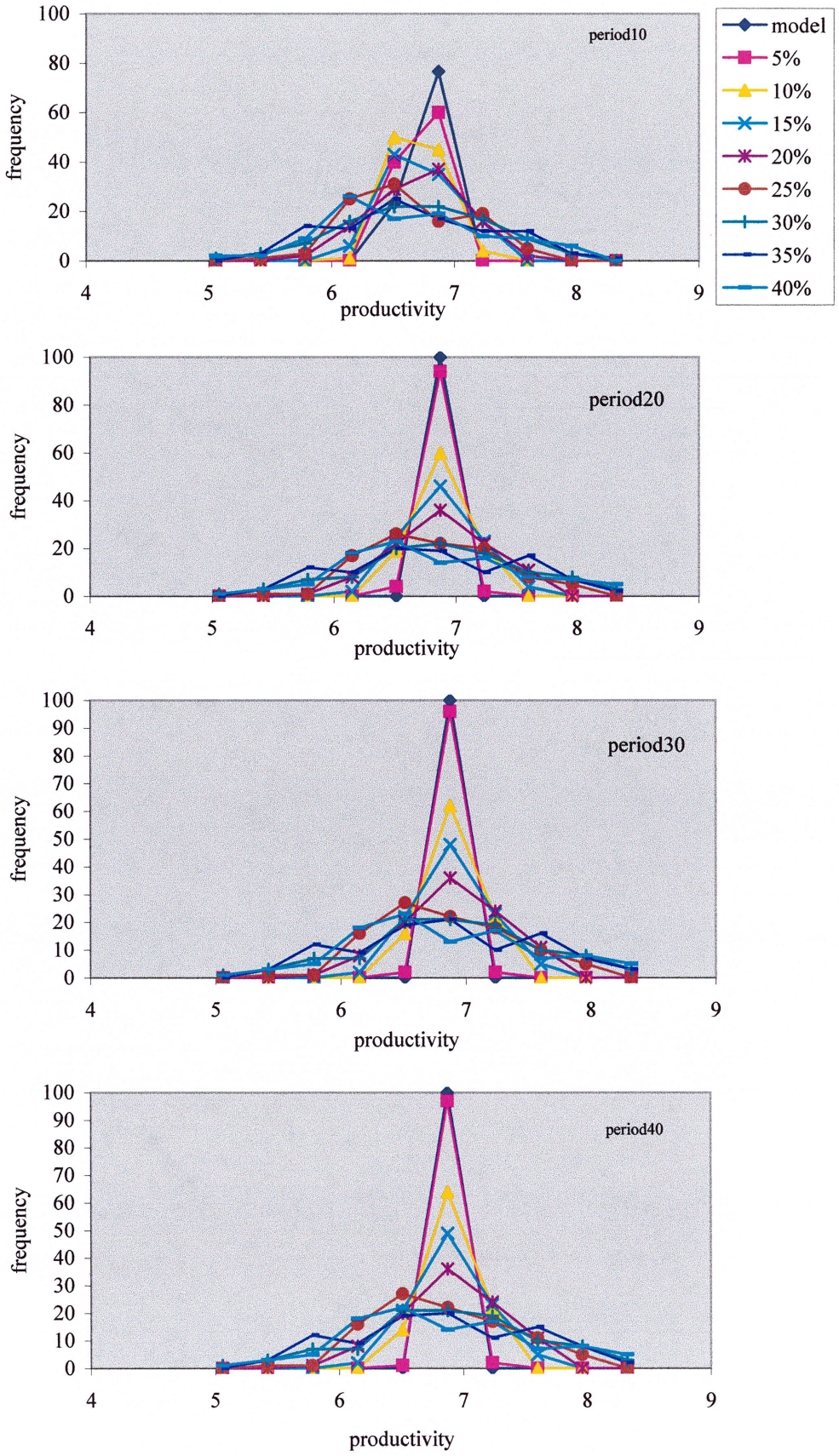
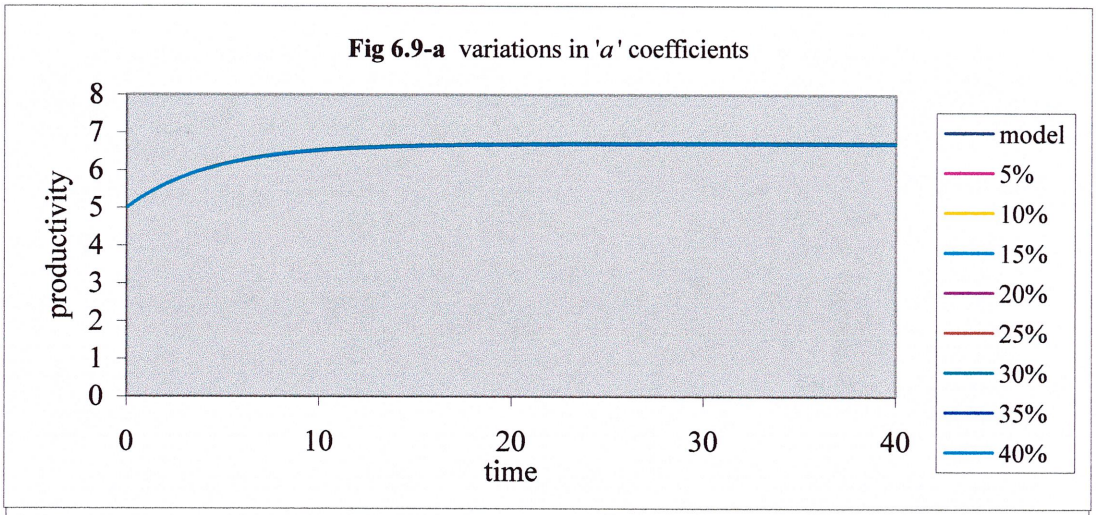
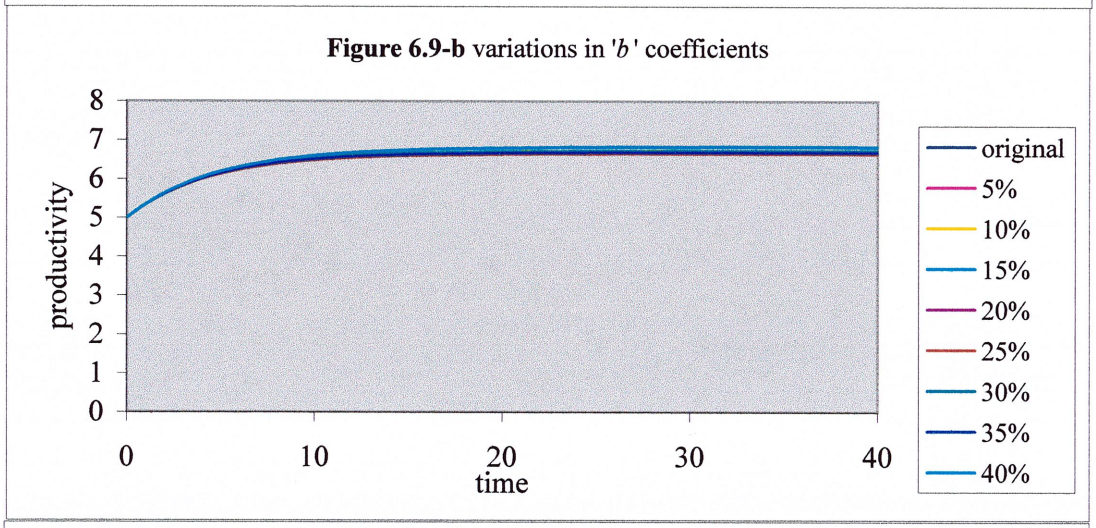
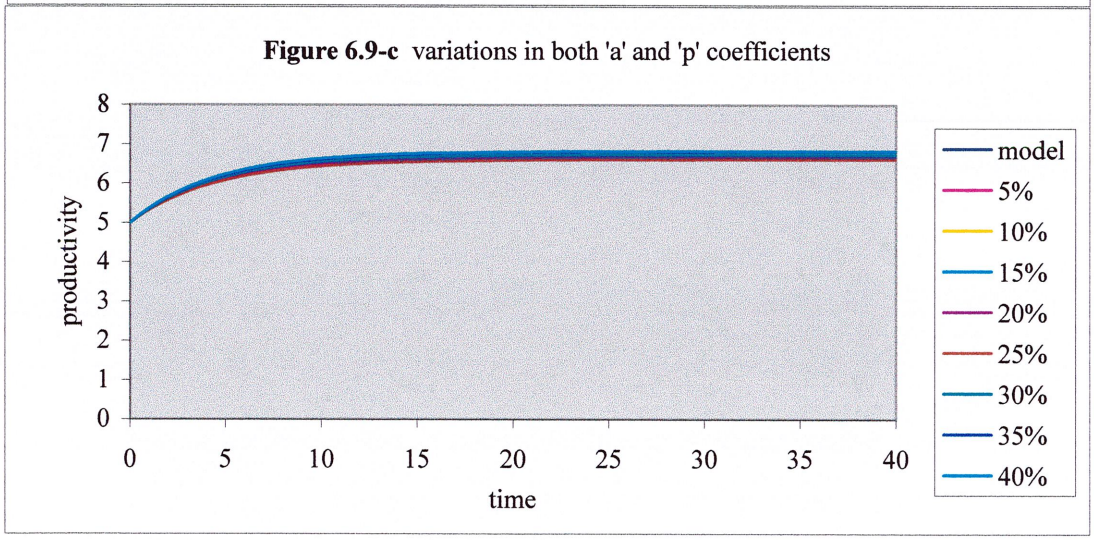


Figure 6.9 Productivity with different variations in coefficients







'Productivity coefficients' ('p') is already illustrated in Figure 6.7. All the graphs in these figures show that the average productivity of the model with different variations differs slightly from the model with no variation. This may lead to the conclusion that the model is reliable to be used.

Standard deviation for productivity outcome, shown in Table A.2 (Appendix A) and the frequency distribution curve shown in Figure 6.10, both indicate that although there are variations to the coefficients of the model, the behaviour of the model is sensible and this indicates the reliability of the coefficients used.

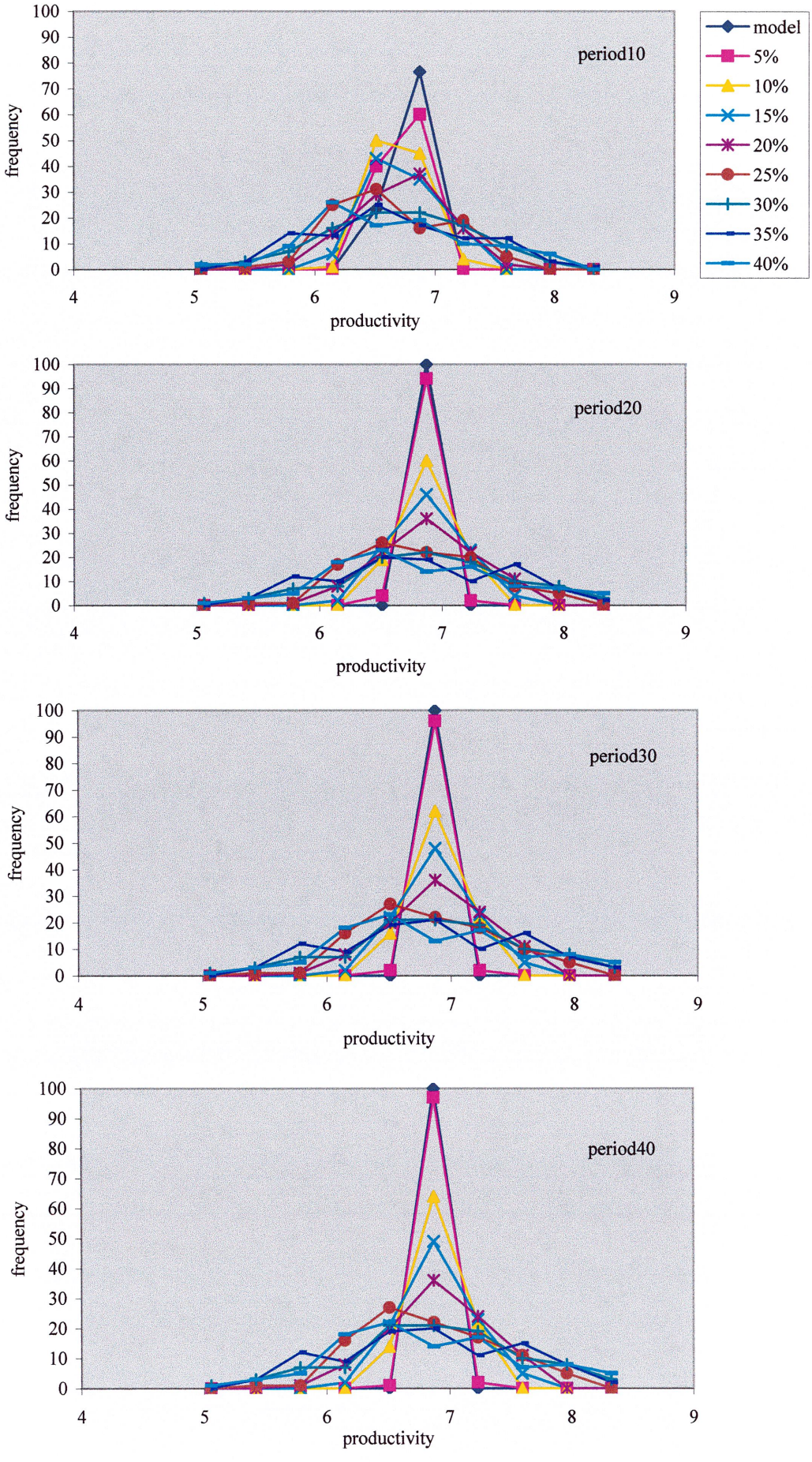
6.6 SUMMARY AND CONCLUSIONS

This chapter represents the sixth step of the systems approach considered for the work. It has discussed the testing of the model developed in Chapter 5. In particular, it looked at the coefficients produced for the transition equations as these coefficients represent the foundations of these equations.

The coefficients tested were of three types: the significant factors coefficients or type '*a*', total factors coefficients or type '*b*', and productivity coefficients or type '*p*'. All these types of coefficient were tested for a variation in their values to see how the model behaved. Up to ±40% variations in these coefficients were tried but no significant change was reported.

Based on the results obtained from the testing, it can be said that the model is behaving

Figure 6.10 Frequency distribution for productivity outcome with different variations in '*p*' coefficients



sensibly and is robust enough to be used. The use of this model is the topic of the next chapter.

CHAPTER 7

USING THE MODEL TO EVALUATE MANAGEMENT STRATEGIES

CHAPTER 7

USING THE MODEL TO EVALUATE MANAGEMENT STRATEGIES

7.1 INTRODUCTION

The model development and the testing of the coefficients of the equations have been discussed in Chapters 5 and 6 respectively. This chapter discusses the possible applications of the model in order to help to direct the management of construction projects towards strategies which may be adopted. In particular, it pinpoints the areas where an improvement could lead to better productivity, and directs the management's attention to areas where lack of awareness could result in losses to the project in general.

7.2 DEFINITIONS

In this chapter, the terms 'spending' and 'expenditure' refer to the magnitude of funding, effort and time allocated by the project management in improving factors. Spending on planning, for example, does not merely imply putting more money into the project to purchase new equipment, such as new personal computers for the head office, but also devoting more time and effort to the planning process and giving it a higher profile.

'Original line' refers to the productivity line in any graph with no management input to the project either in the initial stages or throughout the project.

7.3 MANAGEMENT STRATEGIES

The significant factors used to build the model in Chapter 5 constitute a group which can be described as 'management factors'. Control, planning, motivation and safety are all factors which management of the construction project can manipulate in order to influence the running of projects.

This chapter studies several scenarios. They represent strategies which management might adopt on a real site. They are not meant to cover all possible situations, but rather to represent typical ones. Initially, only 'simple' strategies involving a single factor were considered. In the later experiments (Section 7.4.2.2) more complex strategies were modelled. By examining these strategies, it is possible to show how the model might be used to examine any strategy which the management might want to use on a particular project. The strategies considered are:

- **Group 1 strategies**: considering all spending on factors to be concentrated at the start of a project: **'Spending on Initial Values of Factors'**

- **Group 2 strategies**: considering spending on factors to be in all periods: **'Time-Based Spending on Factors'**

- **Group 3 strategies**: considering more spending on situations where total disruptions at arbitrary chosen periods occur in the project: **'Disruptions In Construction Projects'**

The management of construction projects is, in general, concerned about what effect more funding has on productivity, and therefore all of these strategies are assessed in terms of the productivity predicted in the model. In all cases, the initial productivity is set to be either very low (0) or average (5). This is considered to be representative of the extremes of real projects. Very high initial productivity is not considered because it is unlikely to occur in reality. However, if a manager wished to consider it, the methods described below could be used.

7.3.1 Group 1 Strategies: Spending on Initial Values Of Factors

This group depends on varying the initial values of the factors. The objective behind this is to see how the productivity reacts with the increase in spending on different management factors (e.g. planning) at the outset of the project. The following experiments have been carried out:

1. Vary the initial values of each factor one at a time to see what effect that factor has on productivity. This represents, for example, a situation where management spends more on control while no spending is considered in other factors. The idea here is first, to see how each factor will affect productivity and second, to find out which factor would produce the best productivity for a given expenditure.

2. Vary all the initial values simultaneously. This represents a situation where the management decides to spend on all factors at the beginning of the project rather than concentrating on one factor only.

For each of these strategies the initial values of management factors are set at three levels to represent the amount of management spending. These levels are shown in Table 7.1. Levels of '0' represent those where there is no spending on that factor, '5' represents a moderate level, and '9' represents a high level of spending.

Table 7.1 Level of spending for factors at the initial stage

	EXPERIMENTS								
	1	2	3	4	5	6	7	8	9
Control	5	0	0	0	5	9	0	0	0
Planning	0	5	0	0	5	0	9	0	0
Motivation	0	0	5	0	5	0	0	9	0
Safety	0	0	0	5	5	0	0	0	9

The results for productivity for each experiment are considered individually and also compared against each other to trace any difference between the two situations. This comparison should give an answer as to whether spending on one factor at a time would be more advantageous than spending on all factors simultaneously.

7.3.2 Group 2 Strategies: Time-Based Spending On Factors

This group represents the management strategy of expending effort on particular factors throughout the project. The initial values of factors and productivity are set at a fixed level (0 or 5) and spending on selected factors is increased at various periods throughout

the project. This increase may be time-based (i.e. in every period of the project) or only at some stages of the project (i.e. at every 4 periods). This represents situations where management plan from the beginning of the project to adopt a strategy of spending on a continuous basis. This spending could either be in every period of the project or at selected intervals. The first situation might be considered to represent a project in which control action is taken whenever information is available. The second might represent a project on which information is collected weekly and control action is taken monthly. In both cases the behaviour of productivity is analysed.

