QUANTITATIVE METHODS FOR PERFORMANCE MEASUREMENT SYSTEMS

By

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Patdono Suwignjo

To my wife Susi
and
sons Wawan and Farid

For their invaluable support.

Abstract

The business environment has changed dramatically since the 1980s. Many researchers have shown that the traditional financially-based performance measurement systems have failed to cope with the current dynamic business environment. Even although new performance measurement systems have been proposed, such as Activity-Based Costing, the Balanced Scorecard, the SMART system, the Performance Measurement Questionnaires and the Cambridge model, the problem of quantifying the interaction of the factors affecting business performance still remains.

The objectives of this thesis are:

1. To develop a performance measurement system model that can be used to quantify the effects of factors on performance and consolidate them into a single performance indicator.
2. To develop a model for reducing the number of performance reports.
3. To carry out experiments for testing the validity, applicability and stability of the models developed.

To achieve these objectives this thesis reviews research methodology literature, studies the traditional and new performance measurement systems, identifies the current problems of performance measurement systems, reviews existing methods for identifying, structuring and prioritising performance measures, reviews the multi-criteria methods, studies the analytic hierarchy process (AHP) and its controversy, develops quantitative methods for performance measurement systems and carries out experiments to test the validity, stability and applicability of the methods developed.

To quantify the effect of factors on performance and consolidate them into a single performance indicator a quantitative method for performance measurement system

(QMPMS) was developed. The method uses cognitive maps for identifying factors affecting performance and their relationship, structured diagrams for structuring the factors hierarchically and analytic hierarchy process for quantifying the effects of factors on performance. The method was then extended to reduce the number of performance reports.

The QMPMS and its extension were implemented in three case studies to test their theoretical and application validity. The first case study applied the models to 'J&B Scotland Ltd.' to identify whether the models can produce the intended outputs. The second case study applied the QMPMS to 'Seagate Distribution (UK) Ltd.' to test the validity (accuracy) and stability of the QMPMS. Finally, the third case implemented the QMPMS to quantify and consolidate Inland Revenue, Cumbernauld's performance measures.

It was found from the experiments that the QMPMS is quite accurate (the mean percentage of deviation is less than 4 percent), stable for a reasonable period of time and it can be applied comfortably to real cases. The QMPMS is now being used by the Inland Revenue – Cumbernauld for producing a single performance indicator of their business processes and overall office.

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Chapter 1

INTRODUCTION

1.1 Research Background

The changing nature of competition in world markets during the last two decades has had a great impact on the environment, externally and internally, within which most companies operate. Customers are becoming more critical about quality and customer services. Quality, speed and flexibility, in addition to cost, have emerged as the three most important competitive attributes [Garvin, 1987; Stalk, 1988; Gerwin, 1987; Slack, 1987]. Companies which have not been aware of the changes have suffered from losing a share of the market. To cope with this new external environment and to try and regain a competitive edge companies have shifted from a low cost strategy to one focusing on quality, flexibility, shorter lead time and delivery reliability and have implemented new philosophies and technologies of production management such as Total Quality Management (TQM), Just In Time (JIT), Computer Integrated Manufacturing (CIM) and Flexible Manufacturing Systems (FMS) [Ghalayini and Noble, 1966]. These internal changes certainly would affect the organisational and managerial aspects of a company.

Many researchers have shown that the traditional financially based performance measurement systems have failed to cope with the current dynamic business environment [Kaplan, 1983; Kaplan, 1984; Eccles, 1991; Maskell, 1992]. To deal with the new environment, new performance measurement systems have been proposed, such as the Activity Based Costing System [Cooper, 1988a; Cooper, 1988b; Cooper, 1989a; Cooper, 1989b], the Balanced Scorecard [Kaplan and Norton, 1996], the SMART System [Cross and Lynch, 1988-1989], the Performance Measurement

Questionnaire [Dixon et al., 1990] and the Cambridge Model [Neely, 1995]. Some researchers, rather than providing general frameworks of performance measurement system design, preferred proposing criteria for the design of performance measurement systems [Maskell, 1991; Globerson, 1985]. Extensive, continuing research is also being carried out at the Centre for Strategic Manufacturing (CSM), University of Strathclyde – Glasgow to develop a reference model for a robust and integrated performance measurement system. This research has developed a Reference Model and an Audit Method to assess the robustness and integrity of performance measurement systems used within manufacturing industries [Bititci et. al., 1997].

Despite the availability of various approaches to developing performance measurement systems, few of them have tried to quantify the effects of the factors on performance and express them in quantitative terms [Globerson, 1985; Swamidass and Newell, 1987; Rangone, 1996]. However, the problem of quantifying the interaction of the factors in affecting business performance still remains.

Moreover, audits conducted by the researchers at the CSM based on the Integrated Performance Measurement System (IPMS) Reference Model demonstrate that most companies use both financial and non-financial performance measures. However, they do not attempt to structure these measures in a logical manner as required by the IPMS Reference Model. They also do not try to understand and manage the relationships (interactions) between measures. Therefore, the model suggests the necessity for modelling the interactions between factors affecting performance [Bititci et al, 1997].

Maskell (1991) proposed seven common characteristics for the design of performance measurement systems, three being that the new performance measurement system should:

- relate directly to strategy,
- vary between companies, and
- change over time.

Some people believed that implementing a performance measurement system compatible with those criteria usually produces unmanageable performance reports [Maskell, 1991]. As reported by Neely et al. (1995) one of the future research issues on performance measurement would be to try and develop a technique to reduce the list of possible measures into a manageable set.

1.2 Research Problems, Hypotheses and Objectives

Even although several models for a performance measurement systems have been developed so far, there are still many problems needing to be addressed [Neely et al, 1995]. This research works deal with the problems of performance measurement systems. The followings are the stages of the developments of the research problems, hypotheses and objectives:

A. Tentative research problems, hypotheses and objectives

At the beginning of the research, the research problems, hypotheses and objectives were tentatively defined as:

Tentative research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between the factors affecting performance.
3. Quantifying the effects of the factors on performance.

Tentative research hypotheses:

1. A quantitative method for a performance measurement system can be developed. The method can be used for:
   - ✓ identifying factors affecting performance and their relationship,
   - ✓ quantifying the effect of the factors on performance.
2. The method is valid and can be applied to real cases.

Tentative research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship and quantify the effect of the factors on performance.
2. To carry out experiments for testing the validity and applicability of the method developed.

B. Modification of research problems, hypotheses and objectives

Extensive related theory exploration was carried out in this research. It was found in the exploration that:

✓ One of the future research issues on performance measurement would be to develop a technique to reduce the number of performance reports [Neely et al, 1995].

✓ Business environment is becoming more dynamic [D'Aveni and Gunther, 1995], therefore it is important to examine the stability of the method developed over a period of time.

Based on these findings the issues of reducing the number of performance reports and the stability of the method were added to the tentative research problems, hypotheses and objectives. The modified research problems, hypotheses and objectives are as follows:

Modified research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between the factors affecting performance.
3. Quantifying the effects of the factors on performance.
4. Reducing the number of performance reports.

Modified research hypotheses:

1. A quantitative method for a performance measurement system can be developed. The method can be used for:

- ✓ identifying factors affecting performance and their relationship,
- ✓ quantifying the effect of the factors on performance.

2. The method is valid and can be applied to real cases.
3. The method developed can help managers to reduce the number of performance reports.
4. The method is stable for a reasonable period of time.

Modified research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship and quantify the effect of the factors on performance.
2. To carry out experiments for testing the validity, applicability and stability of the method developed.
3. To develop a method for reducing the number of performance reports.

C. Final research problems, hypotheses and objectives

The methods developed were applied to three case studies to test their validity, applicability and stability. When implementing the methods at Inland Revenue, Cumbernaud it was found that the office has been for a long time wanted to have a tool for consolidating performance measures into a single performance indicator. Therefore, the issue of consolidating performance measures into a single performance indicator was added to the modified research problems, hypotheses and objectives.

The final research problems, hypotheses and objectives are as follows:

Final research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between the factors affecting performance.
3. Quantifying the effects of the factors on performance.
4. Reducing the number of performance reports.
5. Consolidating performance measures into a single performance indicator.

Final research hypotheses:

1. A quantitative method for a performance measurement system can be developed. The method can be used for:
   - ✓ identifying factors affecting performance and their relationship,
   - ✓ quantifying the effect of the factors on performance.
   - ✓ consolidating performance measures into a single performance indicator.
2. The method is valid and can be applied to real cases.
3. The method developed can help managers to reduce the number of performance reports.
4. The method is stable for a reasonable period of time.

Modified research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship, quantify the effect of the factors on performance and consolidate them into a single performance indicator.
2. To carry out experiments for testing the validity, applicability and stability of the method developed.
3. To develop a method for reducing the number of performance reports.

1.3 Structure of the Thesis

The research undertaken is described in this thesis with the structure indicated in Figure 1.1. Chapter 1 introduces the background of the research undertaken and formulates the specific problems of performance measurement to be tackled. It goes on to formulate the research problems, hypotheses and objectives to be addressed.

Once the research problems, hypotheses and objectives were formulated the appropriate research design could be identified. To achieve this, literature on research methodology was reviewed and the appropriate research method selected based on the characteristics of the research undertaken.

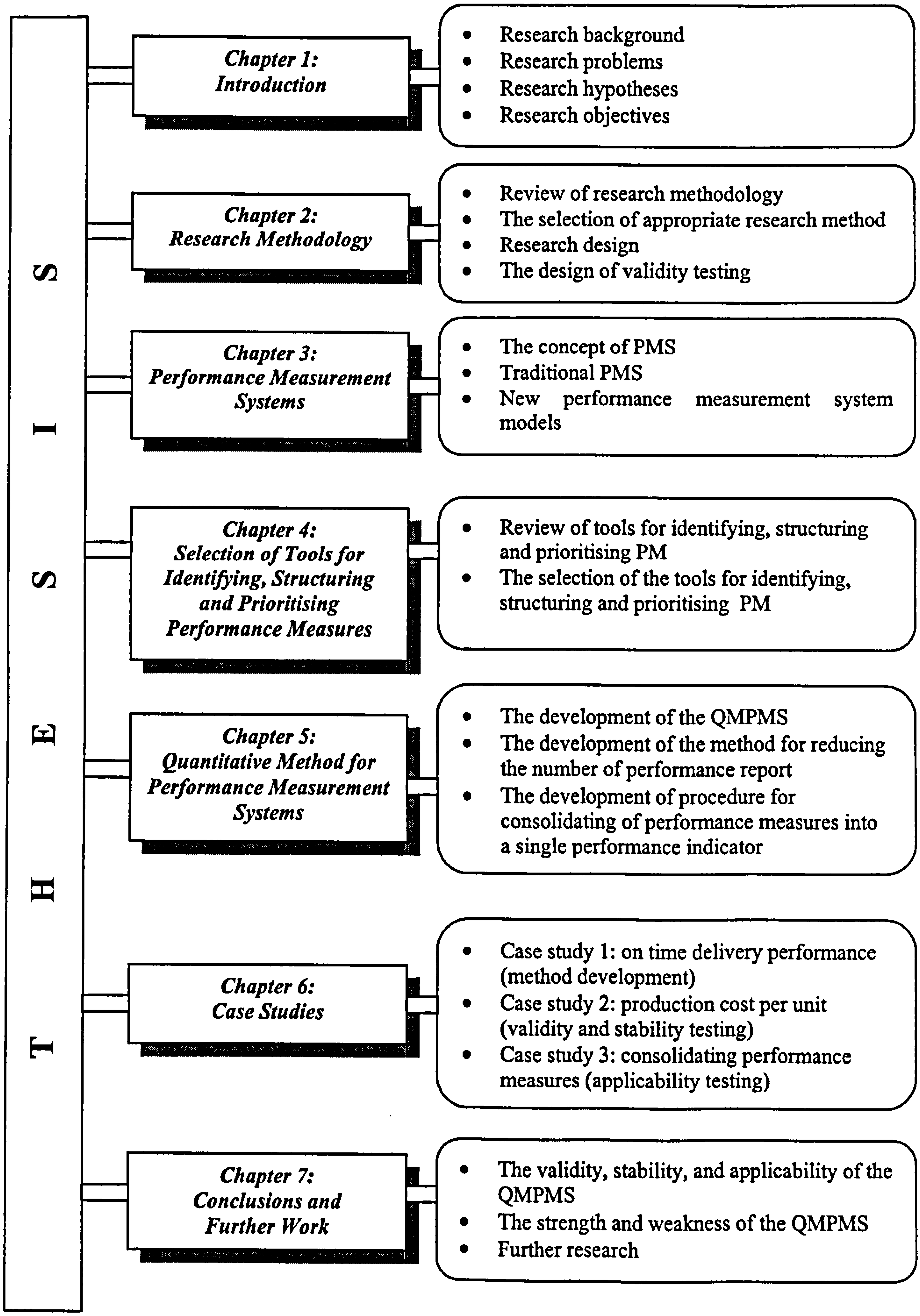


Figure 1.1. Structure of the thesis.

Then the design of the research was constructed using the selected research method. Finally, the design of validity testing was constructed. All of these issues are covered in Chapter 2.

Chapter 3 presents a literature review on performance measurement systems. It discusses the changes in business environment over the last two decades which have made traditional performance measurement system less relevant. New performance measurement systems which have been developed so far including a critical assessment of each model, are also presented.

Chapter 4 presents the selection of the tools for identifying factors affecting performance and their relationship, structuring the factors hierarchically and prioritising the effect of the factors on performance.

To achieve the objectives of the research, a Quantitative Method for Performance Measurement System (QMPMS) was developed. The framework of the method and how the method works are presented in Chapter 5. An extension of the QMPMS to help reduce the number of performance reports, and a procedure for consolidating performance measures, are also discussed in this chapter.

The QMPMS are tested through a series of case studies. The first case study is to test the theoretical validity of the QMPMS, while the second case study is to test the accuracy and stability of the QMPMS. Finally, the applicability of the QMPMS is tested through case study three. These applications of the QMPMS to three case studies are presented in Chapter 6.

Based on the experiences of applying the QMPMS to various cases the robustness, benefits, and limitations of the QMPMS are presented in Chapter 7.

Chapter 2

RESEARCH METHODOLOGY

2.1 Research Objectives and Questions

The research method used in a research project depends on the nature of the research objectives and problems. Therefore, it is necessary here, before selecting the appropriate research method to be used in this research, to outline the objectives and problems.

The objectives of this research, as stated in the previous chapter, are to develop a quantitative method of a performance measurement system, extend the method for reduction of performance reports and carry out field experiments to test the validity, applicability and stability of the method. To achieve these objectives, the following questions should be addressed:

Question 1

How can the factors affecting performance and their relationship, especially in performance measurement for improvement, be identified and quantified?

Question 2

How can the effects of factors on performance be consolidated and expressed in a single performance indicator?

Question 3

How can the method developed be extended to reduce the number of performance reports?

Question 4

Is the method valid and can it be applied to real cases?

Question 5

Is the method stable for a reasonable period of time?

It is expected that the research can produce a valid and applicable method of a performance measurement system that can be used to quantify and aggregate the effects of factors on performance. Then the method can be extended to reduce the number of performance reports.

2.2 Research Philosophy

Before selecting the research strategy to be adopted it is important to understand the philosophy of research design. Easterby-Smith et al (1991) argued that there are three reasons why an understanding of philosophical issues is important:

1. It can help clarify research designs.
2. Knowledge of philosophy can help the researcher to recognise which research design may work and which may not.
3. Knowledge of philosophy can help the researcher identify, and even create, designs that may be outside his or her experience.

There are two main extremes of philosophical position from which research methods can be derived, positivism paradigm and phenomenological paradigm. These two paradigms lie at the two extremes of a continuum [Esterby-Smith et al, 1991]. Positivists believe that reality is external and objective and that its properties should be measured through objective methods, rather than being inferred subjectively through sensation, reflection, or intuition, while phenomenologists believe that reality is socially constructed rather than subjectively determined. The characteristics of these two extremes are indicated in Table 2.1. There is a growing move to develop research methods that provide a middle ground between the two extreme points.

Table 2.1. The characteristics of positivist and phenomenological paradigms [Esterby-Smith et al, 1991].

	Positivist paradigm	Phenomenological paradigm
Basic beliefs :	➢ the world is external and objective ➢ observer is independent ➢ science is value-free	➢ the world is socially constructed and subjective ➢ observer is part of what is observed ➢ science is driven by human interests
Researcher should:	➢ focus on facts ➢ look for causality and fundamental laws ➢ reduce phenomena to simplest elements ➢ formulate hypotheses and then test them	➢ focus on meaning ➢ try to understand what is happening ➢ look at the totality of each situation ➢ develop ideas through induction from data
Preferred methods include:	➢ operationalising concepts so that they can be measured ➢ taking large samples	➢ using multiple methods to establish different views of phenomena ➢ small samples investigated in depth or over time

2.3 Research Methodology

The types and context of research vary widely. There is no single research method or strategy that is ideal for all types of research [Easterby-Smith et al, 1991]. Consequently, a researcher must continually use his own judgement to select the most appropriate research strategy under the circumstances. In fact, acquiring the knowledge and skill to select the most appropriate research strategy is one of the most important outcome of conducting management research [Buchanan, 1980]. However, frameworks have been developed which can be used as guidelines in selecting the appropriate research method.

Buckley et al (1976) proposed a comprehensive framework of research methodology as depicted in Figure 2.1. The critical issues of the methodology important to this research are outlined below.

Problem Definition

Research methodology can be divided into two wide areas - problem finding and problem solving. Research problems may be generated formally or informally. Formal problem finding implies that careful and methodical procedures are used to discover the research problems. Obviously, scientific research needs a formal approach to ascertain the research problems, while an informal approach uses a subjective and non-routine process of problem finding. Formal and informal methods are indicated in Figure 2.1.

Problem definition is a very important aspect in conducting research. Many research projects have failed because of poor problem definition. An appropriate research problem is characterised by the following attributes [Buckley et al, 1976]:

1. The problem is defined properly. It is labelled and described accurately.
2. The problem is expressed in solvable terms.
3. The problem is connected logically to the environment from which it is drawn and the solution can be applied within such an environment.
4. The problem has been screened against the existing body of knowledge to assure its uniqueness, i.e. it has not been solved previously.
5. The solution to the problem must be viewed as making a potential contribution to the body of knowledge.

Research Mode

There are two modes of research methodology; induction and deduction. The characteristics of induction and deduction modes are indicated in Table 2.2.

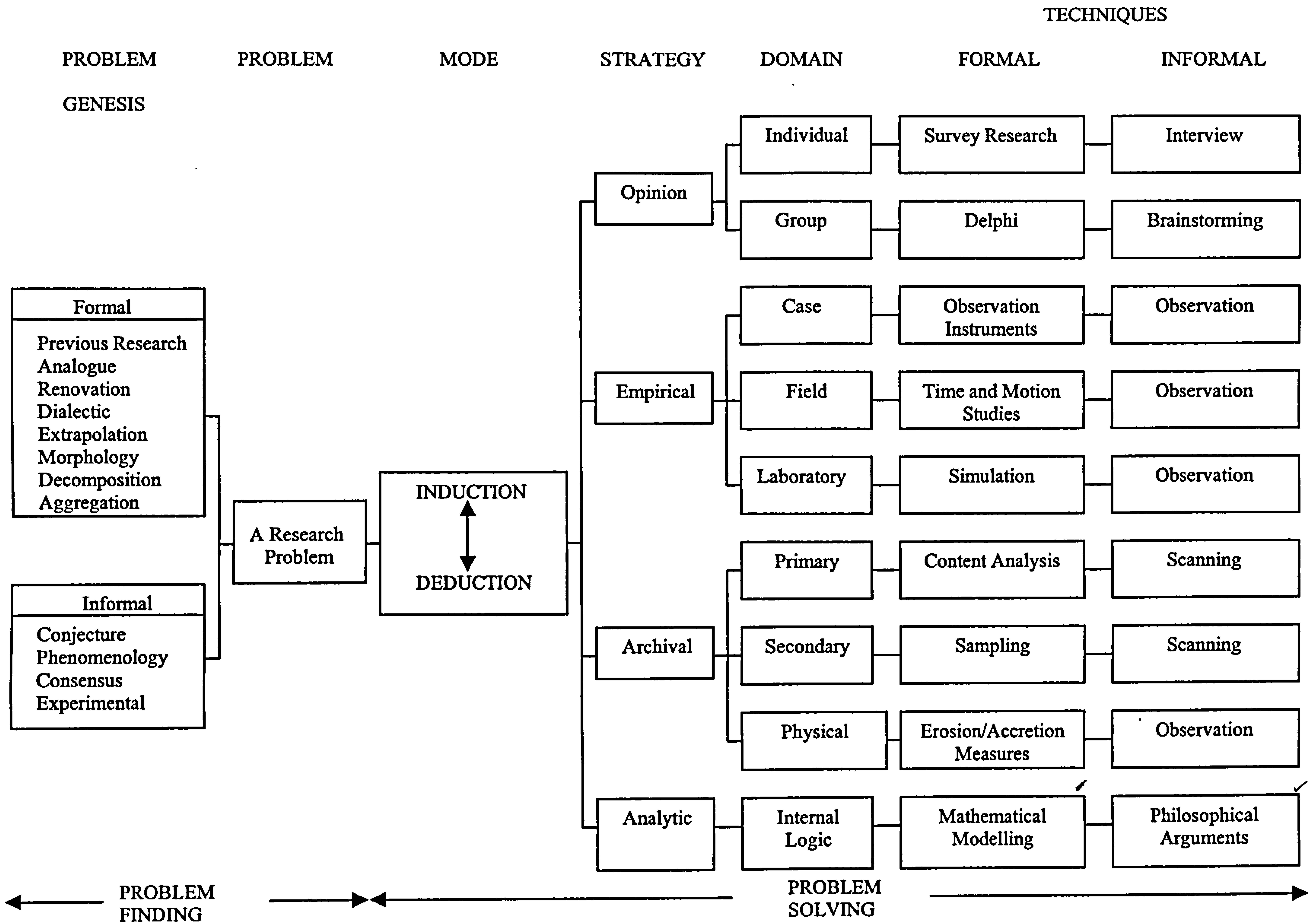


Figure 2.1. Framework of research methodology [Buckley et al, 1976].

Table 2.2. Characteristics of induction and deduction modes.

Research Mode	Objective	Hypothesis	Type of Question
Induction	Theory generating, fact finding	Priori	Which, where, who, why, whether, how and what
Deduction	Theory testing	A priori	Will, is, if, set-responses questions, task-responses questions.

The aim of inductive research is to generate theory based on the fact-finding activities carried out in the research, i.e. when the researcher does not have an answer to a question on the research, or when the outcome of the research is not known in advance. In other words, there is no substantive "a priori" hypothesis. Researchers who adopt the phenomenological research philosophy use inductive mode. Easterby-Smith (1991) pointed out that one of key features of phenomenological paradigms is that the researcher develops ideas through induction from data. The research moves from general phenomena to more specific ideas as indicated by Figure 2.2.

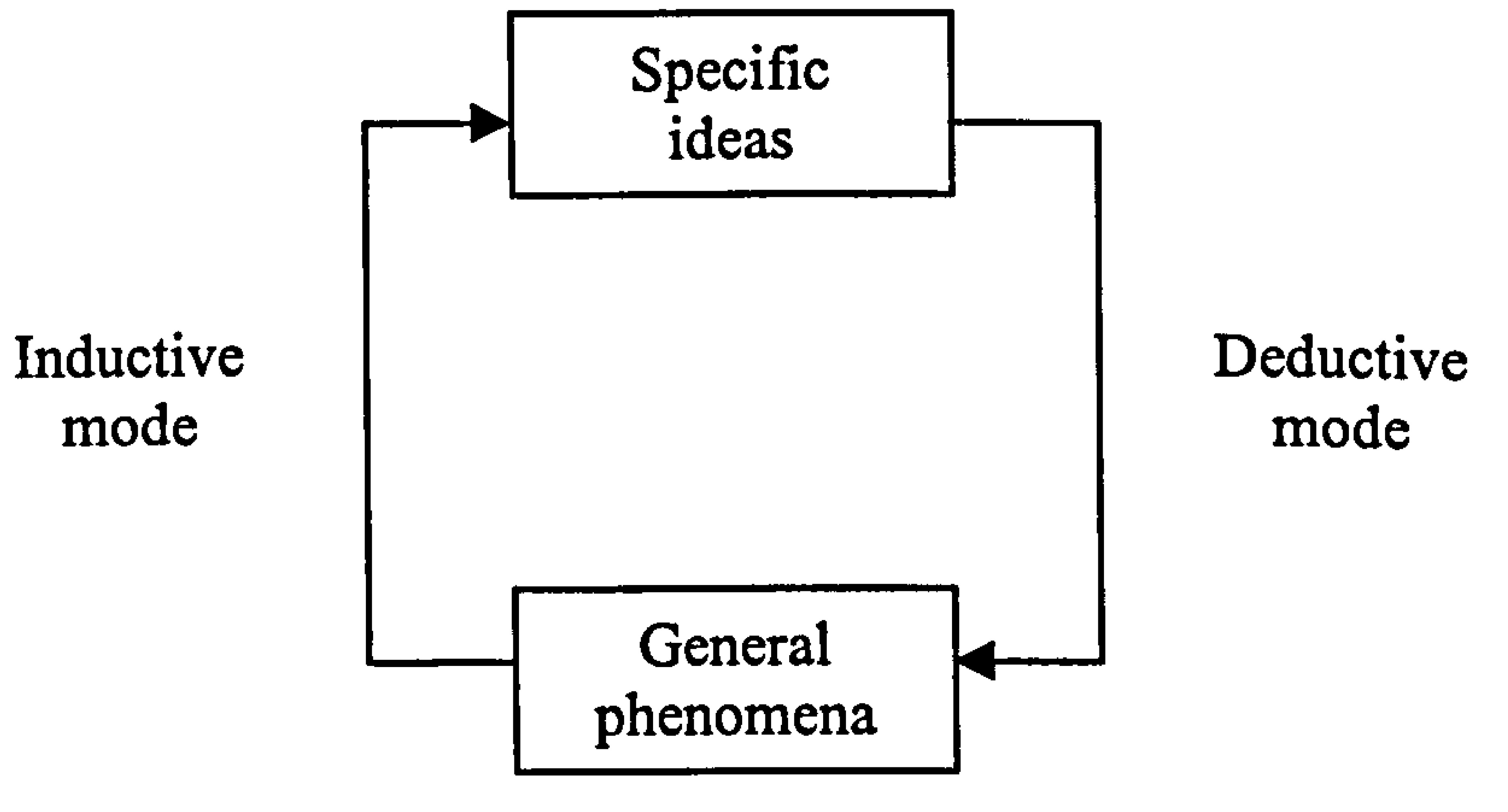


Figure 2.2. Inductive and deductive mode.

In deductive research, theory is tested. This may be done by validating theory or testing its applicability to a given set of circumstances. Deductive research is guided by "a priori" hypotheses which precede the research activity. The results of the research may prove or disprove the hypotheses. Deductive mode is used when a researcher adopts positivism paradigm. Easterby-Smith et al (1991) pointed out that one of the implications of positivism ideas is that "*science proceeds through a process of hypothesising fundamental laws and then deducing what kinds of observations will demonstrate the truth or falsity of these hypotheses*." They also stated that positivism paradigm tries to generalise about regularities in social behaviour through investigating sufficient size of samples. Deductive research moves from specific ideas to general phenomena as indicated in Figure 2.2.

Identification of whether research mode is induction or deduction is an important issue, since it affects the definition of problems, the researcher's attitudes and the selection of research methodology.

Research Methodology

Buckley et al (1976) argued that research methodology consists of strategies, domains and techniques, defined as follows:

- Methodology is the particular set of strategies, domains and techniques employed in generating or testing theory.
- Strategy refers to the essential nature of the data and the process by which it is found and analysed.
- Domain refers to the data source and environment.
- Technique refers to the instrument that is used to find and analyse data.

Four strategies can be adopted to conduct research. These are opinion, empirical, archival and analytic research. The domains and techniques that can be used for each research strategy are indicated in Figure 2.1. The characteristics of these strategies are indicated in Table 2.3.

It is clear from Table 2.3 that no research methodology is perfect. The objective of this chapter is therefore to select the best methodology from the options available.

Table 2.3. The characteristic of research strategies [Buckley et al, 1976].

Strategy	Objective/Application	Strengths	Deficiencies
Opinion	• To seek the views, judgements, or appraisals of other persons • It is best suited for research on attitudes, impressions, beliefs and future research	• The ability to capture people's impressions • Simplicity • The ability to sample large population • The opportunity to analyse data through various statistical procedures	• The bias introduced in survey instruments • Non-factual, unrealistic • Unstable over time
Empirical	• To observe and/or experience things for oneself rather than through mediation • It is best suited to analyse actual behaviour, fact-finding and seeking reality	• The contact with reality • Using laboratory studies, the most stringently controlled research can be carried out	• It is limited to present situation • Sensory error • Psychological interpretation • Lack of precision of the instruments used • Bias due to the investigator's prejudice
Archival	• To examine recorded facts • It is best suited to historical analysis, extrapolation of past trends into the future and gathering hard evidence	• The ability to access and manipulate a vast quantity of factual information	• Selective de-positioning • Selective survival • Selective retrieval • Filling in the gaps • Skill deficiencies
Analytical	• By the use of internal logic to break down the problem into its component parts in order to discover its true nature and the causal relationships among variables • It is best suited to cerebral activity and provides most scope for imagination and creativity	• The obviation of the need to search for additional data • The requirement for mental power to be brought to the task	• Requires first-rate mental ability • Unwillingness or inability to apply the scientific method of research • Can only create theory - hard to be proved • Logical error • Problem semantics • Temptation to focus on trivial and irrelevant problems

2.4 The Selection of Research Method

Having reviewed the research methods available, a method must be selected that is best suited to the prevailing circumstances. Buckley et al (1976) provided a framework for selecting a research method as depicted in Figure 2.3. More than one research method may be used in research, especially if more than one problem needs to be addressed.

Since this research has more than one problem, selection of the appropriate research methodology using this framework must be done for each problem.

The selection of research method to address research question 1 is carried out as follow:

Question 1
How can the factors affecting performance and their relationship, especially in performance measurement for improvement, be identified and quantified?

Research Mode
The first question is in the form of 'how', which is the type of question that must be solved using inductive research.

Research Strategy
The research intends to find a technique that will identify factors affecting performance, their nature in terms of their relationship and their quantitative effects. In order to simplify the process it is also necessary to find a technique to break down one large problem into several smaller problems. This research is suited to the objectives and approach of analytical research described as "*By the use of internal logic to break down the problem into its component parts in order to discover its true nature and the causal relationship among variables*".

Research Domain
Analytical research has only one domain, i.e. internal logic.