These strategies can be summarised as follows:

- Set the initial values of all factors at 0 and improve one of the factors, constantly (increase in every period).

- Set the initial values of all factors at 0 and improve two of the factors, constantly (increase in every period).

- Set initial values of all factors at 0 and improve one of the factors at every fourth period.

- Set initial values of all factors at 0 and improve two of the factors at every fourth period.

7.3.3 Group 3 Strategies: Disruptions In Construction Projects

All the strategies considered above in groups 1 and 2 assume that a certain percentage of disruption occurs during the work. It is taken to be a value in the range of zero to 10 percent of the work. The reason behind assuming such a percentage is to measure the effect of spending on management factors while disruption to the work is at its lowest values.

This group is designed to study the effect of disruptions occurring at varying rates throughout the project. In some cases during the project, such as with adverse weather conditions, work could come to a complete halt. In this case disruptions are considered to be at a maximum and productivity will drop to a very low level, perhaps near zero. Disruptions and their degree of impact on the work is something that is completely unpredictable by the project management, and this group of strategies therefore assumes disruptions to be random in all periods.

7.4 RESULTS OF EXPERIMENTS

Due to the randomness considered in the values of other factors in significant factors equations, the graphs shown in Figures 7.1 to 7.15 are the product of averaging the values obtained from 10 runs of each experiment.

7.4.1 Group 1 Strategies: Initial Values

This group of strategies shows the management's effort to concentrate on the improvement of factors at the beginning of the project.

The model was tested with initial values set at 5 and 9 for each variable separately and with disruptions up to the value of one, which represents a disruption to the work of up to 10%, at all periods. Initial values for productivity were set at 0 and 5 respectively.

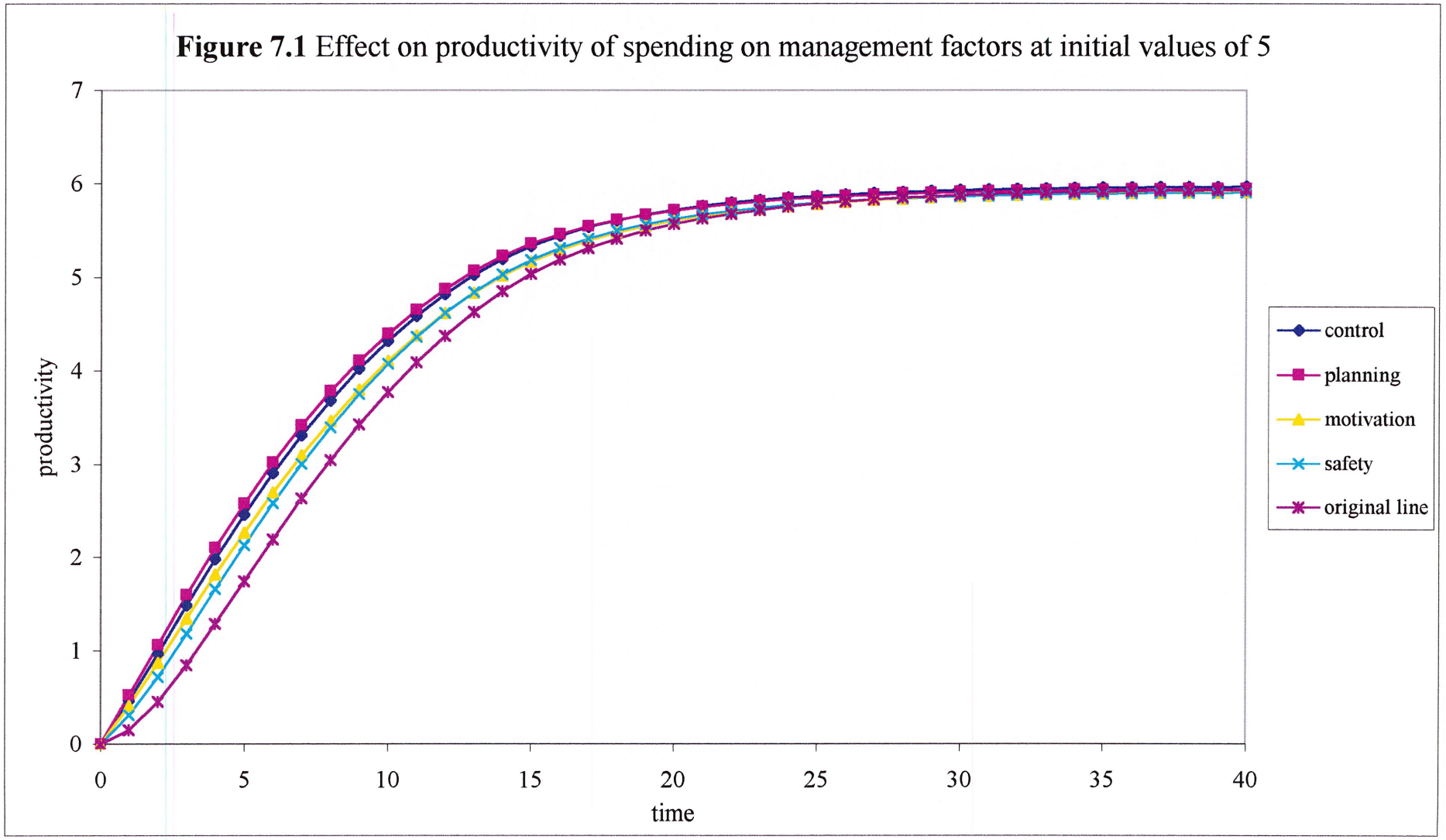
The results of the experiments are shown in Figures 7.1 to 7.5. In Figure 7.1 each line on the graph shows the change in productivity over time where the initial value of each of the control factors, in turn, is set at 5 with the others remaining at 0. This represents, for example, a situation in which the management spends more on planning at the start of the project than might be considered normal and more than it spends on the other control factors.

Since over the first 20 periods all the lines are higher than the original line, it can be seen that improving the initial state of management factor improves productivity early in a project.

The productivity in later periods differs little from that obtained with no specific management effort. This indicates that as it is in practice, if management ignores spending more on control factors at later stages of the project and concentrates only on the initial stages, then the effect will be limited to early periods of the project.

Another important point which should be mentioned when considering Figure 7.1 is that the improvement in productivity as a result of more spending on planning has an earlier

Figure 7.1 Effect on productivity of spending on management factors at initial values of 5



effect than the 'original line'. For example, with productivity at 4, the original line lags behind that of planning by approximately 2 periods.

It can also be seen that throughout the experiment, the 'planning' and 'control' management factors produce a higher productivity than motivation or safety. This is not to say that planning and control are the factors to be improved because it may be much more expensive to improve these than to improve safety or motivation. Indeed, it may be more expensive to improve these than the benefit to be gained by so doing.

A measure of the benefit to be gained by altering a factor might be considered to be

$$\sum_{i=1}^{j} (Pa_i - Po_i) \times W_i \qquad \textbf{Equation 7.1}$$

Where: Pa_i = productivity in period 'i' where the factor is altered

Po_i= productivity in period 'i' where no factors are altered

W_i = average work in period 'i'

j= number of periods

So, if, for example, an average of 100 m^2 of formwork are to be installed in a period and the productivity goes from 2.2 to 3.02 as it does in period 6 in Figure 7.1, the benefit in period 6 would be

$$\frac{3.02 - 2.2}{10} \times 100 = 8.2 \ m^2$$

Which at £y / m^2 would give a benefit of £ 8.2 y in period 6.

The idea of gained benefit can be made clearer if the example of period 6 is applied to a number of periods in a project.

Table 7.2 shows how to calculate the benefits gained from improving the productivity of a project through the improvement of planning. This procedure will be referred to as 'method A'. Equation 7.1 is used for this purpose. To avoid repetition, calculations of the benefit for other factors are shown in Tables B.1-3 in Appendix B. However, the final outcome of these tables is given in Table 7.3.

The calculations considered in Table 7.2 assume that formwork is to be installed for 10 periods and with the quantities as shown in the table.

Table 7.2 Benefits gained in formwork as a result of improvement in planning

period	P_a	P_o	$P_a - P_o$	W (m^2)	Benefit (m^2)
(1)	(2)	(3)	(4) = [(2)-(3)]/10	(5)	(4) × (5)
1	0.5248	0.1555	0.037	100	3.7
2	1.064	0.4572	0.061	100	6.1
3	1.5954	0.8484	0.075	100	7.5
4	2.1044	1.2875	0.082	100	8.2
5	2.5818	1.7445	0.084	100	8.4
6	3.0225	2.1988	0.082	100	8.24
7	3.4242	2.6365	0.079	100	7.9
8	3.7868	3.049	0.074	100	7.4
9	4.1113	3.4311	0.068	100	6.8
10	4.3997	3.7804	0.062	100	6.2
Total benefit (m^2)					70.44

The total benefit gained as a result of improvement in planning in the initial values up to

a level of 5 is 70.44 m^2. The benefits gained for other factors are shown in Table 7.3.

Table 7.3 shows the benefit gained in terms of quantities and in terms of money. For this purpose the labour rate considered here is about £19/m^2 of formwork. (Spon's, 99) (this rate is for insitue-concrete, plain formwork, basic finish, vertical walls).

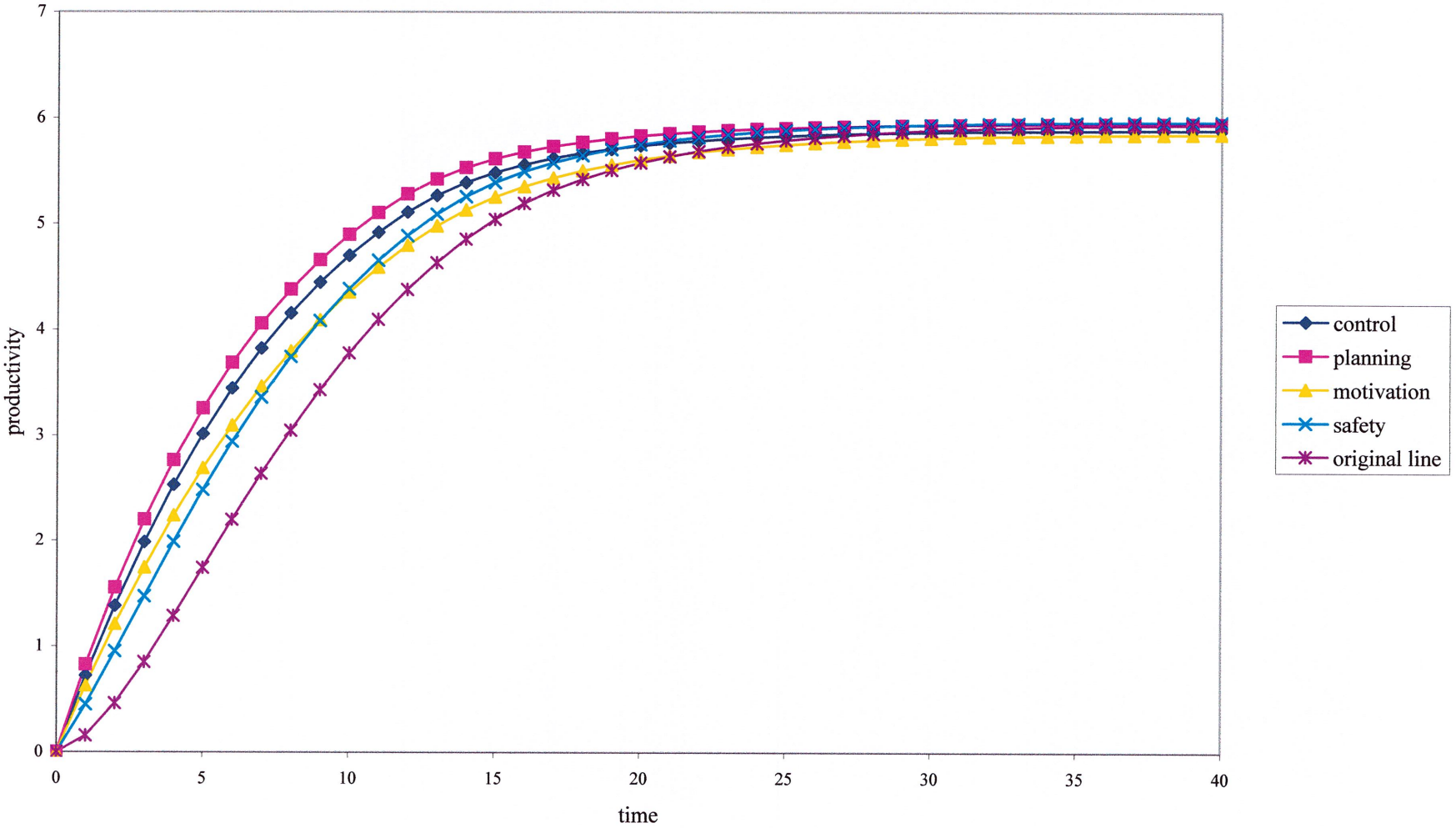
Table 7.3 Benefits gained in formwork as a result of improvement in the significant factors to a level of 5 of the initial values

Factor	Benefits in m^2	Benefits in £	Relative benefits
Planning	70.44	1338.36	100
Control	60.52	1149.88	86
Motivation	43.4	824.6	61
Safety	32.8	623.2	46

The results shown in Table 7.3 indicate that the benefit gained because of the improvement in planning is approximately twice that given by improving safety, 1.6 times that given by improving the value of the motivation and 1.2 times that of control. These figures indicate that spending on planning at the beginning of a project has considerable benefits compared to the others. However, it should be remembered that the real spending necessary to improve planning by 50% may be different to that required to improve the others by the same amount.

Figure 7.2 considers a similar situation to that in Figure 7.1 but with the initial values of the factors at 9 instead of 5. If the same procedure for calculating the benefits in Figure

Figure 7.2 Effect on productivity of spending on management factors at initial values of 9



7.1 is followed here, then these benefits would be as that shown in Table 7.4 (details of these calculations are shown in Appendix B Tables B4-7).

Table 7.4 Benefits gained in formwork as a result of improvement in the significant factors to a level of 9 of the initial values

Factor	Benefits in m^2	Benefits in £
Planning	156	2964
Control	126.2	2397.8
Motivation	97.2	1846.8
Safety	82.7	1571.3

As can be seen from Tables 7.3 and 7.4 the amount of benefits gained in adopting the strategy of improving initial values of factors is encouraging. However, it is to be emphasised that management should study the situation carefully and compare the gained benefits to the costs, as spending on one factor such as planning may be more expensive than spending on others.

A second way of looking at the benefits considered in Figure 7.1 and Table 7.2 is to consider a project with a fixed amount of work and to determine how long it would take to complete. This method will be referred to as 'method B'.

For example, if there are 1000 m^2 of formwork to be installed and resources are provided to give an average output of 100 m^2 per period with productivity at 5, then the amount produced in each period (when the productivities are as shown in Figure 7.1) is shown in Table 7.5.

Table 7.5 is divided into two parts. Part (a) shows the benefits gained if there is improvement in the initial value of planning, whereas part (b) shows the benefits gained when there is no improvement in the initial value of planning. It can be seen that with no improvement the project takes approximately 17 periods to do the 1000 m^2 of formwork but with improvement it takes 15 periods only. This is a direct saving to the project of 2 periods.

In the case of improvement in the initial value to a level of 9 in planning (as in Figure 7.2) the saving to the project is 3 periods as the 1000 m^2 of formwork is done within 14 periods. This is shown in Table B8 in Appendix B.

Each project will be different in the amount of work and the cost of improving the initial value of the control factor; management must decide what strategy to employ. This could be a matter of management style.

Possibly a more practical situation is shown in Figures 7.3 and 7.4. In these, the initial value of the productivity is set at 5 while the initial values of the control factors are altered, in turn, from 0 to 5 in Figure 7.3 and from 0 to 9 in Figure 7.4. This is more

(a) Improvement of planning at initial value of 5

Period [1]	Productivity P_a [2]	$P_a/5$* [3]	Work (m^2) W [4]	Benefit (m^2) ($P_a/5$)*W [5]=[3]*[4]	Cumulative benefit (m2) [6]
1	0.525	0.105	100	10.50	10.50
2	1.064	0.213	100	21.28	31.78
3	1.595	0.319	100	31.91	63.68
4	2.104	0.421	100	42.09	105.77
5	2.582	0.516	100	51.64	157.41
6	3.022	0.604	100	60.45	217.86
7	3.424	0.685	100	68.48	286.34
8	3.787	0.757	100	75.74	362.08
9	4.111	0.822	100	82.23	444.30
10	4.400	0.880	100	87.99	532.29
11	4.654	0.931	100	93.09	625.38
12	4.878	0.976	100	97.56	722.94
13	5.074	1.015	100	101.48	824.42
14	5.235	1.047	100	104.70	929.12
15	5.364	1.073	100	107.27	1036.39
16	5.467	1.093	100	109.33	1145.72
17	5.551	1.110	100	111.01	1256.74
18	5.619	1.124	100	112.38	1369.12
19	5.675	1.135	100	113.50	1482.62
20	5.721	1.144	100	114.43	1597.05

(b) No improvement of planning at initial value

Period [1]	Original productivity Po [2]	Po/5* [3]	Work (m^2) W [4]	Benefit (m^2) (Po/5)*W [5]=[3]*[4]	Cumulative benefit (m^2) [6]
1	0.156	0.031	100	3.11	3.11
2	0.457	0.091	100	9.14	12.25
3	0.848	0.170	100	16.97	29.22
4	1.287	0.257	100	25.75	54.97
5	1.745	0.349	100	34.89	89.86
6	2.199	0.440	100	43.98	133.84
7	2.637	0.527	100	52.73	186.57
8	3.049	0.610	100	60.98	247.55
9	3.431	0.686	100	68.62	316.17
10	3.780	0.756	100	75.61	391.78
11	4.096	0.819	100	81.93	473.71
12	4.380	0.876	100	87.60	561.31
13	4.632	0.926	100	92.64	653.95
14	4.855	0.971	100	97.10	751.06
15	5.042	1.008	100	100.84	851.90
16	5.194	1.039	100	103.89	955.79
17	5.319	1.064	100	106.37	1062.16
18	5.421	1.084	100	108.42	1170.58
19	5.506	1.101	100	110.12	1280.70
20	5.577	1.115	100	111.54	1392.24

* The productivity calculated is divided by the ideal productivity assumed for calculations to be 5

Figure 7.3 Effect on productivity of spending on management factors at initial values of 5