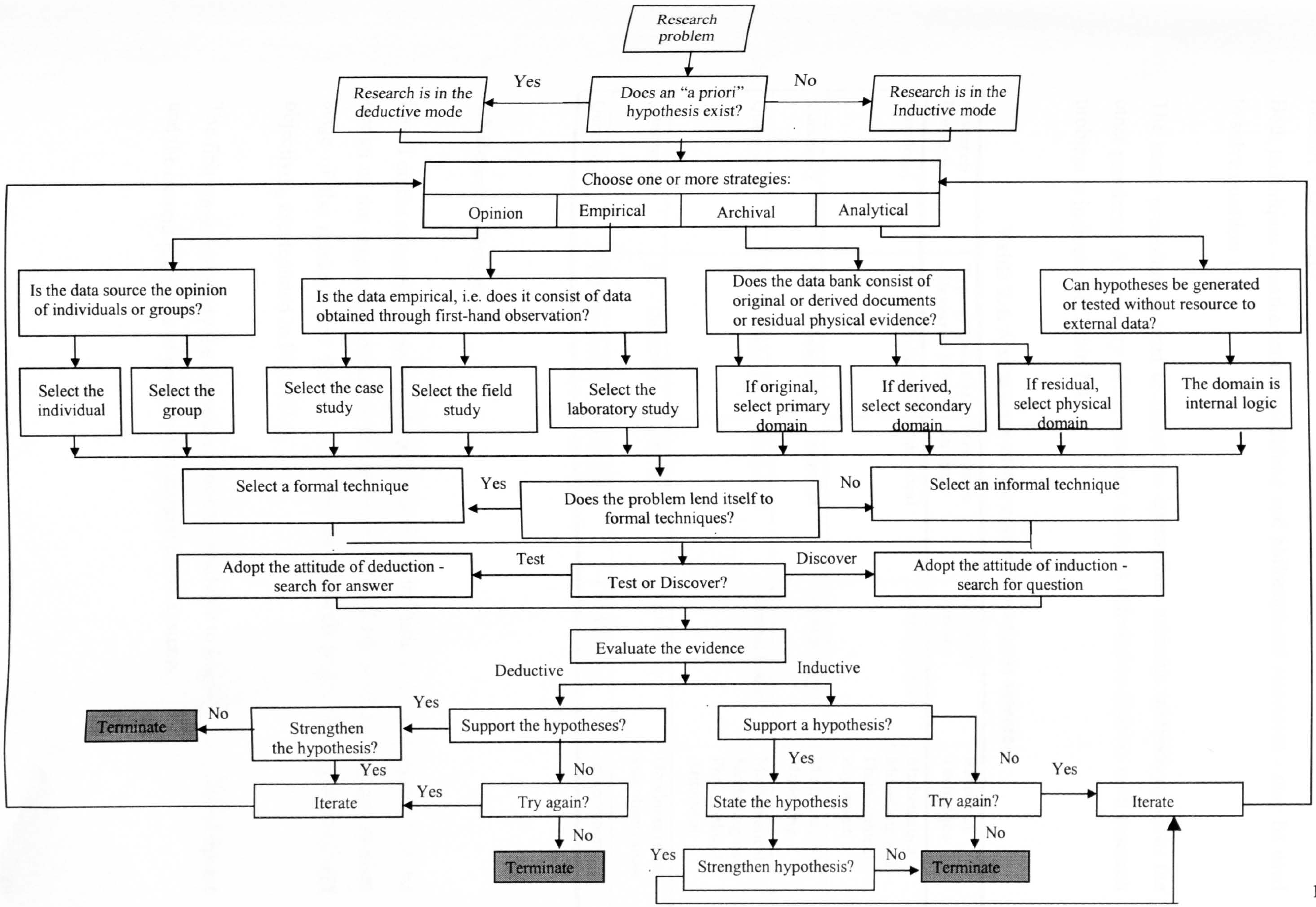


Figure 2.3. A framework for selecting a research method [Buckley et al, 1976].

Research Technique

Both techniques - mathematical modelling and philosophical argument - may be used to solve question 1.

The same procedure is used to select the appropriate research methods to solve the other problems. A summary of the research methods selected to address each research problem is indicated in Table 2.4.

Table 2.4. A summary of the research methods selected.

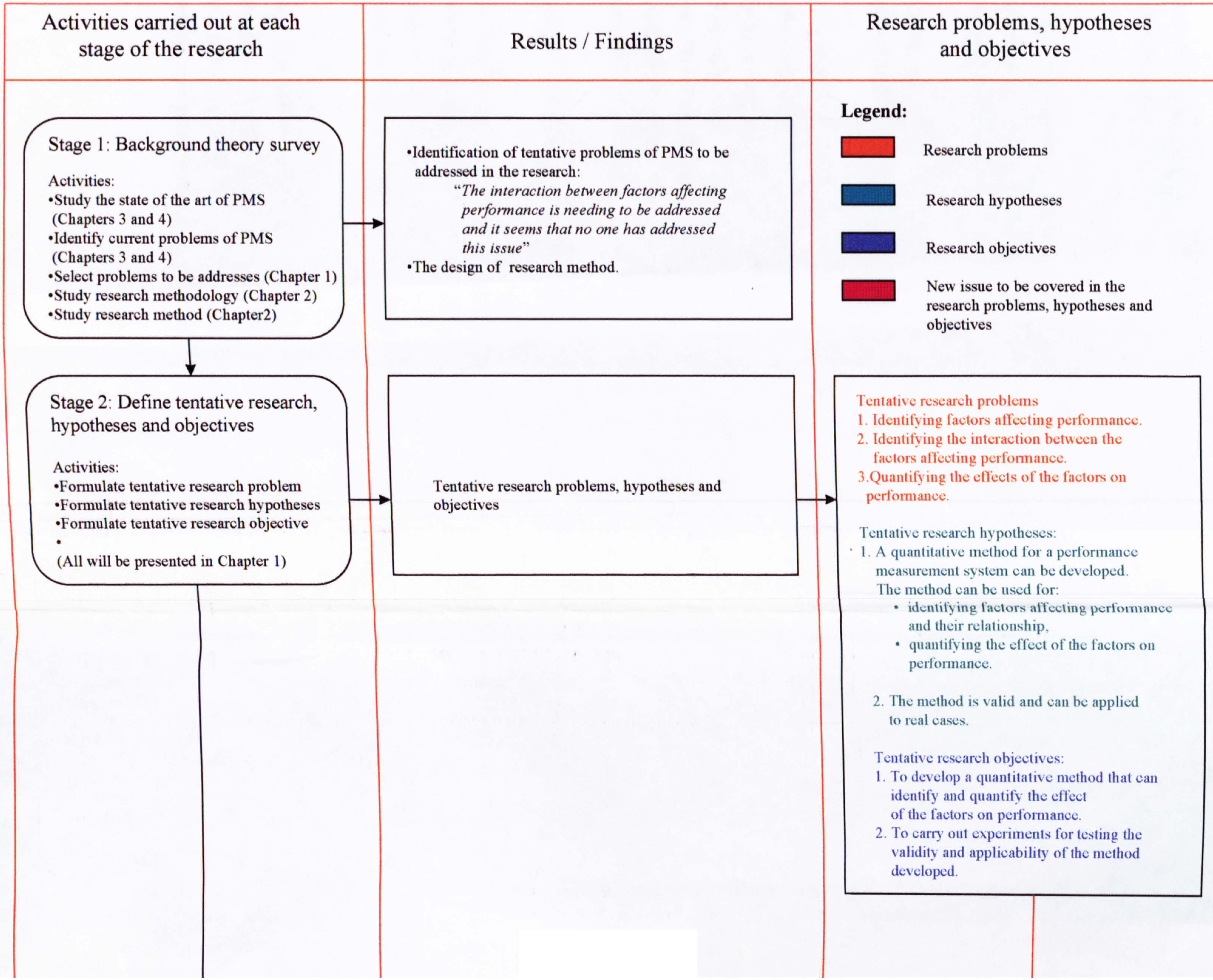
Research Problem	**Type of Question - Research Mode**	**Research Strategy**	**Research Domain**	**Research Technique**
Question 1	How? – Inductive	Analytical	Internal Logic	Mathematical Modelling and Philosophical Argument
Question 2	How? – Inductive	Analytical	Internal Logic	Mathematical Modelling
Question 3	How? – Inductive	Analytical	Internal Logic	Mathematical Modelling and Philosophical Argument
Question 4	Is? – Deductive	Empirical	Field Study	Goodness of fit and observation
Question 5	Is? – Deductive	Empirical	Field study	Observation

2.5 Research Design

Based on the selected research methods summarised in Table 2.4, the framework of the design of the research undertaken, the activities carried out and the findings at each stage of the research and the development the research problems, hypotheses and objectives, are depicted in Figure 2.4.

The first stage will study the literature currently available to identify the state-of-the art and the current problems of performance measurement systems.

Figure 2.4 The framework of the design of the research undertaken, the activities carried out and the findings at each stage of the research and the development of the research problems, hypotheses and objectives.



Stage 3: Related theory exploration

Activities:

- Study traditional performance measurement system models
- Study new performance measurement system models
- Study multi-criteria methods
- Study tools for identifying, structuring and prioritisng performance mesasures.
- Select the appropriate tools to be used.

(Chapter 3, Chapter 4)

- Neely (1995) stated that one of the future problems of performance measurement is reducing the number of performance reports. As a result, a new problem, hypothesis and objective are added to the list.

The additional research problem: *"Reducing the number of performance reports."*

The additional hypothesis: *"The model can be extended to address the problem of how to reduce the number of performance reports"*

The additional research objective: *"To develop a method for reducing the number of performance reports"*

- Globerson (1985), Swamidass and Newell (1987), Chenhall (1996) and Rangone (1996) have developed methods for quantifying the effect of factors on performance. However, there is still room for developing a more easily understood and implemented method, which can be used to quantify the interaction of the effect of factors on performance. (Closing the gap)

- As the environment is becoming more dynamic, it is important that the method developed in this research is stable for a reasonable period of time. Consequently, it is important that the stability of the method is tested. As a result, the issue of the *stability* of the model is added to research hypotheses and objectives.

- The selected tools to be used.

At the end of this stage I have:

Research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between factors affecting performance.
3. Quantifying the effect of factors on performance.
4. Reducing the number of performance reports.

Research hypotheses:

1. A quantitative method for a performance measurement systems can be developed. The method can be used for
   - identifying factors affecting performance,
   - quantifying the effect of factors on performance.
2. The model is valid and can be applied to real cases.
3. The methods developed can help manager to reduce the number of performance reports.
4. The method is stable for a reasonable period of time.

Research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship and quantify the effects of the factors on performance.
2. To carry out experiments for testing the validity, applicability and stability of the methods developed.
3. To develop a method for reducing the number of performance reports.

Stage 4: Method development

Activities:
- Develop methods for identifying factors affecting performance and their relationship, structuring the factors hierarchically and quantifying the effects of the factors on performance.
- Develop a method for reducing the number of performance reports.

(Chapter 5)

- A quantitative method which can be used to identify factors affecting performance and their relationship, structure the factors hierarchically and quantify the effect of the factors (including the interaction effects) on performance. (Contribution 1)
- A method for reducing the number of performance reports (a taxonomy of performance measurement). (Contribution 3)

Stage5: Methods validation

Activities:
- Implement the methods developed to J&B case.
- Implement the methods developed to Seagate case.
- Implement the methods developed to Inland Revenue case.
- Disseminate the results at conferences.

(Chapter 6 and Appendix : Publications to date)

Findings from J&B case study:
Using data from previous research [Bititci, 1995], it seems (because this is not a field case study) the methods developed can be used to:

1. Identify and quantify the effects (including interaction effect) of factors on performance. (Contribution 1)
2. Reduce the number of performance reports by classifying them into categories, "critical", "intermediate" and "minor". (Contribution 3)

Findings from Seagate case study:

1. The methods can be used to identify factors affecting performance, their interaction and quantify the effect of factors (including interaction effect) on performance. (Contribution 1)
2. The methods developed are easy to understand and implement. (Contribution 7)
3. The Seagate manager wanted to take into account the interaction effects in the model because he wanted to use the model for monitoring, control and improvement. (Contribution 4)
4. The methods developed are accurate. (Contribution 9)
5. In this case the accuracy of the direct effect was not significantly different from the accuracy of the combined effect. (Part of Contribution 9)
6. The methods developed are stable for a considerable period of time. (Contribution 10)

Findings from Inland Revenue case study:

1. The Inland Revenue needs a methods for consolidating performance measures into a single performance indicator. Issue of consolidating performance measures into a single performance indicator is added to the research problems.
2. The development of a method for consolidating measures into a single performance indicator. (Contribution 2)
3. The methods developed can be used to consolidate performance measures into a single performance indicator. (Contribution 2)
4. Managers at Inland Revenue, Cumbernauld were not interested in taking into account the interaction effects in the model. This may be because they wanted to use the model for monitoring and control. Also, they employed a large number of performance measures - 130 measures. (Contribution 4)
5. Implementing the methods developed leads to better

At the end of this stage I have:

Research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between the factors affecting performance.
3. Quantifying the effects of the factors on performance.
4. Reducing the number of performance reports.
5. Consolidating performance measures into a single performance indicator.

Research hypotheses:

1. A quantitative method for a performance measurement systems can be developed. The method can be used for:
   - identifying factors affecting performance their relationship,
   - quantifying the effect of the factors on performance,
   - consolidating performance measures into a single performance indicator.
2. The method is valid and can be applied to real cases.
3. The method developed can help managers to reduce the number of performance reports.
4. The method is stable for a reasonable period of time.

Research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship, quantify the effects of the factors on performance and consolidate them into a single performance indicator.
2. To carry out experiments for testing the validity, applicability and stability of the method developed.
3. To develop a method for reducing the number of performance reports.

employed a large number of performance measures - 130 measures. (Contribution 4)

5. Implementing the methods developed leads to better understanding of the nature of the business. (Contribution 5)
6. Better understanding of the nature of the business enables the organisation to rationalise the number of performance reports. (Contribution 6)
7. The methods developed can be easily understood and implemented.(Contribution 7)
8. The concept of the application of the methods developed can be transferred to other people quite easily through training. (Contribution 8)
9. The success of the implementation of the methods at Inland Revenue, Cumbernauld may be because of:
   - Inland Revenue - Cumbernauld has, for a long time, wanted to have the QMPMS-like methods.
   - Inland Revenue - Cumbernauld feel that they own the model because they built the system themselves.

   (Contribution 11)

•Feedback from conference.
It was suggested that the methods developed had a procedure to carry out sensitivity analysis for dealing with uncertainty. The method developed (QMPMS) was then equipped with the sensitivity analysis method. This will be discussed in Chapter 5.

Stage 6: Conclusion and further work

Activities:
•Describe the challenge of conducting this research.
•Discuss the findings/contributions of the research.
•Identify future work.
•
(Chapter 7: Conclusions and Further Work.

Presentation and discussion of the following findings/contributions:

1. Provide a method for computing the interaction effect of factors on performance.
2. Provide a method for consolidating performance measures into a single performance indicator.
3. Develop a taxonomy of performance measurement for reducing the number of performance reports.
4. Taking into account interaction effect seems more important in performance measurement for improvement than that in performance measurement system for monitoring and control.
5. Implementing the QMPMS leads to better understanding of the nature of the business.
6. Better understanding of the nature of the business enables the organisation to.rationalise the number of performance measure into a manageable set.
7. The QMPMS can be easily understood and implemented.
8. The implementation concept of the QMPMS can be transferred to other people quite easily through training.
9. The accuracy of the QMPMS is good.
10. The QMPMS is stable for a considerable period of time.
11. The need and the ownership of the model have helped the implementation of the model sucessful.

•Future work.

Stage 7: Final writing up

Activities:
Writing up the research undertaken as a PhD thesis.

PhD thesis

Intensive discussions with the research supervisors will also be held at this early stage to identify the specific problems of performance measurement systems to be addressed by the research.

The tentative problems, the hypotheses and the objectives of the research will be selected. Once the tentative problems to be addressed have been selected, the appropriate research methodology will be reviewed.

The next stage will formulate the tentative problems to be addressed, hypotheses and objectives of the research with reference to research methodology theory.

The third stage will explore the related theories in detail. This will include a detailed literature review on the areas of performance measurement systems, cognitive mapping and multi-criteria decision analysis. The tentative problems, hypotheses and objectives will be examined to check their relevance to the current developments in related theories and research. The most important decision to be made at this stage will be the selection of the methods or tools to be used. Thereafter, the tentative problems, hypotheses and objectives will be refined.

Methods for performance measurement systems will then be developed. The methods can be used to:

- identify factors affecting performance and their relationship,
- quantify the effects of factors on performance,
- reduce the number of performance reports,
- consolidate multi-dimensional performance measures into a single performance indicator.

The methods then will be tested to check their validity, applicability and stability through the implementation of the methods to various case studies. First, the methods will be applied to a particular problem at a collaborator company. The aim of this application is to check whether the methods can produce the intended output. The results of this application will be disseminated at conferences. Based on the feedback from industrial collaborators and the conferences the method will be refined.

In the next application, the methods will be tested to check their validity. A small case study of a collaborator company will be selected as the object of the study. Since the aim of the experiment is to test the validity of the methods, it is important to use real data. A potential problem that may arise in this application might be the unavailability of the case to be used, since this application will need a lot of data over a period of time.

The validity test will be carried out by comparing the output of the method to the actual performance. If the output of the method is similar to the actual performance, the method can be judged as a valid method. If not, further analysis will be carried out to determine the causal factors. Statistical tools will be used to analyse the output of the application. The selection of the statistical tool will be discussed later.

Finally, the methods will be applied to a case study to test the applicability of the method. This application is intended to identify whether the method is easily implemented. It is important in this application to find an organisation that really wants to use the method and this can prove to be very difficult. Intensive explanation required to convince collaborator companies on the benefits of applying the methods.

All feedback from the applications will be used as a basis for improving the method.

From the experience gained from the applications, the robustness, benefits and limitations of the method can be evaluated. Then conclusions and recommendations can be drawn and the future work identified.

The final stage will be writing up the research undertaken as a PhD thesis.

2.6 The Design of Validity Testing

The validity of the method will be tested by implementing the method to a field case study. The outcome of the method will be compared to actual data as indicated in Figure 2.5.

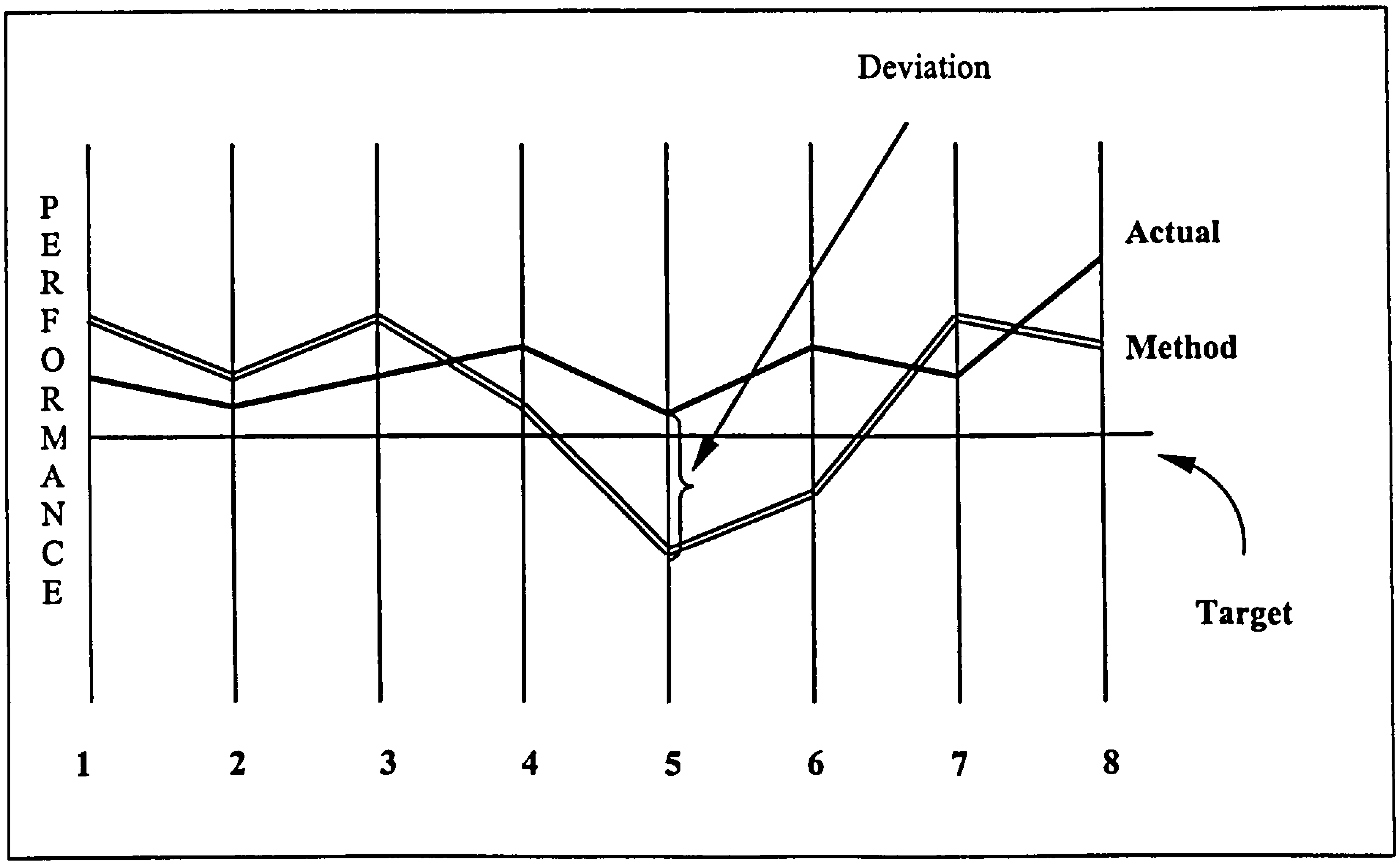


Figure 2.5. Comparison of the outcome of the method to actual data.

The deviation of the outcome of the method from the actual data indicates the accuracy or validity. The more the outcome of the method deviates from the actual data the less the method is valid. A relevant question can be raised i.e. How far is the outcome of the method allowed to deviate from the actual data? Statistical analysis for testing the 'goodness of fit' can be used to answer this question. To be able to select the appropriate statistical test, a review on the related statistical topic will be presented.

Measurement Scales

In measurement, the observed property of the object is transferred into a defined scale. There are four types of scale that can be chosen - nominal, ordinal, interval and ratio. The characteristics of these scales are indicated in Table 2.5.

Table 2.5. The characteristics of various scales [Cooper and Emory, 1995].

Type of Scale	Characteristics of Scale	Basic Empirical Operation
Nominal	No order, distance, or origin	Determination of equality
Ordinal	Order, but no distance or unique origin	Determination of greater or lesser values
Interval	Both order and distance, but no unique origin	Determination of equality of intervals or differences
Ratio	Order, distance and unique origin	Determination of equality of ratios

Selecting the Statistical Test

Cooper and Emory (1995) argued that at least three questions must be considered when selecting the appropriate statistical test:

1. Does the test involve one sample, two samples, or *k* samples?
2. If two samples or *k* samples are involved, are the individual cases independent or related?
3. Is the measurement scale nominal, ordinal, interval, or ratio?

They recommended a statistical test that can be used for different situations as indicated in Table 2.6.

Table 2.6. Recommended statistical test for different situations [Cooper and Emory, 1995].

Measurement Level	One-Sample Case	Two-Sample Case		k-Sample Case	
		Related Samples	Independent Samples	Related Sample	Independent Sample
Nominal	• Binomial • χ^2 one-sample	• McNemar	• Fisher exact test • χ^2 two-sample	• Cochran Q	• χ^2 for k samples
Ordinal	• Kolmogorov-Smirnov one-sample test • Run test	• Sign test • Wilcoxon matched pairs	• Median test • Mann-Whitney U test • Kolmogorov-Smirnov • Wald-Wolfowitz	• Friedman two-way ANOVA	• Median extension • Kruskal-Wallis
Interval and Ratio	• t test • Z test	• t test for paired samples	• t test • Z test	• Repeated measures ANOVA	• One-way ANOVA

The scale used in the method developed is a ratio scale. The validity testing compares the outcome of the method to the outcome of actual performance involves the comparison of some paired data. Based on the recommended statistical test in Table 2.6, the t-test for paired samples should be used. However, the test requires that the samples come from a normally distributed population with equal, known variances. These requirements are not fulfilled in this research since the population is not likely to follow normal distribution. Any variation of performance in this research is not due to random noises, but rather because of the existence of identifiable causes. Consequently, the t test cannot be used in this research. The next choice is the Wilcoxon Matched-Pairs Test. This choice can be justified since the ordinal scale is of the lower hierarchy compared to that of the ratio scale. Any method that can be used for the lower hierarchy scale can be used for the higher hierarchy scale, but not the reverse. The framework of the validity test is indicated in Table 2.7.

Table 2.7. The framework of the validity test.

No	Actual Data Ai	Method Outcome Mi	Deviation (Mi - Ai)	Descriptive	Inference
1 2 3 . . . n				%D = $\frac{\sum (Mi-Ai)}{\sum Ai}$	Wilcoxon Matched-Pairs Test
	$\sum$ Ai		$\sum$ (Mi-Ai)		

The test is carried out as follows:

1. Define the statistical hypothesis:

   H_o: There is no difference between the outcome of the method and the actual Performance

   H_A : There is a difference between the outcome of the method and the actual Performance

2. Find the difference score of each pair (d_i).
3. Rank the order of the differences from the smallest to the largest without regard to signs.
4. Add the actual signs of the differences to the rank values.
5. Calculate the test statistic T, which is defined as the sum of the ranks with the less frequent sign.
6. Find the critical value of T from the statistical table for particular significance level and the number of pairs.
7. Make a decision to accept or reject the null hypothesis.

2.7 Discussions and Conclusions

Following a review of research methodology literature, a research design has been constructed. Several research strategies have been selected to address the five research questions indicated in Table 2.4. Basically, two types of research strategies will be adopted in this research. The first will address research questions 1, 2 and 3. These questions are in the form of 'how' and no "a priori" hypothesis exists. In other words, the tentative solutions were not known in advance, even though the researcher believed that one of the operation research models could be used. However, the exact model to be used was not known in advance. Therefore, analytical research strategy was selected to address research problems 1, 2 and 3.

The second type of strategy adopted addresses research questions 4 and 5. These are 'is' type questions and "a priori" hypotheses are already available. Tentative solutions to the problems were already known in advance, i.e. methods have been developed. The aim of the research is to test whether the methods which have been developed are valid, applicable and stable. Therefore, empirical research strategy was adopted to address questions 4 and 5.

Comparing the outcome of the method to the real data tests the validity of the method developed. A number of paired data will be collected. The Wilcoxon Matched-Pairs

Test, a non-parametric 'goodness of fit' test, will be used to judge whether the method is statistically valid or not.

2.8 Summary

A review on the philosophy of research design, a framework of research methodology and a framework for selecting the appropriate research design have been presented. Next, the appropriate research strategies were selected using the frameworks available. Finally, the design of the validity testing was constructed.

The next chapter will present the literature review on performance measurement systems.

Chapter 3

PERFORMANCE MEASUREMENT SYSTEMS

3.1 Introduction

The business environment has changed dramatically since the 1980s. Traditional performance measurement systems which were developed in the mid-20s are less relevant to the new dynamic environment. New performance measurement systems have been the subject of extensive research.

Many reports on the development and application of new performance measurement systems have been published. Researchers with different backgrounds have used different approaches to designing new performance measurement systems. Some researchers use corporate vision and strategy as starting points, others use stakeholders' requirements, while yet others use strategic objectives of product groups. Even though research has produced significant results, there are still many problems with new performance measurement systems which need to be addressed (Neely et al, 1995).

New performance measurement systems have reshaped the concept of performance measurement systems. This can be seen in the frameworks or models of new performance measurement systems which have been developed so far and which will be discussed in the following sub-chapters.

3.2 Definition of a Performance Measurement System

The implementation of performance measurement systems in various organisations has revealed that people often misunderstand what performance measure, performance measurement and performance measurement system are. Some companies have measured and collected data which they thought were performance measures such as:

- number of cheques processed,
- overpayment of assessed taxes entries,
- charge batches processed,
- size of Bill of Material,
- variety of inventory items.

Even though this data provides some information to management, without additional information they cannot be classed as performance measures, because they do not provide information on the efficiency or effectiveness of the processes. This occurs because managers are not familiar with the definitions of performance measure, performance measurement and performance measurement system. The following are some early definitions relating to performance measurement systems.

Performance Measures

- *Performance measures are characteristics of outputs that are identified for purposes of evaluation* [Euske, 1984].
- *Performance indicator is a tool to compare actual results with a pre-set target and to measure the extent of any deviations* [Fortuin, 1988].
- *Performance measures are the numerical or quantitative indicators that show how well each objective is being met* [Pritchard et al, 1991].
- *Performance measures are the vital signs of the organisation which quantify how well the activities within a process or the outputs of a process achieve a specified goal* [Hronec, 1993].
- *Performance indicators are quantified data which measure the efficiency of an activity or a set of activities of a function in the process to reach the objectives* [Doumeingts, 1995].

- *Performance measure is a quantitative description of the quality of products or services of a process or system* [TRADE, 1997].

Performance Measurement

- *Performance measurement is the process of determining how successful organisations or individuals have been in attaining their objectives* [Evangelidis, 1992].
- *Performance measurement is the systematic assignment of numbers to entities* [Zairi, 1994].

Some authors do not define performance measurement explicitly. However, they underline that performance measurement is a process [De Toni and Tonchia, 1996; TRADE, 1997].

Performance Measurement System

- *A performance measurement system is a systematic way of evaluating the inputs, outputs, transformation and productivity in a manufacturing or non-manufacturing operation* [Globerson, 1985].
- *A performance measurement system is a tool for balancing multiple measures (cost, quality and times) across multiple levels (organisation, processes and people)* [Hronec, 1993].

More systematic definitions, which relate to performance measure, performance measurement and performance measurement system were provided by a Cambridge research group on performance measurement systems [Neely et al, 1995]. These definitions are:

- *A performance measure is a metric used to quantify the efficiency and/or effectiveness of an action.*
- *A performance measurement is the process of quantifying the efficiency and effectiveness of an action.*

- *A performance measurement system is the set of metrics used to quantify both efficiency and effectiveness of actions.*

In this thesis a performance measurement system is defined as:

> ***A performance measurement system is a set of structured metrics and procedures to quantify both effectiveness and efficiency of activities.***

3.3 The Need for a Performance Measurement System

Do companies really need a performance measurement system? Implementation of a performance measurement system needs effort and time. It is also costly. To implement a performance measurement system successfully people may be trained, a data collection and reporting system may be set up, an information system may be developed and an incentive and reward system may be aligned to the performance measurement system. These impose expenditure on the company. Is there any justification for that spending?

Executives and researchers have expressed the need for performance measurement by the following statement:

- "*You get what you measure*" [Dixon et al, 1990].

- "*What gets measured gets attention, particularly when rewards are tied to the measures*" [Eccles, 1991].

- "*If you cannot measure it, you cannot manage it*" [Kaplan and Norton, 1996].

Hrebiniak and Joyce (1984) argued that humans are calculative receptors. If they receive a stimulus, normal tasks, external crisis, or demand from supervisors, they will access the perceived costs and benefits (tangible or intangible) of various possible responses. They will select the one, which maximises their gain. Through rewards and sanctions system, management can influence human behaviour (workers) so that they can give of their best to an organisation.

This suggests that using a performance measurement system, peoples' efforts can be focused to achieve the company's objectives. Without a performance measurement system, the process for achieving company's objectives may not be managed and therefore the company's objectives may not be achieved.

However, the practice of performance measurement also receives criticism particularly when people put excessive effort into measuring and counting the cost of production. They tend to forget the main activities of a business: make and sell. According to Dixon et al (1990) General Doriot used to say *"Spend your time making it or selling it, not counting it"*. This statement is supported by the fact that in the United States, companies have 18 or 19 workers per accountant, while in Japan companies have 57 workers per accountant [Dixon et al, 1990].