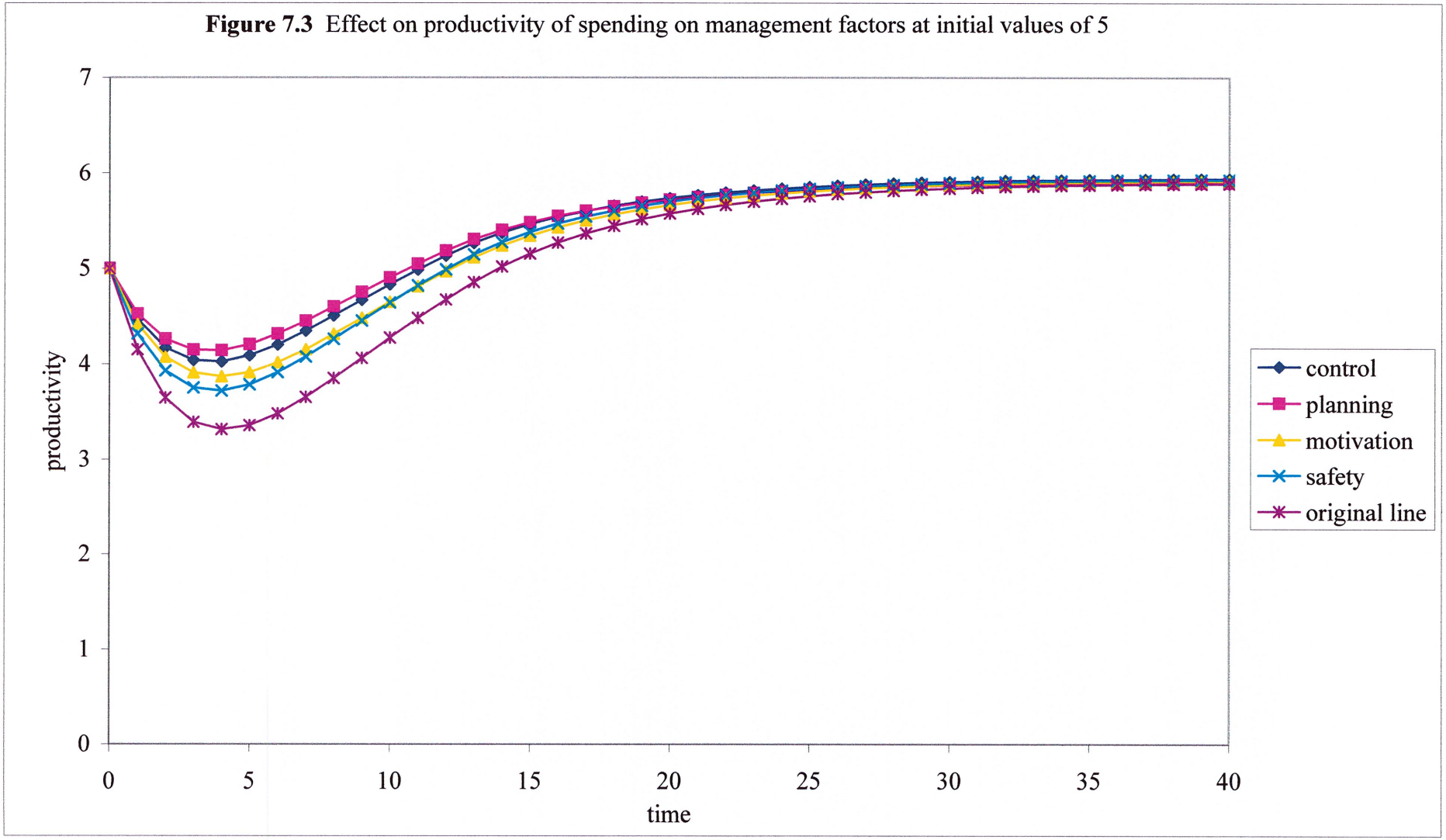
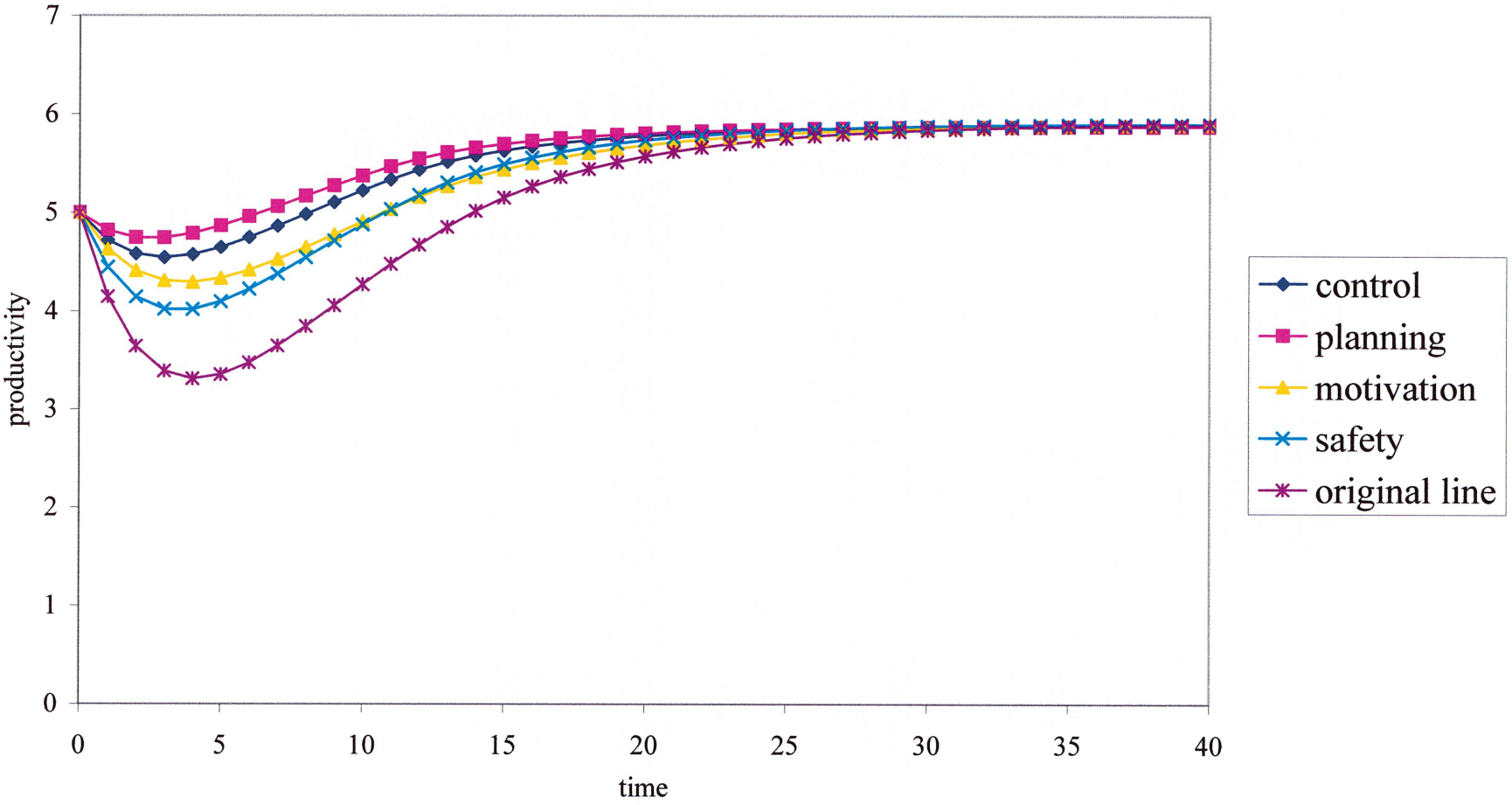


Figure 7.4 Effect on productivity of spending on management factors to initial values of 9



practical because it alters the parameters upon which the management has a direct influence.

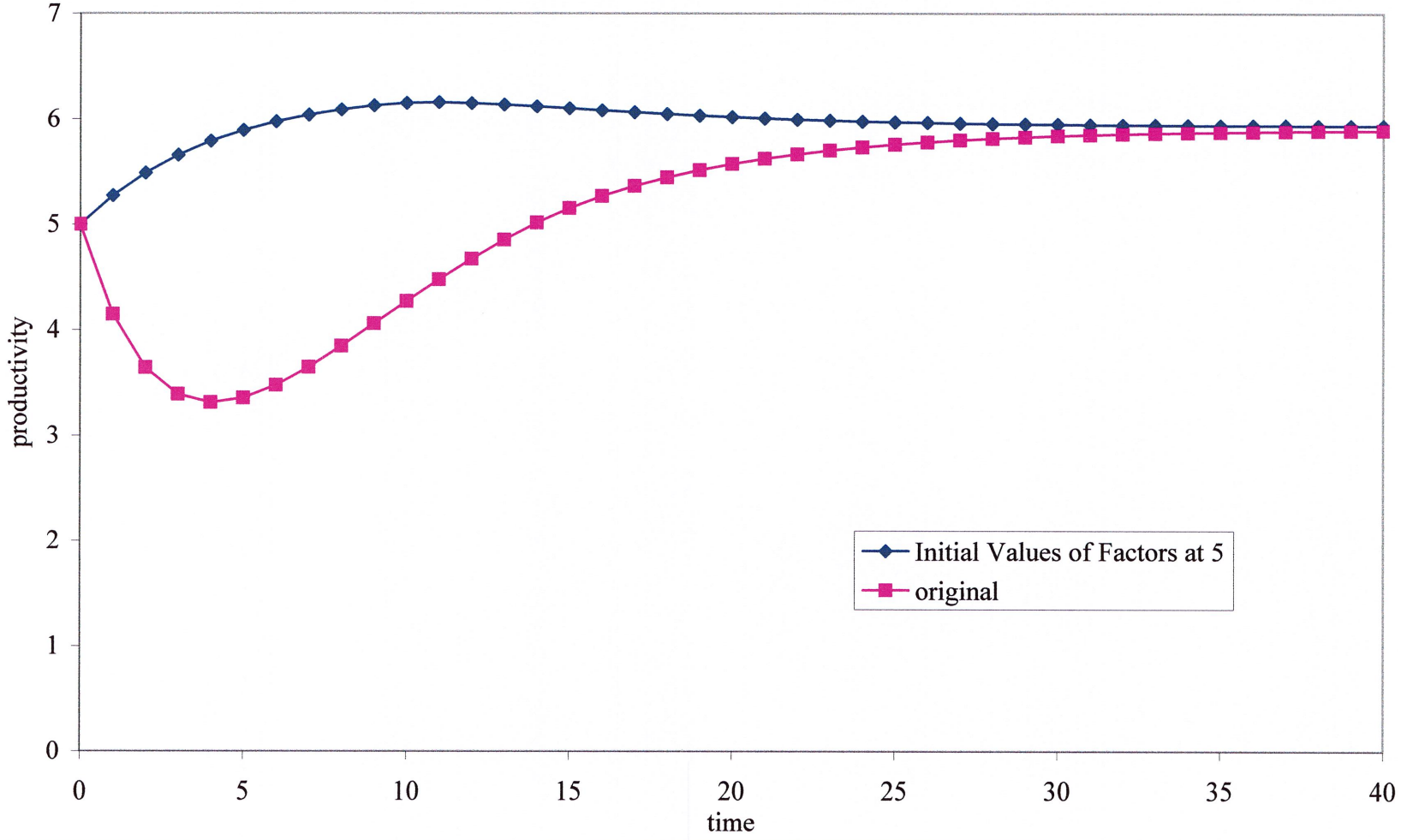
In this situation, the productivity initially drops because of the zero values for the majority of control factors. However, it can be seen that the drop is smaller in both magnitude and duration when initial management action is taken to improve the control factors. 'Planning' and 'control' are the factors which have the most beneficial effect but even 'motivation' and 'safety' have a greater effect than in the original experiment.

The cost of getting this into practice might be expected to be the same as the cost of obtaining the benefit in the initial experiment since all factors start at the same value in each experiment. However, since the initial productivities are different in each situation, it might be agreed that the costs of obtaining the benefits could be different.

Another situation, which is considered to be a practical one, is that shown in Figure 7.5. In this situation management spends on all factors. The graph in this figure shows that the drop witnessed in Figure 7.3 and 7.4 has been alleviated in favour of productivity growth for the first 15 periods. This indicates that in practice, distributing the spending on all factors will have a positive impact on productivity.

The benefit gained because of spending on all factors at the initial values is much higher than just spending on one factor only. In this case it is 233.4 m^2 of formwork in 10 periods as shown in Table 7.6. This value is approximately 3 times more than the

Figure 7.5 Effect on productivity of spending on all management factors at initial values of 5



maximum benefit gained in spending on factors individually. Hence it is beneficial to spread the effort at the initial stages on all factors.

Table 7.6 Benefits of spending on all factors at the initial values

period	Pa	Po	Pa - Po	W (m^2)	Benefit (m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4) × (5)
1	5.273354	4.148247	0.113	100	11.3
2	5.488226	3.644669	0.184	100	18.4
3	5.656883	3.39107	0.227	100	22.7
4	5.789224	3.313456	0.248	100	24.8
5	5.89294	3.356323	0.254	100	25.4
6	5.97413	3.478664	0.250	100	25.0
7	6.037606	3.650318	0.239	100	23.9
8	6.08713	3.849474	0.224	100	22.4
9	6.125767	4.060594	0.207	100	20.7
10	6.150636	4.272787	0.188	100	18.8
Total benefit (m^2)					233.4

If 'method B' for calculating the benefits is applied here, assuming again that there are 1000 m^2 of formwork to be installed and resources are provided to give an average output of 100 m^2 per period with productivity at 5, then the results are as those shown in Table 7.7. In this table, it can be seen that 1000 m^2 of formwork was completed at period 9 when spending concentrates on all factors at the initial values, whereas in the case of no spending the same quantity was done at period 13. The difference in this case is 4 periods which means a lot of direct savings. If other activities in the project, such as steelfixing or excavation are considered, then extra benefits are added. In this case management of the project should certainly consider the strategy of improving spending

Table 7.7 Calculation of gained benefits in formwork when all factors are improved at initial values

(a) Improvement of all factors at initial values to 5

Period [1]	Productivity P_a [2]	$P_a/5$* [3]	Work (m^2) W [4]	Benefit (m^2) ($P_a/5$)*W [5]=[3]*[4]	Cumulative benefit (m2) [6]
1	5.273	1.055	100	105.47	105.47
2	5.488	1.098	100	109.76	215.23
3	5.657	1.131	100	113.14	328.37
4	5.789	1.158	100	115.78	444.15
5	5.893	1.179	100	117.86	562.01
6	5.974	1.195	100	119.48	681.50
7	6.038	1.208	100	120.75	802.25
8	6.087	1.217	100	121.74	923.99
9	6.126	1.225	100	122.52	1046.51
10	6.151	1.230	100	123.01	1169.52
11	6.156	1.231	100	123.11	1292.63
12	6.148	1.230	100	122.97	1415.60
13	6.135	1.227	100	122.69	1538.29
14	6.118	1.224	100	122.35	1660.64
15	6.099	1.220	100	121.99	1782.63
16	6.081	1.216	100	121.62	1904.25
17	6.063	1.213	100	121.26	2025.51
18	6.046	1.209	100	120.93	2146.44
19	6.031	1.206	100	120.62	2267.06
20	6.017	1.203	100	120.35	2387.40

(b) No improvement at initial values

Period [1]	Original productivity Po [2]	Po/5* [3]	Work (m^2) W [4]	Benefit (m^2) (Po/5)*W [5]=[3]*[4]	Cumulative benefit (m^2) [6]
1	4.148	0.830	100	82.96	82.96
2	3.645	0.729	100	72.89	155.86
3	3.391	0.678	100	67.82	223.68
4	3.313	0.663	100	66.27	289.95
5	3.356	0.671	100	67.13	357.08
6	3.479	0.696	100	69.57	426.65
7	3.650	0.730	100	73.01	499.65
8	3.849	0.770	100	76.99	576.64
9	4.061	0.812	100	81.21	657.86
10	4.273	0.855	100	85.46	743.31
11	4.479	0.896	100	89.58	832.89
12	4.674	0.935	100	93.48	926.37
13	4.855	0.971	100	97.11	1023.47
14	5.019	1.004	100	100.37	1123.85
15	5.155	1.031	100	103.10	1226.94
16	5.269	1.054	100	105.38	1332.32
17	5.365	1.073	100	107.30	1439.62
18	5.446	1.089	100	108.92	1548.53
19	5.514	1.103	100	110.29	1658.82
20	5.573	1.115	100	111.46	1770.28

* The productivity calculated is divided by the ideal productivity assumed for calculations to be 5

on all factors at the initial stages, but a balance between the costs of improvement and the gained benefits must be borne in mind.