This is unlikely to apply to new performance measurement systems. In new performance measurement systems, which use balanced financial and non-financial measures, cost is just a small part of the object of measurement. The primary object of new performance measurement systems is non-financial measures such as: quality, delivery, flexibility and learning and growth. Furthermore, in new performance measurement systems, there are frameworks which can be used to derive the key performance measures which are really needed by companies. Using such frameworks the number of performance measures that should be employed by a company can be minimised [Suwignjo, 1997b].

The roles of a performance measurement system in a manufacturing system can be explained graphically using Figure 3.1. Based on the objectives of the manufacturing system, the performance measurement system identifies the key performance indicators of the inputs, the processes and the outputs of the manufacturing system.

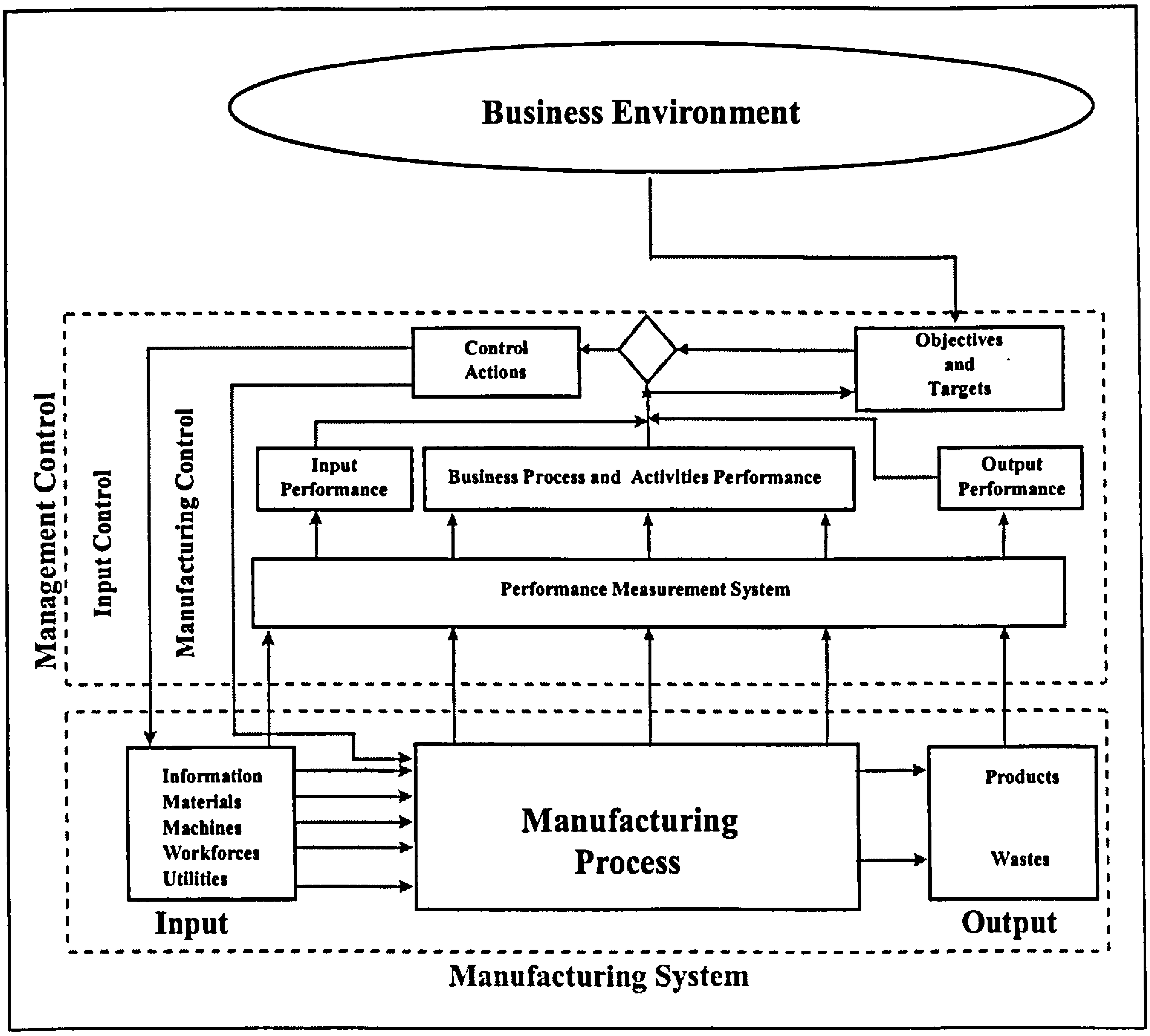


Figure 3.1. The role of a performance measurement system in a manufacturing system.

The key performance indicators are collected and reported to managers periodically. Managers compare the actual performance to the targets and take the necessary controlling actions to assure that the objectives are achieved. Figure 3.1 shows that the performance measures which depend on the activities of a manufacturing system also influence the objectives and target settings. This is consistent with the notion that there are interactions between strategy, objective, action and measure [Dixon et al, 1990; Feurer and Chaharbaghi, 1995].

A performance measurement system may exist for external reporting purposes. By law, companies may report their financial performance to shareholders, creditors and the tax authorities. For management control, performance measurement systems always exist formally or informally. Without a performance measurement system, control functions in a company may not work properly and the objectives and targets may not be defined accurately. Any deviation from the direction of a company's operations relative to the objectives may not be recognised immediately and appropriate control actions may not be taken. Therefore, a performance measurement system is a critical component of a management system.

The role of a performance measurement system is not only to provide managers with information for control. Performance measurement systems also have a behavioural impact on people and this can be used to motivate people [Daniels and Burns, 1997; Hrebiniak and Joyce, 1984]. People modify their behaviour in an attempt to ensure a positive performance outcome [Neely et al, 1997]. Dixon et al (1990) noted that since there are interactions between strategy, measures and action, performance measures can be used as a basis for strategy formulation, while Kaplan and Norton (1996) found that innovative companies used Balanced Scorecard as a strategic management system. Balanced Scorecard was used to manage the implementation of corporate strategy and to assess whether the existing strategy should be replaced by the new strategy.

Finally, Sinclair and Zairi (1995) summarised that performance measurement is important and therefore required, for the following purposes:

- planning, control and evaluation,
- managing change,
- communication,
- measurement and improvement,
- resources allocation,
- measurement and motivation.

In conclusion, a performance measurement system may exist to produce financial reports for external parties. For internal management purposes, performance measurement systems always exist formally or informally. Without a performance measurement system, planning, control, communication, resources allocation and motivation functions may not work properly. However, designing and applying a performance measurement system needs much effort and takes time and is costly. Consequently, designing and applying a performance measurement system should be carried out cautiously.

3.4 Historical Development of Performance Measurement Systems

Performance measurement systems are not a new management issue. The search for the right performance measurement system started with the rapid growth of industries in the early 19th century, even although performance measurement systems already existed far earlier. However, the well-documented performance measurement system was found just after the Industrial Revolution.

Based on Johnson and Kaplan's book entitled *Relevance Lost - The Rise and Fall of Management Accounting,* the development of performance measurement systems, as indicated by Figures 3.2(a), 3.2(b) and 3.2(c) can be classified into the following five eras:

1. Performance measurement systems for measuring the efficiency of internal processes (1800 – 1900).
2. Performance measurement systems for measuring the profitability of units of organisation and the whole organisation (1900 – 1925).
3. Relevance lost (1925 – 1980).
4. The improvement of cost accounting systems and the development of individual, non-financial performance measurement systems (1980 – 1990).
5. Integrated performance measurement systems (1990 – present).

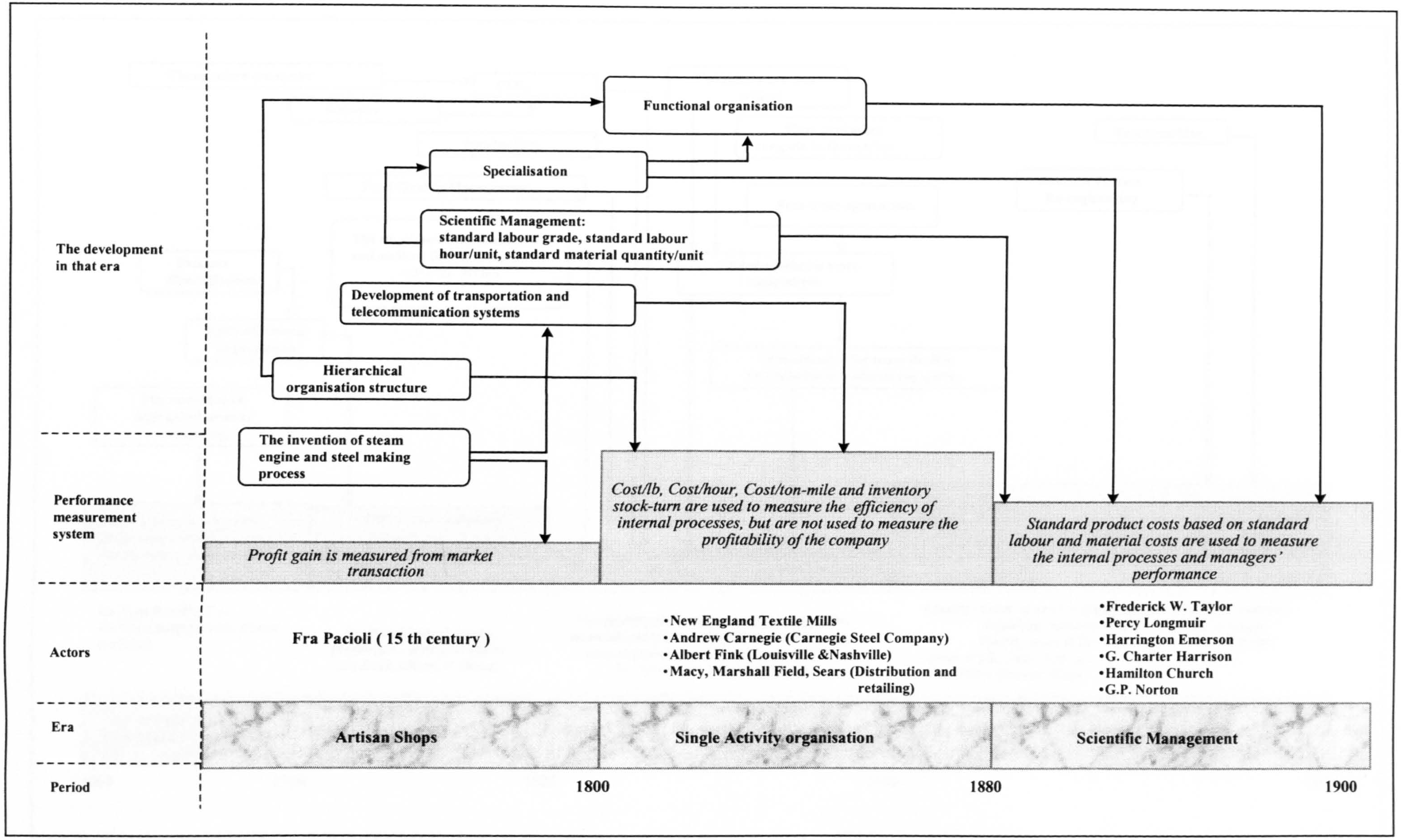


Figure 3.2(a). The development of performance measurement systems up to 1900.

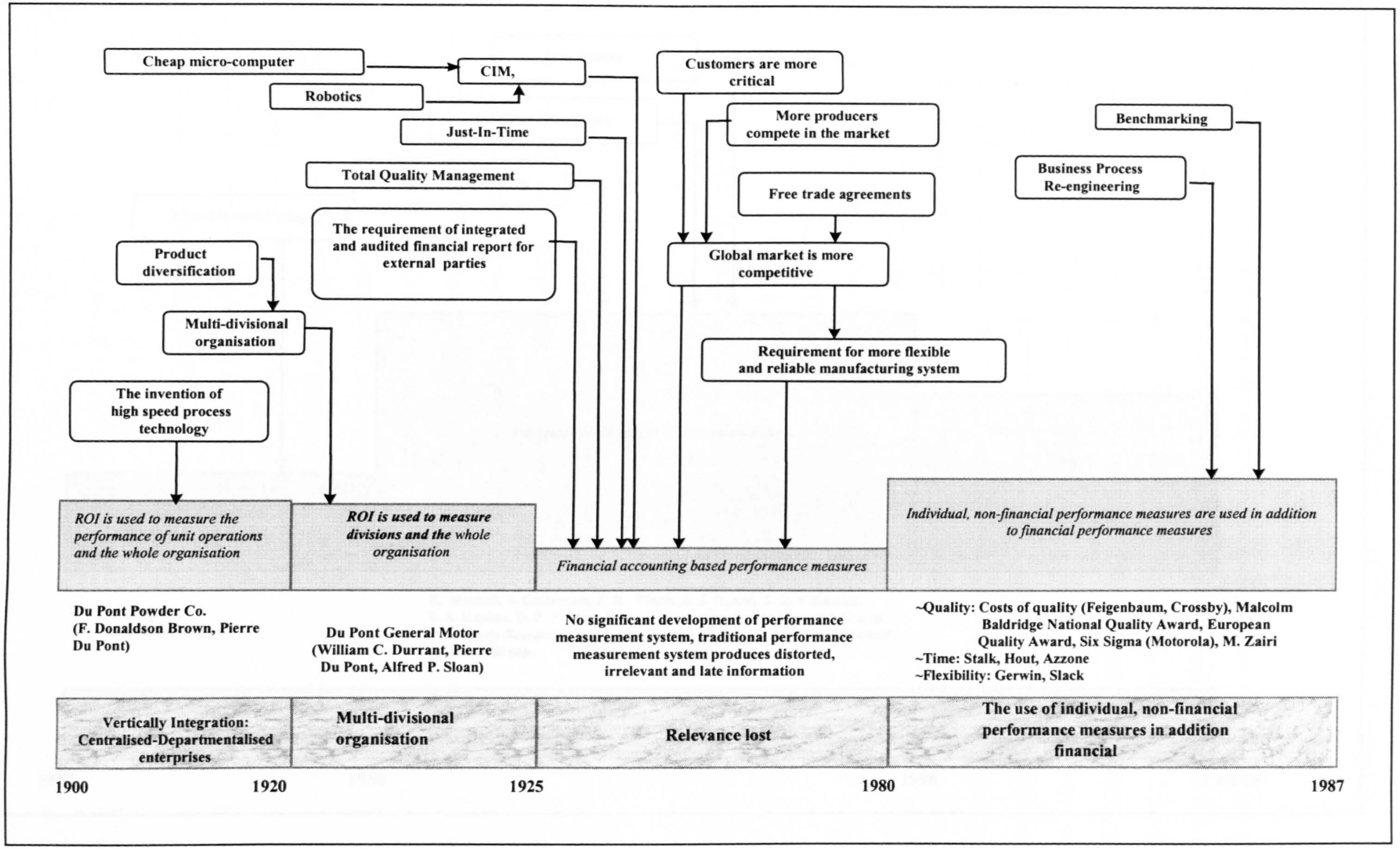


Figure 3.2(b). The development of performance measurement systems from 1900 to 1987.

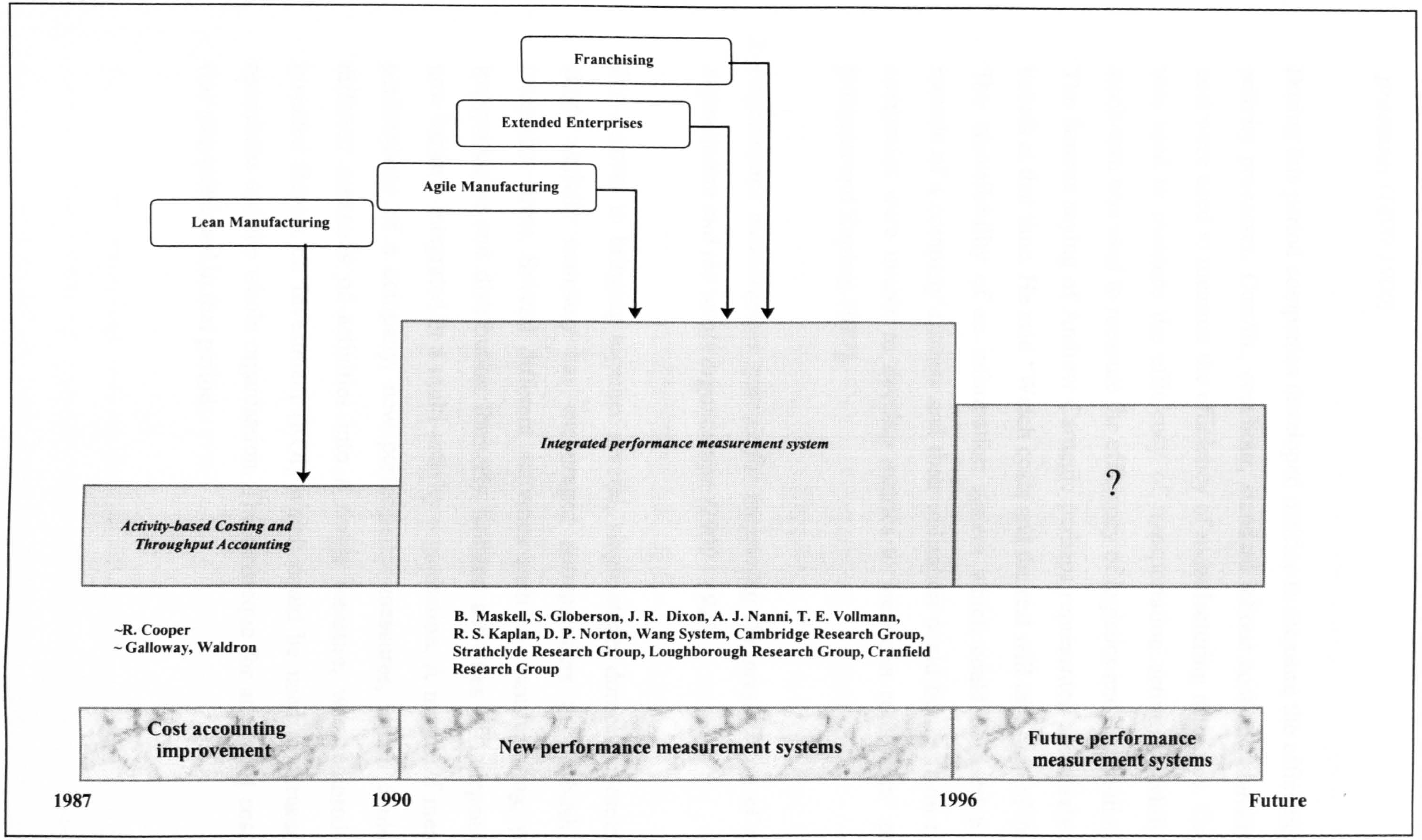


Figure 3.2(c). The development of performance measurement system from 1987 to the present.

1. Performance measurement system for measuring the efficiency of internal business processes (1800-1900)

During this period companies developed metrics to measure the efficiency of single activity processes. Cost/lb., cost/hour, standard labour cost and standard material cost were used to measure the efficiency of manufacturing activities. Cost/ton-mile was used to measure the efficiency of transportation activities, while inventory stock-turn was used to measure the efficiency of logistics and distribution activities. The famous saying of Andrew Carnegie perhaps represented accurately managers' beliefs at that time. He said "Watch costs and the rest will take care of themselves". The unavailability of an information system which could be used to track the records of a company's assets and their utilisation could be the main reason why companies were unable to develop metrics to measures companies' profitability [Johnson and Kaplan, 1987].

2. Performance measurement systems for measuring the profitability of units of an organisation and the whole organisation (1900 - 1925)

The success in bringing together several, single-stage, domestic processes into a single activity company has encouraged entrepreneurs to establish vertically integrated firms. Several different activities such as manufacturing, purchasing, transportation and distribution formerly isolated activities of independent firms, now became integrated in a multi-activity organisation. A means of measuring the performance of a company, new performance measures, which could integrate different measures of activities into a single measure, was required. Du Pont invented Return on Investment (ROI) which could be used to measure units of operations and the whole organisation. The technique for analysing cost variances was also published in that period.

3. *Relevance lost (1925 - 1980)*

By 1925 all the traditional performance measures for measuring production cost and company profitability such as product cost and variances, ROI, profitability and other financial ratios had been developed. No fundamental innovation has occurred since this period, despite enormous changes in the business environment. Traditional performance measurement systems have become less relevant to the business environment.

4. *The improvement of cost accounting systems and the development of individual, non-financial performance measurement systems (1980 - 1990's)*

Having recognised that traditional cost accounting and performance measurement systems were unable to provide accurate, relevant and timely information which could be used by managers for controlling company operations and stimulating correct behaviour, people started to seek new cost accounting and performance measurement systems. Activity-Based Costing was developed in order to calculate more accurate cost absorption. Financial performance was no longer a single measure that determined the long-term survival of companies. Other measures such as quality [Garvin, 1987; Zairi, 1994], delivery [Stalk and Hout, 1990; Azzone, 1991] and flexibility [Gerwin, 1987; Slack, 1987], of no less importance than cost, have emerged. In addition to traditional performance measurement systems, managers also used non-financial performance measures. However, managers used financial and non-financial measures separately rather than integratedly.

5. *Integrated performance measurement systems (1990 - present)*

Managers and researchers realised that non-financial and financial performance measures have to form part of an integrated and coherent performance measurement system. Much research has been done to develop new integrated performance measurement systems [Maskell, 1991; Globerson, 1985; Cross and Lynch, 1988-1989; Dixon et al, 1990; Kaplan and Norton, 1996; Neely, 1995; Bititci et al, 1997; Doumeingts et al, 1995; Feurer and Chaharbaghi, 1995]. However, many problems regarding performance measurement systems need to be resolved [Neely et al, 1995].

3.5 The Traditional Performance Measurement Systems and Their Limitations

Traditional performance measurement system has been primarily based on the management accounting system. Consequently, traditional performance measures have focused on financial data such as cost variance, productivity, return on investment, return on sales, sales per employee, profit per unit production and other financial ratios [Ghalayini and Noble, 1996]. All the techniques used in traditional performance measurement were actually developed completely in the 1920s. Not many fundamental development have been done since then [Johnson and Kaplan, 1987].

The failure of traditional performance measurement systems to provide relevant, comprehensive and timely information was recognised a long time ago. As far back as 1951, General Electric had realised that good performance on product cost and company profitability was not enough to guarantee long-term survival. A high-level task force was set up to identify key corporate performance measures. They came up with a list of key performance indicators which not only consisted of cost and profitability measures, but also included market share, productivity, employee attitudes, public responsibility and a balance between short and long-term goals [Eccles, 1991]. However, dissatisfaction with traditional performance measurement systems was not realised world-wide until the late of 1980s when the business environment was changing enormously.

Most researchers on new performance measurement systems have pointed out the limitations of traditional performance measurement systems [Kaplan, 1984; Johnson and Kaplan, 1987; Maskell, 1991; Zairi, 1994; Dixon et al, 1990; Cross and Lynch, 1988-1989]. Practitioners also observed the same limitations. Most collaborator companies involved in research at the University of Strathclyde on the development and application of an Integrated Performance Measurement System Reference Model already use non-financial measures in addition to financial measures, even although they do not manage the measures as an integrated system.

It is claimed that traditional performance measurement systems are insufficient for use in the current dynamic business environment. The problems with using traditional performance measurement systems can be classified into two categories. These are general limitations and limitations of specific measures [Ghalayini and Noble, 1996].

General limitations of traditional performance measurement systems

The limitations of traditional performance measurement systems have been discussed by many researchers. The following present the seven most commonly cited limitations.

Failure to take into account the customer perspective

Zairi (1994) pointed out that the biggest shortcoming of traditional performance measurement system is the failure to take into account the customer perspective, whether internal or external.

Lack of relevance

Maskell (1991) pointed out that traditional performance measurement financially-based reports are:

- not directly related to strategy,
- not meaningful for the control of production and distribution,
- not relevant and misleading for pricing decisions.

To be relevant performance measurement systems should also use non-financial reports in addition to financial reports.

Lagging metrics

Cost variance reports usually are reported monthly, while profitability reports are reported, at most, quarterly and during those periods many things may happen. Managers may be supplied with the results of past decisions, the information being too late to be useful [Johnson and Kaplan, 1987].

Short-termism

A performance measurement system is not only used to assess a company's performance, but also managers' performances. Measuring managers' performances using quarterly or annual profitability reports has encouraged managers to pursue short-term performance to the sacrifice of long-term performance [Maskell, 1991; Johnson and Kaplan, 1987].

Inflexible

Traditional performance measurement reports are inflexible in that they have a predetermined format which is used across all departments or even across all the business units. However, departments within the same company have their own characteristics and priorities and the format of performance reports is unlikely to be the same [Maskell, 1991].

Does not foster improvement

Fisher (1992) argued that setting standards for performance measures conflicts with continuous improvement principles, in that workers may hesitate to perform to their maximum potential if they realise that the current standard may be revised upward if current results are too good.

Cost distortion

The internal and external environments of companies have changed dramatically and the patterns of cost elements have significantly changed in recent years. Indirect cost, rather than direct labour cost, is now the major part of production cost. Calculating overhead absorption based on the percentage of direct labour cost will distort product cost [Johnson and Kaplan, 1987].

Limitations of specific measures:

Generally there are three measures which are used by traditional performance measurement systems. These are cost, productivity and profitability [Ghalayini and Nobles, 1996]. The following will present criticism on those measures.

Cost

Nowadays, customers are critical, technology development is very fast, product life cycle is shortened and there are many competitors fighting in the same market. Cost is no longer the single competitive attribute. Other competitive attributes have emerged which could be more important than cost [Garvin, 1987; Gerwin, 1987; Stalk and Hout, 1990; Forker et al, 1996]. Skinner (1986) argued that to be competitive one should concentrate on quality, reliable delivery, short lead time, customer service, rapid product introduction, flexible capacity and efficient capital deployment, while research carried out by Vickery et al (1993) indicated that the top five competitive priorities are:

- quality (conformance to specifications, reliability and durability),
- cost,
- flexibility (volume and process),
- delivery dependability,
- speed (delivery speed and lead time).

The results of other research also indicate the emergence of non-cost competitive attributes [White, 1996; Fry, 1995; Noble, 1997; Forker et al, 1996]. Consequently, reducing cost at the expense of any other competitive attribute can be disastrous.

Productivity

In a traditional performance measurement system productivity has been considered as the primary indicator of performance [Ghalayini and Noble, 1996]. Conventionally productivity is defined as the ratio of total output to total input [Burgess, 1990]. Even although research on developing the formula of productivity was continuing up to the 1980s [Craig and Harris, 1973; Gold, 1980; Riggs and Felix, 1983; Hayes et al, 1988], the fundamental concept of productivity, ratio output to input, has actually been used in the very early stages of performance measurement system development. Neely et al (1995) also classified productivity as cost-related performance measure.

Productivity has been the subject of intensive research. Teague and Eilon (1973) found that productivity measurement had been used for four purposes: strategic (i.e. comparison with competitors or related firms), tactical (i.e. control of company's operations), planning (i.e. comparison of the relative benefits from the use of different inputs) and internal management (i.e. collective bargaining with trade unions). Three basic models of productivity have been developed and widely used: partial productivity, total factors productivity and total productivity. Partial productivity is defined as "the ratio of total output to one class of input" [Melman, 1956]. Output per man-hour (labour productivity) is the partial productivity measure most commonly used. Total factor productivity is defined as "the ratio of net output to the sum of associated labour and capital (factors) input" [Mali, 1978; Taylor and Davis, 1977; Kendrick, 1984]. Total productivity is defined as "the ratio of total output to all input factors" [Edosomwan, 1985; Sumanth, 1984; Kendrick, 1984; Craig and Harris, 1973; Hayes et al, 1988].

Edosomwan (1987) developed the productivity measurement hierarchy as depicted in Figure 3.3. He stated that in order for a productivity measurement system to provide useful results, it is important for the level of measurement to be specified and understood within the productivity measurement hierarchy. Productivity measurement hierarchy suggests that productivity measurement should start at the basic level (individual, task and technology). More importantly, the productivity measurement hierarchy shows that the productivity of any nation starts from the basic units.

Productivity measures suffer from criticism. Zairi (1994) identified the following shortcomings of the existing formula for productivity measurement:

- The defined formula of output over input for value-adding has failed to incorporate new operation parameters.
- Productivity measurement is not part of the overall management process and tends to be confined to a specific area only.

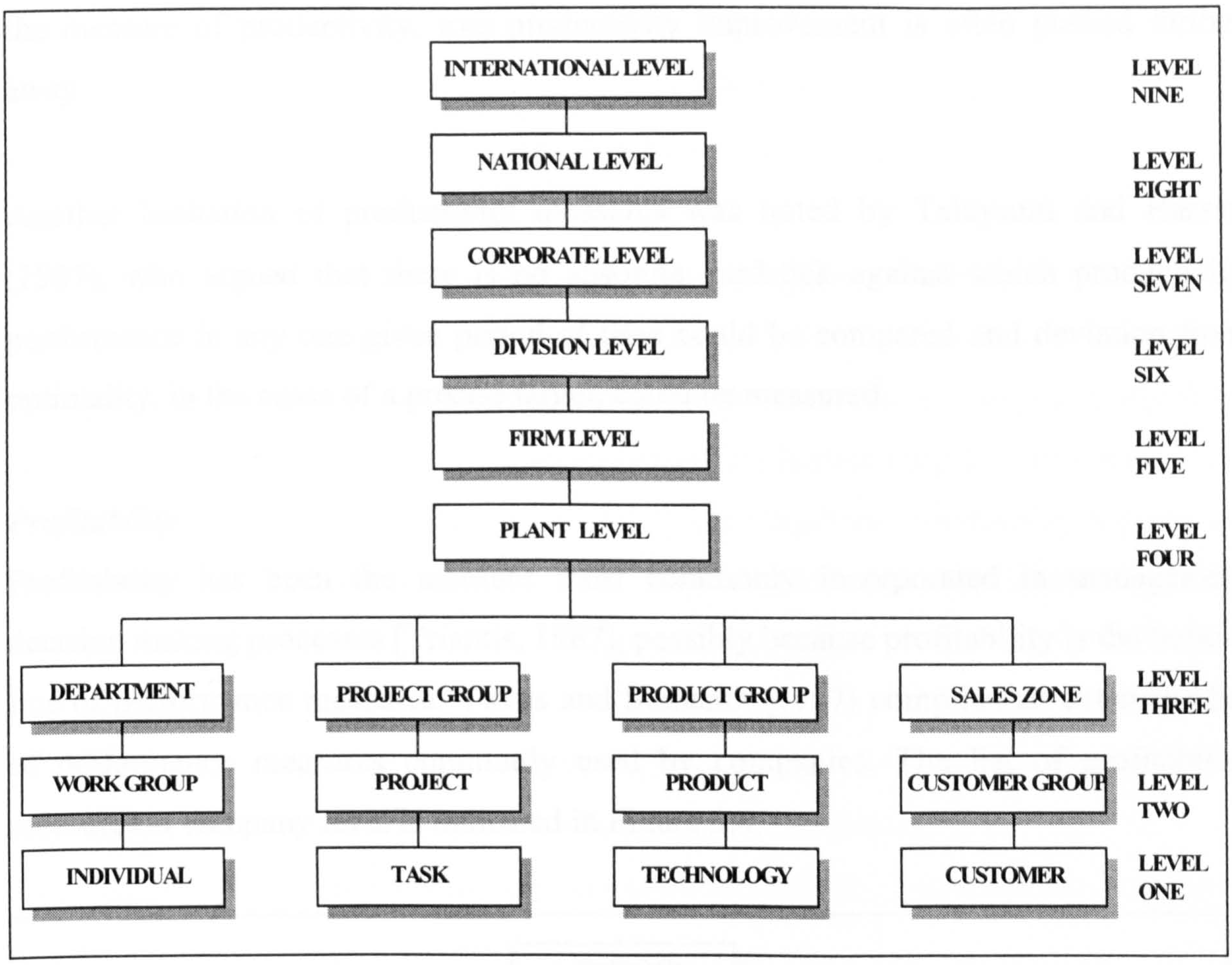


Figure 3.3. The productivity measurement hierarchy [Edosomwan, 1987].

- In a modern business context, it is difficult to measure productivity using output/input and efficiency criteria.
- Information obtained from the output/input formula is not really adequate for planning an improvement programme.
- Review and evaluation are difficult to carry out using traditional productivity measures.

Skinner (1986) called the limitation of productivity "*productivity paradox*". He argued that concentrating on improving productivity had its disadvantages. Productivity is mostly concerned with direct labour which is no longer a significant portion of cost. Thus decreasing the cost of direct labour and/or increasing direct labour efficiency does not contribute significantly to the overall performance of a company. Moreover, focusing excessively on the efficiency of employees and departments detracts attention from improving the production system itself. The harder an employee tries to improve the measure of productivity, true productivity improvement is often pushed further away.

Another limitation of productivity measures was noted by Talaysum and Hassan (1987), who argued that there is no absolute yardstick against which productivity performance in any one given period of time could be compared and deviation from optimality, in the sense of a precise target, could be measured.

Profitability

Profitability has been the measure most commonly incorporated in management decision making processes [Triantis, 1987], possibly because profitability is the bottom line of performance measures. Yavus and Sumanth (1987) compiled an extensive list of performance measures commonly used by companies. The list of profitability measures at company level is indicated in Figure 3.4.

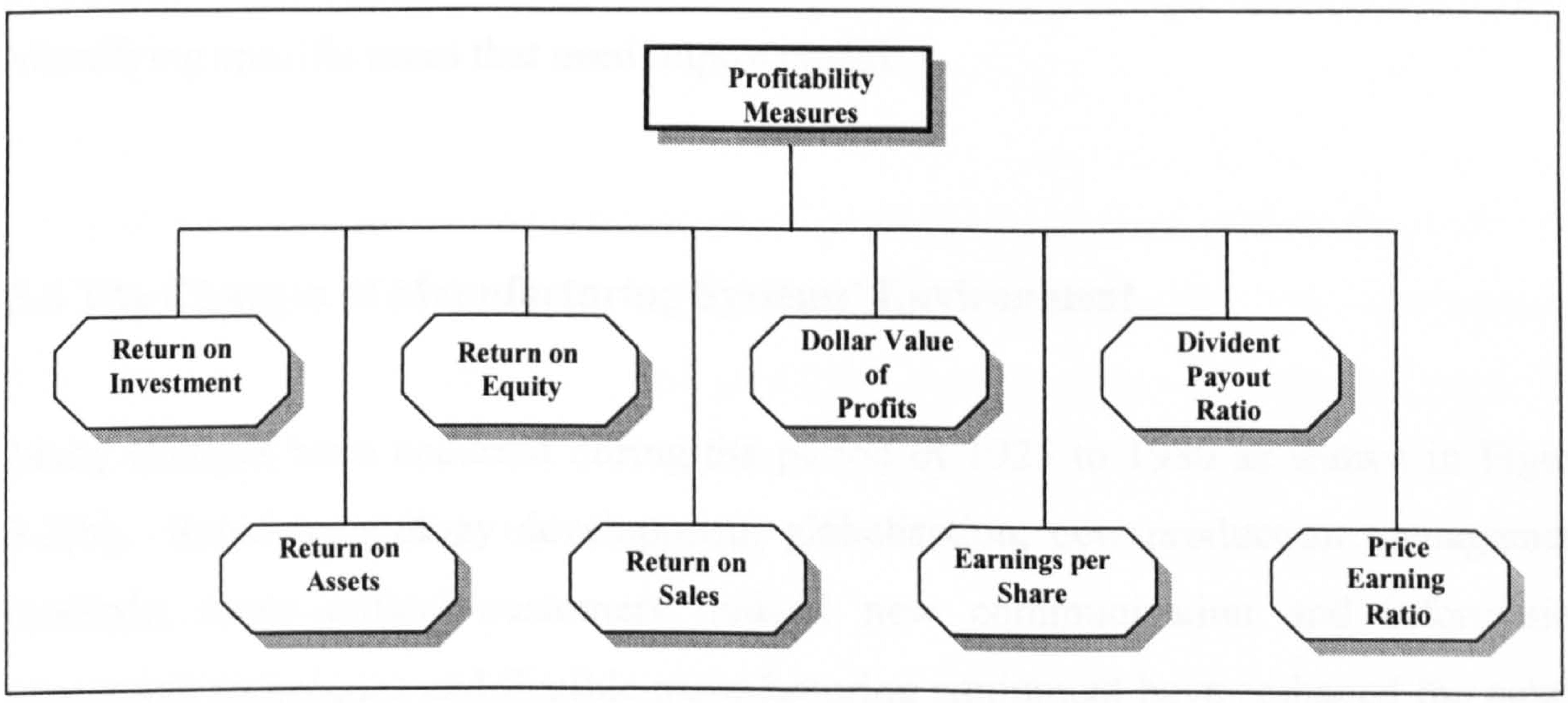


Figure 3.4. Profitability measures at company level [Yavuz and Summanth, 1987].

Measuring a company's overall performance using profitability measures has disadvantages. Maskell (1991) argued that the monthly, quarterly and annual reports which are used by stockholders, market analysts and company executives to judge the performance of a company has led to a short-term view. Managers were motivated by these short-term measures to achieve monthly, quarterly, or annual performance targets while at the same time sacrificing long-term performance. Managers were reluctant to invest in long-term objectives, such as technology development and human resource development, in order to make annual performance look good.

As many things may happen within a one-year period, annual reports on the profitability of a company's performance are unhelpful to managers, consequently, managers receive obsolete information which gives the results of past decisions. What managers actually need is current information which is necessary if they are expected to make decisions to deal with current and future situations. Profitability reports are therefore better for measuring past performance rather than for indicating future performance.

Profitability measures are also criticised for their inability to identify problems. Globerson (1985) argued that poor performance on profitability shows that there are problems in a company's operation. However, profitability measures do not help in identifying specific areas that need improvement.

3.6 The Changes of Manufacturing Systems' Environment

Many changes have occurred during the period of 1925 to 1980 as shown in Figure 3.2(b). Rapid technology development, globalisation, new production management methods, more critical customers, radical new communication and information processing techniques and flexible manufacturing equipment have reshaped the nature of competition. Kaplan and Norton (1996) stated that companies are in the midst of a revolutionary transformation, from industrial-age competition shift to information-age competition. The information-age operating environment is characterised by:

Cross-Functions

To be competitive a company should operate with integrated business processes that cut across traditional business functions.

Link to Customers and Suppliers

Using advanced information technology, customer-supplier relationship becomes closer and enables all organisations to gain improvement in cost, quality and response time.

Customer Segmentation

Companies must be able to offer customised products to their diverse customer segments at low cost and short lead time.

Global Scale

Companies must be able to compete in a global market.

Innovation

As product life cycles continue to shrink, innovations in new product development and manufacturing processes become more important.

Knowledgeable Workers

Automation has reduced the percentage of blue-collar workers and more people are performing analytical functions such as engineering, marketing and management. Therefore, investing in, managing and exploiting the knowledge of every employee has become critical to the success of a business. Kaplan and Norton (1996) argued that to be able to compete successfully in the market, companies should initiate various improvement programs:

- Total Quality Management
- Just-In-Time production and distribution system
- Time-based competition
- Lean production
- Building customer-focused organisations
- Activity-based cost management
- Employee empowerment
- Reengineering

In the industrial age competition, a company's success is determined by its ability to achieve economies of scale and scope by deploying new technology into physical assets rapidly and by excellent management of financial assets and liabilities. In the information age a company's success is determined by its ability to mobilise and exploit intangible or invisible assets such as:

- supplier and customer relationship development,
- innovative new product introduction,
- high-quality products customisation at low cost and short lead times,
- continuous improvement,
- deployment of information technology, data bases and systems.

D'Aveni and Gunther (1995) used the term hyper-competitive environment to describe the current dynamic environment. They stated that companies were experiencing hyper-competition, since the environment was suffering from intense change and flexible, aggressive, innovative competitors moved into markets easily and rapidly, eroding the advantages of the established players. No organisation can build a competitive advantage that is sustainable. In a hyper-competitive environment companies must actively work to erode their own competitive advantage and the advantage of competitors. To be successful in a hyper-competitive environment companies should seek new innovations continuously and move quickly to the top of the 'escalation ladder' and shift to a new arena of competition rapidly. In this dynamic environment it is unlikely that traditional, financial-based performance measurement systems are applicable [Hilton, 1994; Jeans and Morrow, 1989].

Intense change of the business environment inevitably would affect performance measurement systems. Therefore, it is necessary to examine *the stability of a performance measurement system as the business environment changes*. Consequently, a new research problem, hypothesis and objective related to the stability of a performance measurement system were added to the existing research problems, hypotheses and objectives.

3.7 The Development of New Performance Measurement Systems

Researchers and practitioners realised that new performance measurement systems are required to deal with the new dynamic business environment. Many frameworks and models for performance measurement system design and implementation have been proposed. This sub-chapter will present the new frameworks and models which are often cited in the literature.

Dissatisfaction with using financial performance measures to evaluate business performance is nothing new. General Electric has tried to use non-financial measures in addition to financial measures to evaluate its business performance since 1951 [Eccles, 1991]. What is new is the intensity of the criticism of traditional performance measures and the attempts to develop more integrated performance measurement systems. Many articles have been published since the late 1980s on the design of new performance measurement systems.

3.7.1 Individual new performance measurement systems

The dissatisfaction shown towards traditional performance measurement systems has triggered off attempts to develop new performance measurement systems. At the earliest development stage of new performance measurement systems attempts were made to try and develop new cost accounting and management systems which were more appropriate to the new dynamic environment. They also included non-financial measures to the new performance measurement systems.

3.7.1.1 New Performance Measures Relating to Cost: Activity-Based Costing

Traditional cost and management accounting systems have been criticised as lacking in relevance in the current business environment [Kaplan, 1984; Maskell, 1991; Johnson and Kaplan, 1987]. The techniques used by those systems were already been in place by 1925 [Johnson and Kaplan, 1987]. Hilton (1994) argued that a traditional cost accounting system is applicable in the environment when:

- direct cost, especially direct labour cost, represents a major proportion of total manufacturing cost,
- the production process is stable,
- the products are fairly similar and of high volume,
- competition is based on product price.

It is unlikely that traditional cost accounting systems are appropriate for the present situation, since current manufacturing systems are expected to produce a wide variety of products at low volume and must compete in the market on factors such as cost, quality, delivery and flexibility [Garvin, 1987; Stalk and Hout, 1990; Gerwin, 1987]. As a result traditional management accounting systems produce information that is too late, too aggregate and too distorted to be relevant to managers for making planning and control decisions. Therefore, a new system is required [Johnson and Kaplan, 1987].

The source of the failure of a traditional cost accounting system to produce accurate, timely and relevant information may be laid at the necessity for integration and consistency between financial accounting and management accounting [Fry et al, 1995; Johnson and Kaplan, 1987]. Management accounting information is usually extracted from systems that are designed to produce annual financial reports for external parties. Quite often periodic reports used by managers for internal control are little more than periodic slices of the annual report sent to shareholders [Dodge, 1994]. Linking the management accounting system to the financial accounting system strongly encourages operational managers to emphasise crude and late financial measures, rather than more accurate, meaningful and timely measures. Furthermore, according to Jeans and Morrow (1989) the main factors which make the traditional cost accounting system of less relevance and which lead to the development of the Activity-Based Costing system are:

- management accounting practice has been distorted by the needs of financial reporting,

- direct labour as a percentage of total cost has shrunk in the majority of manufacturing companies,
- overhead costs are no longer a mere burden to be minimised,
- complexity has increased,
- the market-place is more competitive.

Activity-Based Costing (ABC) was developed to provide more realistic and accurate information on production costs. The fundamental difference between the ABC system and the traditional cost accounting system is that the traditional costing system assumes products cause costs, whereas the ABC system assumes that ***activities cause costs and the cost objects create demand for activities*** [Bharara and Lee, 1996]. A series of articles on Activity-Based Costing were first published by Cooper (1988a, 1988b, 1989a, 1989b), even though the concept of activity analysis had has been adopted by General Electric in the late 1960s [Johnson, 1991].

Although ABC and traditional cost accounting are fundamentally different in concept, they both use a two-stages approach for allocating indirect cost as indicated in Figure 3.5 (Cooper et al, 1992).

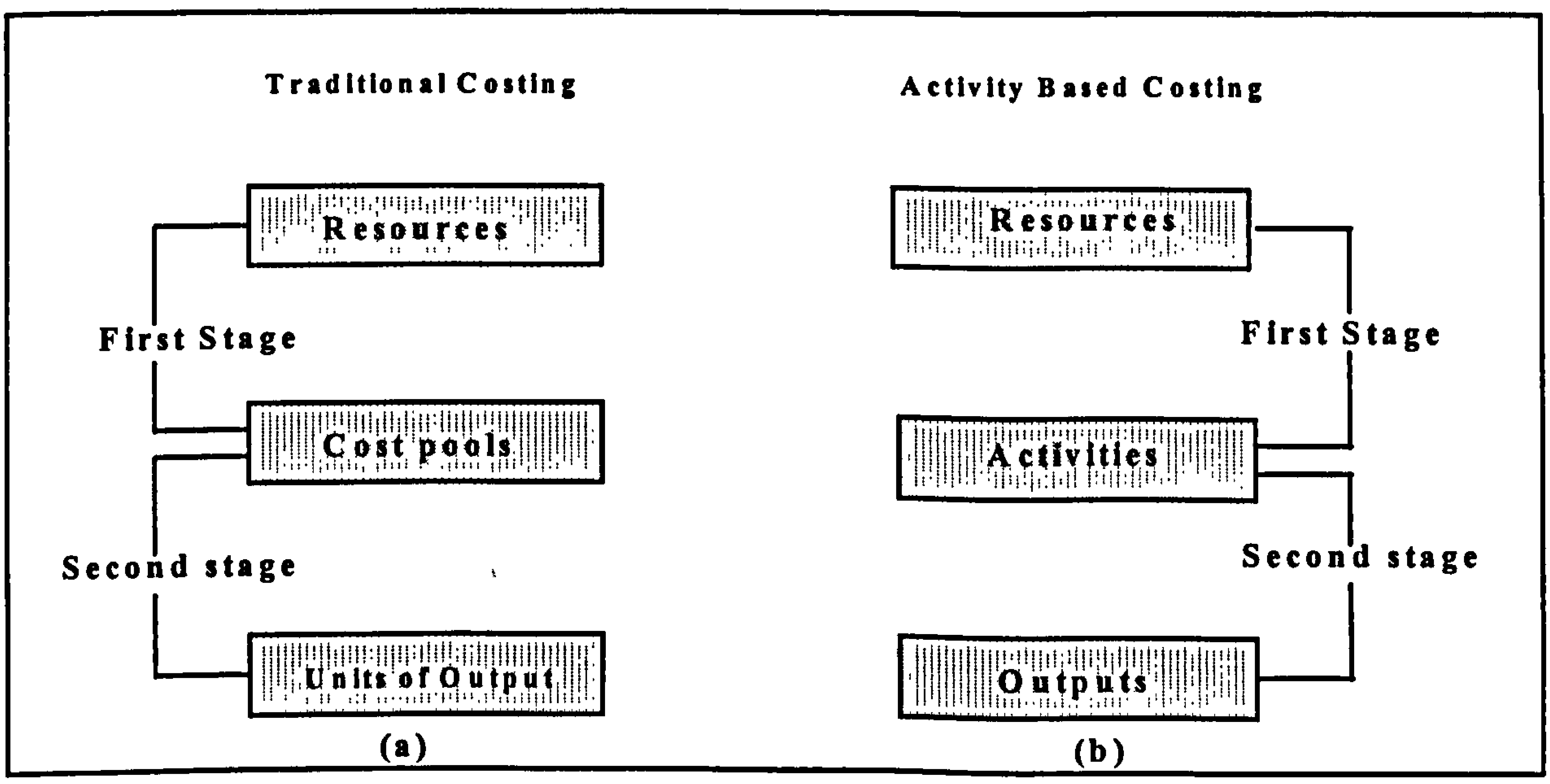


Figure 3.5. Two-stage approach: (a) traditional accounting system and (b) activity-based costing system [Cooper et al, 1992].

In the traditional system as indicated by Figure 3.5 (a) operating expenses are assigned firstly to cost pools and secondly to outputs. This procedure distorts product cost considerably. The traditional system assigns costs from cost pools to outputs using volume drivers such as labour and machine hours, material purchases and units produced. Because many indirect and support resources are not used in proportion to the number of output units produced, distortions in the cost of products could occur.

An activity-based costing system differs from a traditional system by modelling the usage of all organisational resources on the activities performed by these resources and then linking the cost of these activities to outputs such as products, services, customers and projects as indicated by Figure 3.5 (b). This procedure makes ABC systems measure cost more accurately, particularly in situations where the intensity of activities used by the outputs are not proportional to the volume of outputs [Bharara and Lee, 1996].

Computer-Aided Manufacturing International (CAM-I) defines Activity-Based Costing as follows [Raffish and Turney, 1991]:

> "*Activity-Based Costing is a methodology that measures the cost and performance of activities, resources and cost objects. Resources are assigned to activities, then activities are assigned to cost objects based on the use or consumption of the relevant activities. Activity-Based Costing recognises the causal relationships of costs drivers to activities.*"

CAM-I also provides the pictorial presentation of the basic structure of an Activity-Based Costing system as depicted in Figure 3.6. **Resources** (economic elements directed towards the performance of activities) such as labour, power and depreciation are traced to **activities** (work performed within an organisation and also as an aggregation of actions performed within an organisation) utilising the resources **cost drivers** (the causal factors that cause costs of an activity to change) such as time for labour, kilowatts for power and value of equipment employed for depreciation. Activities then are traced to **cost objects** such as products, services, marketing and distribution channels, business processes and customers, using a bill of activities.

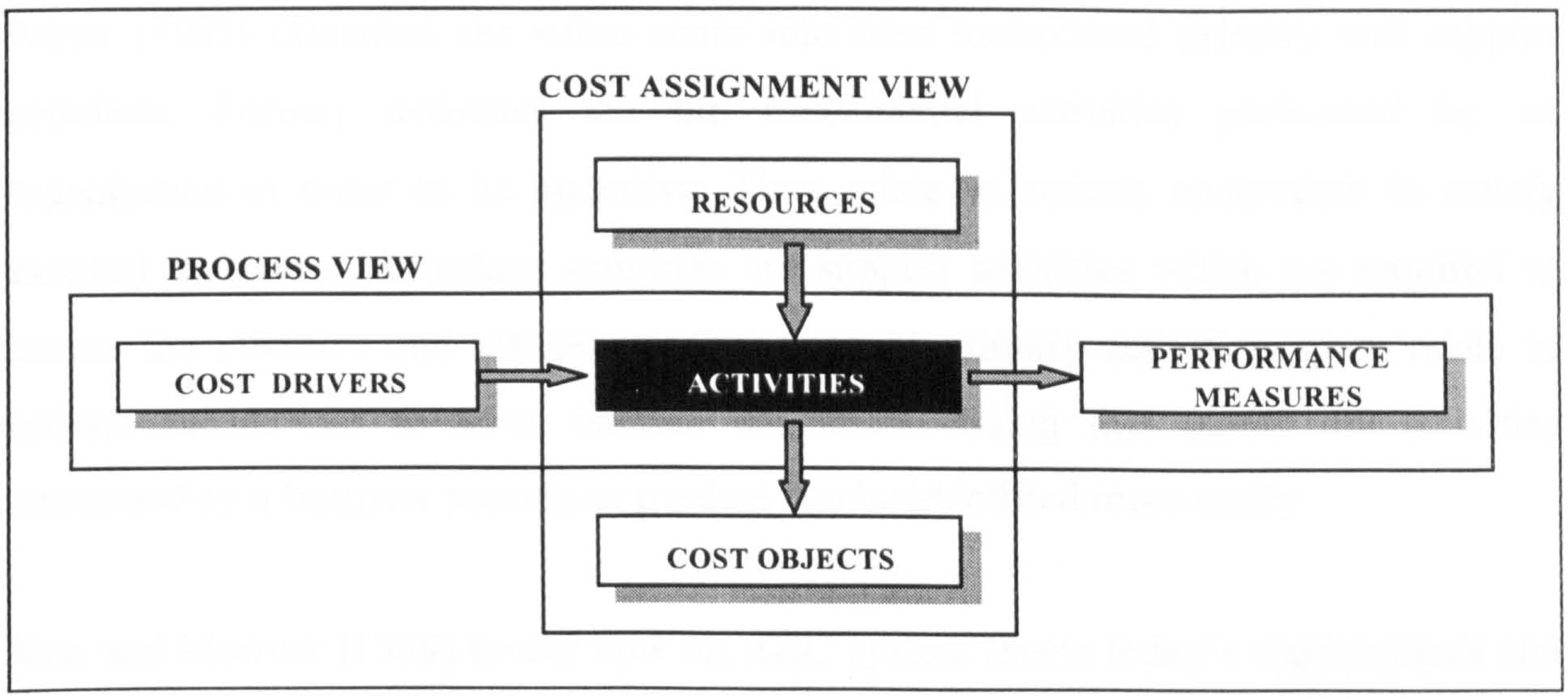


Figure 3.6. Basic structure of Activity-Based Costing (CAM-I).

Finally, performance measures (output measures) are used to measure the output of an activity.

Porter's value-chain model as depicted in Figure 3.7 is a useful mechanism for analysing an organisation to determine what activity it performs to convert inputs to outputs [Glad and Becker, 1995].

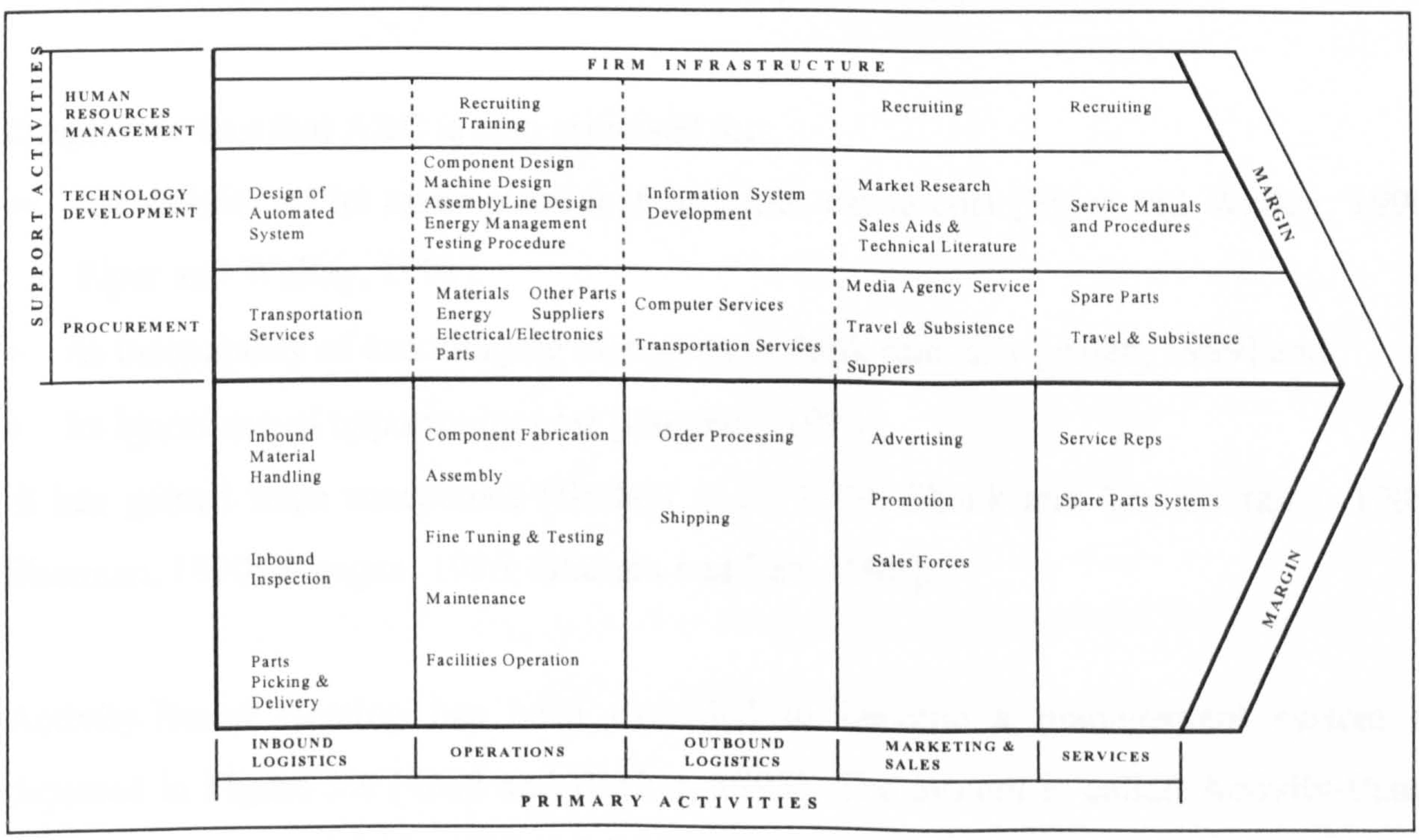


Figure 3.7. Porter's value-chain model [Porter, 1985].

Porter (1985) classified the value chain into nine interrelated primary and support activities. Primary activities are the fundamental activities performed by an organisation in order to be operative. They relate to actions undertaken to satisfy external demands. Secondary activities are support activities which are required to ensure the effective and efficient performance of primary activities. They relate to actions carried out to serve internal customers. Using this model the activities consumed by a business process or product can be identified more easily.

Jean and Morrow (1989) reveal how an ABC system meets today's requirements and therefore can perform better than a traditional cost accounting system as follows:

- ABC is concerned with understanding the cost of activities and their relationship to products,
- ABC uses multiple cost drivers as a means of attributing overhead costs to activities and then to products,
- ABC is concerned with all overhead costs; it does not treat the factory floor as a boundary for cost to be included,
- ABC recognises the complexity of the business through the use of multiple cost drivers and attributes the resultant costs to products and customers which cause it,
- ABC provides meaningful product cost and profitability information.

Despite the fact that ABC is also criticised for:

- the validity of its assumption that activities cause cost [Piper and Walley, 1990; Piper and Walley, 1991],
- its incapability of encouraging managers to think radically [Allen, 1989] and
- its ignorance of opportunity cost [Dugdale, 1990],

it has gained wide acceptance [Berlant et al, 1989; Shank and Govindarajan, 1989; Sharman, 1990; Mangan, 1995; Bharara and Lee, 1996].

Activity-Based Costing has been extended to become a management system as depicted in Figure 3.8 [Glad and Becker, 1995]. The system is called Activity-Based Management (ABM) system. CAM-I defines the ABM as "*A discipline that focuses on* *the management of activities as the route to improving the value received by the customer and the profit achieved by providing this value. This discipline includes cost driver analysis, activity analysis and performance measurement. Activity-Based Management draws on Activity-Based Costing as its major source of information.*" [Raffish and Turney, 1991]. In Figure 3.8 the elements of Activity-Based Costing are indicated in black.

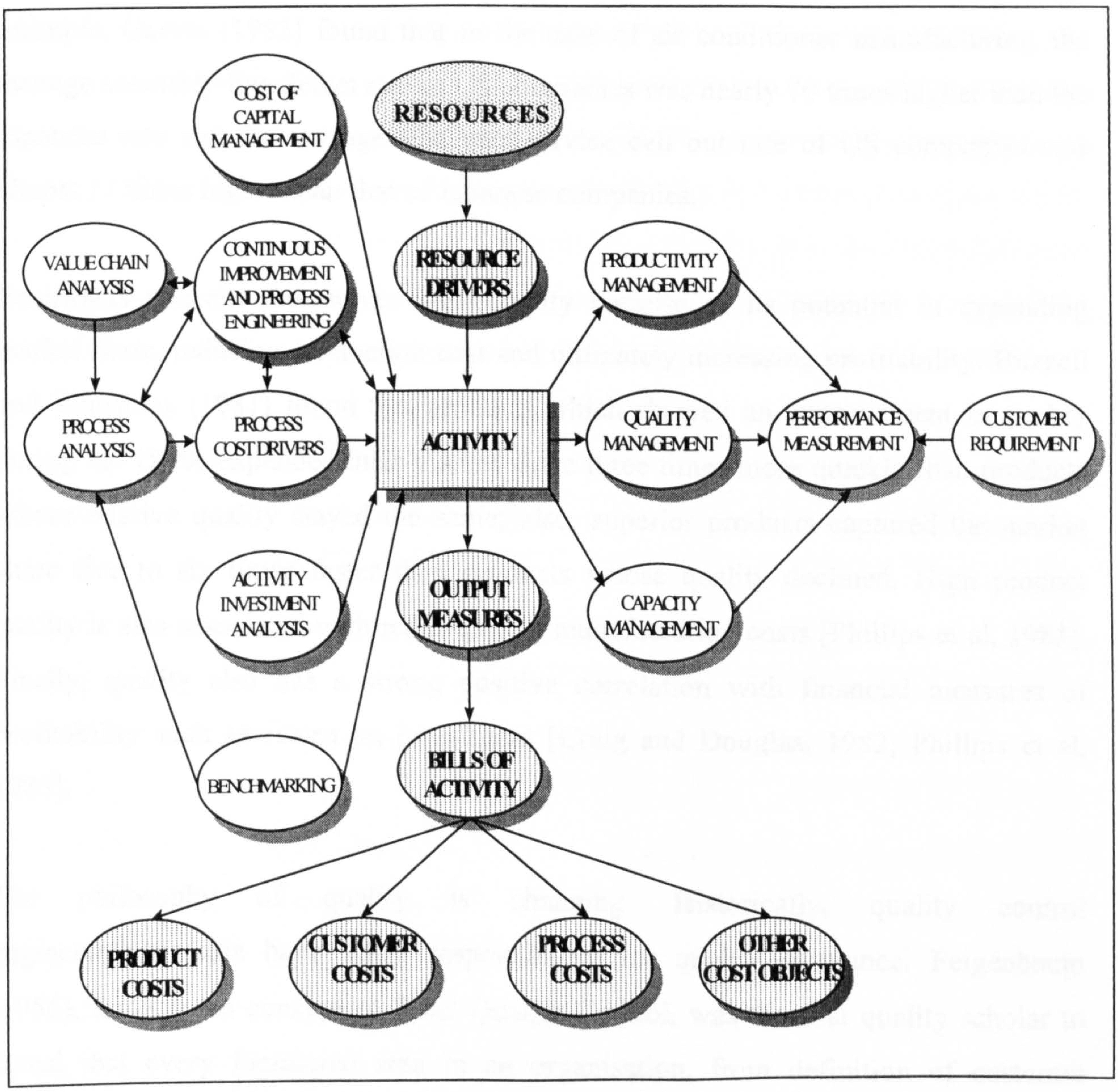


Figure 3.8. Framework of activity-based management system [Glad and Becker, 1995].