7.4.2 Group 2 Strategies: Time-Based Spending on Factors

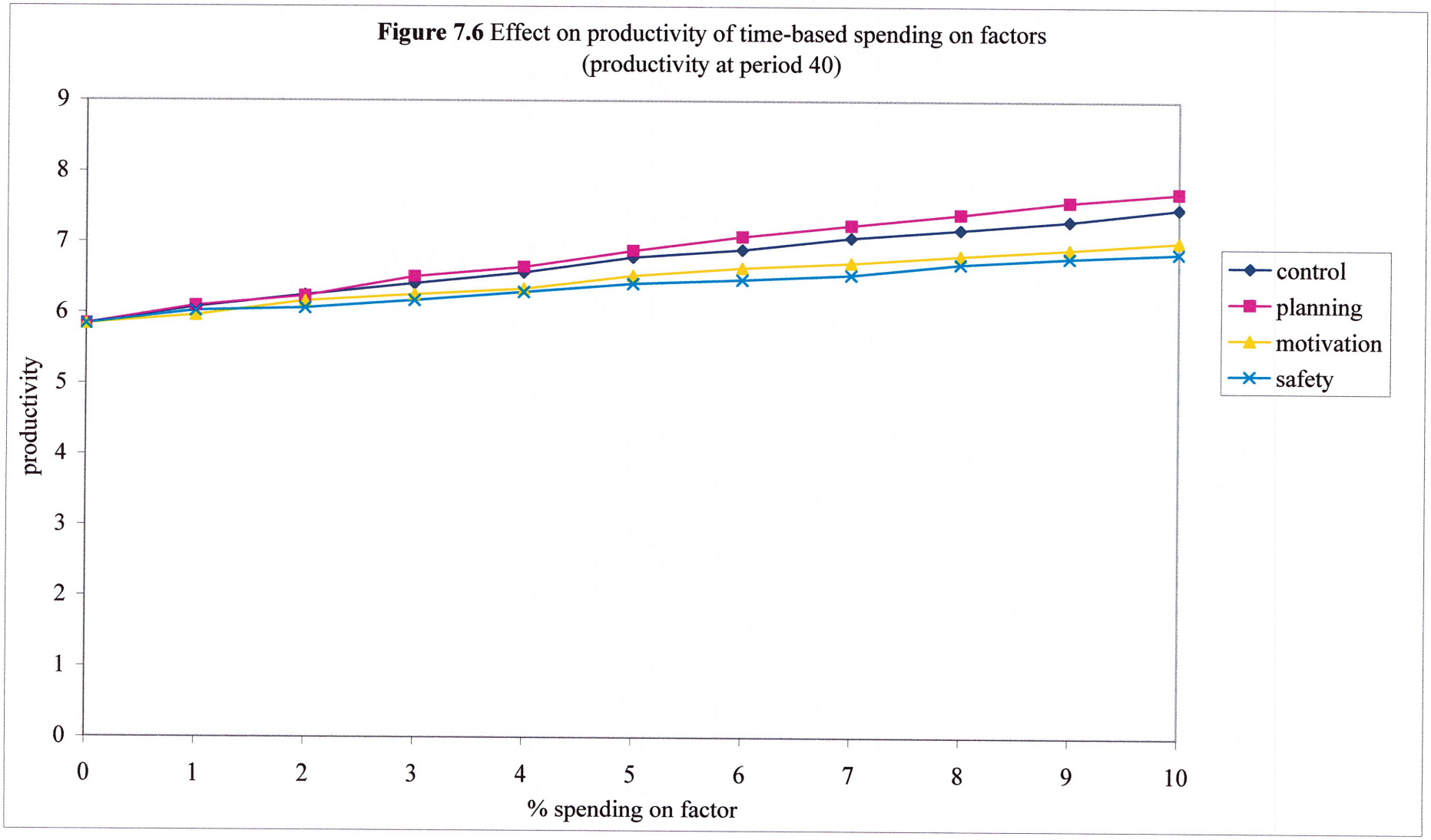
The effects of adopting these strategies are represented by the curves shown in Figures 7.6 to 7.12. This group of strategies is concerned with spending in all periods or at selected intervals throughout the life of the project, rather than just spending at the beginning and ignoring the rest of the project. Spending throughout the life of the project will be studied through four different scenarios:

1. Spend more on one factor on a continuous basis: *Time-Based Spending* ***on Single Factor***; represented by Figures 7.6 to 7.8.
2. Spend more on two factors in every period: *Time-Based* ***Spending on Two Factors;*** ***r***epresented by Figures 7.9 and 7.10.
3. Spend more on two factors every 4 periods: ***Intermittent Spending on Single Factor***; represented by Figures 7.11.
4. Spend more on two factors every 4 periods: ***Intermittent Spending on Two Factors***; represented by Figures 7.13.

7.4.2.1 Time-Based Spending on Single Factor

Figure 7.6 shows the change in productivity as spending on significant factors is increased. For example, the 'control' line shows how productivity is improved with an increase in spending in 'control' while no improvements are made for other factors.

Figure 7.6 Effect on productivity of time-based spending on factors (productivity at period 40)



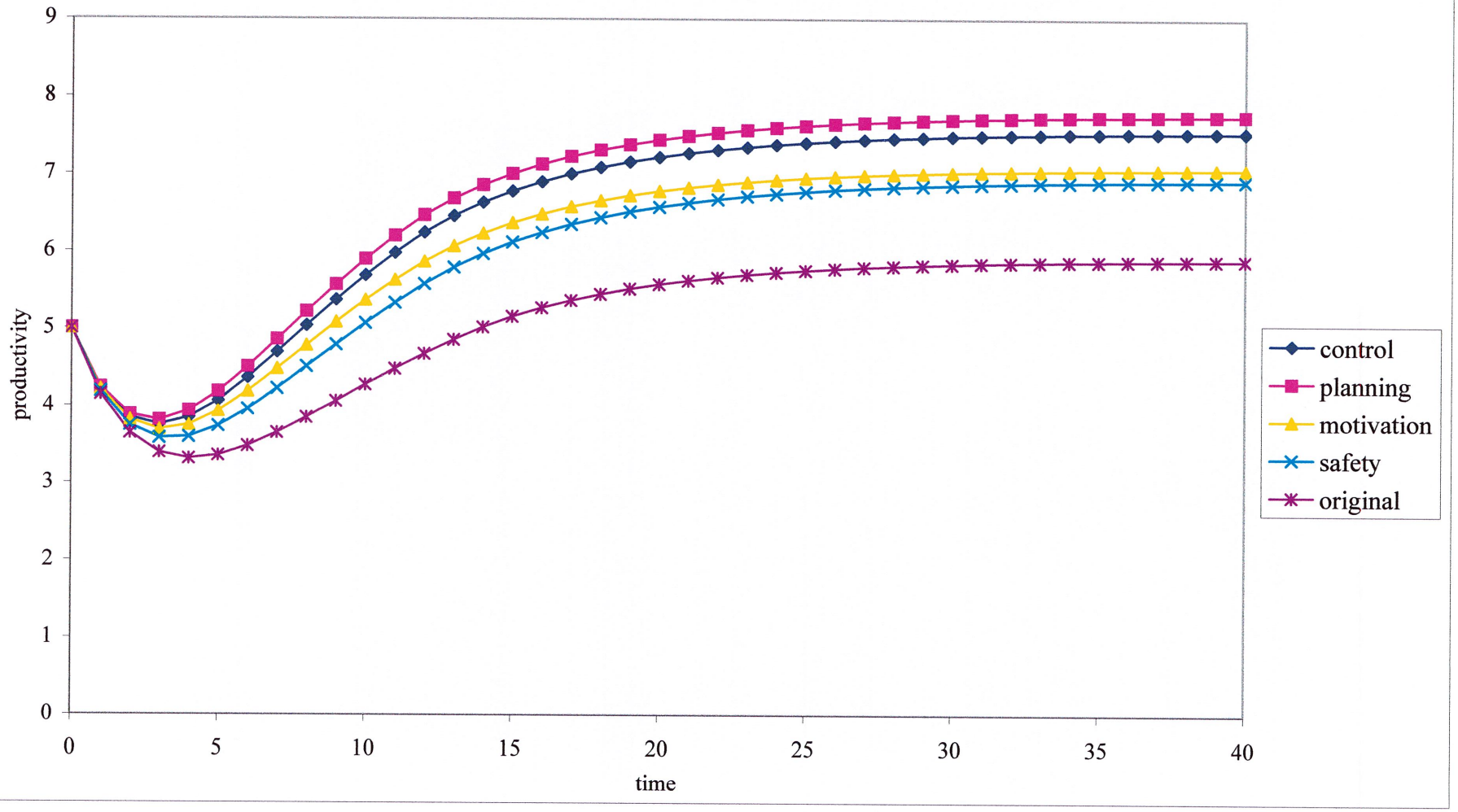
In Figure 7.7 each line on the graph shows the change in productivity over time where spending in each single factor, in turn, is increased by 10% while no increase in spending is carried out in the other factors. This represents, for example, a situation in which the management spends more on control in all periods than might be considered normal and where it spends more on control than it might on all the other factors.

It can be seen from the graph in Figure 7.6 that improvement in 'planning' and 'control' factors have better results for productivity than motivation and safety. At small percentages this difference is not considerable but with higher spending the difference becomes clearer.

The situation at early periods differs from that at later ones for a spending of 10% as shown in Figure 7.7. For almost 5 periods, the difference between the original line and those with the management effort is negligible. Such results give an impression that the process of continuous improvement in the control factors has more of an impact on the later stages of the project.

As can be seen from the graphs in Figures 7.6 and 7.7, the magnitude of improvement in productivity with 10% more spending on planning is approximately 20%. At 6% spending, the improvement is approximately 12%. Such figures might motivate management to invest in this direction as achieving 12% is a reasonable level, but the situation is not that easy. Management has to work out a careful balance between the spending on planning on the one hand, and spending on remaining factors on the other,

Figure 7.7 Effect on productivity of 10% time-based spending on factors



to achieve similar results.

Figure 7.8 shows productivity as a function of time for spending on planning at selected values of 3, 6 and 10%. These curves support the argument in the previous paragraph in that it shows that a 6% increase in spending on variables is considered to have an acceptable rate of improvement for productivity and could be recommended for use.

Applying equation 7.1 can help to illustrate what benefits can be gained from such strategy.

At period 30 (Figure 7.8) the difference between original productivity and productivity with increased planning is approximately 17%. For 100 m^2 of formwork considered at period 30 the benefit would be 17 m^2.

Table 7.8 shows the calculations of benefits for improvement in planning at 10 % in every period, again considering method B. It can be seen from the table that if 1000 m^2 is considered as a target, then savings of two periods are achieved. This saving increases at later periods where it can be seen that a cumulative benefit of approximately 1700 m^2 is achieved at period 20. However, the same cumulative quantity is achieved at period 16 if there is improvement in planning in all periods.

7.4.2.2 Time-Based Spending on Two Factors

In this group of strategies more spending on two selected factors at a time is considered.

Figure 7.8 Effect on productivity of different percentages of spending on planning

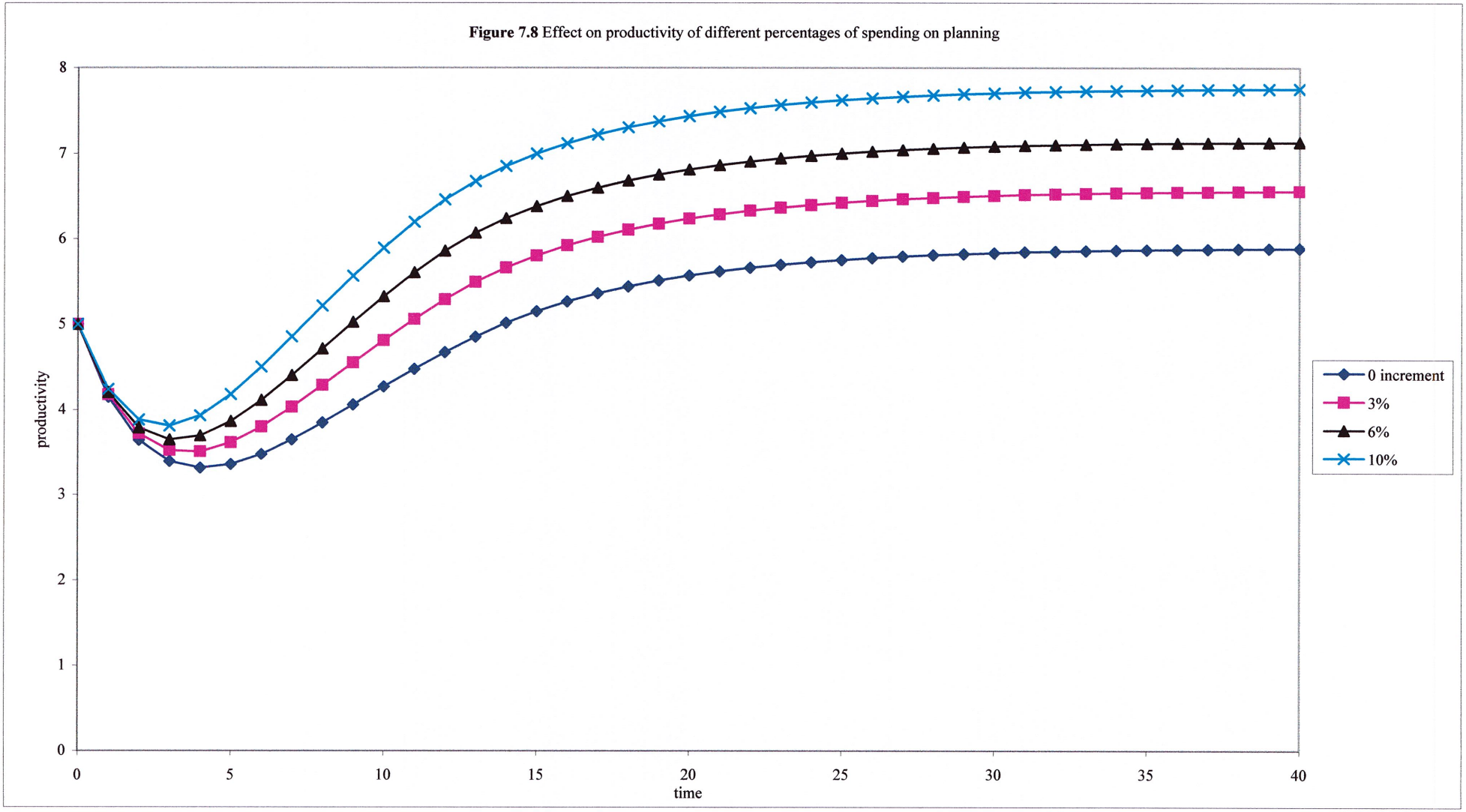


Table 7.8 Calculation of gained benefits in formwork with 10% improvement in every period

(a) Improvement of planning in every period of 10%

Period [1]	Productivity P_a [2]	$P_a/5$* [3]	Work (m^2) W [4]	Benefit (m^2) $(P_a/5)*W$ [5]=[3]*[4]	Cumulative benefit (m2) [6]
1	4.239	0.848	100	84.77	84.77
2	3.883	0.777	100	77.66	162.43
3	3.812	0.762	100	76.23	238.67
4	3.933	0.787	100	78.66	317.33
5	4.180	0.836	100	83.60	400.93
6	4.502	0.900	100	90.05	490.98
7	4.857	0.971	100	97.15	588.13
8	5.218	1.044	100	104.35	692.48
9	5.567	1.113	100	111.34	803.82
10	5.896	1.179	100	117.92	921.74
11	6.199	1.240	100	123.97	1045.71
12	6.463	1.293	100	129.25	1174.96
13	6.677	1.335	100	133.53	1308.49
14	6.853	1.371	100	137.05	1445.55
15	6.999	1.400	100	139.97	1585.52
16	7.120	1.424	100	142.40	1727.92
17	7.221	1.444	100	144.43	1872.35
18	7.307	1.461	100	146.13	2018.48
19	7.378	1.476	100	147.56	2166.04
20	7.438	1.488	100	148.76	2314.81

(b) No improvement

Period [1]	Original productivity Po [2]	Po/5* [3]	Work (m^2) W [4]	Benefit (m^2) (Po/5)*W [5]=[3]*[4]	Cumulative benefit (m^2) [6]
1	4.148	0.830	100	82.96	82.96
2	3.645	0.729	100	72.89	155.86
3	3.391	0.678	100	67.82	223.68
4	3.313	0.663	100	66.27	289.95
5	3.356	0.671	100	67.13	357.08
6	3.479	0.696	100	69.57	426.65
7	3.650	0.730	100	73.01	499.65
8	3.849	0.770	100	76.99	576.64
9	4.061	0.812	100	81.21	657.86
10	4.273	0.855	100	85.46	743.31
11	4.479	0.896	100	89.58	832.89
12	4.674	0.935	100	93.48	926.37
13	4.855	0.971	100	97.11	1023.47
14	5.019	1.004	100	100.37	1123.85
15	5.155	1.031	100	103.10	1226.94
16	5.269	1.054	100	105.38	1332.32
17	5.365	1.073	100	107.30	1439.62
18	5.446	1.089	100	108.92	1548.53
19	5.514	1.103	100	110.29	1658.82
20	5.573	1.115	100	111.46	1770.28

* The productivity calculated is divided by the ideal productivity assumed for calculations to be 5

This represents the management effort on spending more on two selected factors such as control and planning at every period of the project than it spends on others. Considering such situations will guide management to the possible ways of spending if there is a decision to invest in two factors at a time rather than one factor only.

The combinations considered for testing are as follows:

- Control and planning
- Control and motivation
- Control and safety
- Planning and motivation
- Planning and safety
- Motivation and safety.
- Planning and planning (double the spending on planning)

Values of 1 to 10% of increased spending on each factor were used. For example, if the value of 4% is considered then the combination is 4% more spending on control and 4% more spending on planning. Initial values are set at 0 for all factors in order to study the effect on productivity of spending during the construction phase.