3.7.1.2 New Performance Measures Relating to Quality

Since many western companies lost their markets to Japanese companies in the 1980s quality has gained stronger emphasise. Womack et al (1990) found that quality was one of the factors which made Japanese automobile companies perform better in global competition than North American and European companies. Much research has been done to examine the quality of US products compared to Japanese products. For example, Garvin (1983) found that in the case of air conditioner manufacturers, the average assembly-line defect rate of US companies was nearly 70 times higher than the Japanese rate and the average first-year service call out rate of US companies was almost 17 times higher than that of Japanese companies.

Businesses concern themselves with quality because of its potential in expanding market share, reducing production cost and ultimately increasing profitability. Buzzell and Wiersema (1981) found that products which showed an improvement in quality during the 1970s expanded their market share three times more quickly than products whose relative quality stayed the same; also, superior products captured the market share five to six times faster than products whose quality declined. High product quality is also associated with reductions in manufacturing costs [Phillips et al, 1983]. Finally, quality also has a strong positive correlation with financial measures of profitability such as return on investment [Craig and Douglas, 1982; Phillips et al, 1983].

The philosophy of quality is changing. Historically, quality control engineers/inspectors have taken responsibility for quality assurance. Feigenbaum (1956), through his concept of Total Quality Control, was the first quality scholar to reveal that every functional area in an organisation, from definition of customer requirements to after-sales service, has responsibility for building quality into a product. He was also the first researcher to suggest that the true cost of quality is a function of prevention, appraisal and failure cost [Feigenbaum, 1961]. Optimum quality is defined as the level which minimises total quality cost. Plunket and Dale (1988) challenged the existence of that optimum quality level. Furthermore, Crosby

(1972) considered that '*quality is free*', based on the assumption that for most companies an increase in prevention costs would be less than offset by a decrease in failure cost. Consequently, there is no limit in pursuing better quality.

The definition of quality is also evolving. With the emergence of Total Quality Management the emphasis of quality has shifted from '*conformance to specification*' to '*customer satisfaction*'. It is no wonder, therefore, that the Malcolm Baldridge National Quality Award and the European Quality Award place strong emphasis on customer satisfaction [Zairi, 1994]. Garvin (1984) found that since quality is a major competitive priority to manufacturing companies, much discussion is devoted to defining quality by researchers and practitioners. Quality definitions were classified by Garvin (1984) into five approaches, as depicted in Table 3.1. It is clear form this table that the variables can be different depending on the approach use, i.e. the manufacturing department measures quality differently to the marketing department.

Table 3.1. Quality definitions-approached used [Garvin, 1984].

Approach	**Definitional Variable**	**Underlying Discipline**
Transcendent	Innate excellence	Philosophy
Product based	Quantity of desired attributes	Economics
User based	Satisfaction of customer preference	Economics, marketing and operations management
Manufacturing based	Conformance to requirements	Operations management
Value based	Affordable excellence	Operations management

While quality has been accepted as a major competitive priority to manufacturing organisations, not many explorations have been carried out to identify what attributes of quality are important for business performance. Garvin (1987) proposed the following eight dimensions of quality which have an impact on business performance:

(1) *performance*: the product's primary operating characteristics;

(2) *characteristics*: attributes that supplement the product's primary operating characteristics;

(3) *reliability*: the probability that a product will operate properly over a specified period of time under stated conditions of use;

(4) *conformance*: the extent to which a product's design and operating characteristics meet predetermined standards;

(5) *durability*: the amount of use the customer gets from a product before it physically deteriorates or until a replacement is preferable;

(6) *serviceability*: how fast, how easily and with what degree of courtesy and competence repairs are performed;

(7) *aesthetics*: how a product appeals to the five senses; and

(8) *customer-perceived quality*: reputation, image, or other inferences regarding the attributes of a product.

Each quality dimension has its own operational requirements. For example, excellent in performance dimension requires superior product design and strong in engineering function, while excellent in serviceability dimension requires responsive and capable field support personnel as well as a knowledgeable and efficiently-run customer service department. Furthermore, Garvin (1983) suggested that to be successful firms do not need to excel in all eight-quality dimensions. Pursuing a quality niche can lead to better performance, especially if the dimension singled out is one that other companies have not targeted. In other words, the degree of importance of quality dimension will be different from one company to another depending on the business strategy adopted. Consequently, the quality measures used by one company will be different from those used by others. Some of the most commonly used measures relating to quality are as follows (Maskell, 1991; Kaplan and Norton, 1996]:

- incoming quality from supplier,
- production quality, including the use of SPC and process capability,

- product quality, including critical defect of products received by customers,
- direct measures of the customer's satisfaction, including returns by customers, warranty claims and field service requests,
- data accuracy;
- effectiveness of preventive maintenance programs,
- cost of quality.

3.7.1.3 New Performance Measures Relating to Time

Time, as a competitive weapon, is considered as the next strategic frontier to manufacturing firms operating in a global market [Istvan, 1988; Stalk, 1988]. Traditionally, until the late 1970s, companies competed in a global market using cost advantage. Quality emerged as a competitive priority in the early 1980s and companies shifted their competitive priority from cost to cost and quality. Since the early 1990s most companies world-wide have successfully implementing Total Quality Management, hence customers are taking low cost and higher quality for granted. Companies that want to win orders in a global market have to use a new competitive priority - responsiveness [Wilding and Newton, 1996]. Today time is considered as the new competitive advantage [Stalk, 1988]; consequently, it must be measured.

In a time-based competition context; time is defined as "*the totality of time required to perform all activities on a critical path that commences with the identification of a market need and terminates with the delivery of a matching product to the customers*" [Kumar and Motwani, 1995]. Time measure has many advantages over both cost and quality measures as follows [Stalk and Hout, 1990]:

- it is understood; everybody knows what it is,
- it is easy to measure; all clocks use the same units,
- improvement on time will improve cost and quality.

Furthermore Stalk and Hout (1990) also suggest that as time is compressed, productivity increases, selling prices can be increased, risks are reduced and share is increased.

Kumar and Motwani (1995) demonstrated that time compression can increase profit through the three primary sources indicated in Figure 3.9.

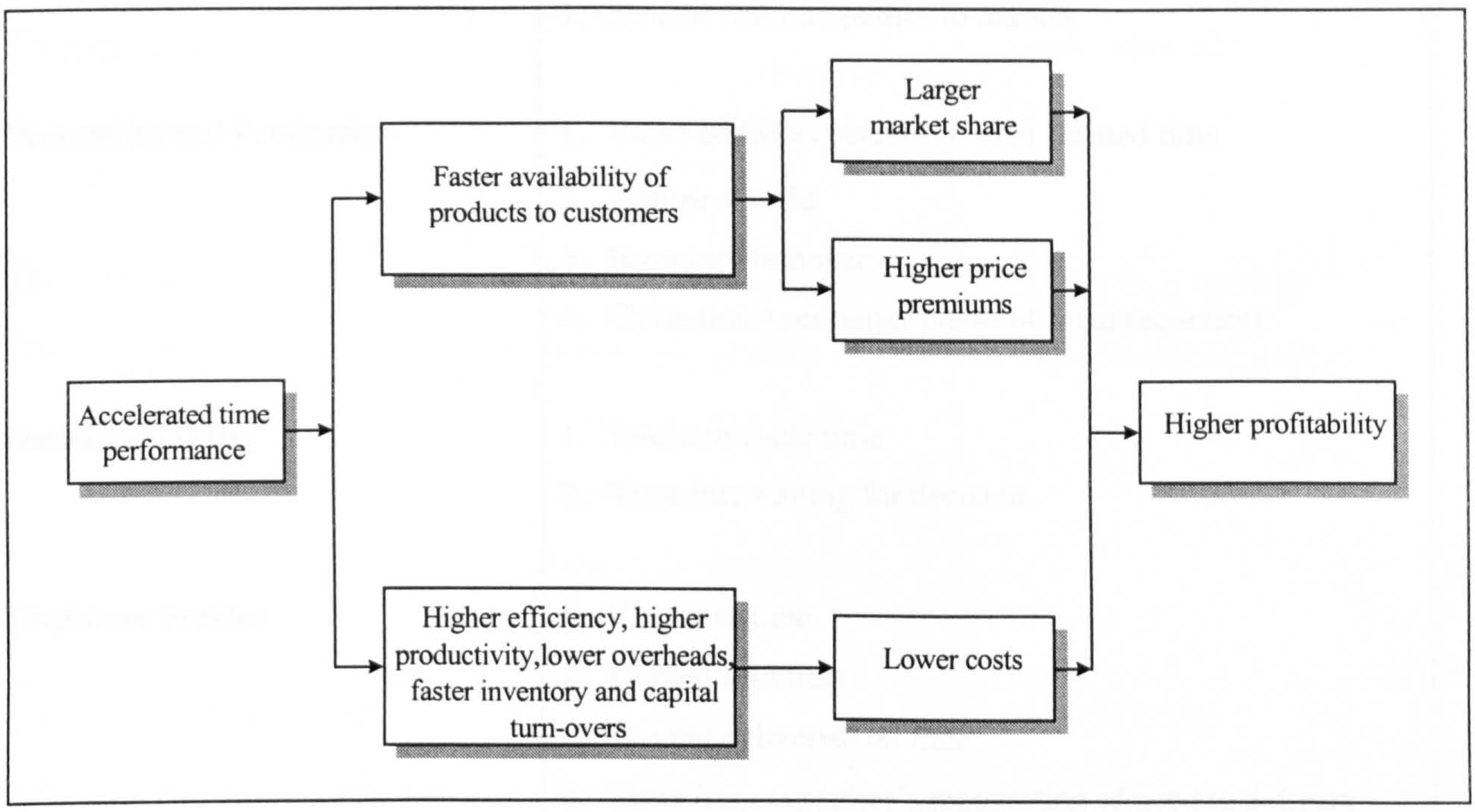


Figure 3.9. The effects of time compression on profitability [Kumar and Motwani, 1995].

As time is accelerated the following situations will arise:

- faster response time will command a price premium,
- faster delivery of customised products will attract more customers and encourages brand loyalty, thus increasing market share,
- shortened time in production and logistical activities will reduce costs and, in turn, result in higher profitability.

Much research has been done to identify measures relating to time. Stalk and Hout (1990) provided 13 time-related measures which can be used to measure the performance of time-based competitive companies. These measures are organised into four areas as depicted in Table 3.2.

Table 3.2. Time-based performance measures [Stalk and Hout, 1990].

Areas	Time-based performance measures
New-Product Development	1. Time from idea to market 2. Rate of new-product introduction 3. Percent first competitor to market
Processing and Production	1. Value added as percent of total elapsed time 2. Uptime x yield 3. Inventory turnover 4. Cycle time (per major phase of main sequence)
Decision Making	1. Decision cycle time 2. Time lost waiting for decision
Customer Service	1. Response time 2. Quoted lead time 3. Percent deliveries on time 4. Time from customer's recognition of need to delivery

Furthermore, they stated that measure such as time to market new products, or lead time on delivery, are good starting places, particularly if there is a competitor or best practices standard available.

Different to Stalk and Hout (1990), Azzone et al (1991) presented a framework of time-based performance measurement which contains three main areas - research and development, operations and sales and marketing as depicted in Table 3.3. "*The columns of the table represent the ways through which the company benefits from time to create a competitive advantage, while the rows represent the macro-activities which could be critical in developing such a competitive advantage*" [Azzone et al, 1991].

Table 3.3. The framework of time-based performance measurement [Azzone et al, 1991].

Methods / Macro-activities	Internal Configuration	External Configuration
R&D Engineering time	1. Number of changes in projects 2. Δ average time between two subsequent innovations	1. Development time for new products
Operations Throughput time	1. Adherence to due dates 2. Incoming quality 3. Distance travelled 4. Value-added time 5. Schedule attainment	1. Outgoing quality 2. Manufacturing cost
Sales and Marketing Order processing lead time	1. Complexity of procedures 2. Size of batches of information	1. Cycle time 2. Bid time

3.7.1.4 Performance Measures Relating to Flexibility

Flexibility has been widely recognised as a competitive priority [Hayes and Wheelwright, 1984; De Meyer et al, 1989; Leong et al, 1990; Vickery et al, 1993; Gerwin, 1993]. However, flexibility is "*a complex, multi-dimensional and hard-to-capture concept*" [Sethi and Sethi, 1990]. The flexibility concept has different meanings to different people. Therefore, different people give different definitions of flexibility [Nilsson and Nordahl, 1995].

Sethi and Sethi (1990) defined flexibility as "*adaptability to a wide range of possible environments that it may encounter*" while Buzacott and Mandelbaum (1985) defined flexibility as "*the ability of a manufacturing system to cope with changing circumstances*".

Gerwin (1993) argued that operationalising flexibility is a difficult task because:

1. No rigorous method exists for establishing a priori the domain of flexibility, that is, the relevant dimensions of the concept.
2. Multi-dimensionality compounds the effort that must go into creating scales, testing them and collecting data.
3. One can study flexibility at a number of different hierarchical levels.
4. Operationalisations which span industries are more useful for research purposes than those limited to a single industry.
5. A lack of communication exists between those doing formal work with implications for measurement and those constructing scales to do empirical works.

Flexibility is required to support manufacturing strategy in dealing with environmental uncertainty [Garrett, 1986; Swamidass and Newell, 1987]. Gerwin provided the conceptual framework in understanding the relationship between environmental uncertainties, manufacturing strategy, manufacturing flexibility, methods and performance measurement as depicted in Figure 3.10.

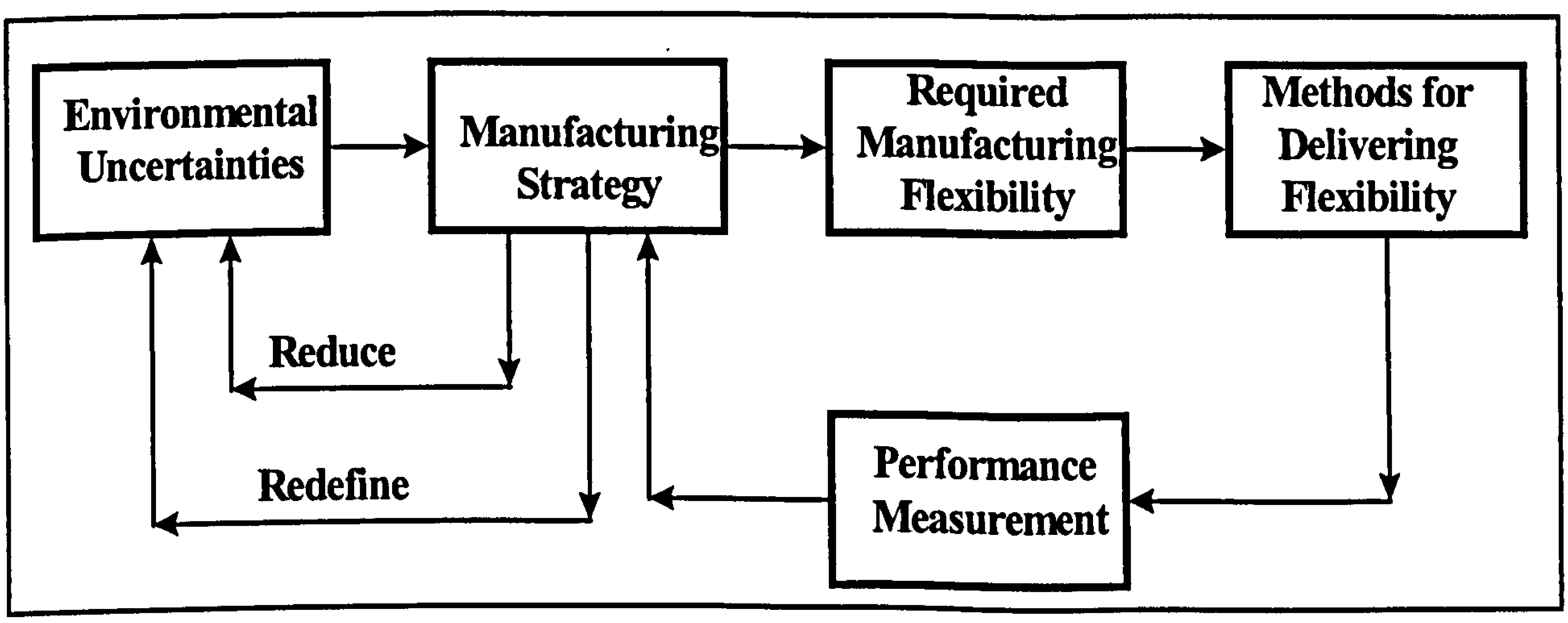


Figure 3.10. Conceptual framework of flexibility [Gerwin, 1993].

Management uses strategy reactively or proactively to cope with uncertainties; reactive strategy reducing uncertainties, proactive strategy redefining uncertainties. Different manufacturing strategies need different manufacturing flexibility. A variety of methods, including production equipment, product design, work organisation, planning and control system, materials management and information technology can be used to attain flexibility. Performance measurement is used to ensure that the existing flexibility supports the strategy.

Not many researchers have provided empirical evidence that improved flexibility will enhance performance [Chenhall, 1996]. Swamidass and Newell (1987) are among a very limited number of researchers who provided empirical evidence of the positive effect of flexibility on financial performance. They developed a path analytic model to analyse the effects of environmental uncertainty, flexibility and the role of manufacturing managers in strategic decision making on economic performance.

They found that flexibility (new product introduction, introducing new production processes, product varieties, product characteristics and R&D efforts) is significantly correlated to financial performance (growth in return on total assets, growth in sales and growth in return on sales). Other research by Chenhall (1996) identified that for entities achieving a high level of flexibility, the use of manufacturing measures was significantly associated to high performance.

No common measures of flexibility are available. However, many classifications of flexibility types have been proposed [Slack, 1983; Brown et al, 1984; Gerwin, 1987; Sethi and Sethi, 1990]. Sethi and Sethi (1990) provided the most comprehensive classification of flexibility types as indicated in Table 3.4. Based on this classification, Gupta and Somers (1992) provided a set of measures which can be used to measure manufacturing flexibility. They collected all the measures relating to the types of manufacturing flexibility which were available in the literature.

Table 3.4. Definitions of flexibility types [Sethi and Sethi, 1990].

Flexibility Type	Definition
Machine	The various types of operations that a machine can perform without requiring excessive operation changeover costs and/or time.
Material Handling	The ability of the material handling system to move part types efficiently through the system.
Operations	The ability to be produced in different ways.
Process	The set of part types that a system can produce without major set-ups.
Product	The ease with which new parts can be introduced into the system or substituted for existing parts.
Routing	The ability to produce a part using different output volumes.
Volume	The ability to operate profitably at different output volumes.
Expansion	The ease and capability to expand volumes as needed.
Production	The range of part types that can be produced without the need to purchase new equipment.
Programme	The ability of a system to operate unattended for additional shifts.
Market	The ability of a manufacturing system to adapt to a changing market environment.

They found there were 34 measures cited. From a survey of 269 firms and employing factor-analytic techniques, the measures were modified into 21 performance measures relating to nine flexibility types as shown in Table 3.5. Finally, performance measures relating to flexibility will vary between companies. It is not necessary for all companies try to use exactly the same measures as listed in Table 3.5. The table can be used as a guideline for companies to design their own measures.

Table 3.5. Performance measures relating to manufacturing flexibility [Gupta and Somers, 1992].

Flexibility Type	Measures
Volume	The range of volume in which the firm can run profitably.
Programming	The manufacturing system is capable of running virtually unattended during the second and third shift.
Process	Changeover cost between known production tasks within the current production program. The ratio of the total output and the waiting cost of part processed.
Product & Production	Number of new parts introduced per year. Scope of parts the manufacturing system is capable of producing without adding major capital equipment.
Market	Shortage cost of finished products. Cost of delay in meeting customer orders.
Machine	The number of different operations a typical machine can perform without requiring prohibitive cost in switching from one operation to another. The number of different operations a typical machine can perform without requiring a prohibitive time in switching from one operation to another.
Routing	Decrease in throughput because of a machine breakdown. Cost of production lost as a result of expediting a pre-emptive order.
Material Handling	The ability of material handling systems to move different part types for proper positioning and processing through the manufacturing facility. The ratio of number of paths the material handling systems can support to the total number of paths. The material handling system can link every machine to every other machine.
Expansion & Market	Time that may be required to double the output of the system. Cost of doubling the output of the system. The capacity (e.g. output per unit time) the system can be increased with ease when needed. The capacity (e.g. quality) the system can be increased with ease when needed. Time required to introduce new products. Time required to add a unit of production capacity.

3.7.2 Integrated performance measurement system

According to Kaplan and Norton (1996) *"managers realised that focusing on individual performance measures such as cost, quality, time and flexibility will lead to local optimisation"*. Performance measures must be treated as an integrated system to support a company's strategy. Using this concept, global optimisation can be achieved instead of local optimisation. Some models for developing integrated performance measurement systems have been proposed, and will be discussed in the following section.

The Requirements of Integrated Performance Measurement Systems

Most researchers have mentioned the need for a good performance measurement system. However, not many provide a complete description of the requirements or characteristics of a 'good' performance measurement system. Only two researchers have tried to describe the requirements of good performance measures [Neely et. al. 1997] or good performance measurement system [Bititci et. al, 1996].

After reviewing extensively the literature available on performance measurement systems, Neely et al (1997) provided the recommendations for designing performance measures as indicated in Table 3.6. The recommendations are intended for designing performance measures, not for designing performance measurement systems.

These recommendations describe what a good performance measure should be, even though some of them are just common sense. Since performance measures are the output of designing a performance measurement system, the proposed recommendations are not very helpful for the process of designing a performance measurement system. For example, the need for aligning performance measures with external factors (competitor, market and stakeholder) is not strongly expressed in the recommendations.

Table 3.6. Recommendations for designing performance measures [Neely et al, 1997].

No	Recommendation
1	Performance measures should be derived from strategy
2	Performance measures should be simple to understand
3	Performance measures should provide timely and accurate feedback
4	Performance measures should be based on quantity that can be influenced, or controlled.
5	Performance measures should reflect the 'business process'
6	Performance measures should relate to specific goals (targets)
7	Performance measures should be relevant
8	Performance measures should be part of a closed management loop
9	Performance measures should be clearly defined
10	Performance measures should have visual impact
11	Performance measures should be focused on improvement
12	Performance measures should be consistent
13	Performance measures should provide fast feedback
14	Performance measures should have an explicit purpose
15	Performance measures should be based on an explicitly defined formula and source of data
16	Performance measures should employ ratios rather than absolute number
17	Performance measures should use data which are automatically collected
18	Performance measures should be reported in a simple consistent format
19	Performance measures should be reported on trends rather than snapshots
20	Performance measures should provide information
21	Performance measures should be precise - be exact about what is being measured
22	Performance measures should be objective - not based on opinion

Different from Neely et al (1997) who provided recommendations for designing good performance measures, Bititci et al (1996) provided the requirements for an effective and efficient performance measurement system as indicated in Table 3.7.

Table 3.7. Requirements for an effective and efficient performance measurement system [Bititci et al, 1996].

No	Requirement
1	Reflect stakeholder's requirement
2	Reflect external/competitive position of an organisation
3	Reflect competitive criteria of the organisation markets
4	Differentiate between control and improvement measures
5	Facilitate strategy development
6	Deploy strategic objectives through a logical path to business processes and activities
7	Focus on critical areas of the business
8	Be expressed in a locally meaningful terminology
9	Facilitate resource bargaining
10	Facilitate performance planning
11	Promote proactive management by focusing on leading measures
12	Accommodate both quantitative and qualitative measures
13	Measure organisational capability and learning where appropriate
14	Use measures at correct levels
15	Promote understanding of the relationship between various measures
16	Facilitate simple reporting – demonstrating trends where possible

These requirements are intended for designing performance measurement systems. Broader aspects of performance measurement have been covered, including: the requirement to consider external factors, resource bargaining, interaction between factors, objective deployment, characteristics of performance measures, strategy development and criticality of performance measures. Consequently, this requirement is very helpful for designing a performance measurement system.

Some models for developing integrated performance measurement systems have been proposed. Each model will be critically reviewed. For the purpose of the review, the researcher designed 13 attributes for describing the models. These attributes are:

1. **Framework**: steps which can be followed to identify the appropriate measures.
2. **Starting point**: highest level of factor which is used as a basis for deriving appropriate measures.
3. **Control/Improvement**: the measures used as control measures, improvement measures, or both.
4. **Prioritisation**: the process to assign the weight to each measure.
5. **Relate to strategy/objectives**: whether the model explicitly states that the measures must relate to strategy/objectives or not.
6. **Deployment**: the process of translating higher level measures to lower level measures.
7. **Levels of organisation**: whether or not the model identifies different levels of organisation such as business, business unit, business process and activities.
8. **Stated specific objective**: what the specific objectives of the model are.
9. **Review**: whether or not the model states that the measures should be reviewed periodically.
10. **External monitor**: whether or not the model considers external monitor.
11. **Timely feedback**: whether or not the model states the importance of timely feedback.
12. **Integration**: whether or not the model produces the integrated and coherent measures.
13. **Interaction**: whether or not the model recognises the interaction among factors affecting performance.

3.7.2.1 Performance Measurement for World Class Manufacturing

Maskell (1991) provided characteristics of performance measurement systems that were suited to world-class manufacturing. Even though he agreed that the performance measures used by world-class manufacturers would vary considerably, they have seven common characteristics as follows:

- they are directly related to the manufacturing strategy
- they primarily use non-financial measures
- they vary between locations
- they change over times as needs change
- they are simple and easy to use
- they provide fast feedback to operators and managers
- they are intended to foster improvement rather than just monitor

The characteristics of this model can be seen in Table 3.8.

Table 3.8. Characteristics of performance measurement for world-class manufacturing.

Model: Performance Measurement for World Class Manufacturing	
Framework	None
Starting point	None
Control/Improvement	Both
Prioritisation	None
Relate to strategy/objectives	Relate to manufacturing strategy
Deployment procedures	None
Levels of organisation	None
Stated objective	As stated in seven common characteristics
Review	Yes
External monitor	None
Timely feedback	Yes
Integration	No
Interaction	No

3.7.2.2 Performance Criteria System

Globerson (1985) proposed a framework for developing a performance criteria system through the following four stages:

1) Choosing the preferred set of performance criteria.
2) Measuring the chosen performance criteria.
3) Assigning standard to the performance criteria.
4) Designing a feedback loop to respond to discrepancies between standards and actual performance.

For choosing the preferred set of performance criteria he gave the following guidelines:

a) Performance criteria must be derived from the company's objective.
b) Performance criteria must make it possible to compare organisations which are in the same business.
c) The purpose of the performance criteria is clear.
d) Data collection and methods of calculating the performance criteria must be clearly defined.
e) Ratio performance criteria should be preferred on absolute numbers.
f) Performance criteria should be under the control of the evaluated organisational unit.
g) Performance criteria should be selected through discussion with the people involved (customers, employees, managers).
h) Objective performance criteria should be preferred to subjective performance criteria.
i) The value of the performance criteria must be the same, or insignificantly different, for the same performance.

Globerson (1985) provided three techniques which could be used for assigning weight to each performance criterion. The weights indicate the relative importance of performance criteria. He also provided the techniques for assigning targets for each performance criterion. Table 3.9 shows the characteristics of the performance criteria system.

Table 3.9. The characteristics of the performance criteria system.

Model: Performance Criteria System	
Frame work	Yes
Starting point	Performance criteria
Control/Improvement	Both
Prioritisation	Yes
Relate to strategy/objectives	Relate to objectives
Deployment procedures	None
Levels of organisation	None
Stated objective	As stated in the guidelines
Review	Yes
External monitor	Yes
Timely feedback	Yes
Integration	No
Interaction	No

3.7.2.3 SMART System

The SMART (Strategic Measurement Analysis and Reporting Technique) System was developed at Wang Laboratory, Inc., Lowell, Massachusetts [Cross and Lynch, 1988-1989]. Following their success in implementing a Just-In-Time approach additional effort was sought to try and define a framework for:

- Measuring departments and functions to ascertain if they were contributing separately and/or together in meeting manufacturing's strategic mission.
- Linking operations to strategic goals.
- Integrating financial and non-financial information in a way that could be used by operating managers.

- Focusing all business activities on the future requirements of the business, as dictated by customers.
- Changing performance, incentive and reward systems as necessary.

The result of the effort was the SMART system. Figure 3.11 shows the framework of the SMART system [Dixon et al, 1990].

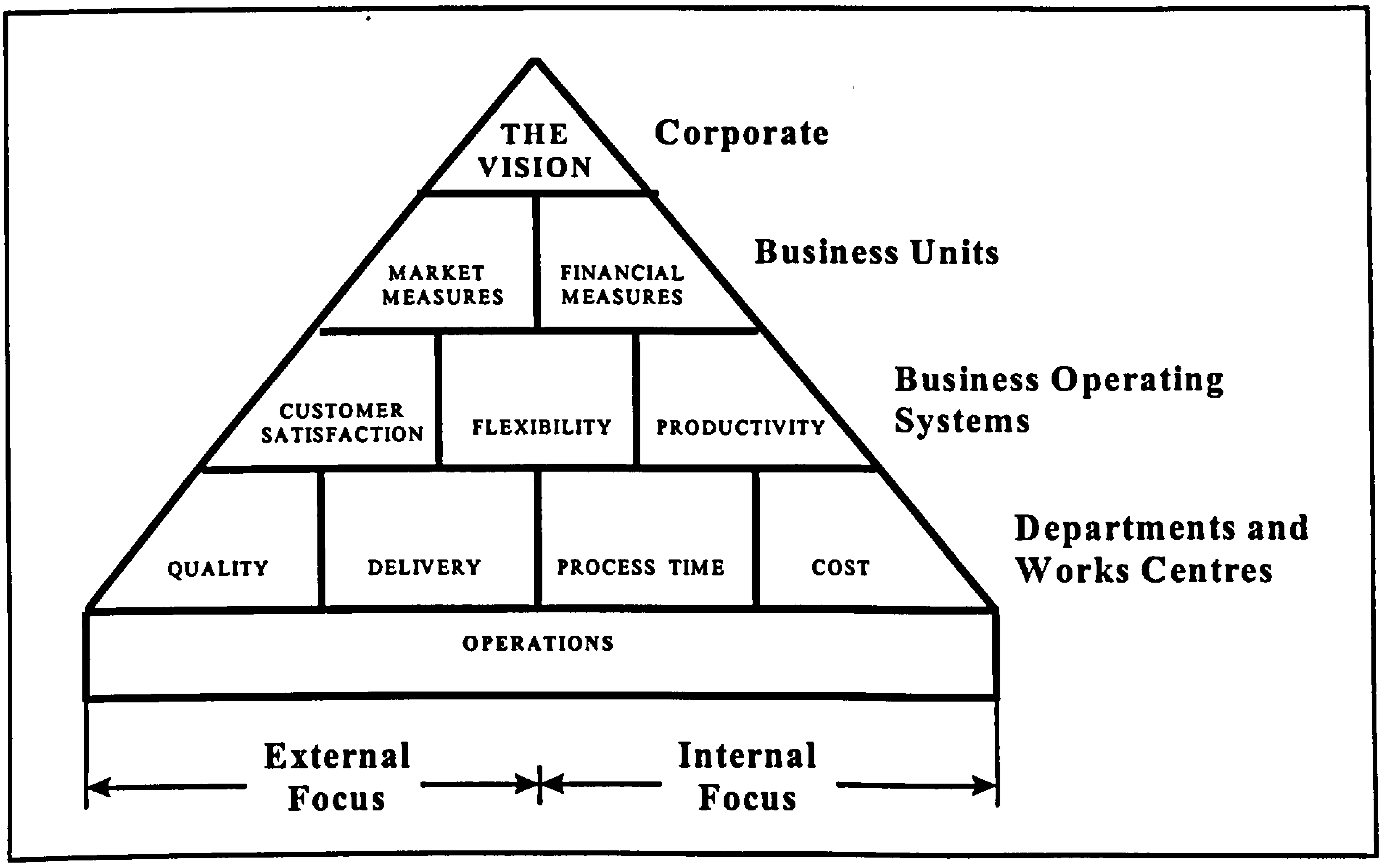


Figure 3.11. The framework of the SMART system [Dixon, et al, 1990].

At the top level the business vision forms the basis for corporate strategy. Management then can assign a corporate portfolio role to each business such as cash flow, growth and innovation. The resources are allocated to support the roles. However, it is not clear how management assign roles and allocate resources to each business unit.

At the second level, objectives for each business unit are defined in market and financial terms. Strategies to meet these objectives are then outlined. Most business units define their success in terms of:

1) Reaching the short-term goals of specified levels of positive cash flow and profitability.

2) Achieving long-term goals of growth and market penetration.

At the third level, for each Business Operating System (BOS) supporting business strategy, more tangible operating objectives and priorities can be defined in terms of 'customer satisfaction', 'flexibility' and 'productivity'. The SMART system recognises the existence of Business Operating Systems such as 'filling customer orders', 'new product introduction', 'change control' and 'sales administration'.

At the lowest level, the objectives of any function or department in the Business Operating Systems are to increase 'quality', 'delivery' and reduce 'process time' and 'cost'. The characteristics of SMART system model are indicated in Table 3.10.

Table 3.10. The characteristics of the SMART system.

Model: SMART System	
Frame work	Yes
Starting point	Corporate vision and strategy
Control/Improvement	Both
Prioritisation	Yes
Relate to strategy/objectives	Yes
Deployment procedures	Yes
Levels of organisation	Yes
Stated specific objective	Continually self-adjusted to the future needs of the business
Review	Yes
External monitor	Partly
Timely feedback	No
Integration	Yes
Interaction	No

3.7.2.4 Performance Measurement Questionnaires

In 1980s manufacturing environment underwent fundamental changes. These changes affected three interconnected areas - strategy, actions and measures. Dixon et al (1990) argued that in the current context, strategy, actions and measures are interconnected. Actions are required to support strategy. Traditionally, strategy is always assumed to come first and then the required actions. Dixon et al (1990) considered that actions also lead to changes in strategy. Actions of improvement programme place a business in a better position to gain new competitive advantage and then strategy can be changed to optimally exploit this new competitive advantage. Finally, measures must support the strategy and actions. Different strategy needs different actions, which in turn need different measures. The results of actions will be reflected in performance measurement data and these may lead to changes in strategy. The interconnected relations between strategy, actions and measures are indicated by Figure 3.12.

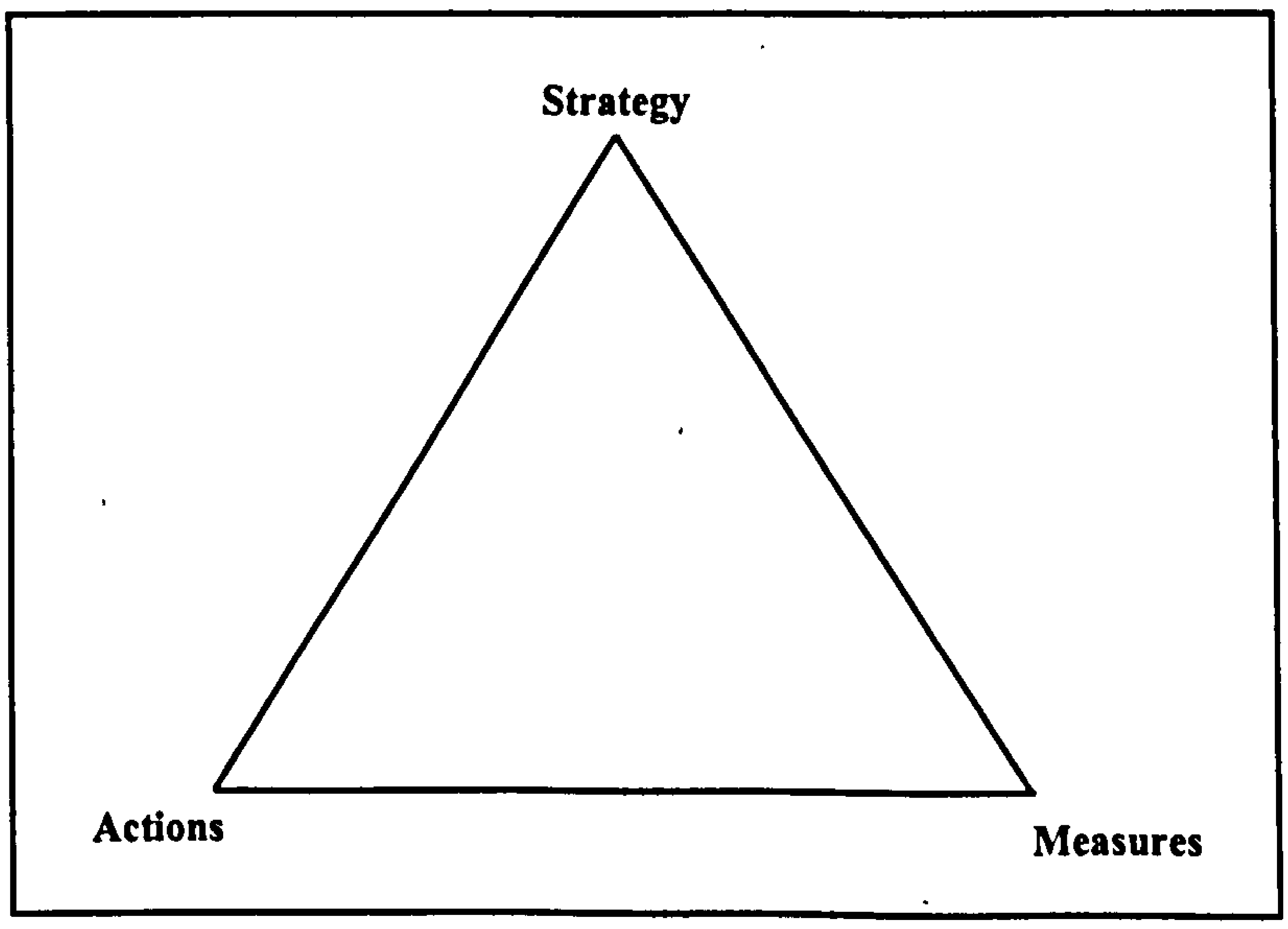


Figure 3.12. The interconnection of strategy, actions and measures [Dixon et al, 1990].

Dixon et al (1990) developed four sets of questionnaires which could be used to design performance measurement systems. The questionnaires were constructed based on the strategy, actions and measures interconnection concepts. The objective(s) of each questionnaire is indicated in Table 3.11.

Table 3.11. The objective(s) of each questionnaire [Dixon et al, 1999].

Questionnaire	Objective(s)
Questionnaire I	To gather data on: • management level and manufacturing affiliation of the respondents in order to examine the degree of consensus among managerial levels and functional areas.
Questionnaire II	To gather data on: • the relative degree of the importance of improvement area. • to what extent current performance measures support or inhibit the improvement in that area. The model provides 24 items of generic improvement areas.
Questionnaires III	To gather data on: • the degree of importance of achieving excellence in performance factors or measures for the long running survival of the company, • the company's current emphasis on performance measures.
Questionnaires IV	To gather data on: • the most important measures against which respondents' individual performance should be judged.

The data collected through the questionnaires is then interpreted using the following analysis:

- **Alignment analysis** : to identify the extent to which a company's strategy, actions and measures line up with each other.

- **Congruence analysis:** to provide a detailed look at how well the measurement system supports an organisation's actions and strategy through gap and false alarm signals.

- **Consensus analysis** : to contrast the perceptions between hierarchical levels and across functional organisations on the importance of improvement areas and performance measures (ranking the means).

- **Confusion analysis** : to determine the relative extent of consensus of opinion on each improvement area and performance factor item within a group (ranking the standard deviations).

The characteristics of the model are indicated by Table 3.12.

Table 3.12. The characteristics of the Performance Measurement Questionnaires.

Model: Performance Measurement Questionnaires	
Frame work	Yes
Starting point	Improvement areas
Control/Improvement	Both
Prioritisation	Yes
Relate to strategy/objectives	Yes
Deployment procedures	No
Levels of organisation	Partly
Stated specific objective	Linking strategy, actions and measures
Review	Yes
External monitor	No
Timely feedback	No
Integration	Yes
Interaction	No

3.7.2.5 Balanced Scorecard

The Balanced Scorecard was developed at Harvard Business School by Robert S Kaplan and David P Norton [Kaplan and Norton, 1996]. Nowadays the Balanced Scorecard is the most popular model of a new performance measurement system [Neely et al, 1995]. The structure of the Balanced Scorecard is given in Figure 3.13.

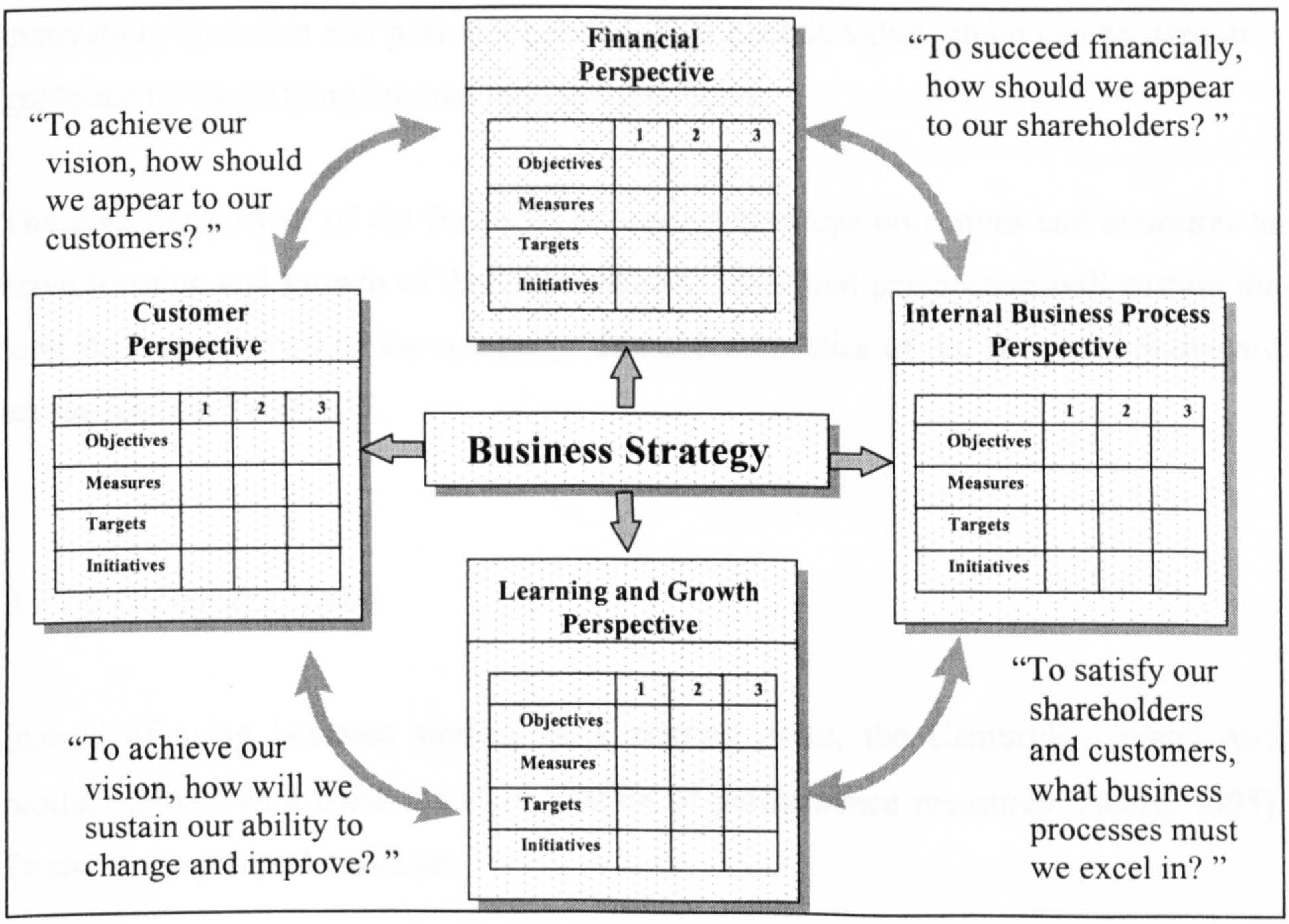


Figure 3.13. The framework of Balanced Scorecard [Kaplan and Norton, 1996].

In the Balanced Scorecard performance measures identification is started from vision and business strategy, similar to the SMART model. Business strategy is translated into four objectives and measures perspectives: financial, customers, internal business process and learning and growth. The financial objectives serve as a focus for the objectives and measures in all the other scorecard perspectives. Every measure selected should be part of a link of a cause-and-effect relationship that culminates in improving financial performance.

The financial objectives are translated into customer objectives. In this perspective, the company identifies the customer and market segments in which it has chosen to compete. The generic measures of customer perspective are customer satisfaction, customer acquisition, customer retention, market share and customer profitability. In the internal business process perspective, managers identify the most critical process for achieving customer and financial objectives. Kaplan and Norton (1996) provided the generic value-chain model which consists of three principal business processes: innovation, operation and post-sale service. This generic value- chain can be used as a guideline for identifying internal business processes.

The final perspective of the Balanced Scorecard develops objectives and measures to drive learning and growth of the organisations. This final perspective will sustain the long running survival of the company. The characteristics of the Balanced Scorecard are depicted in Table 3.13.

3.7.2.6 Cambridge Model

Instead of using business strategy as a starting point, the Cambridge model uses product groups as a basis for identification of performance measures [Neely, 1995]. Products are grouped based on:

- sales as a percentage of total sales,
- contribution as a percentage of total contribution,
- market share, ranking/number of competitor,
- sales growth,
- market growth/life cycle stage.

Table 3.13. The characteristics of Balanced Scorecard.

Model: Balanced Scorecard	
Framework	Yes
Starting point	Business strategy
Control/Improvement	Learning
Prioritisation	Partly
Relate to strategy/objectives	Yes
Deployment procedures	Partly
Levels of organisation	Partly
Stated specific objective	Balanced Scorecard is a communication, informing and learning system; Balanced Scorecard is also used as a management technique for implementing business strategy
Review	Yes
External monitor	No
Timely feedback	Yes
Integration	Yes
Interaction	No

The business objectives of each product group are agreed and their related performance measures and key activities are then identified. The structure of the model is depicted in Figure 3.14.

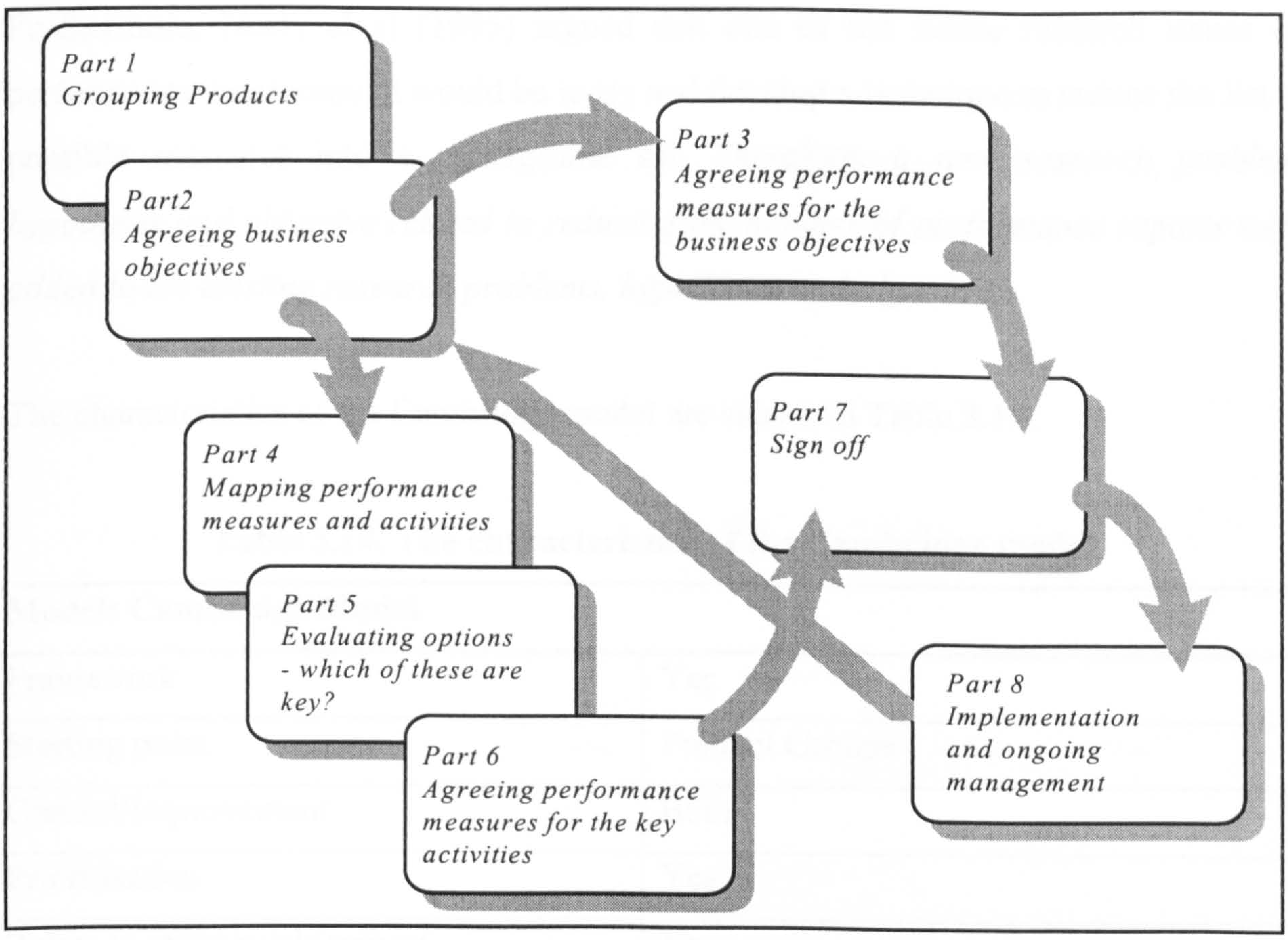
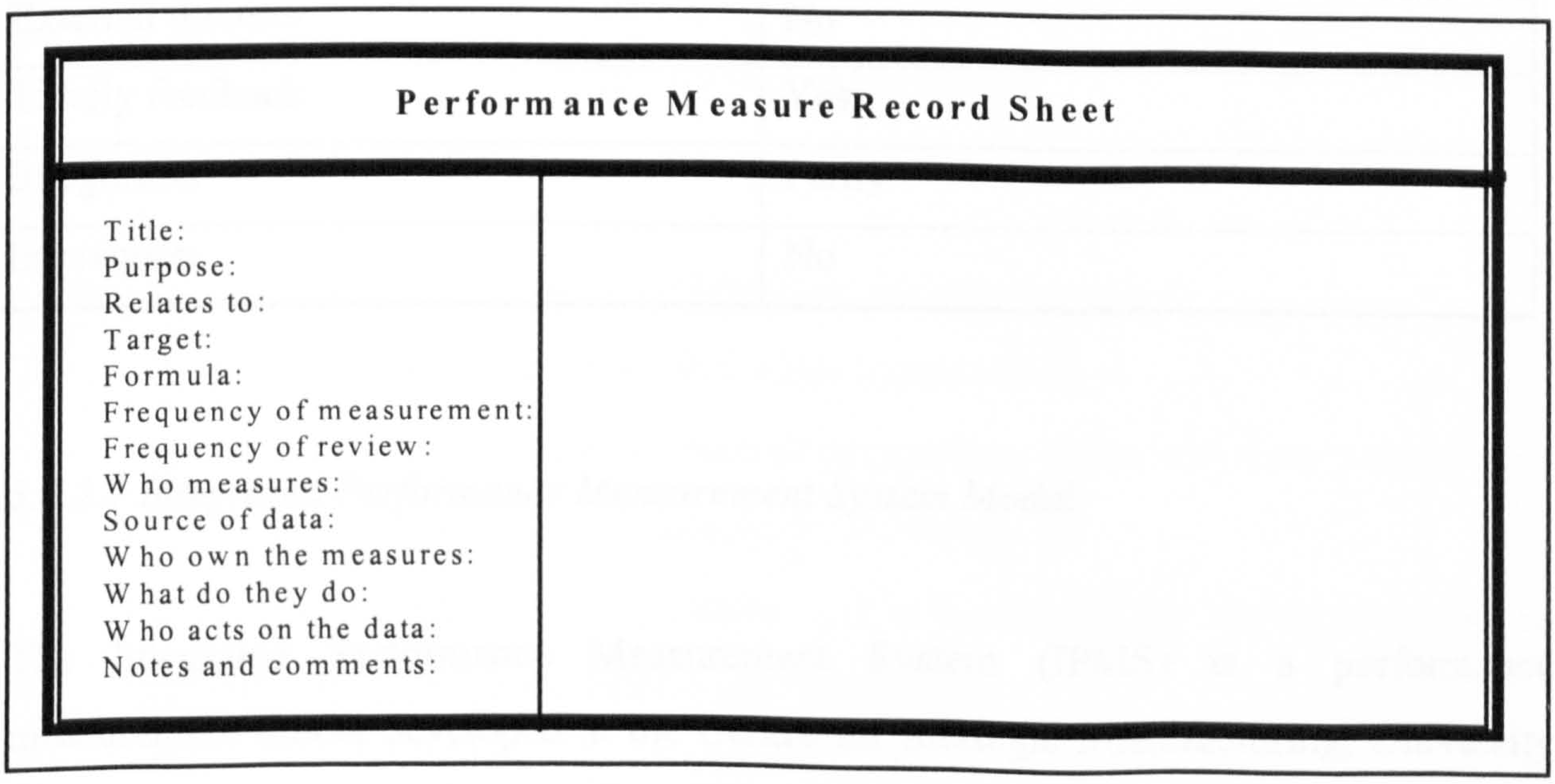


Figure 3.14. Cambridge model of performance measurement system [Neely, 1995].

For each performance measure used, the model provides a performance measure record sheet to describe the measure as depicted in Figure 3.15 [Neely et al, 1997].



Performance Measure Record Sheet

Title:
Purpose:
Relates to:
Target:
Formula:
Frequency of measurement:
Frequency of review:
Who measures:
Source of data:
Who own the measures:
What do they do:
Who acts on the data:
Notes and comments:

Figure 3.15. Performance measure record sheet [Neely et al, 1997].

Furthermore, Neely et al (1995) argued that one of the future research issues on performance measurement would be to try and develop a technique to reduce the list of possible measures into a manageable set. Therefore, *a new research problem, hypothesis and objective related to reducing the number of performance reports were added to the existing research problems, hypotheses and objectives.*

The characteristics of the Cambridge model are shown in Table 3.14.

Table 3.14. The characteristics of the Cambridge model.

Model: Cambridge Model	
Framework	Yes
Starting point	Product Groups
Control/Improvement	Both
Prioritisation	Yes
Relate to strategy/objectives	Yes
Deployment procedures	No
Levels of organisation	No
Stated specific objective	Integrates, closes management loop, considers behavioural implications
Review	Yes
External monitor	No
Timely feedback	Yes
Integration	Partly
Interaction	No

3.7.2.7 Integrated Performance Measurement System Model

The Integrated Performance Measurement System (IPMS) is a performance measurement model developed at the Centre for Strategic Manufacturing, University of Strathclyde. The model describes the structure and constituent parts of a robust, integrated, efficient and effective performance measurement system. It also contains an audit methodology to assess the robustness and integrity of performance measurement systems used within manufacturing industries. The IPMS was constructed based on past and present academic work and industry best practices [Bititci et al, 1996; Bititci et al, 1997]. The structure of the model is shown in Figure 3.16.

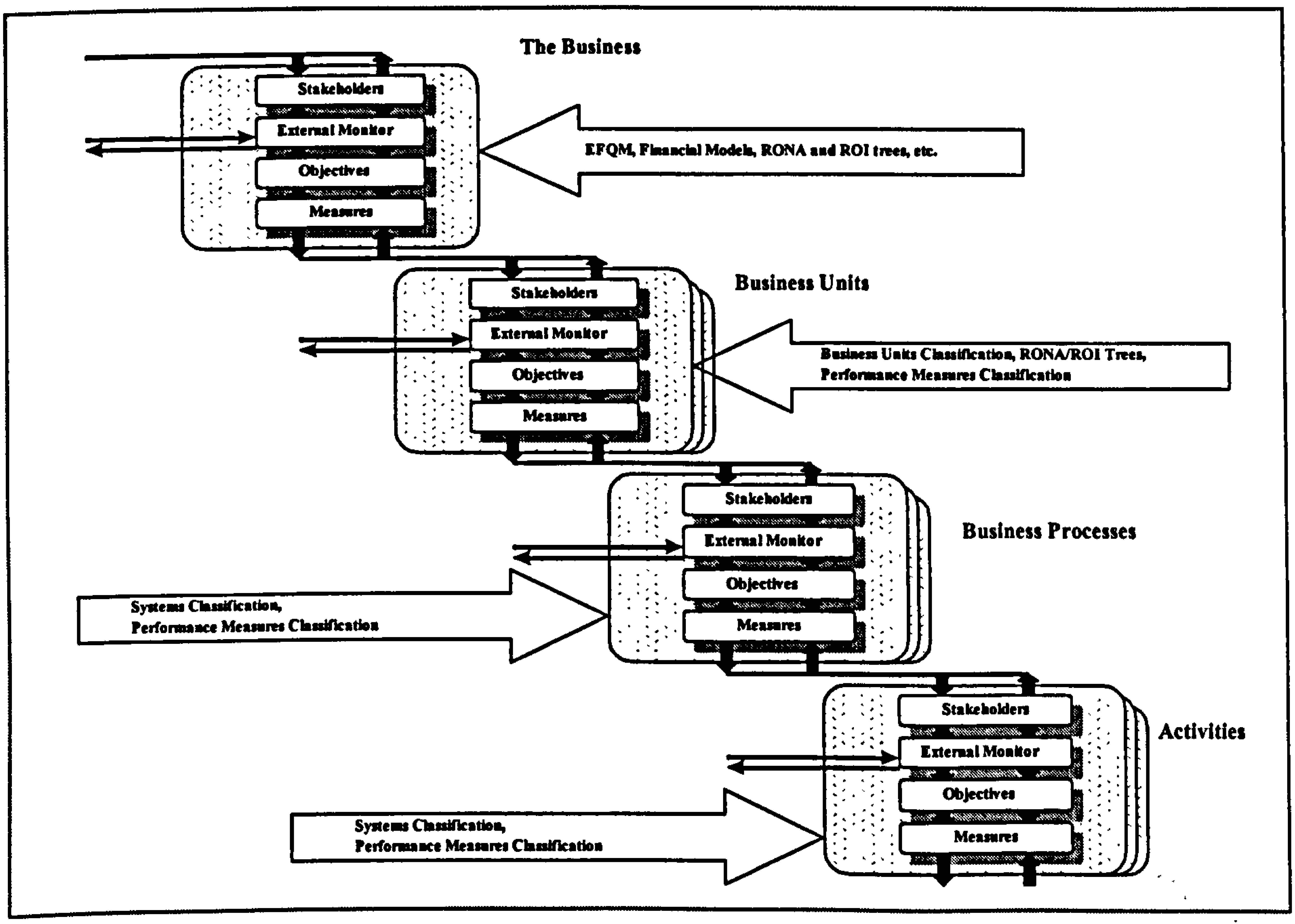


Figure 3.16. The structure of the Integrated Performance Measurement System model [Bititci et al, 1996].

At each level of the business the model requires the organisation to:

- recognise and understand its stakeholder requirements,
- externally monitor its position against competitors and world class performance to identify the development needs of the business,
- set objectives based on implications and criticality of the development needs together with appropriate targets and time scales,

- define, report, monitor and review these objectives through a performance measures report.

The characteristics of the IPMS model are given in Table 3.15.

Table 3.15. The characteristics of the Integrated Performance Measurement System model.

Model: Integrated Performance Measurement System	
Framework	Yes
Starting point	Stakeholder requirements and external monitors
Control/Improvement	Both
Prioritisation	Yes
Relate to strategy/objectives	Relates to objectives
Deployment procedures	Yes
Levels of organisation	Yes
Stated specific objective	• Align critical tasks and activities with top-level objectives • Facilitate control • Drives improvement • Maximise improvement
Review	Yes
External monitor	Yes
Timely feedback	Not explicitly stated
Integration	Yes
Interaction	Yes

3.8 Discussion and Conclusions

Many models of performance measurement systems have been developed so far. Some models deal with a specific area of performance such as cost, quality, delivery or flexibility; other models propose an integrated system. From the extensive literature review presented in this chapter it is clear that none of the performance measurement system models developed so far mention the need to identify the relationship between factors affecting performance, except the Integrated Performance Measurement System. Even though some models mention prioritisation of performance measures, none has used such a technique with a sound theoretical background and simple enough to be implemented on a daily basis.

It was also found from literature review that:

- ✓ One of the future problems of performance measurement is reducing the number of performance reports [Neely et al, 1995].
- ✓ Business environment is becoming more dynamic [D'Aveni and Gunther, 1995], therefore it is important to examine the stability of the model developed over a period of time.

Based on these findings the issues of reducing the number of performance reports and the stability of the model is added to the tentative research problems, hypotheses and objectives. The modified research problems, hypotheses and objectives are as follows:

Modified research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between the factors affecting performance.
3. Quantifying the effects of the factors on performance.
4. Reducing the number of performance reports.

Modified research hypotheses:

1. A quantitative method for a performance measurement system can be developed. The method can be used for:

✓ identifying factors affecting performance and their relationship,

✓ quantifying the effect of the factors on performance.

2. The method is valid and can be applied to real cases.
3. The method developed can help managers to reduce the number of performance reports.
4. The method is stable for a reasonable period of time.

Modified research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship and quantify the effect of the factors on performance.
2. To carry out experiments for testing the validity, applicability and stability of the method developed.
3. To develop a method for reducing the number of performance reports.

Some researchers have not only developed models of new performance measurement systems, but have also provided recommendations of on what a good performance measurement system or performance measure should look like. Neely et al (1997) provided 22 recommendations for designing performance measures, while Bititci et al (1996) provided 16 requirements for designing performance measurement systems. The latter covered broader aspects of performance measurement systems and it would appear that they are therefore more suitable for designing performance measurement systems than the former.

The objectives of this research are in keeping with the requirements of the Integrated Performance Measurement System in that a performance measurement system should focus on critical areas and promote an understanding of the relationship between various measures. To achieve these objectives a performance measurement system method, which can be used to identify factors affecting performance, quantify the effect of factors on performance (including the interaction effects) and consolidate them into a single performance indicator, will be developed.