The productivity results given by running the model with the above combinations are shown in Figures 7.9 and 7.10. The curves of the change of productivity over time in

Figure 7.9 Effect on productivity of time-based spending on two factors at 10%

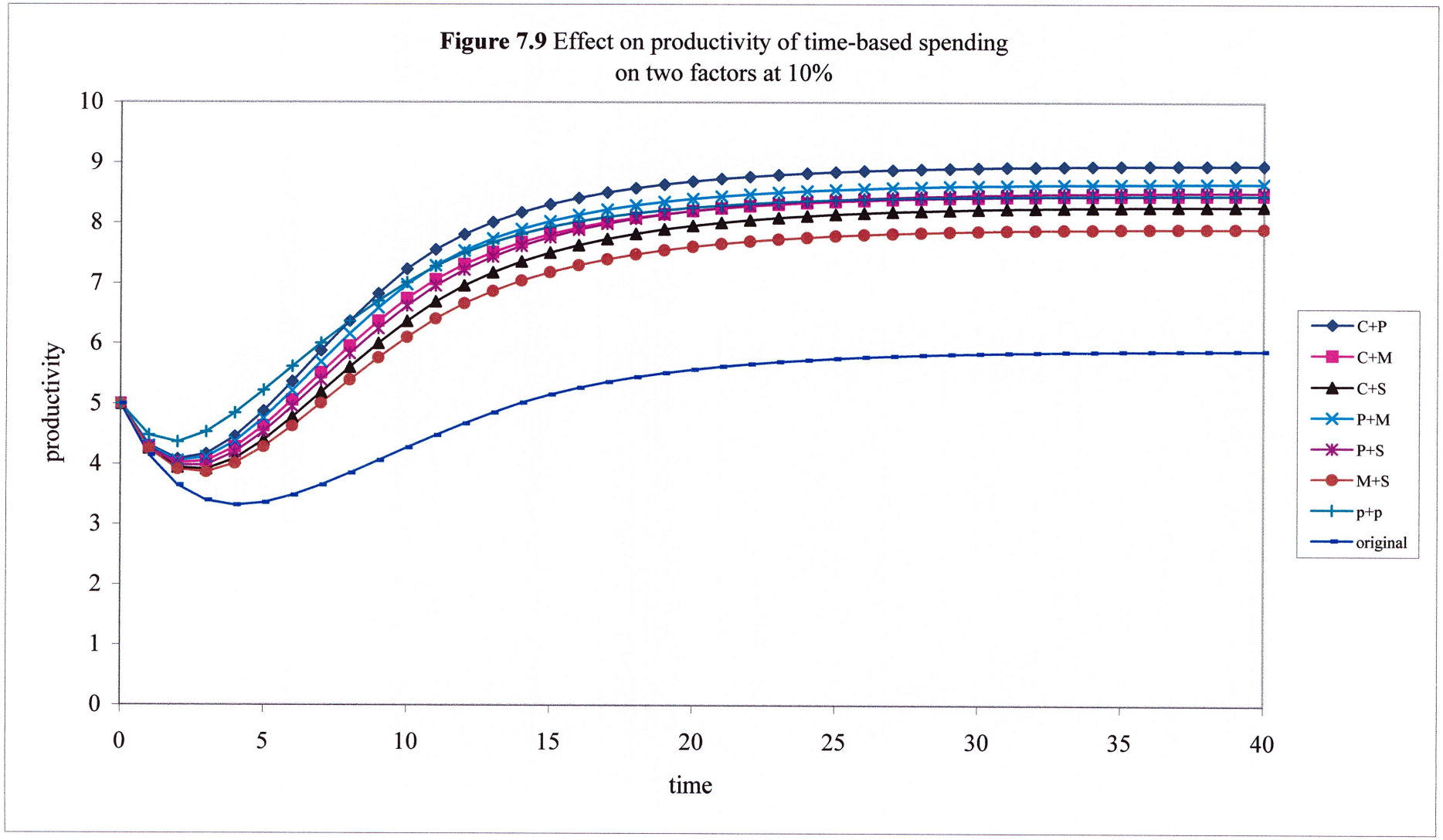


Figure 7.10 Spending on two factors at a time in every period-productivity at period 40

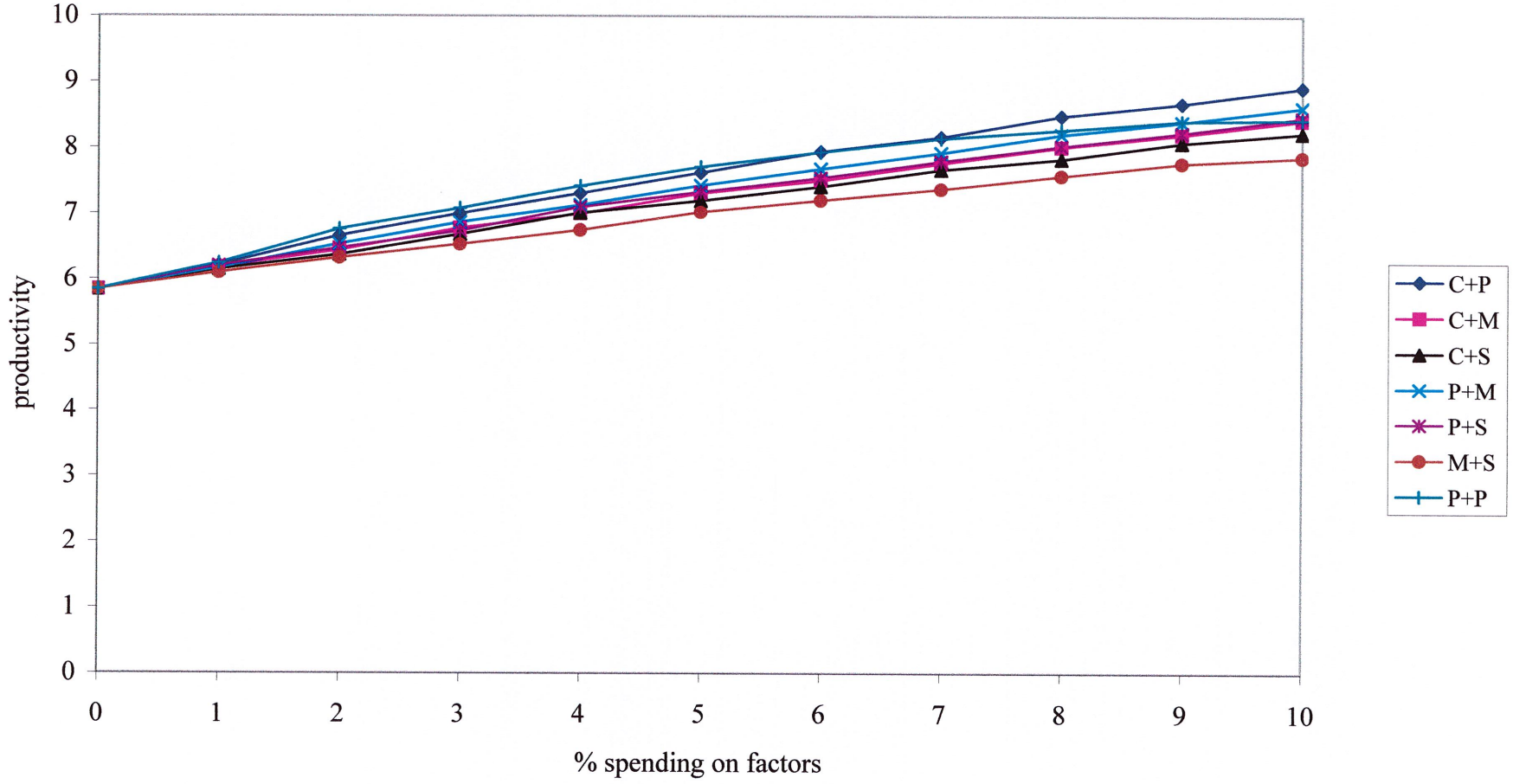


Figure 7.9 show that 'control and planning' and 'planning and planning' combinations give the highest improvements in productivity. The minimum improvement is given by the 'motivation and safety' combination. All other combinations lie between these two. However, all these combinations improve productivity by a considerable amount, as the figures show that there is wide gap (more than 20%) between all combinations and the original line. This may imply that management should invest more on combinations of two factors and in particular on 'control and planning' and 'planning and planning' combinations.

An important point, which can be extracted from Figure 7.10, is that a 10% improvement in productivity could be achieved by approximately a 3% increase in spending on the combination of 'control and planning' and 'planning and planning'. This same value of improvement in productivity could be achieved with 'planning' in all periods at 6% as discussed in the previous section. This may suggest that it would be better for management to concentrate on spending more on planning in all periods only, rather than a combined spending of 'planning and control' and 'planning and planning'.

7.4.2.3 Intermittent Spending On Single Factors.

These strategies represent a consideration by management of spending on factors at certain periods in the project's life. The span of time for the improvement of variables in these strategies is every four periods which might represent a monthly based plan of spending if considered periods are units of a week. This represents a situation, for

example, in which management spends on motivation every fourth week while no additional spending is considered on other factors.

Figure 7.11 shows how productivity changes with the increase in spending on factors in every fourth period. It can be seen from the graph that throughout the experiment, the productivity produced by 'planning' and 'control' is higher than that of others. With small increases, such as a 1% increase in spending in control and planning, the difference in productivity is small but with higher spending the gap widens. This is an indication that more expenditure in 'control' and 'planning' gives better results than expenditure on other factors. However, as can be seen, this difference is relatively small and if cost/benefit ratio is considered a different outcome may arise. In other words, management is required to evaluate each situation carefully.

7.4.2.4 Intermittent Spending On Two Factors

In this group of strategies management considers spending on two factors at a time on an intermittent basis. The combinations of factors considered in this situation are the same as those in Section 7.4.2.2 and the interval of spending is every 4 periods.

Figure 7.12 shows the change in productivity with increased spending on combinations. The greatest value produced is for the combination of 'control and planning' which once again emphasises the importance of directing more attention to that area. However, the magnitude of improvement in productivity in this situation is relatively small when compared to that of continuous spending on two factors. This is demonstrated in Figure

Figure 7.11 Effect on productivity of intermittent spending on factors one at a time (productivity at period 40)

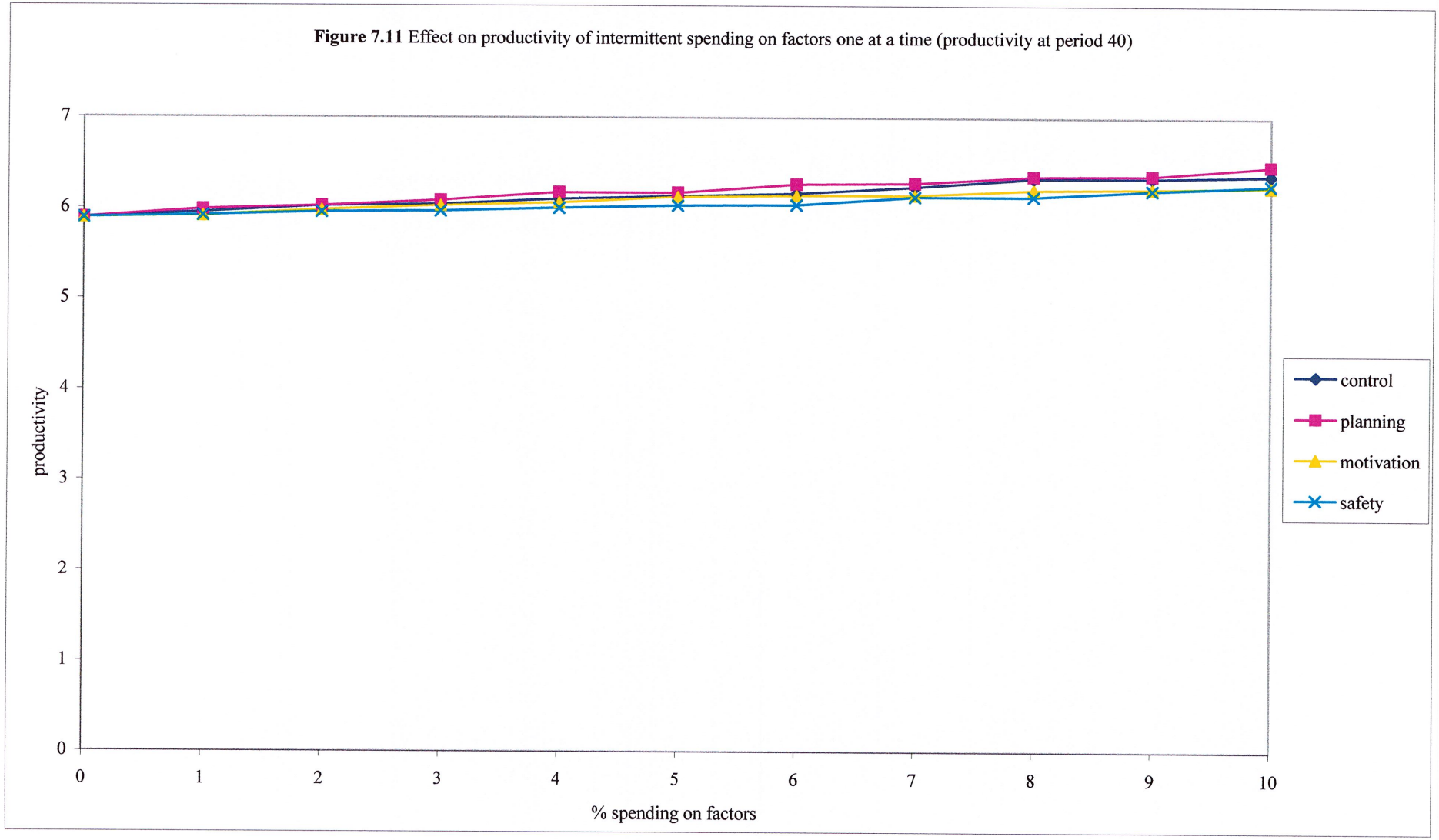


Figure 7-12 effect on productivity of intermittent spending on two factors at a time (productivity at period 40)

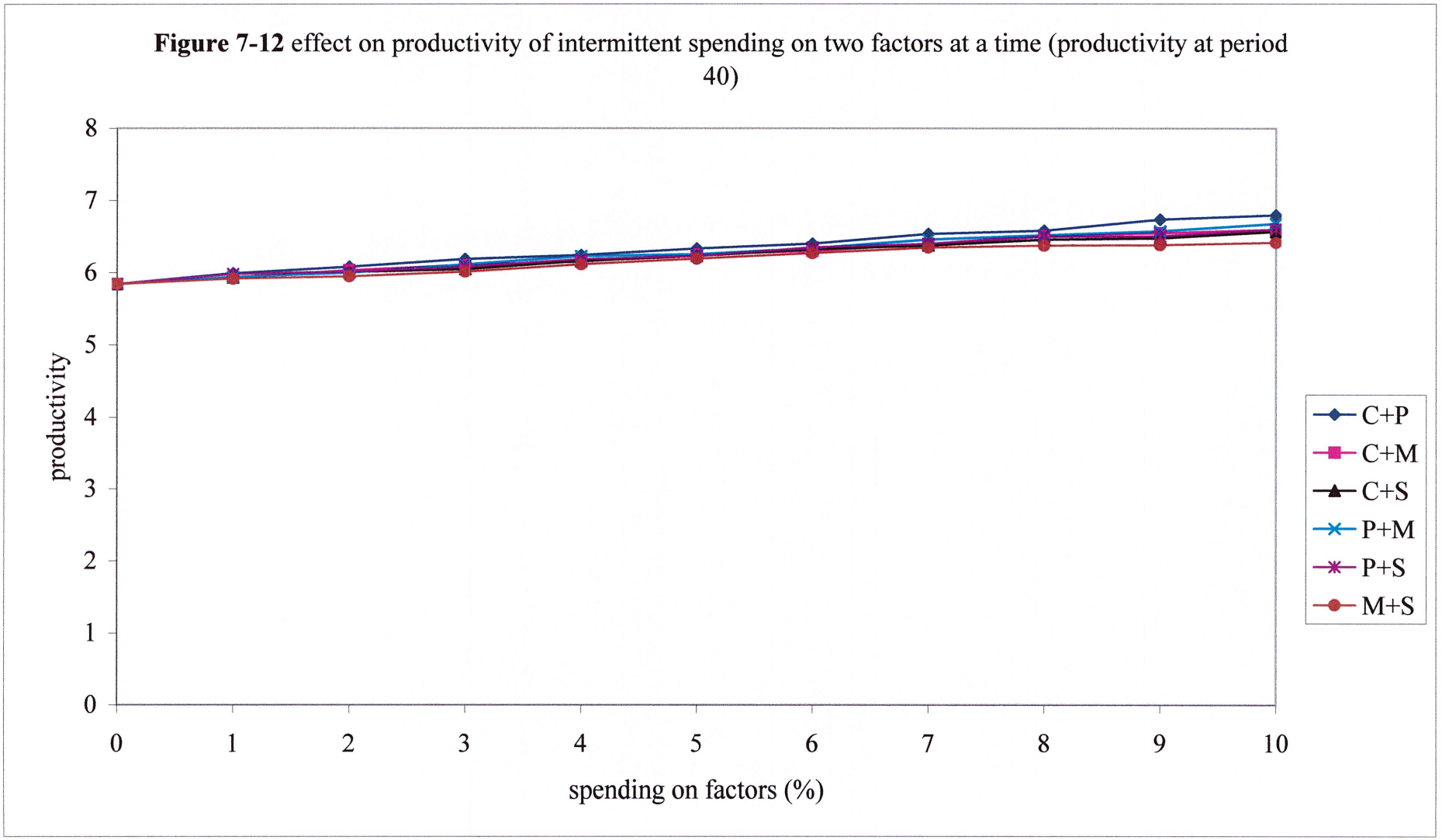
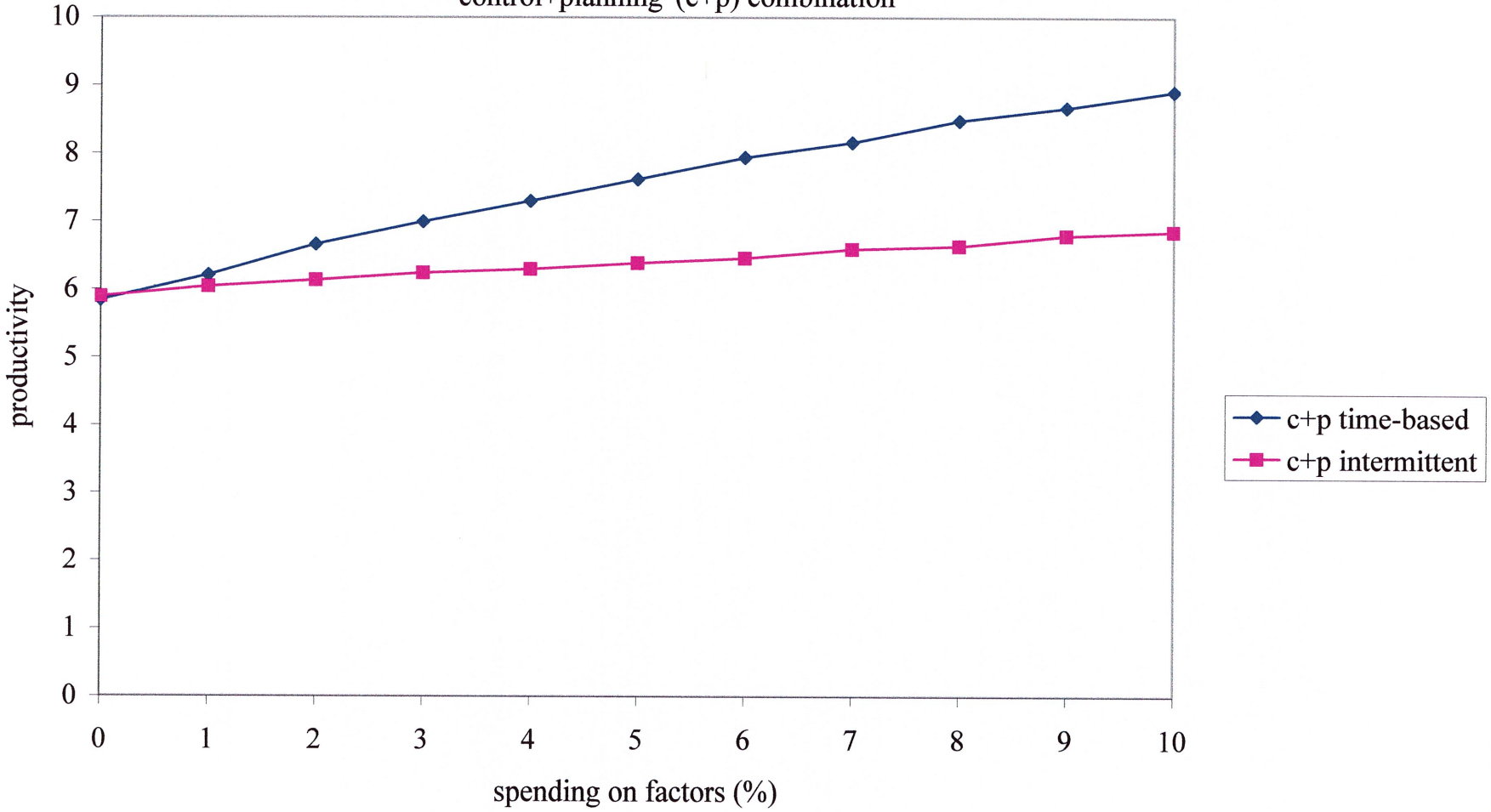


Figure 7.13 Effect on productivity of more spending on 'control+planning' (c+p) combination



7.13 where it shows that with small percentage increases in spending (i.e. 1%) the difference between the benefits is small but increased spending shows greater productivity improvements with the time-based process rather than on an intermittent basis. For example, in the case of a 10% increase in spending on the combinations, this difference is approximately 2 which represents a 20% increase in productivity. This difference could be significant when converted to the benefit it offers to the project. For example, if an average of 100 m^2 of brick wall is to be built in period 40, then this figure becomes 110 m^2 for the intermittent and 130 m^2 for the continuous or time-based scheme. The difference between the two is 20 m^2 and this means greater benefit to the project.

One cannot automatically conclude that continuous spending on two factors is better than the intermittent based on the difference in benefit shown above. An important point should be borne in mind before any judgement is made. This is that although intermittent expenditure on two factors gives less productivity than that of the continuous scheme, the amount spent is greater.

7.4.3 Group 3 strategies: Disruptions In Construction

Management at the pre-construction stage prepares the plans for the project. These plans include mainly schedules of the work and resource requirements for the project. Effective plans prepared by management should consider risks inherent in construction activities, but even with great care there still remains the possibility of some risks which are totally unpredictable. Such unexpected events may create serious disruptions to the

construction project. These disruptions may result in significant losses of productivity. Lengthy strikes and severe weather are two such occurrences which may result in a total disruption to the work and may adversely affect the productivity.

Disruption is a dependent factor which occurs as a result of other factors. Changes to the work, for example, disrupt activities in progress and hence lower the productivity.

This section considers this important issue and discusses the effects of disruptions on productivity. On some occasions disruption is considered at a maximum to reflect a situation where adverse conditions occur during the project.

Total disruption of the work will cause a great loss to the productivity but this loss is something that no one can easily predict. Therefore this section assumes certain scenarios with assumed productivity levels at the start of the project and on periods directly after total disruptions.

Figure 7.14 shows the change in productivity over time for a situation where the initial values of all factors are at 5 with productivity starting at 5. The model is run with random values for disruptions to the work in a range from 10% to 30% at each period. At arbitrary chosen periods, in this case 10 and 11, there is a total disruption. The idea of assuming 10% to 30% disruption is that in every period of any project there is some percentage of disruption to the work. This percentage might be very small or might be

large depending on the type of disruption. Change orders, for example, may disrupt the work by 5% or by 30%.

Figure 7.14 shows two lines. One of the lines represents the conditions where it is assumed that total disruption will result in a total loss of productivity (solid line). The other line (dashed line) represents the idea that even with complete disruptions there still remain some activities going on such as management activities, offsite material fabrication, etc. Such activities will be considered to maintain some productivity of the project. This level of productivity is assumed here to be at 1 (10% of the productivity). The second situation is a better reflection of reality and hence it is the one which will be considered for discussion.

Another assumption, which is taken into consideration regarding the matter of disruption, is that in reality if total disruption occurs at a certain period, then the productivity at the subsequent period is to start at a certain level.

What is important here is to find out how management can contribute to help in raising the level of productivity directly after total disruption. In order to fulfil this, it is assumed that management will spend more on the subsequent period after a total disruption has occurred. This spending will be in the form of more effort in rescheduling the work, efforts made to accelerate the work to make up for lost time and motivating workers to increase their productivity.

Figure 7.14 Effect of disruptions on construction productivity with no management input

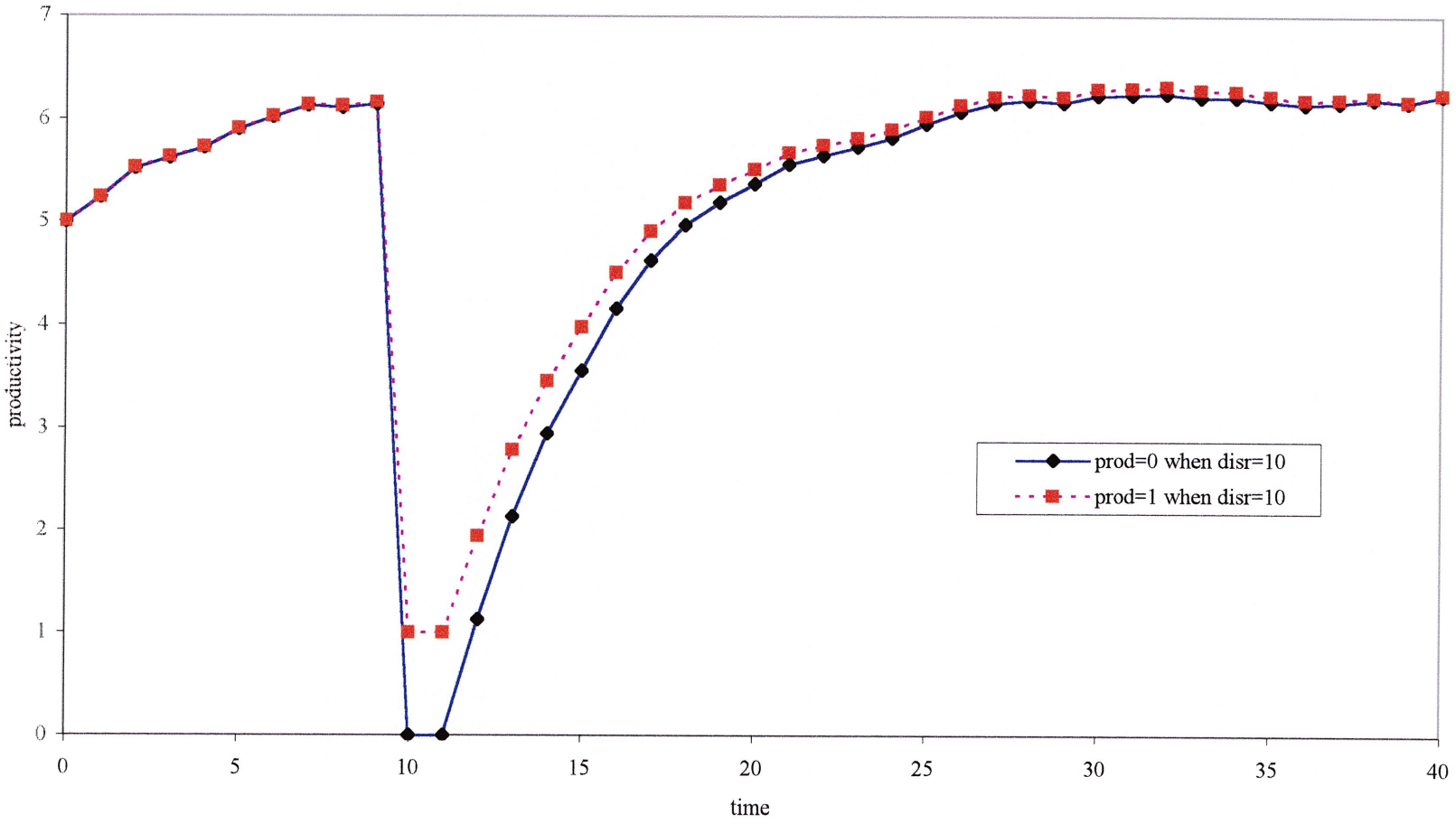


Figure 7.15 shows how productivity is affected after management has considered more input to the project in period 12. This input is concentrated on more spending on control and planning (in this case it is 10% in control and 10% in planning). The figure shows that the rate of improvement in the case of more input from management is faster than that of no input.

7.5 SUMMARY

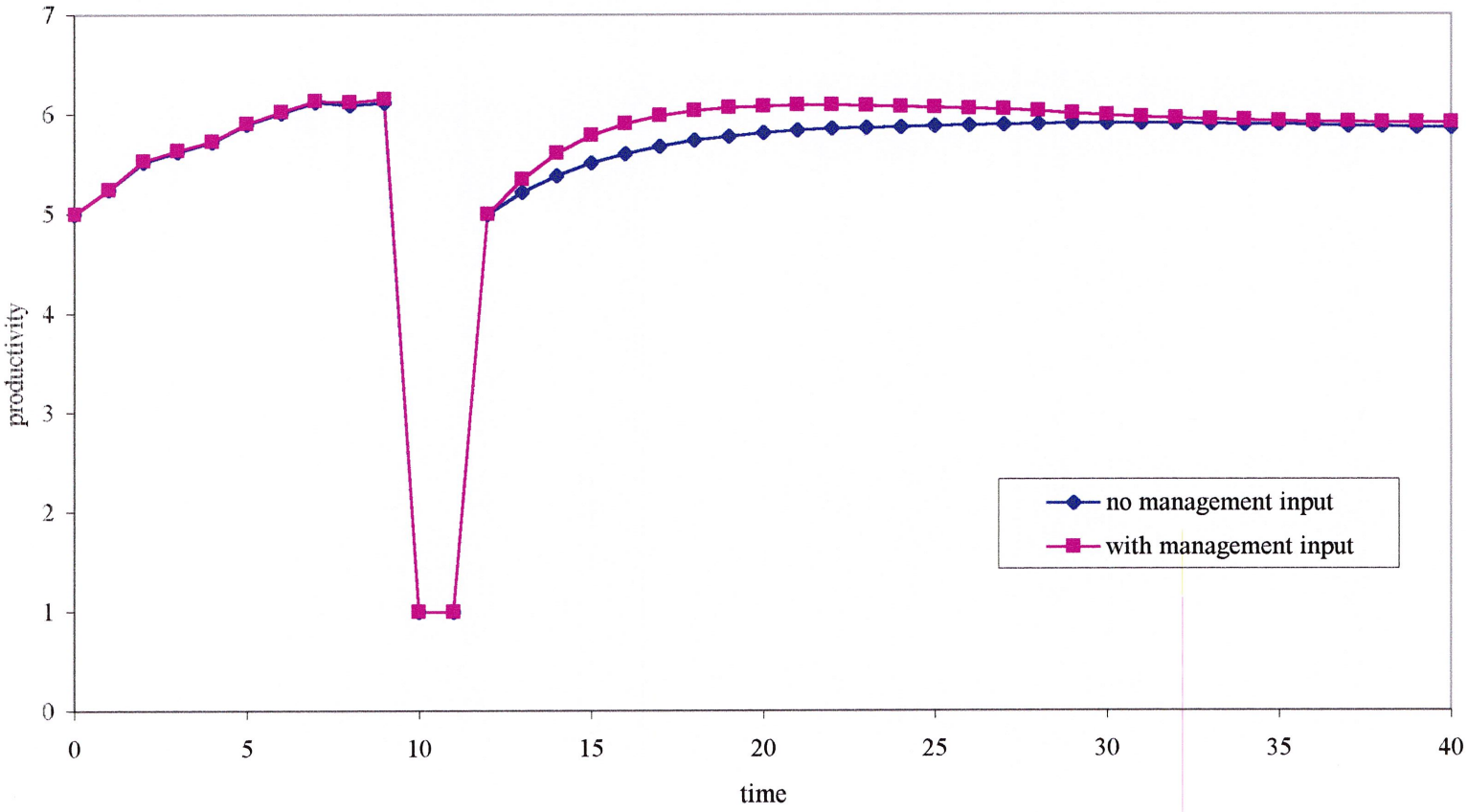
This chapter has studied some of the applications of the model described in Chapter 5. These applications were centred around how management of construction projects can make use of the model to assess its possible strategies.

Experiments on a number of assumed management strategies were conducted and the results showed that management should pay more attention to 'planning' and 'control' both at the initial stages of the project and during construction.

The problem of disruptions in construction was also considered. An assumed scenario of disruptions to a construction project was discussed together with the possible remedial actions to be taken in such situations.

A method of evaluating management strategies numerically has been presented and used.

Figure 7.15 Effect of disruptions on construction productivity with management input directly after total disruptions



CHAPTER 8

CONCLUSIONS AND FURTHER WORK

CHAPTER 8

CONCLUSIONS AND FURTHER WORK

8.1 INTRODUCTION

This chapter considers the conclusions drawn from the research together with some recommendations for further work. The conclusions relate to the objectives of the research set out in Chapter 1. These conclusions are divided into general conclusions (Section 8.2) and specific conclusions (Section 8.3). The general ones are conclusions that are related to the work in general whereas the specific conclusions are drawn from the discussion of the use of the model in Chapter 7.

The whole of the work is concerned with productivity of a construction project rather than that of the industry as a whole or that of a group of workers on a specific task. For this reason, it is difficult to define the productivity in measured terms and the model, its analysis and testing is therefore concerned with relative productivity. This means that the figures given for improvement or other changes are not absolute and, without the validation discussed in Section 8.4, and should only be taken as indications of trends.

8.2 GENERAL CONCLUSIONS

The objectives of the research, set out in Chapter 1, have been achieved. It has been shown in a systematic way that productivity in construction can be modeled using a systems approach. The main general conclusions drawn from the work are as follows:

1. A review of the literature in construction productivity revealed that a huge number of factors affects productivity in construction. These factors interact with each other in such a manner that any attempt to study productivity as if it is affected by one factor only, ignoring any other factors, will lead to a deficiency in that study.

2. There have been a limited number of studies which relate construction productivity to 'systems theory'.

3. Analysis of the knowledge obtained from experts indicated that there is a group of factors considered to be the most important factors. This has been concluded based on the fact that the majority of the important interactions exist within this group.

4. Of the important group of factors, mentioned in point 3 above, there exists a sub-group which was used to build the model in order to help to improve productivity in construction projects. This sub-group consists of five factors described as 'management factors' as they are factors which management can manipulate some of them in order to influence the running of projects. These factors are: planning, control, motivation, safety and disruptions.

5. It is possible to use systems theory to model productivity in construction.

6. Building a model that is to be used for predicting and improving productivity in construction needs a lot of knowledge to ensure that the model is correct.

7. The 'factors matrix' built for the purpose of this research is a good way of obtaining information about factors affecting construction projects and how these factors interact with each other.

8. There are wide variations in views about the interactions between factors affecting construction productivity. This could be related to a number of issues such as experience, project size, and project complexity.

9. The testing of the model (Chapter 6) has proved that all the coefficients, produced from the data provided by experts and used in the transition equations of the model, are not sensitive to small variations in their values. Therefore, the model is robust enough to be used.

10. The Excel spreadsheet used for the experimentation of the model proves to be a good tool for such use.

8.3 SPECIFIC CONCLUSIONS

The conclusions drawn from the discussion of the use of the model to evaluate management strategies are as follows:

1. Control and planning are essential management functions on which the management should make no compromise, if the success of the project is desired. Furthermore, Management should adopt certain plans to improve safety on the construction site

and to stimulate workers' enthusiasm. All this is bound to improve project productivity.

2. Spending on factors in the initial stages of the project has a considerable effect on productivity early on.

3. Planning proved to be the best area for the improvement of productivity, both at the initial stages and during construction. However, this does not lessen the importance of other factors concerning productivity.

4. Doubling the expenditure on planning on a continuous basis has a significant effect on productivity.

5. Management should take into account the cost/benefit ratio when adopting any strategy.

6. More expenditure by management directly after a complete disruption to the work will help to improve productivity.

8.4 FURTHER WORK

The following recommendations for further work are derived from this study:

1. Although the model has been shown to work in theory, several aspects would have to be evaluated and calibrated for use in practice. For example, the additive effects of the factors on overall productivity is an assumption which would need verification.

   To validate and calibrate an integrated model such as this is a difficult task because so many measurements are required. One possible method for doing this on a given project would be to take measurements of all the factors in the model and the productivity of the project. The results could then be analysed, using statistical techniques such as linear regression and correlation, to obtain the values of the coefficients and the form of the relationships.

   The measurement of some factors, such as 'planning' would be difficult and a mean of incorporating subjective assessments of this information into the analysis would be required.

2. The model developed in this research considered only five factors as they represented the most important factors in a construction project. This number can be increased to cover other factors which are less important than the modeled group, but may still have a considerable influence.

3. Further development of the model in the Excel spreadsheet is recommended in order for it to be user friendly. This development could be in the following areas:

- Develop a data base which contains all the interactions in the 'average normalised form' (shown in Figure 4.8). This enables the user to recall any interactions between any two factors if he/she is interested to include it in the model.

- Use the spreadsheet as a knowledge-base system where the user is asked to give certain conditions and final outcomes are required in the form of both quantitative results and written recommendations.