3.9 Summary

The changes in the manufacturing environment which cause the traditional, financial-based performance measurement systems to become less relevant to the new dynamic environment have been described in this chapter. In order to understand more fully the problems of traditional performance measurement systems, the historical development of performance measurement systems was reviewed. Next, the development of new performance measurement systems was presented which included the development of individual new performance measurement systems and integrated performance measurement systems. The individual new performance measurement systems consist of Activity-Based Costing and new performance measurement systems relating to quality, time and flexibility. The integrated performance measurement system consist of the Performance Measurement System for World Class Manufacturing, the Performance Criteria System, the SMART System, the Performance Measurement Questionnaires, the Balanced Scorecard, the Cambridge Model and the Integrated Performance Measurement System. To compare and contrast the models, a framework consisting of 13 attributes was used to identify the characteristics of each model.

This chapter concludes that even though many performance measurement systems have been developed to deal with the new dynamic environment, none provides a sound technique for identifying relationships between factors affecting performance and quantifying the effects of factors on performance. These gaps will be addressed in this work by developing quantitative methods for performance measurement systems.

The following chapter discusses the selection of the tools for identifying factors affecting performance and their relationship, structuring the factors hierarchically and quantifying the effects of the factors on performance.

Chapter 4

SELECTION OF THE TOOLS FOR IDENTIFYING, STRUCTURING AND PRIORITISING PERFORMANCE MEASURES

4.1 Introduction

Performance measurement involves a large number of factors or measures. One of the collaborator organisations involved in this research, which will be discussed later in Chapter 6 on Case Studies, employs 130 measures for measuring the overall performance of its office. The effects of factors on performance are not always equal; some factors have greater effects on performance than others. For the purposes of resource allocation and monitoring, each factor must be treated differently. Resources should be primarily allocated to factors which have the greatest effects on performance and critical factors should be monitored more frequently than minor factors. Therefore, a procedure for structuring and prioritising the effects of factors on performance is required.

This chapter firstly will present the selection of the tool for identification factors affecting performance and their relationship. Secondly, the selection of the tool can be used to structure the factors affecting performance hierarchically will be discussed. Finally, this chapter will present the selection of the tool for prioritising performance measures.

4.2 Requirements Specifications

The external environment of a manufacturing system is becoming more complex, so does its internal environment. Customers demand better quality, faster delivery times, more reliable customer service, a wider range of products and more rapid new product development. These demands require a better approach to the whole operations of an enterprise, from the identification of customers' requirement to product development, manufacturing processes, distribution and customer services. Integration between business functions is becoming more important and therefore understanding the interactions between factors affecting performance needs to be addressed.

Another important issue in performance measurement systems is quantifying the effect of factors on performance [Rangone, 1996]. Even although there are some techniques already available which can be used to quantify and prioritise the effect of factors on performance as has been discussed in the Chapter 3, [Globerson, 1985; Rangone, 1996; Swamidass and Newell, 1987], none can be considered as satisfactory in terms of theoretical and applicability reasons. A new method which can be used to quantify the effects of factors on performance, including the interaction effects, is therefore required.

To be able to fulfil this requirement, the researcher thought that the new method should have the following characteristics:

1. *It can identify and quantify the effects of factors on performance*

   The method should be able to identify the major factors affecting performance and generate numbers which reflect the effects of factors on performance.

2. *It facilitates the aggregation or consolidation of the effects of factors on performance*

   The factors affecting performance are multi-dimensional. Unless the aggregation of the effects of factors on performance can be performed, the overall performance of the business cannot be measured.

3. *It accommodates the direct as well as the interaction effects*

   The method should be able to quantify the direct and the interaction effects of factors on performance.

4. *It is simple*

   Since the method is intended for managers, not all of whom are familiar or comfortable with mathematical methods, the application concept of the method should be easy to understand. A method which requires complicated mathematical analysis should be avoided.

5. *It is accurate*

   Many important decisions such as performance evaluation, performance improvement and resources allocation will be made based on the information provided by the method. As the method should be able to provide accurate information on the effects of factors on performance, it must be theoretically justified.

6. *It is easily implemented*

   The method, which may be used frequently to identify the effects of a large number of factors on performance, must be easy to be implemented. The implementation of the method should not require excessive efforts, resources and time.

These characteristics will be used as criteria for the selection of the tools used in the research.

4.3 The Selection of a Tool for Identifying Factors Affecting Performance and Their Relationship

As mentioned earlier, performance measurement usually involves a number of factors and personnel from different departments. The factors to be measured are often not well defined at the start and uncovering what the real factors to be measured are and their relationship is not always an easy task. Eden et al (1983) pointed out that in organisational life the individual is an irrational and subjective person. He or she is involved in complicated social relationships and internal (organisational) political games. Therefore, different individuals will interpret a particular situation differently depending on their mental framework and political concerns. The followings are the tools can be used to identify factors affecting performance and their interaction often cited in literature.

4.3.1 Repertory Grids

In the 1930s Kelly developed the personal construct theory [Kelly, 1955]. A central notion of this theory is that all women and men are scientists. Each of us actively, based on experiences, develops hypotheses, tests them, modifies them or discards them. As a result, each of us has our own personal ideas, philosophies and theories about the world [Beail, 1985; Fransella and Bannister, 1977]. In other words, people have different constructs about the world. Kelly defined construct as "*a way in which two or more things are alike and thereby different from a third or more things* " [Kelly, 1955].

Repertory grid is part of the personal construct theory, and is the method for exploring the personal construct system. When administer a repertory grid we are basically saying to the subject "*Construe me these elements*" or "*How do you see these things*" [Beail, 1985]. Stewart et al (1981) pointed out that we could learn repertory grid without bothering too much with the personal construct theory. However, when constructing a repertory grid, it is important to remember the key points of the personal construct theory. These are:

- ✓ Perceptions influence expectations and expectations influence perceptions.
- ✓ The medium through which this happens is known as the construct system.
- ✓ Construct systems are unique to the individual and develop through life.

The administration of a repertory grid can be carried out in the five stages as follows [Beail, 1985]:

1. Eliciting elements.

   Elements are the domain in which construing is to be investigated. People, occupations, radio programmes, cars and methods all can be chosen as the elements of a repertory grid. The elements of a repertory grid can be supplied by the investigator or by providing a description of the situation to the subject of the study.

2. Eliciting constructs.

   Triadic method is usually used to elicit the construct. Triads of elements are presented to the subject of the study. For each triad of elements a question is asked to the subject *"In what important way are two alike and thereby different from the third?"* and then *"In what way does the third element differ from the other two?"* The questions are repeated for different triads of elements until enough information is collected.

3. Completing the grid.

   A table is drawn and the elements are listed at the top of the columns. For each construct of a triad a rating score of 1 to 7 is assigned to each element. An example of a repertory grid is indicated in Figure 4.1.

4. Analysis.

   Analysis is carried out to clarify the information contained in the grid and to identify the similarity, association, pattern or structure of the constructs. A number of computer programs are available on the market for analysing the grid, for example FLEXIGRID/MULTIGRID computer program.

5. Interpretation.

   Based on the results of the analysis the grid can be used to reveal the patterns of relationships between elements of the grid.

Kelly developed repertory grid in the 1930s for applications in clinical settings. However, repertory grids are now used widely in business [Stewart et al, 1981; Senior, 1997].

	1	Training centre	Psychiatric ward	Social Service	Prison	Halfway house	Hospital	Workshop	Parents' home	Parents' home (Past)	7
1	Boring	3	5	2	6	4	3	6	5	4	Not boring
2	Did not enjoy	6	7	4	5	6	3	5	6	6	Enjoyed
3	Felt upset	3	6	5	5	4	2	5	4	5	Did not feel upset
4	Nobody bothered with me	6	5	6	4	4	3	4	5	4	People cared
5	Learnt nothing	4	4	4	3	3	5	3	6	3	Learnt from experience
6	Did not like	6	5	3	6	4	4	5	4	5	Liked
7	Did not help me feel clear	3	6	7	7	6	6	6	3	6	Helped me feel clear
8	Felt confused	2	3	3	5	7	5	5	5	4	Not confused
9	Felt annoyed/mad	5	7	4	4	5	5	4	6	5	Did not feel annoy/mad

Figure 4.1. An example of a repertory grid [Adapted from Beail, 1985]

4.3.2 Mind Map

Mind map was originated by Tony Buzan [Buzan, 1974]. Buzan (1993) argued that a range of skills is available at either the right or left side of the cerebral cortex of the human brain. These skills include language (words, symbols), number, logic (sequence, listing, linearity, analysis, time, association), rhythm, colour, imagery (daydreaming, visualisation), and spatial awareness (dimension, gestalt). The standard practice of note-making/taking does not utilise fully the skill available in the human brain. They mainly use only linear patterning, letters, words, numbers and analysis. Buzan proposed radiant thinking as a new way of thinking which would enable us to utilise fully the skills available in the human brain. He defined radiant thinking as *"associate thought processes that proceed from or connect to a central points"* [Buzan, 1993].

Mind map is a tool for practising radiant thinking. Buzan (1993) defined mind map as *"a powerful graphic technique which provides a universal key to unlocking the potential of the brain"*. Mind map has the following characteristics [Buzan, 1993]:

1. The subject of investigation is represented as a central image.
2. The main themes of the subject radiate from the central image as branches.
3. Branches comprise a key image or key word printed on an associated line.
4. Topics of lesser importance are represented as branches attached to higher level branches.
5. The branches form a connected nodal structure.

Buzan (1993) also provided the following laws for constructing a mind map:

1. Use emphasis.
   - ✓ Always use a central image.
   - ✓ Use images throughout your mind map.
   - ✓ Use three or more colours per central image.
   - ✓ Use dimension in images and around words.
   - ✓ Use synaesthesia (the blending of the physical senses).
   - ✓ Use variations of size of printing, line and image.

✓ Use organised spacing.

✓ Use appropriate spacing.

2. Use association.

✓Use arrows when you want to make connections within and across the branch patterns.

✓Use colours.

✓Use codes.

3. Be clear.

✓Use only one key word per line.

✓Print all words.

✓Print key words on lines.

✓Make line length equal to word length.

✓Make major branches connect to central image.

✓Connect line to other lines.

✓Make the central lines thicker.

✓Make your boundaries 'embrace' your branch outline.

✓Make your images as clear as possible.

✓Keep your paper placed horizontally in front of you.

✓Keep your printing as upright as possible.

4. Develop a personal style.

✓Every map you make should be slightly more colourful, slightly more three-dimensional, slightly more imaginative, and slightly more associatively logical.

5. Develop a good layout.

✓Use hierarchy.

✓Use numerical order.

Figure 4.2 shows an example of a mind map.

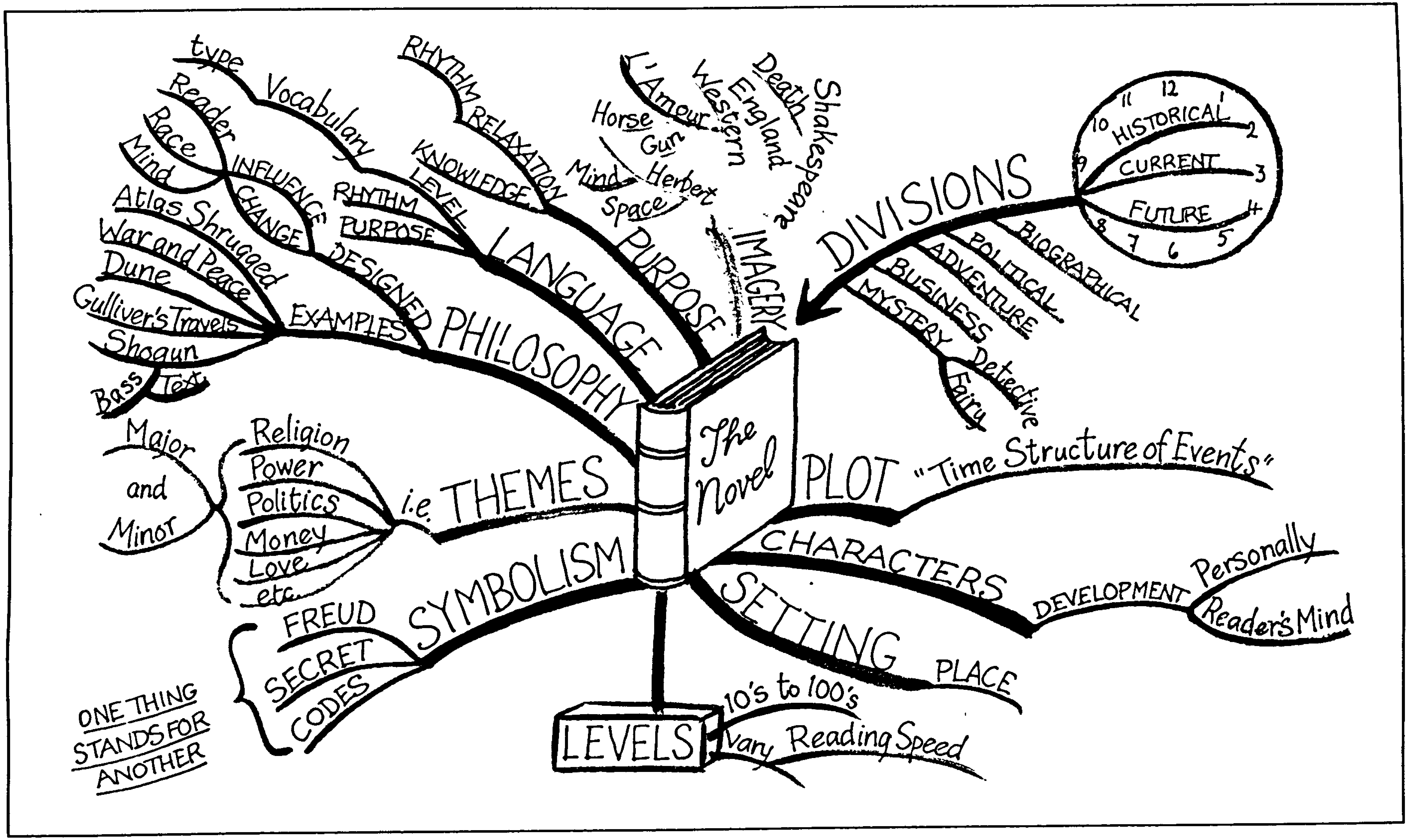


Figure 4.2. An example of a mind map [Buzan, 1993].

4.3.3 Focus Group

Focus group is a qualitative research method of obtaining possible ideas or solutions on a particular topic from a group of respondents (typically about 8 to 12) by discussing it in informal fashion in the presence of a well-trained, objective moderator [Dillon et al, 1993]. Focus group is the most widely used research method in marketing. In 1981, 95% of the largest consumer product companies in the United States used focus group as their marketing research method [Parasuraman, 1986].

There are four main steps in conducting a focus group [Greenbaum, 1998]:

1. Planning

   Planning is the most important step in conducting focus group. It should begin as soon as it has been decided that focus group research is to be conducted. The following are some important issues of focus group planning.

   Define research objectives: what the client wishes from the results of the focus group should be documented briefly.

   Select a moderator: a qualified moderator should be selected as soon as possible to help the client conducting a focus group session.

   Decide the detail execution: how many groups, where, when and how long the focus group will be conducted should be decided with the help of the moderator.

   Brief the moderator: provide the moderator with all the required information in order to develop an efficient moderator guide.

   Develop a screening questionnaire: the moderator should develop a questionnaire to screen participants based on the specification provided by the client.

   Develop a moderator guide: the moderator should develop an outline of the discussion.

2. Select a facility

   Physical plant, recruitment sources and costs are among the important aspects should be considered when selecting the facility of the focus group.

3. Discussion preparation

   Before discussion is started it is important to make sure that:

   ✓ the noise level is managed,

   ✓ food is provided for participants,

   ✓ Name cards are provided for participants,

   ✓ the rooms are set up properly, and

   ✓ the temperature is set properly.

4. Conducting discussion

   The moderator should be able to encourage all participants to discuss their feelings about discussion issues and the discussion should be carried in three parts:

   ✓ Warm-up discussion: the moderator should encourage the participants to discuss general issues

   ✓ Main discussion: the moderator should encourage the participants to discuss the main issues.

   ✓ Post-group discussion: the moderator should encourage the participants to express their overall feelings on the session to enable notes on any serious disagreement among the client and the participants to be taken by the moderator.

5. Analysis and reporting

   The report should capture the impressions and observations on each topic and interpret them in the light of the objectives of the discussion.

Dillon et al (1993) reported that focus group can provide the following benefits:

1. Management has an opportunity to listen to consumers' experiences of the company's products and services.

2. The results of the research will usually the available a week after the study has been carried out.
3. The cost of conducting focus group research is relatively inexpensive.
4. Focus group is flexible because it uses unstructured interviewing format.
5. Focus group allows a highly sensitive concept to be exposed to a limited, pre-selected group of individuals.

4.3.4. Cognitive Map

Eden et al (1983) developed cognitive maps to represent the problem as perceived by individuals or groups of peoples [Belton et al, 1997]. Cognitive mapping is a modelling technique which intends to portray ideas, beliefs, values and attitudes and their relationship one to another in a form which is amenable to study and analysis [Eden et al, 1983]. Cognitive mapping is developed based on Kelly's theory of *personal construct* [Kelly, 1955]. The three key assertions of the theory, which cognitive mapping is based on, are as follows [Eden, 1988]:

- Man makes sense of his world through contrast and similarity.
- Man seeks to explain his world - why it is as it is and what made it so.
- Man seeks to understand the significance of his world by organising concepts hierarchically so that some constructs are super-ordinate to others.

Ackermann et al (1990) provided 12 guidelines which can be used to construct a cognitive map. Even though the guidelines do not guarantee to produce the right map for a specific problem, they provide a powerful way of thinking about, representing and asking questions on an issue or problem.

Guideline 1

Separate the sentences into distinct phrases. These phrases are likely to be no more than about 10-12 words long.

Guideline 2

Build up the hierarchy. Get the structure of the model right, by placing the goals at the top of the map and supporting these first with strategic issue type concepts and further on with potential options.

Guideline 3

Watch out for goals as the discussion unfolds. These will end up at the 'top' of the map, the most super-ordinate concept. It can help to mark them as goals when writing them down.

Guideline 4

Watch out for potential strategic issues by noting those concepts that have some or all of the following characteristics: long-term implications, high cost, irreversible, need a portfolio of actions to make them happen, may require a change in culture. They often form a flat hierarchy themselves but will be linked to Goals (above) and Potential Options (below).

Guideline 5

Hold on to opposite poles for additional clarification. These may be added to the concept later on in the interview when they are mentioned. In some cases where the meaning is not immediately obvious, it is useful to ask the problem owner for the opposite pole. Try putting the word 'not' in front of the proffered pole, doing so often suggests the more likely psychological contrast implied by the problem owner.

Guideline 6

Add meaning to concepts by placing the concepts in the imperative form and where possible including actors and actions. Through this action perspective the model becomes more dynamic.

Guideline 7

Retain ownership by not abbreviating but rather keeping the words and phrases used by the problem owner. In addition identify the name of the actor(s) who the problem owner states and incorporate them into the concept text.

Guideline 8

Identify the option and outcome within each pair of concepts. This provides the direction of the arrow linking concepts. Alternatively think of the concepts as a 'means' leading to a 'desired end'. Note that each concept therefore can be seen as an option leading to the super-ordinate concept which in turn is the desired outcome of the sub-ordinate concept.

Guideline 9

Ensure that a generic concept is super-ordinate to the specific items that contribute to it. This follows Guideline 8 and helps increase the accuracy of the map's hierarchy. Generic concepts are those for which there may be more than one specific means of achieving it (generic concept).

Guideline 10

It is generally helpful to code the first pole as that which the problem owner sees as the primary idea (usually this is the idea first stated). This means that links may be negative even though it would be possible to transpose the two poles in order to keep link positive.

Guideline 11

Tidying up can provide a better more complete understanding to the problem. But ensure that you ask why isolated concepts are not linked in, often their isolation is an important clue to the problem owner's thinking about the issues involved.

Guideline 12

Practical tips for mappers. Start mapping about two thirds of the way up the paper in the middle and try to keep concepts in small rectangles of text rather than as continuous lines of text. If it is possible ensure the entire map is on one A4 sheet of paper so that it is easy to cross link things (30-40 concepts can usually be fitted onto a page). Thus pencils are usually best for mapping and soft, fairly fine (e.g. 5mm) propelling pencils are ideal.

A cognitive map can be constructed based on interview or documents [Ackermann et al, 1990]. Figure 4.3 shows an example of a cognitive map which is constructed based on an interview transcript [Ackermann et al, 1990].

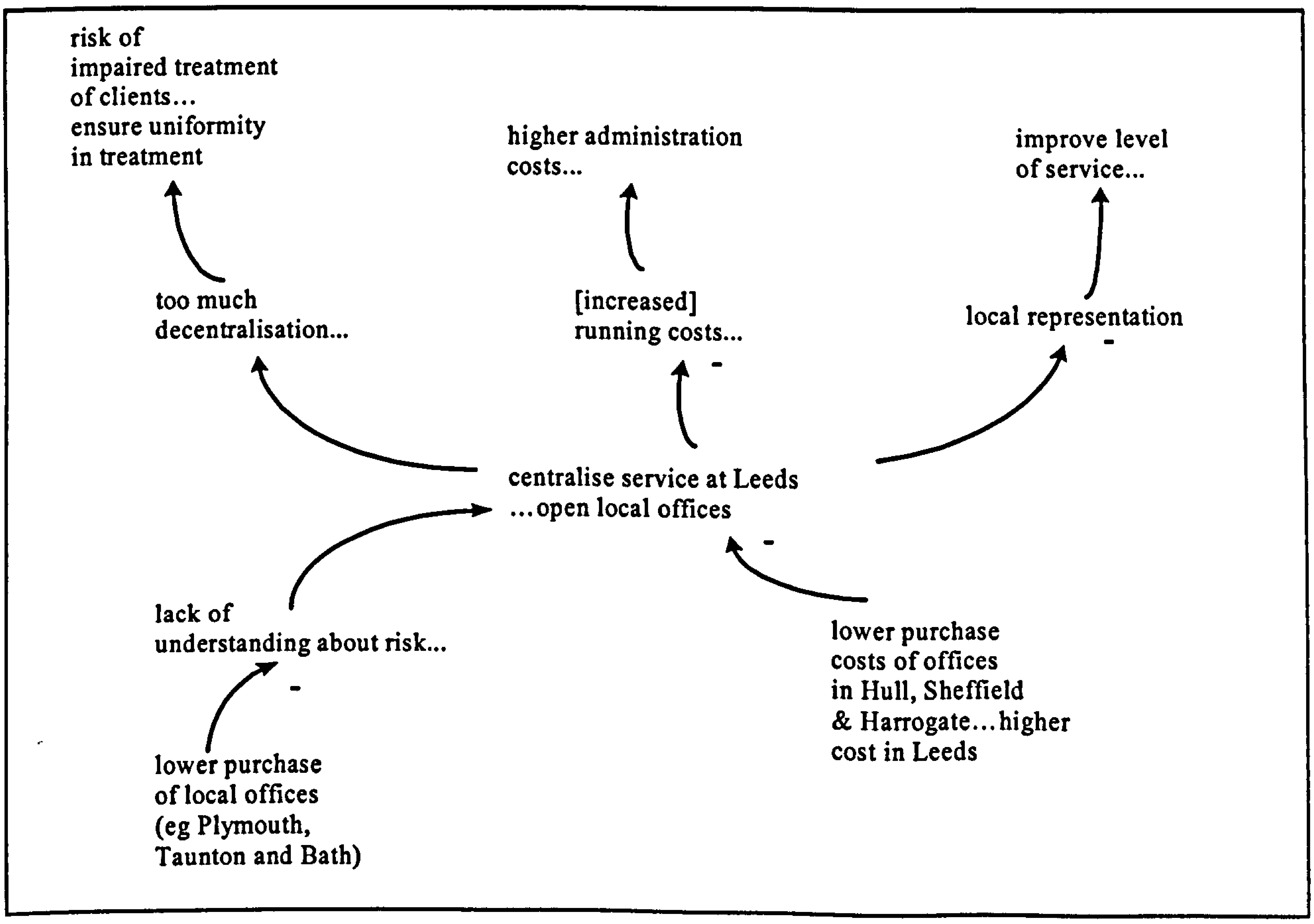


Figure 4.3. An example of a cognitive map [Ackermann et al, 1990].

To select a tool used in this research for identifying factors affecting performance and their relationship, Table 4.1 was constructed.

Table 4.1. The characteristics of tools for identifying factors affecting performance and their relationship.

	Criteria of selection					
	Facilitate the identification quantification of the effect of factor on performance	Facilitates the consolidation of performance measures	Accommodates interaction effect	Simple	Accurate	Easily implemented
Repertory grid	* * *	* *	*	* * *	* *	* * *
Mind map	* * *	* *	* *	* * *	* *	* * *
Focus group	* * *	* *	* *	* * *	* * *	* * *
Cognitive map	* * *	* *	* * *	* * *	* * *	* * *

Legend:

- \- does not fulfil the criteria of selection
- * weakly fulfils the criteria of selection
- * * fulfils the criteria of selection
- * * * strongly fulfils the criteria of selection

The table shows the characteristics of the four tools (repertory grids, mind map, focus group and cognitive map) which can be used to identify factors affecting performance. All four can accommodate the consolidation of performance measures into a single performance indicator. All of them are also relatively simple and easily implemented.

In term of accuracy, focus group and cognitive map are more accurate than repertory grid and mind map since both focus group and cognitive map are more easily used in group settings than that of repertory grid and mind map. However, compared to the other three tools, cognitive map is the best tool for representing the interaction of factors affecting performance. Based on those considerations, cognitive map has been selected to be used in this research.

4.4 The Selection of a Tool for Structuring Factors Affecting Performance Hierarchically

Performance measurement usually involves a number of factors affecting performance. To simplify the analysis, it is important to organise the factors hierarchically. The following are the tools can be used to structure the factors hierarchically:

4.4.1 Cause and Effect Diagram

Cause and effect diagram, which is also often called Ishikawa diagram or fishbone diagram, is a method widely-used in quality control to identify the causes of quality problems or characteristics. Cause and effect diagram consists of two parts: cause part and effect part. The effect part of a cause and effect diagram can be the problems of product quality, delivery, production cost and safety. The cause part of a cause and effect diagram includes factors that affect the problems.

The construction of a cause and effect diagram can be carried out as follows [Ozeki and Asaka, 1990]:

1. Clarify the problem to be investigated and write the title of the problem.
   Define the problem precisely so that everyone concerned with the problem can understand the problem well. Write the title of the problem in the effect part of the diagram and draw a thick arrow running from left to right pointing to the title of the problem.
2. Identify factors affecting the problems.
   This is the most important step in constructing a cause and effect diagram. It will be helpful to identify factors affecting the problem using the categories of the factors such as: operator, machine, material, method and environment. For each category, identify all the possible causes of the problems.
3. Draw arrows to indicate the relationship between factors, categories and problem.
4. Check the completeness of the factors affecting the problem.
   Once the cause and effect diagram has been constructed check the diagram to make sure that no factor has been omitted.
5. Write down the related information of the diagram.
   The cause and effect diagram will be easy to understand if it is completed with some notes on the related information.

Figure 4.4 shows an example of a cause and effect diagram.

4.4.2 Relations Diagram

A relations diagram is used when the relationships between the causal factors are relatively complex. These relationships are very difficult to represent by a cause and effect diagram.

The construction of a relations diagram can be carried out as follows:

1. Describe the problem.
   Write down the specific problem to be investigated on a small card. Place the card in the centre of a large piece of paper.

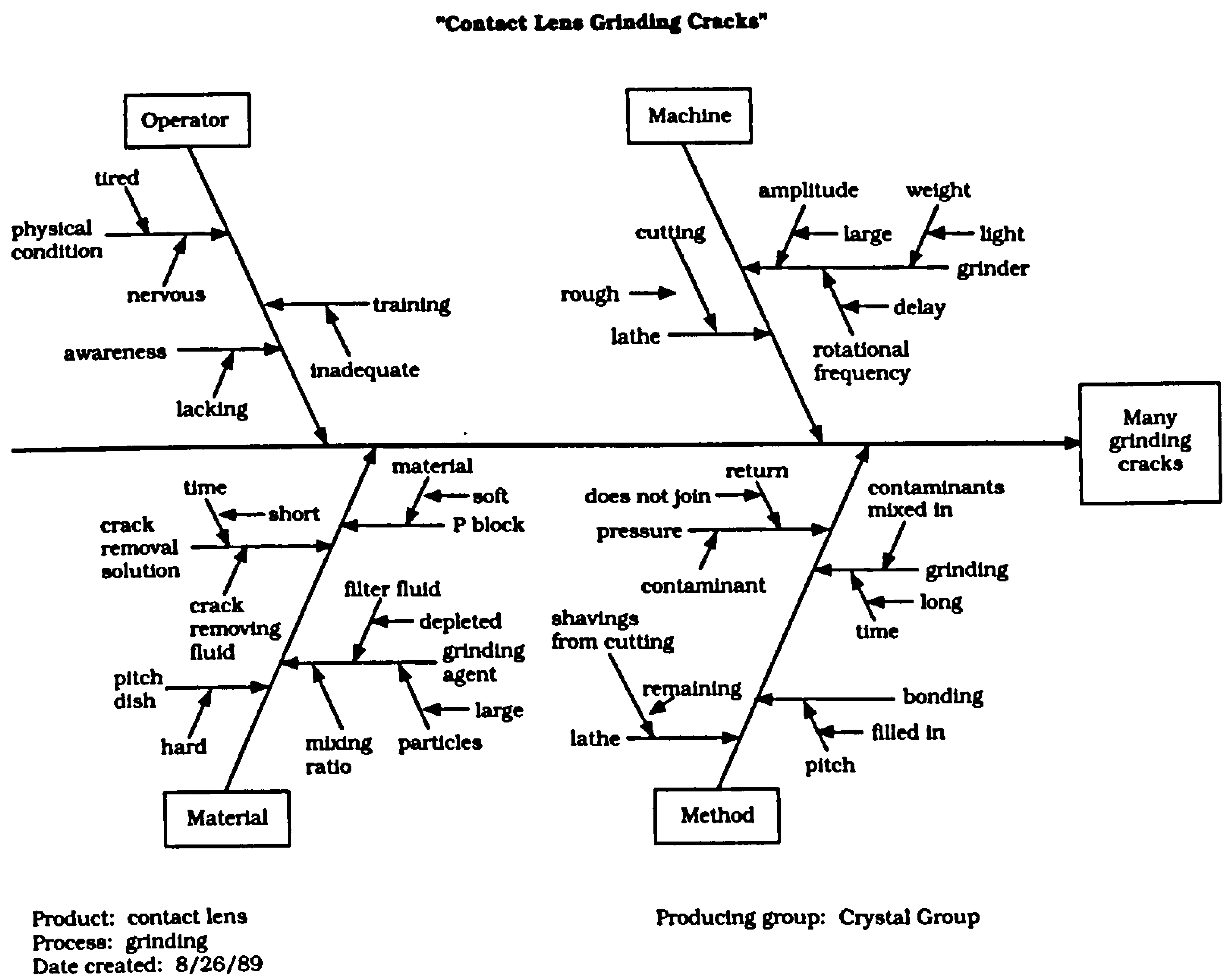


Figure 4.4 An example of a cause and effect diagram [Ozeki and Asaka, 1990].