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APPENDIX A

FIGURES AND TABLES OF CHAPTER 6

Figure A.1 Frequency distribution for planning outcome with variations in 'a' coefficients

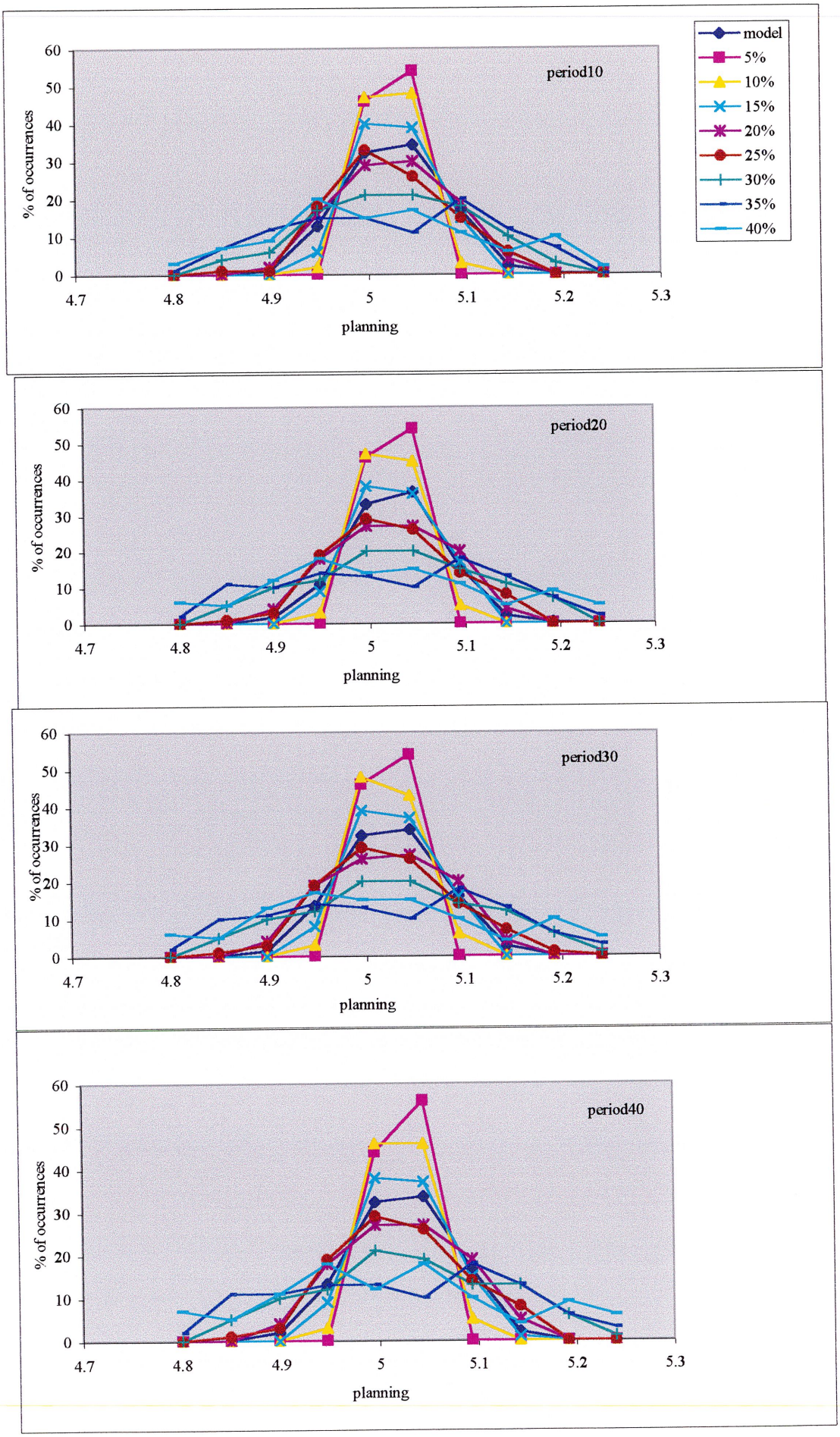


Figure A.2 Frequency distribution for motivation outcome with variations in '*a*' coefficients

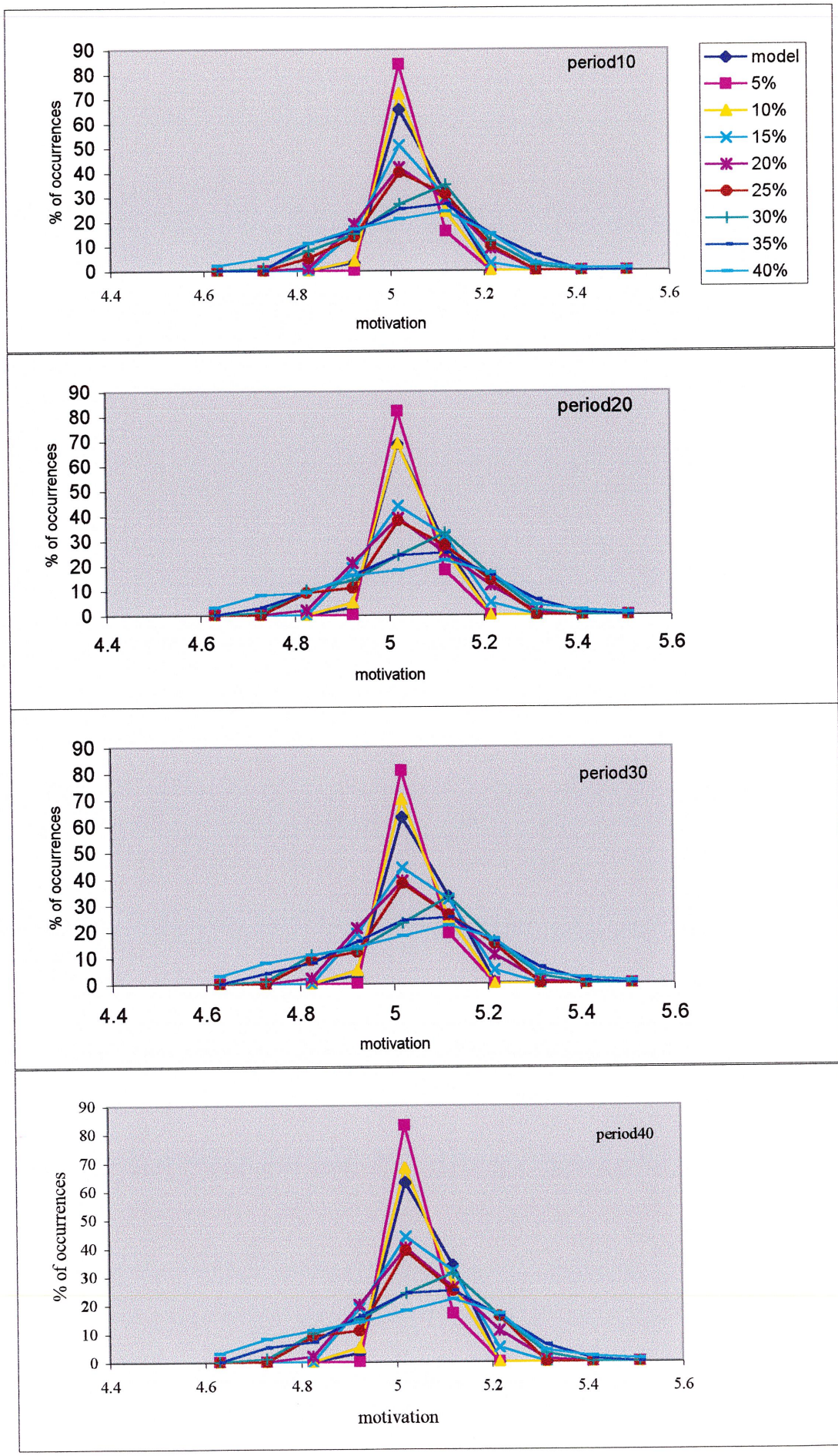


Figure A.3 Frequency distribution for safety outcome with variations in '*a*' coefficients

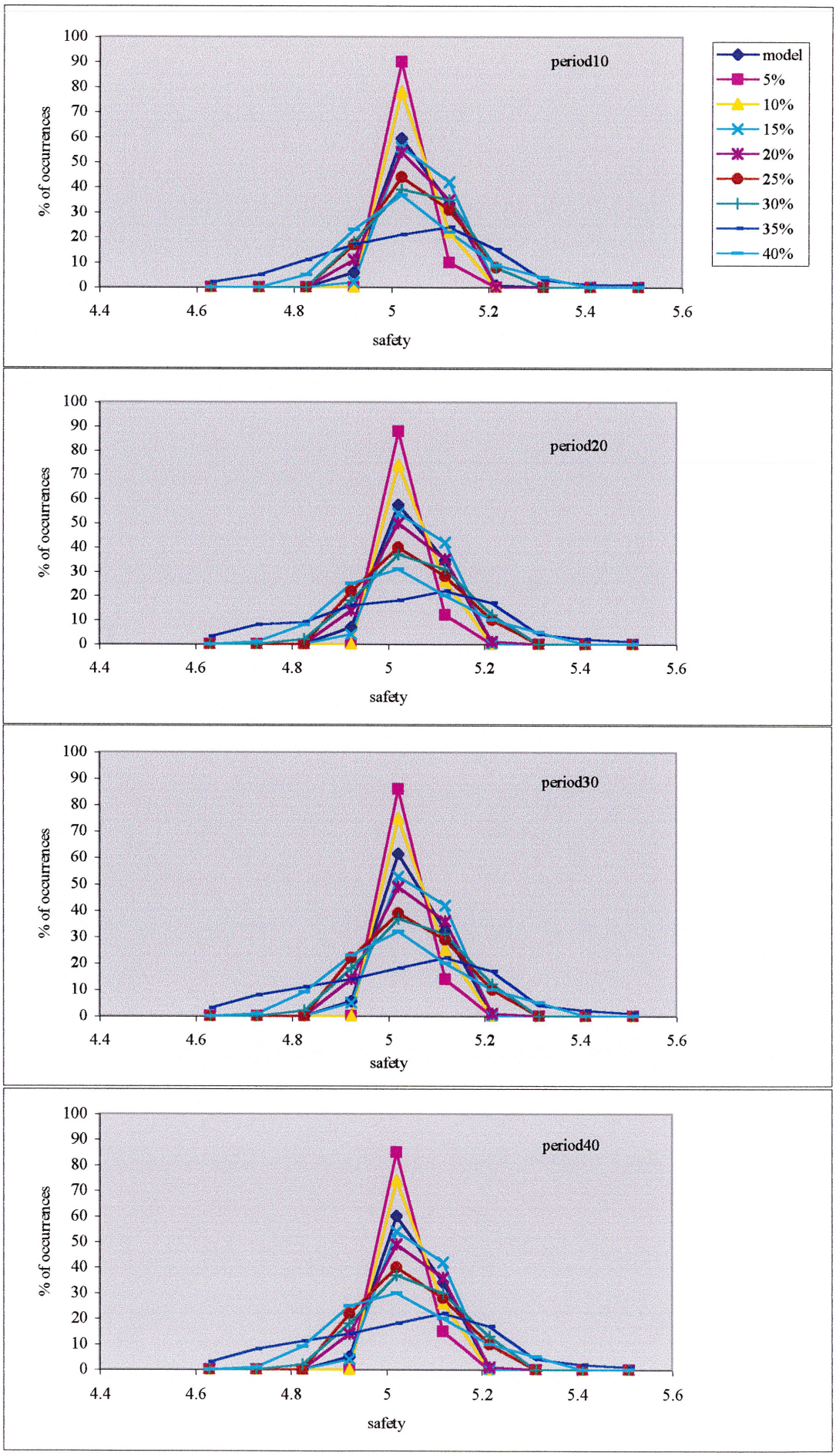


Figure A.4 Frequency distribution for control outcome with variations in '*b*' coefficients

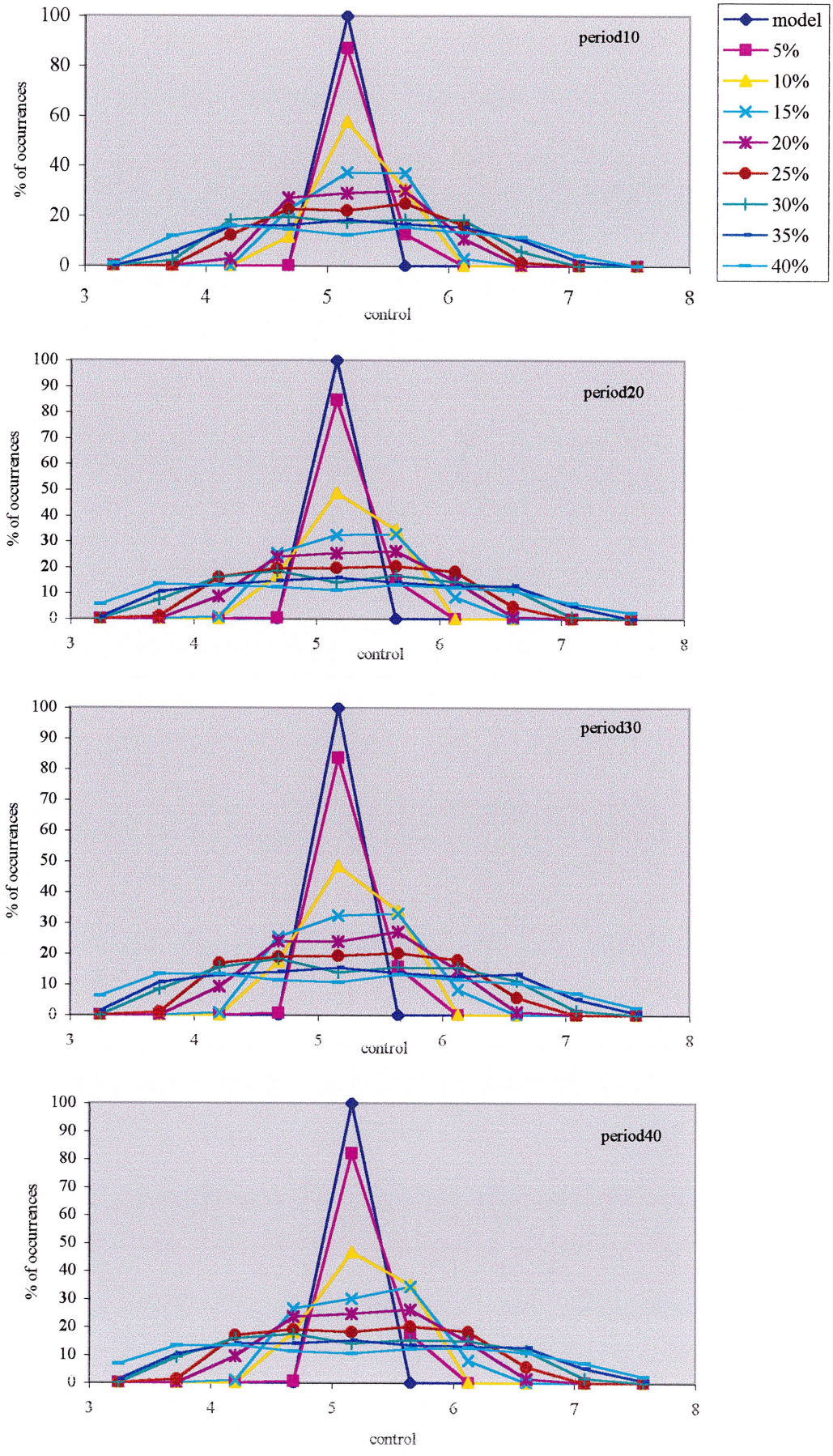


Figure A.5 Frequency distribution for planning outcome with variations in '*b*' coefficients

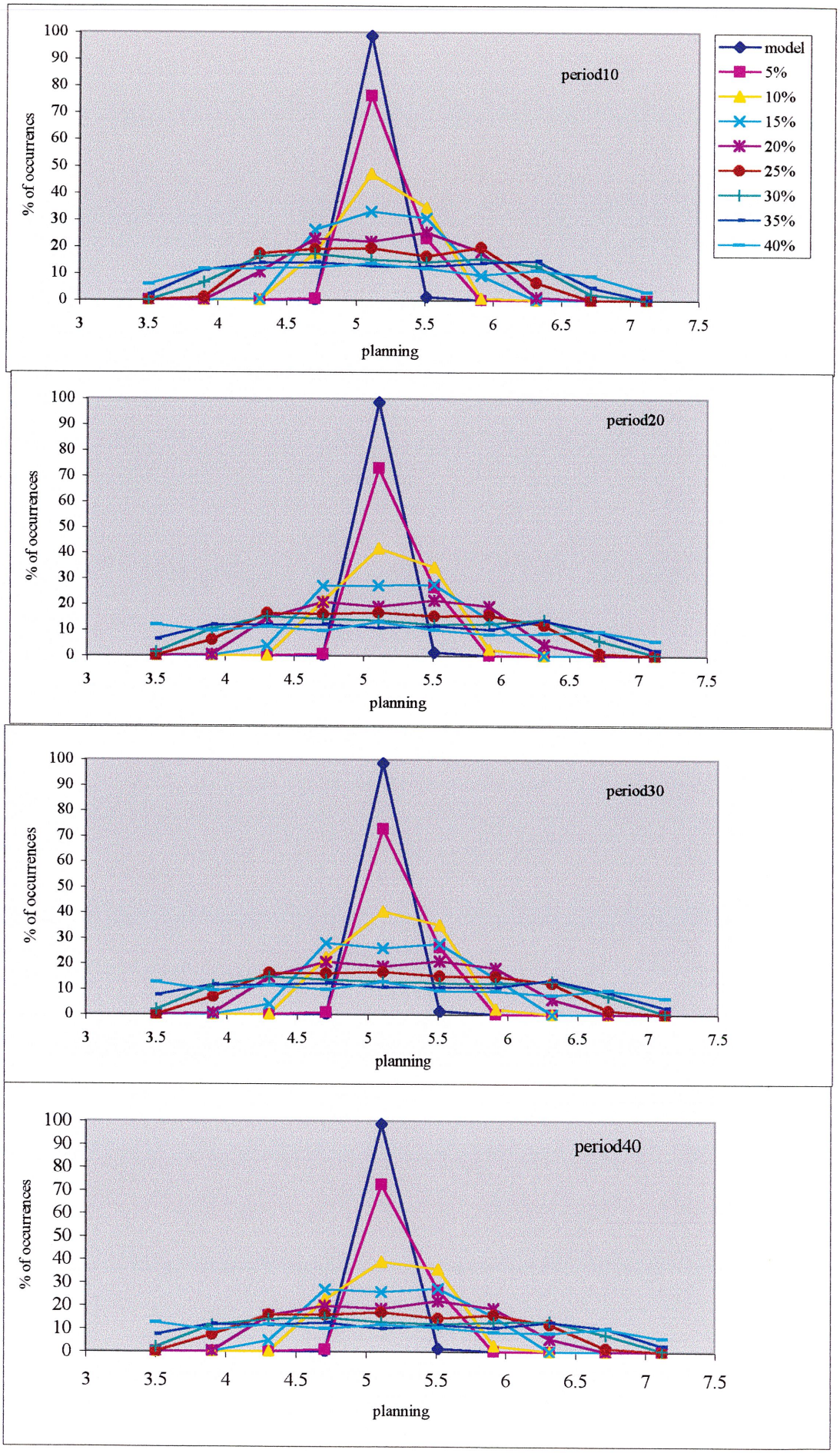


Figure A.6 Frequency distribution for motivation outcome with variations in '*b*' coefficients

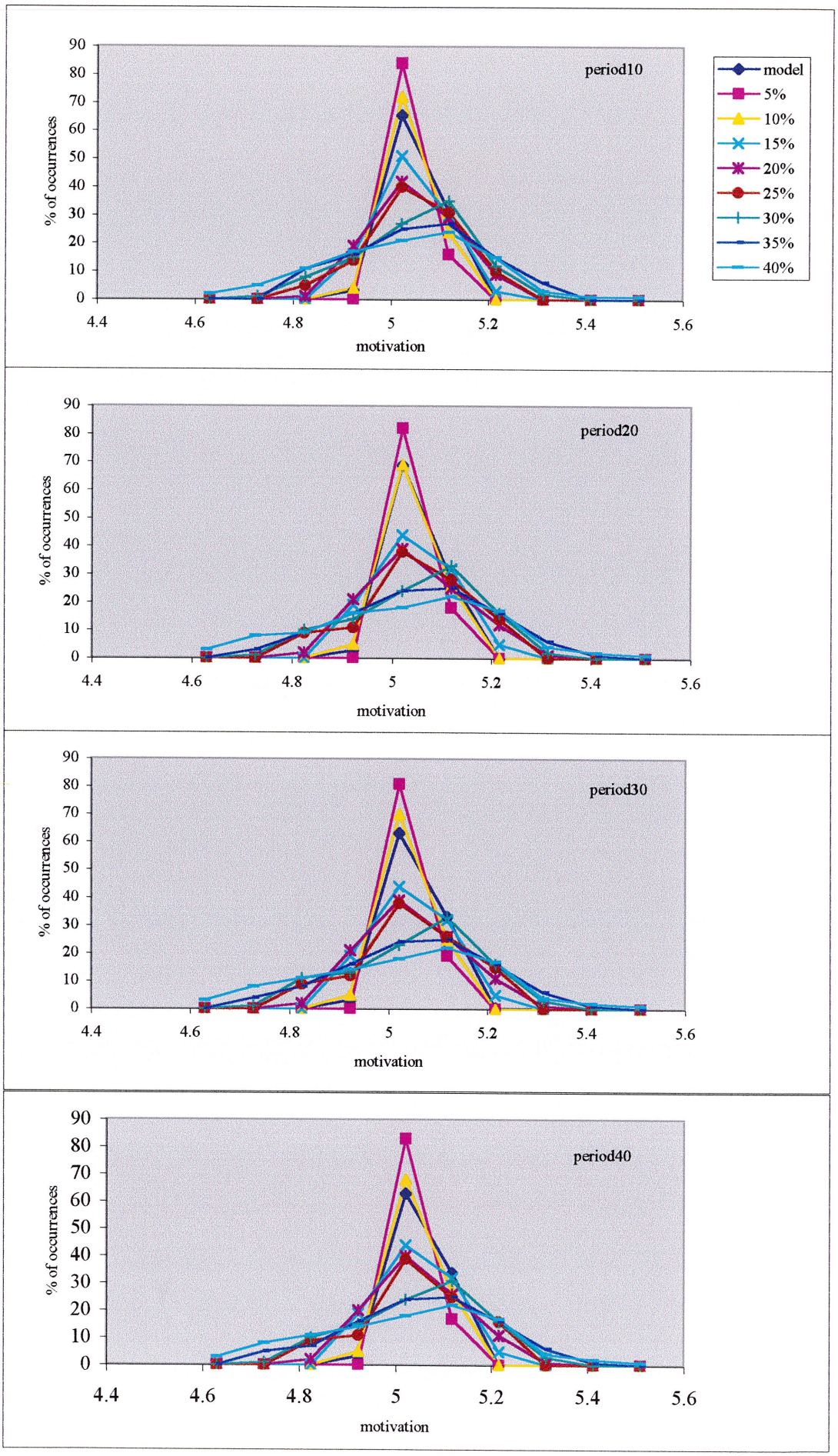


Table A.1 mean and standard deviation of factors -with variations in "a" coefficients

control values

	period									
	1		10		20		30		40	
% variation	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.
0	5.000	0.027	4.999	0.045	5.000	0.047	4.999	0.047	5.001	0.048
5	4.999	0.004	4.997	0.016	4.997	0.018	4.997	0.018	4.997	0.018
10	5.000	0.007	4.999	0.033	4.999	0.037	4.999	0.037	4.999	0.037
15	5.001	0.011	5.003	0.049	5.003	0.054	5.003	0.055	5.003	0.055
20	5.000	0.013	4.997	0.060	4.996	0.066	4.996	0.067	4.996	0.067
25	4.997	0.020	4.988	0.089	4.986	0.100	4.986	0.101	4.986	0.101
30	5.005	0.020	5.023	0.088	5.027	0.099	5.027	0.100	5.027	0.100
35	5.001	0.029	5.006	0.133	5.007	0.149	5.008	0.151	5.008	0.151
40	4.998	0.032	4.989	0.147	4.989	0.165	4.989	0.167	4.989	0.167

planning values

	period									
	1		10		20		30		40	
% variation	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.
0	5.000	0.029	5.002	0.049	5.001	0.048	5.000	0.050	5.000	0.051
5	5.000	0.003	4.999	0.012	4.998	0.014	4.998	0.014	4.998	0.014
10	5.000	0.006	4.998	0.027	4.997	0.030	4.998	0.031	4.997	0.031
15	5.001	0.009	5.004	0.039	5.004	0.043	5.004	0.044	5.004	0.044
20	5.000	0.011	5.001	0.052	5.001	0.059	5.001	0.060	5.001	0.060
25	4.999	0.013	4.997	0.056	4.997	0.063	4.997	0.064	4.997	0.064
30	5.000	0.018	5.000	0.081	5.000	0.091	5.000	0.092	5.000	0.092
35	4.999	0.022	4.996	0.100	4.996	0.111	4.996	0.113	4.996	0.113
40	4.998	0.024	4.988	0.106	4.986	0.118	4.986	0.119	4.986	0.119

motivation values

	period									
	1		10		20		30		40	
% variation	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.
0	4.999	0.025	5.000	0.041	5.000	0.042	4.999	0.043	4.999	0.041
5	5.000	0.004	5.001	0.020	5.001	0.022	5.001	0.022	5.001	0.023
10	4.999	0.009	4.996	0.041	4.995	0.045	4.995	0.045	4.995	0.045
15	4.998	0.014	4.992	0.064	4.991	0.072	4.991	0.073	4.991	0.073
20	4.999	0.018	4.998	0.082	4.999	0.092	4.999	0.093	4.999	0.093
25	5.000	0.023	4.999	0.099	4.999	0.109	4.999	0.109	4.999	0.110
30	5.002	0.026	5.006	0.116	5.006	0.128	5.006	0.129	5.006	0.130
35	5.002	0.029	5.005	0.131	5.005	0.146	5.005	0.147	5.005	0.148
40	4.996	0.037	4.982	0.165	4.980	0.183	4.979	0.184	4.979	0.185

safety values

	period									
	1		10		20		30		40	
% variation	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.
0	5.000	0.030	5.002	0.049	4.999	0.051	4.998	0.050	5.001	0.048
5	5.000	0.003	5.002	0.014	5.002	0.016	5.002	0.016	5.002	0.016
10	5.000	0.006	5.001	0.027	5.001	0.030	5.001	0.030	5.001	0.031
15	5.002	0.010	5.009	0.043	5.009	0.048	5.010	0.049	5.010	0.049
20	4.999	0.012	4.996	0.054	4.996	0.060	4.997	0.061	4.997	0.061
25	5.000	0.018	4.998	0.078	4.998	0.087	4.998	0.088	4.998	0.088
30	5.001	0.019	5.006	0.083	5.007	0.093	5.007	0.095	5.007	0.095
35	4.996	0.037	4.982	0.165	4.980	0.183	4.979	0.184	4.979	0.185
40	4.997	0.025	4.985	0.111	4.983	0.123	4.983	0.125	4.983	0.125

Table A.2 Mean and standard deviation for productivity at different periods with different variations in coefficients

productivity values-'*a*' coefficients

	period									
	1		10		20		30		40	
% variation	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.
0	5.342	0.004	6.525	0.024	6.690	0.027	6.705	0.026	6.707	0.027
5	5.342	0.001	6.527	0.010	6.691	0.014	6.707	0.016	6.711	0.016
10	5.342	0.001	6.525	0.017	6.689	0.025	6.704	0.026	6.708	0.027
15	5.342	0.001	6.534	0.026	6.701	0.038	6.717	0.041	6.722	0.041
20	5.342	0.002	6.526	0.041	6.691	0.060	6.706	0.064	6.710	0.065
25	5.342	0.003	6.527	0.049	6.692	0.072	6.707	0.076	6.711	0.078
30	5.341	0.003	6.517	0.051	6.677	0.074	6.692	0.078	6.696	0.080
35	5.341	0.003	6.515	0.064	6.674	0.093	6.689	0.098	6.693	0.100
40	5.342	0.004	6.522	0.070	6.684	0.103	6.699	0.110	6.703	0.112

productivity values '*b*' coefficients

	period									
	1		10		20		30		40	
% variation	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.
0	5.342	0.004	6.525	0.024	6.690	0.027	6.705	0.026	6.707	0.027
5	5.342	0.007	6.523	0.121	6.685	0.178	6.701	0.190	6.706	0.195
10	5.342	0.014	6.532	0.254	6.699	0.373	6.715	0.395	6.720	0.406
15	5.341	0.020	6.526	0.363	6.692	0.539	6.708	0.572	6.710	0.586
20	5.341	0.026	6.515	0.489	6.677	0.725	6.693	0.773	6.697	0.792
25	5.340	0.032	6.487	0.610	6.635	0.904	6.648	0.964	6.650	0.986
30	5.342	0.038	6.530	0.721	6.698	1.072	6.714	1.141	6.721	1.170
35	5.341	0.045	6.508	0.840	6.664	1.247	6.676	1.328	6.679	1.360
40	5.345	0.052	6.595	0.980	6.798	1.457	6.822	1.553	6.829	1.592

productivity values - '*p*' coefficients

	period									
	1		10		20		30		40	
% variation	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.
0	5.342	0.004	6.525	0.024	6.690	0.027	6.705	0.026	6.707	0.027
5	5.341	0.020	6.521	0.091	6.685	0.100	6.700	0.101	6.704	0.102
10	5.338	0.042	6.511	0.186	6.673	0.206	6.688	0.208	6.692	0.208
15	5.345	0.060	6.541	0.266	6.707	0.294	6.722	0.297	6.726	0.297
20	5.343	0.082	6.530	0.368	6.694	0.407	6.710	0.411	6.714	0.412
25	5.329	0.107	6.466	0.478	6.624	0.530	6.639	0.535	6.642	0.536
30	5.341	0.135	6.521	0.604	6.684	0.669	6.700	0.675	6.704	0.677
35	5.330	0.144	6.473	0.642	6.631	0.711	6.646	0.718	6.650	0.719
40	5.325	0.149	6.453	0.666	6.609	0.738	6.624	0.745	6.627	0.746

productivity values - '*a*' and '*p*' coefficients

	period									
	1		10		20		30		40	
% variation	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.
0	5.342	0.004	6.525	0.024	6.690	0.027	6.705	0.026	6.707	0.027
5	5.342	0.018	6.526	0.080	6.690	0.089	6.705	0.090	6.709	0.090
10	5.344	0.043	6.533	0.193	6.697	0.216	6.713	0.218	6.717	0.219
15	5.337	0.062	6.502	0.279	6.663	0.311	6.678	0.314	6.682	0.315
20	5.337	0.078	6.509	0.349	6.673	0.389	6.689	0.393	6.693	0.394
25	5.322	0.104	6.439	0.462	6.594	0.513	6.609	0.518	6.613	0.520
30	5.347	0.137	6.544	0.607	6.707	0.671	6.722	0.677	6.726	0.679
35	5.360	0.152	6.614	0.688	6.790	0.766	6.807	0.774	6.811	0.776
40	5.365	0.151	6.626	0.671	6.799	0.744	6.815	0.751	6.819	0.753

APPENDIX B

TABLES OF CHAPTER 7

Table B.1 Benefits gained in formwork with improvement in control at initial value to a level of 5

period	Pa	Po	Pa - Po	W (m^2)	benefit(m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(4)*(5)
1	0.468539	0.155517	0.031	100	3.1
2	0.973266	0.457197	0.052	100	5.2
3	1.485802	0.848443	0.064	100	6.4
4	1.98684	1.287493	0.070	100	7
5	2.463827	1.744507	0.072	100	7.2
6	2.909128	2.198802	0.071	100	7.1
7	3.318616	2.636525	0.068	100	6.82
8	3.690739	3.048979	0.064	100	6.4
9	4.025656	3.431084	0.059	100	5.9
10	4.324693	3.780436	0.054	100	5.4
Total benefit (unit)					60.52

Table B.2 Benefits gained in formwork with improvement in motivation at initial value to a level of 5

period	Pa	Po	Pa - Po	W (m^2)	benefit(m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4)*(5)
1	0.415774	0.155517	0.026	100	2.6
2	0.873686	0.457197	0.042	100	4.2
3	1.347215	0.848443	0.050	100	5
4	1.817718	1.287493	0.053	100	5.3
5	2.272245	1.744507	0.053	100	5.3
6	2.70243	2.198802	0.050	100	5
7	3.103178	2.636525	0.047	100	4.7
8	3.471861	3.048979	0.042	100	4.2
9	3.807487	3.431084	0.038	100	3.8
10	4.110462	3.780436	0.033	100	3.3
Total benefit (unit)					43.4

Table B.3 Benefits gained in formwork with improvement in safety at initial value to a level of 5

period	**Pa**	**Po**	**Pa - Po**	**W (m^2)**	**benefit(m^2)**
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4)*(5)
1	0.313725	0.155517	0.016	100	1.6
2	0.723811	0.457197	0.027	100	2.7
3	1.183764	0.848443	0.034	100	3.4
4	1.661066	1.287493	0.037	100	3.7
5	2.133536	1.744507	0.039	100	3.9
6	2.586703	2.198802	0.039	100	3.9
7	3.011546	2.636525	0.038	100	3.8
8	3.403258	3.048979	0.035	100	3.5
9	3.75954	3.431084	0.033	100	3.3
10	4.080286	3.780436	0.030	100	3
Total benefit (unit)					32.8

Table B.4 Benefits gained in formwork with improvement in planning at initial value to a level of 9

period	Pa	Po	Pa - Po	W (m^2)	benefit(m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4)*(5)
1	0.824283	0.155517	0.067	100	6.7
2	1.554768	0.457197	0.110	100	11.0
3	2.198659	0.848443	0.135	100	13.5
4	2.763451	1.287493	0.148	100	14.8
5	3.256846	1.744507	0.151	100	15.1
6	3.686147	2.198802	0.149	100	14.9
7	4.058572	2.636525	0.142	100	14.2
8	4.380642	3.048979	0.133	100	13.3
9	4.658409	3.431084	0.123	100	12.3
10	4.897419	3.780436	0.112	100	11.2
Total benefit (unit)					156

Table B.5 Benefits gained in formwork with improvement in control at initial value to a level of 9

period	Pa	Po	Pa - Po	W (m^2)	benefit(m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4)*(5)
1	0.719707	0.155517	0.056	100	5.6
2	1.382672	0.457197	0.093	100	9.3
3	1.985794	0.848443	0.114	100	11.37
4	2.529007	1.287493	0.124	100	12.4
5	3.014148	1.744507	0.127	100	12.7
6	3.444397	2.198802	0.125	100	12.46
7	3.823754	2.636525	0.119	100	11.87
8	4.156472	3.048979	0.111	100	11.1
9	4.447007	3.431084	0.102	100	10.2
10	4.699726	3.780436	0.092	100	9.2
Total benefit (unit)					126.2

Table B.6 Benefits gained in formwork with improvement in motivation at initial value to a level of 9

period	Pa	Po	Pa - Po	W (m^2)	benefit(m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4)*(5)
1	0.626905	0.155517	0.047	100	4.7
2	1.209146	0.457197	0.075	100	7.5
3	1.746503	0.848443	0.090	100	9.0
4	2.239454	1.287493	0.095	100	9.5
5	2.689023	1.744507	0.094	100	9.4
6	3.096839	2.198802	0.090	100	9.0
7	3.464903	2.636525	0.083	100	8.3
8	3.795615	3.048979	0.075	100	7.5
9	4.09148	3.431084	0.066	100	6.6
10	4.355117	3.780436	0.057	100	5.7
Total benefit (unit)					97.2

Table B.7 Benefits gained in formwork with improvement in safety at initial value to a level of 9

period	Pa	Po	Pa - Po	W (m^2)	benefit(m^2)
(1)	(2)	(3)	(4)=[(2)-(3)]/10	(5)	(6)=(4)*(5)
1	0.447736	0.155517	0.029	100	2.9
2	0.951451	0.457197	0.049	100	4.9
3	1.473558	0.848443	0.063	100	6.3
4	1.988885	1.287493	0.070	100	7.0
5	2.481073	1.744507	0.074	100	7.4
6	2.940475	2.198802	0.074	100	7.4
7	3.361786	2.636525	0.073	100	7.3
8	3.743091	3.048979	0.069	100	6.9
9	4.084375	3.431084	0.065	100	6.5
10	4.38713	3.780436	0.061	100	6.1
Total benefit (unit)					82.7

Appendix B

Table B.8 Calculation of gained benefits in formwork as a result of improvement in productivity

(a) Improvement of planning at initial value of 9

Period	Productivity		Work (m^2)	Benefit (m^2)	Cumulative benefit (m2)
	P_a	P_a/5*	W	(P_a/5)*W	
[1]	[2]	[3]	[4]	[5]=[3]*[4]	[6]
1	0.8242834	0.165	100	16.49	16.49
2	1.5547682	0.311	100	31.10	47.58
3	2.1986588	0.440	100	43.97	91.55
4	2.7634512	0.553	100	55.27	146.82
5	3.2568458	0.651	100	65.14	211.96
6	3.6861467	0.737	100	73.72	285.68
7	4.0585721	0.812	100	81.17	366.85
8	4.3806418	0.876	100	87.61	454.47
9	4.6584091	0.932	100	93.17	547.64
10	4.8974195	0.979	100	97.95	645.58
11	5.102613	1.021	100	102.05	747.64
12	5.278426	1.056	100	105.57	853.20
13	5.4202046	1.084	100	108.40	961.61
14	5.5294192	1.106	100	110.59	1072.20
15	5.6139066	1.123	100	112.28	1184.48
16	5.6794207	1.136	100	113.59	1298.06
17	5.7311443	1.146	100	114.62	1412.69
18	5.7718564	1.154	100	115.44	1528.12
19	5.804557	1.161	100	116.09	1644.21
20	5.83097	1.166	100	116.62	1760.83

(b) No improvement of planning at initial value

Period	Original productivity		Work (m^2)	Benefit (m^2)	Cumulative benefit (m^2)
	Po	Po/5*	W	(Po/5)*W	
[1]	[2]	[3]	[4]	[5]=[3]*[4]	[6]
1	0.156	0.031	100	3.11	3.11
2	0.457	0.091	100	9.14	12.25
3	0.848	0.170	100	16.97	29.22
4	1.287	0.257	100	25.75	54.97
5	1.745	0.349	100	34.89	89.86
6	2.199	0.440	100	43.98	133.84
7	2.637	0.527	100	52.73	186.57
8	3.049	0.610	100	60.98	247.55
9	3.431	0.686	100	68.62	316.17
10	3.780	0.756	100	75.61	391.78
11	4.096	0.819	100	81.93	473.71
12	4.380	0.876	100	87.60	561.31
13	4.632	0.926	100	92.64	653.95
14	4.855	0.971	100	97.10	751.06
15	5.042	1.008	100	100.84	851.90
16	5.194	1.039	100	103.89	955.79
17	5.319	1.064	100	106.37	1062.16
18	5.421	1.084	100	108.42	1170.58
19	5.506	1.101	100	110.12	1280.70
20	5.577	1.115	100	111.54	1392.24

* The productivity calculated is divided by the ideal productivity assumed for calculations to be 5