2. Identify the factors affecting the problem.

   Identify factors affecting the problem and write down each factor on a small card.

3. Distribute the cards.

   Distribute the cards on the paper. Group similar cards together side by side.

4. Arrange the cards.

   Place the cards around the problem. The stronger the effect of the cards on the problem the closer the card to be placed to the problem.

5. Determine the relationship between cards.

   If all the cards have been arranged on the paper, study the cards as a whole to understand the relationship between groups of cards.
6. Draw the relations diagram.

   Draw the relations diagram based on the relationships identified on the paper.
7. Identify the principal factors.

   Identify the factors which have particularly important causal relationships with the problem. Highlight these boxes with colour lines.

Figure 4.5 shows an example of a relations diagram.

4.4.3 Structured Diagram

Structured diagram, which is also often called tree diagram or systematic diagram, is used to break down the whole problem into its components and structure the components hierarchically. This diagram is widely used in multi-criteria decision analysis and quality control areas. The development of a structured diagram can be carried out as follows:

1. Define the problem.

   Write the problem of the study on the middle of the top of a piece of paper.
2. Identify the primary factors affecting the problem.

   Identify the primary factors directly affect the problem. Write down the primary factors below the problem and draw lines connecting the primary factors with the problem. The primary factors serve as the first level factors of the diagram.
3. For each primary factor, identify the secondary factors affecting the problem. The secondary factors are the factors which directly affect the primary factors. Draw lines connecting a primary factor with the secondary factors directly affect this primary factor. The secondary factors serve as the second level factors of the diagram.

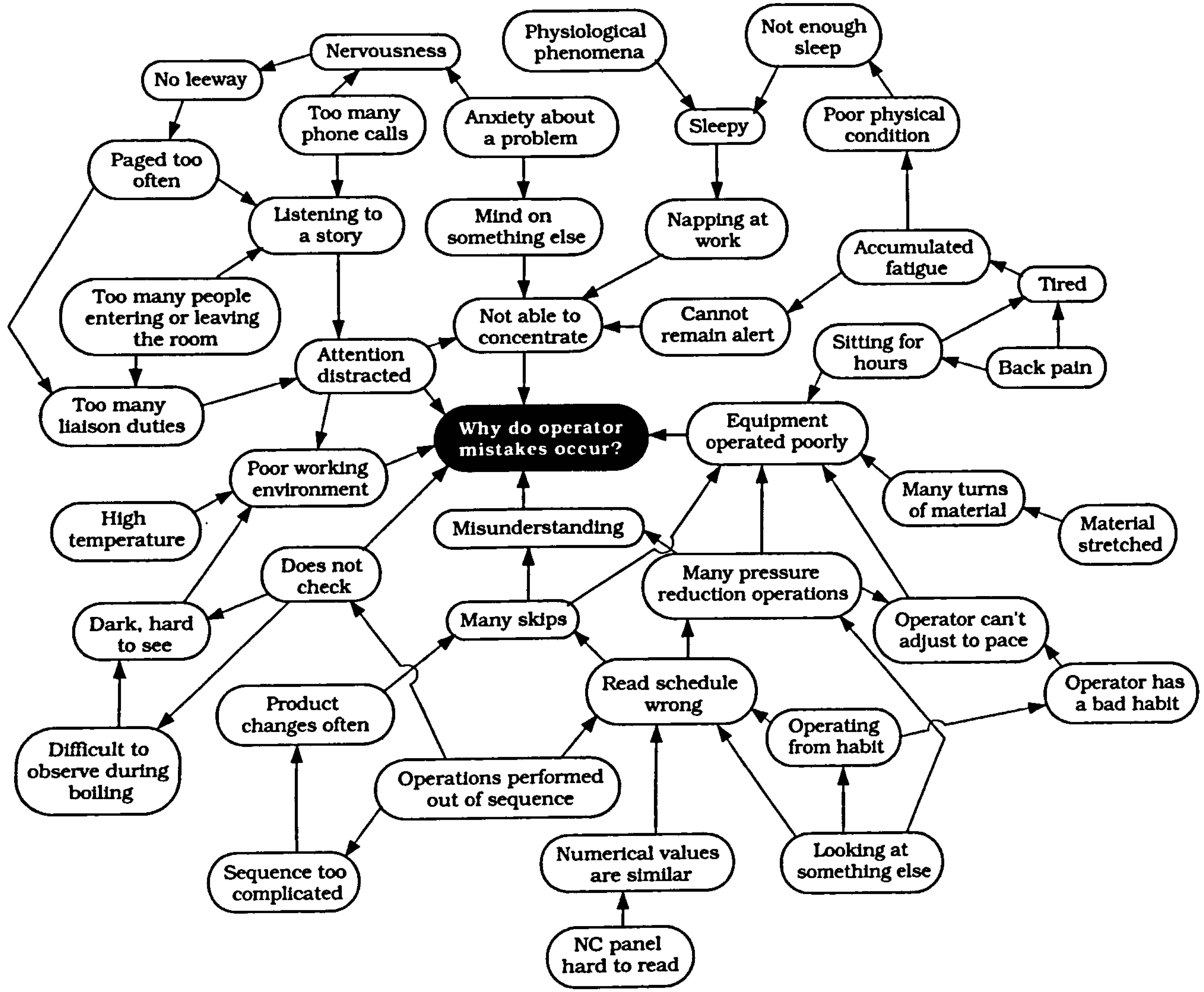


Figure 4.5. An example of a relations diagram [Ozeki and Asaka, 1990].

4. Carry out step 3 for the higher level factors of the diagram until all important factors have been included in the diagram.
5. Examine the whole diagram and check if there are important factors that have been omitted.

Figure 4.6 shows an example of a structured diagram.

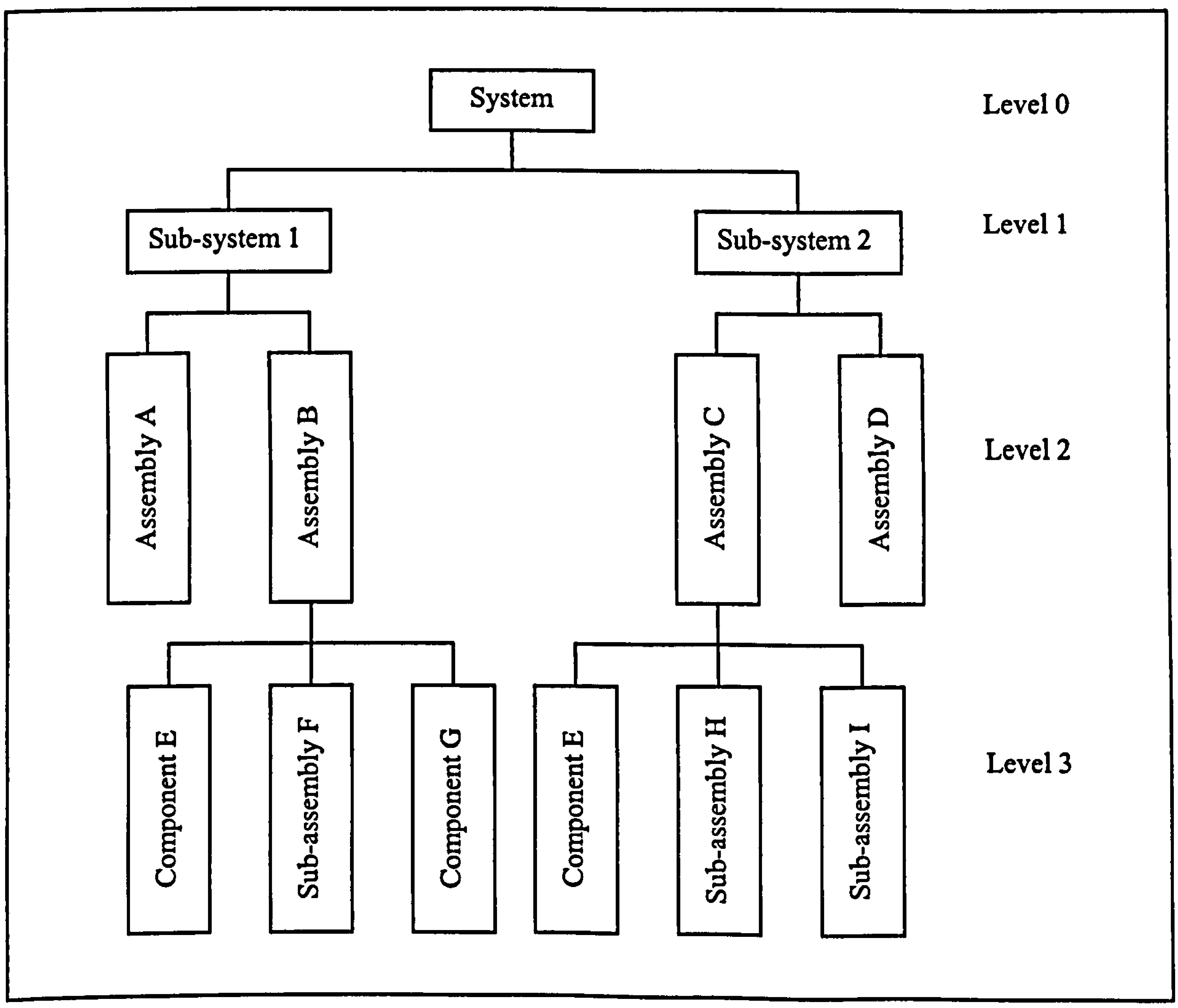


Figure 4.6. An example of a structured diagram.

To select a tool used in this research for structuring factors affecting performance hierarchically, Table 4.2 was constructed. The table shows that all three tools do not impose barriers for identification, quantification and consolidation of performance measures.

Table 4.2. The characteristics of the tools for structuring the factors hierarchically.

	Criteria of selection					
	Facilitate the identification and quantification of the effect of factor on performance	Facilitates the consolidation of performance measures	Accommodates interaction effect	Simple	Accurate	Easily implemented
Cause and effect diagram	* *	* *	*	* * *	* *	* * *
Relations diagram	* *	* *	* * *	* *	* * *	* *
Structure diagram	* *	* *	* *	* * *	* *	* * *

Legend:

- \- does not fulfil the criteria of selection
- * weakly fulfils the criteria of selection
- * * fulfils the criteria of selection
- * * * strongly fulfils the criteria of selection

Relations diagram is the best tool for representing the interaction of factors effecting performance, therefore, compared to the others it is the most accurate tool. However, relations diagram is difficult to implement because it is complicated. Cause and effect diagram and structured diagrams are easy to implement but they do not show the interaction of factors. For structured diagram, however, the interaction of factors can be presented by numbering the factors affecting performance and writing the number of the factors in boxes. Figure 4.7 shows how this technique is done.

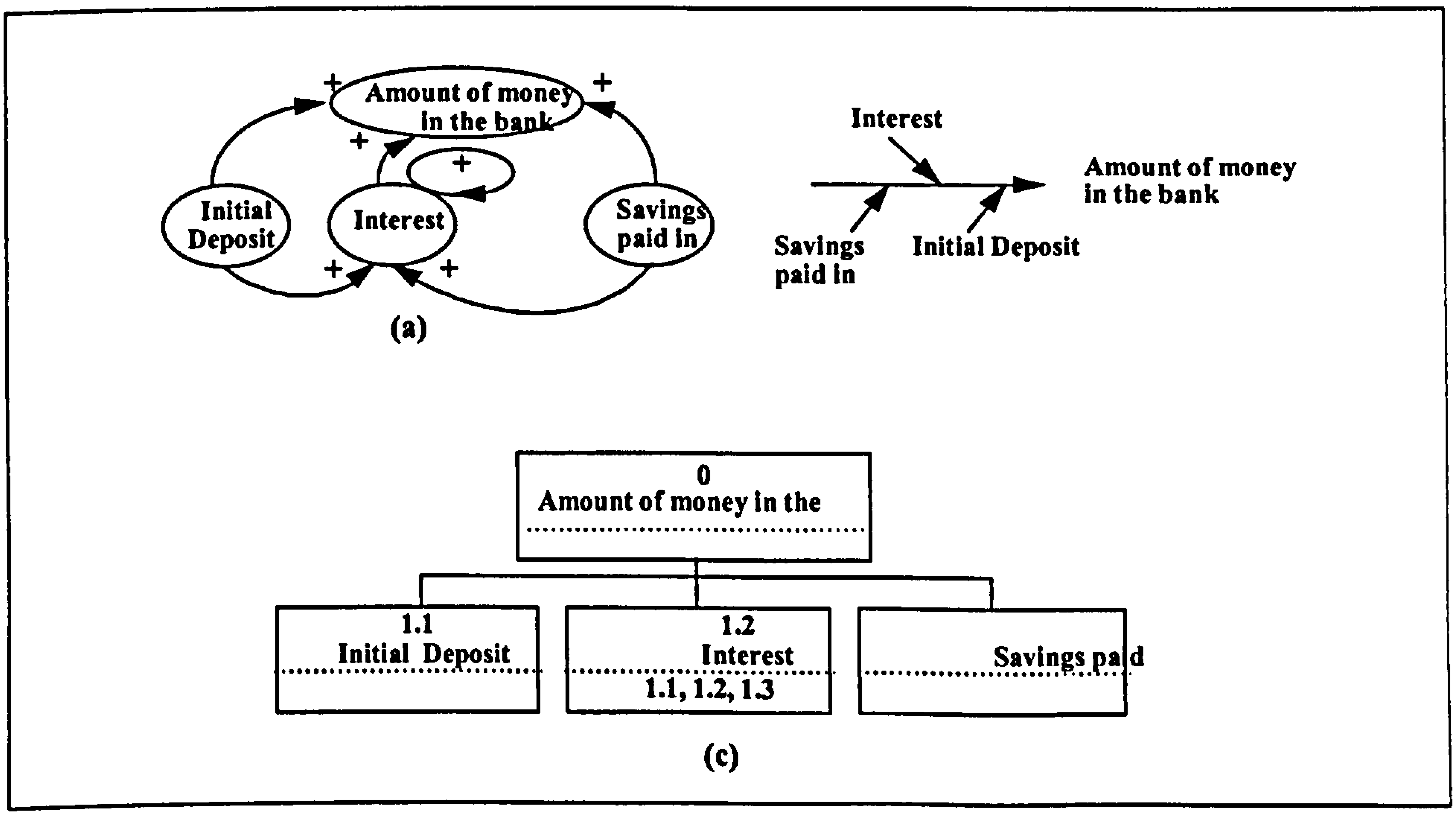


Figure 4.7. Structuring the factors hierarchically.

Figure 4.7(a) shows a cognitive map of factors affecting the "Amount of money in the bank". Factors "Initial deposit", "Interest" and "Savings paid in" have interaction effects on the "Amount of money in the bank". These interactions can be shown in the structured diagram in Figure 4.7(c). The numbers below the title of a factor in a box indicate the list of the other factors which have interaction effects with this factor. This is explained in detail in another part of the thesis.

Furthermore, structured diagram is widely used in multi-criteria decision analysis tools, the same tool used in this research to quantify the effects of factors on performance, to structure the problems hierarchically. It is also used widely in performance measurement software. Based on these considerations, structured diagram is selected in this research to structure the factors affecting performance hierarchically.

4.5 Selection of a Tool for Prioritising Performance Measures

From the literature review carried out in this research it was found that there are three works which discuss the prioritisation of performance measures. These are:

1. Performance Criteria System [Globerson, 1985].
2. Path Analytic Model [Swamidass and Newel, 1987].
3. Analytic Hierarchy Process [Rangone, 1996].

4.5.1 Performance Criteria System

Globerson (1985) proposed three techniques which can be used to prioritise performance measures, those are:

1. Pair-comparison.
2. Graphical.
3. Simultaneous Comparison.

Pair Comparison Technique

In this method the person who evaluates the measures is asked to compare every two measures by assigning relative weights to them. The weights can take any number between 0 and 100, where the sum of the relative weights has to be 100. Figure 4.8 shows an example of this technique.

The weight of a factor is computed by dividing the sum of the relative weights of this factor by the sum of the relative weights of all factors. The result is then multiplied by 100. This can be expressed in the following equation:

$$\text{Weight (A)} = \frac{\text{Sum of the relative weights of factor A}}{\text{Sum of the relative weights of all factors}} \text{ X } 100 \qquad (4\text{-}1)$$

Weight	Relative Weight						Performance Indicator	No.
280 (13.3)	1: 50; 7: 50	1: 60; 6: 40	1: 40; 5: 60	1: 30; 4: 70	1: 40; 3: 60	1: 60; 2: 40	Efficiency	1
280 (13.3)		2: 60; 7: 40	2: 50; 6: 50	2: 40; 5: 60	2: 30; 4: 70	2: 60; 3: 40	Percentage of defects	2
280 (13.3)			3: 40; 7: 60	3: 60; 6: 40	3: 40; 5: 60	3: 40; 4: 60	Satisfaction	3
380 (18.1)				4: 70; 7: 30	4: 60; 6: 40	4: 50; 5: 50	Profitability	4
370 (17.1)					5: 70; 7: 30	5: 70; 6: 30	Growth in profit	5
240 (11.4)						6: 40; 7: 60	Cost per item	6
270 (12.9)							Response time	7
Total								
2100 (100)								

Figure 4.8. Pair comparison technique [Globerson, 1985].

For example the weight of factor Profitability can be computed as follows:

$$\text{Weight (Profitability)} = \frac{(70+70+60+70+60+50)}{(280+280+280+380+370+240+270)} \text{ X } 100$$

$$= \frac{380}{2100} \text{ X } 100 = 18.1$$

Graphical Technique

This technique asks the evaluator to mark on scale the degree of importance of each performance measure. Ten scales which range from not important at one end to important at the other end are used. The graphical technique is indicated by Figure 4.9.

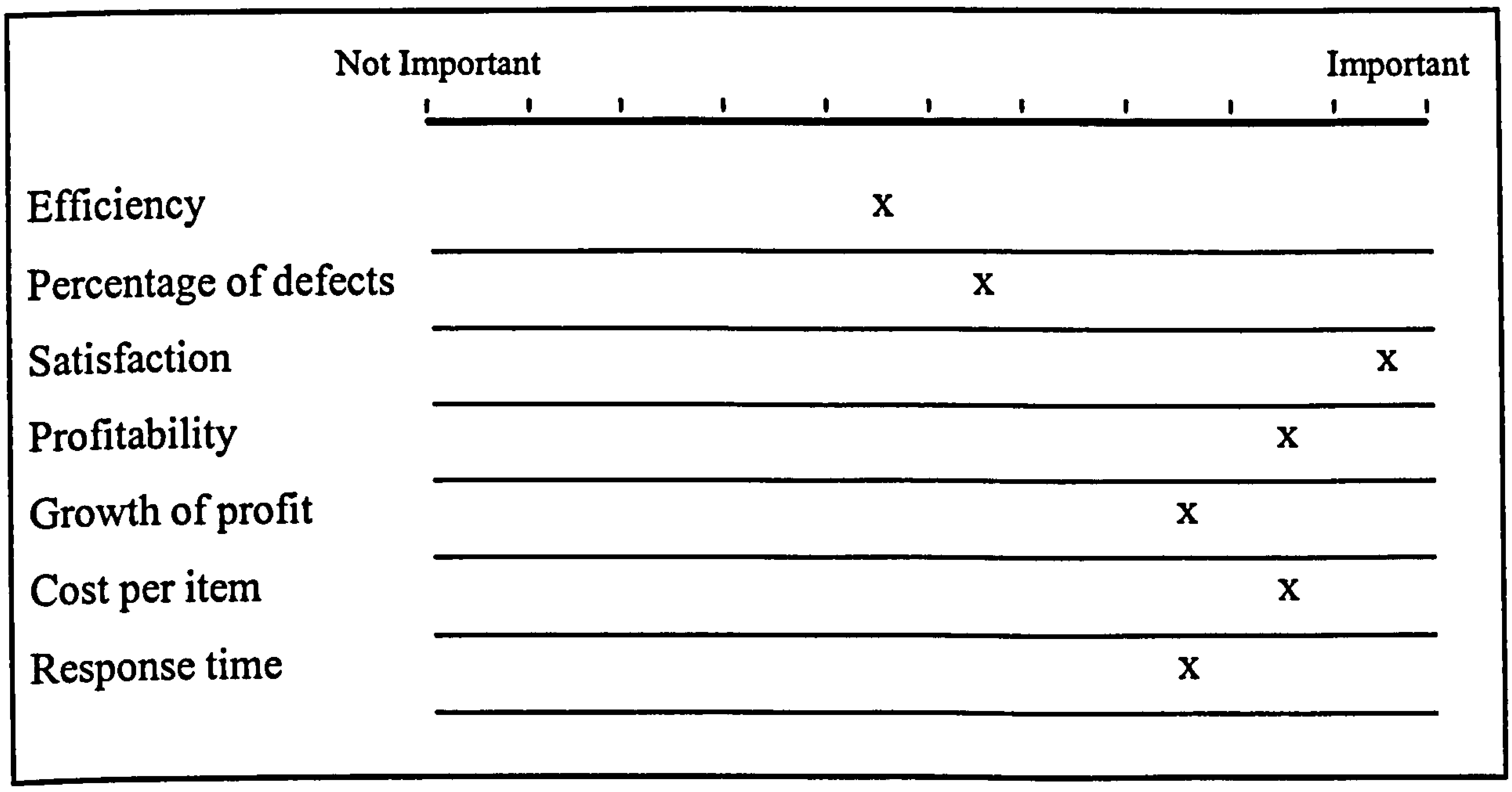


Figure 4.9. Graphical technique [Globerson, 1985].

Simultaneous Comparison Technique

In this method the evaluator is asked to assign weights to all the performance measures so that the sum of the weights is equal to 100. Table 4.3 is an example of the application of the simultaneous comparison technique.

Table 4.3. Simultaneous comparison technique [Globerson, 1985].

Performance measure	Relative weight
Efficiency	15
Percentage of defects	10
Satisfaction	25
Profitability	25
Growth in profit	15
Cost per item	10
Response time	10
Total	100

4.5.2 Path Analytic Model

Swamidass and Newell (1987) were the first researchers to present empirical research on the impact of manufacturing flexibility on business performance. They used the path analytic model to investigate the impact of environmental uncertainty on manufacturing strategy content and process and manufacturing strategy's influence on business performance. The path analytical model basically is the application of regression analysis on networks.

Swamidass and Newell (1987) developed a model of sequential relationship between environmental uncertainty, manufacturing strategy process and content and business performance as depicted in Figure 4.4.

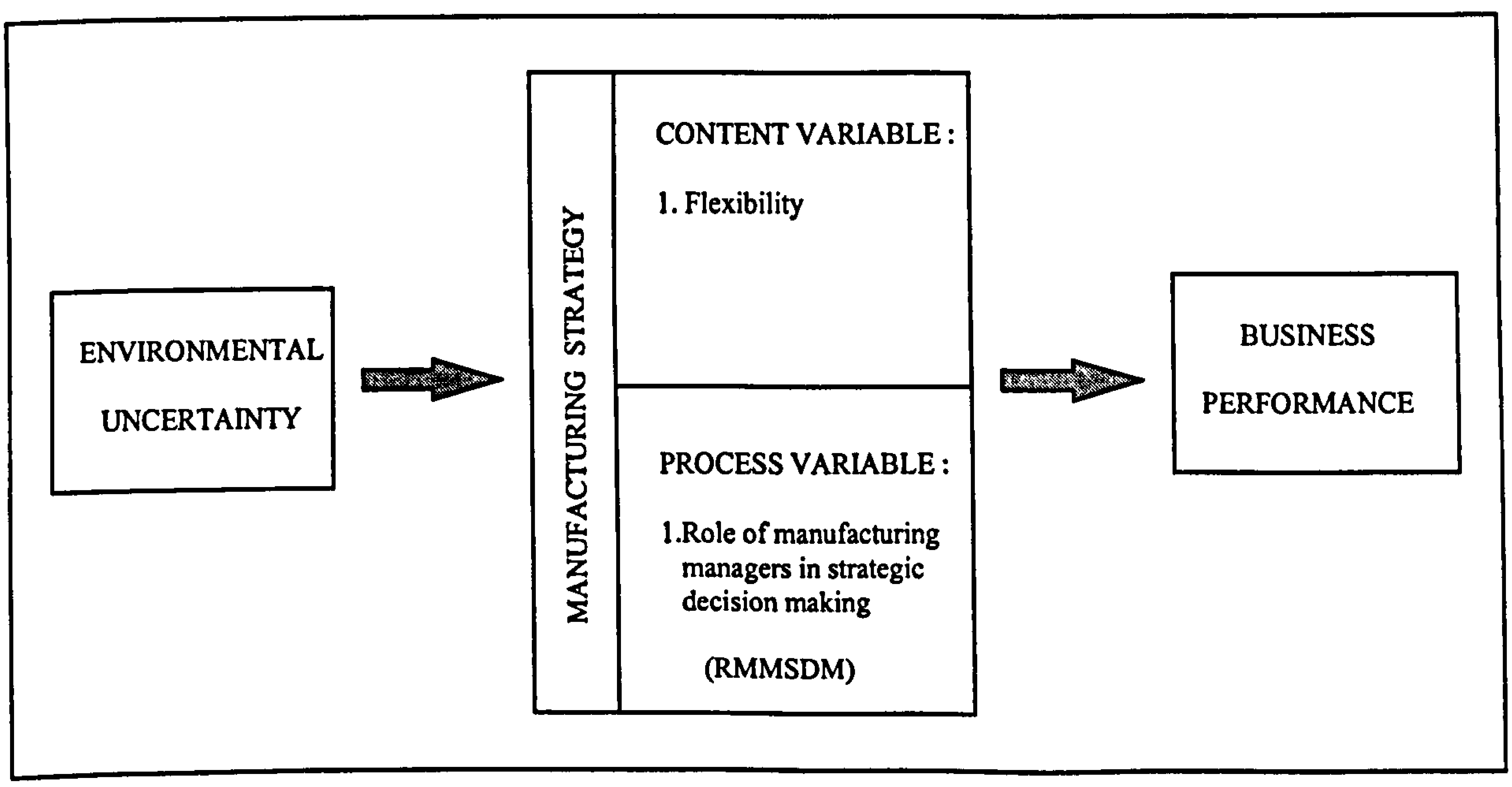


Figure 4.10. The relationship between environmental uncertainty, manufacturing strategy and business performance [Swamidass and Newell, 1987].

Based on this model, Swamidass and Newell (1987) then built a path analytic model as depicted in Figure 4.11. Variables D1, D2, D3 in Figure 4.11 represent the disturbance terms associated with the three endogenous variables (B, C and D).

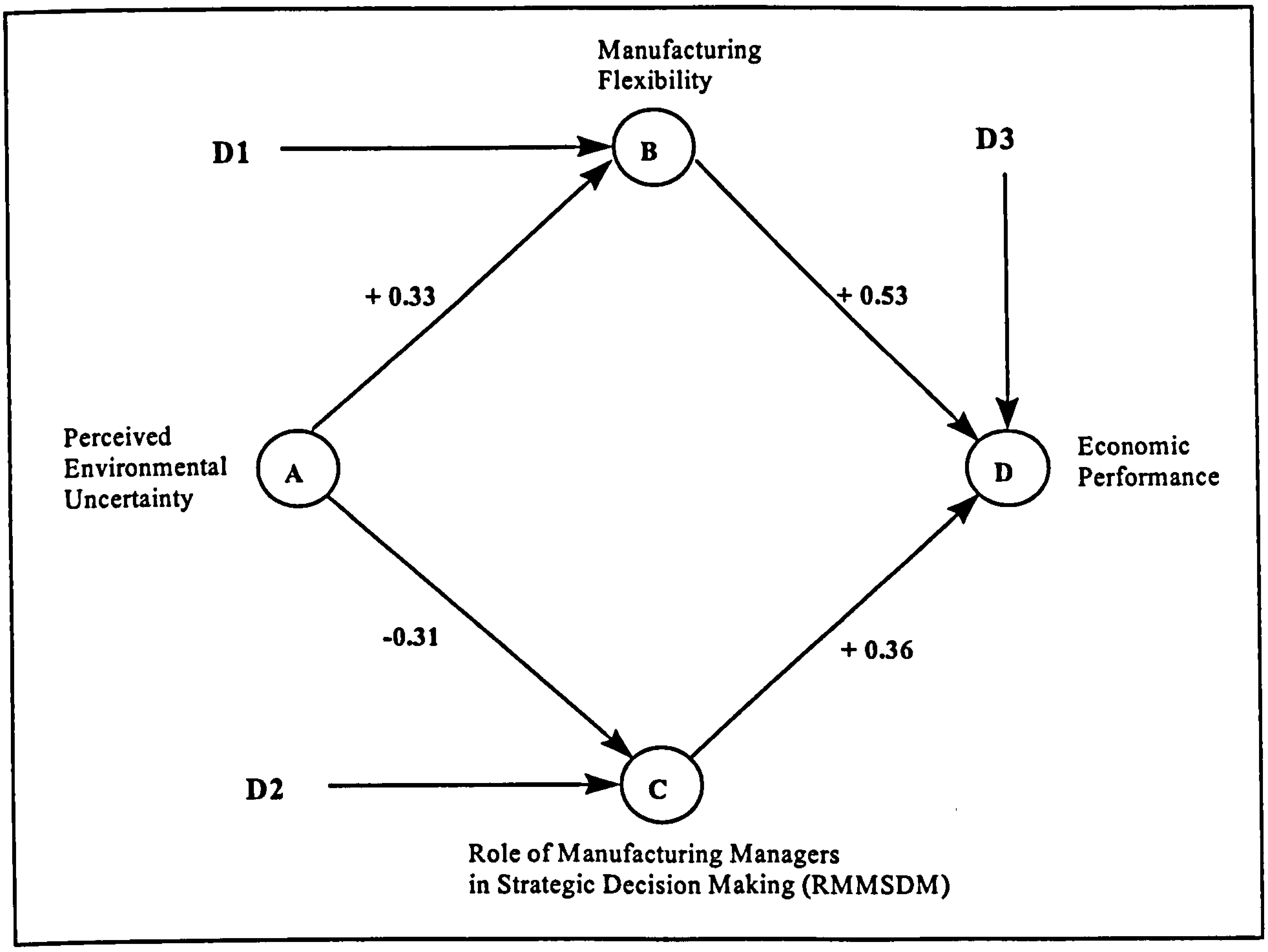


Figure 4.11. Path analytic model of environmental uncertainty, manufacturing strategy and business performance [Swamidass and Newell, 1987].

Data on *Perceived Environmental Uncertainty, Flexibility, the Role of Manufacturing Managers in Strategic Decision Making and Business Performance Measures* was collected using questionnaires. Using the path analytic method [Billing and Wroten, 1978; Asher, 1981], the regression coefficient of each path was analysed by Swamidass and Newell (1987) and the results are as indicated in Table 4.4.

Table 4.4. Regression coefficient of each path [Swamidass and Newell, 1987].

Path	Regression Coefficient
A - B	+ 0.33
A - C	- 0.31
B - D	+ 0.53
C - D	+ 0.36

Variables can affect Economic Performance either directly, indirectly, or both. In this research, as indicated in Figure 4.11, the factors Manufacturing Flexibility and RMMSDM directly affect Economic Performance. Factor Perceived Environmental Uncertainty actually can affect Economic Performance directly and indirectly through its effects on factors Manufacturing Flexibility and RMMSDM. However, in this case, there is no significant effect by factor Perceived Environmental Uncertainty on Economic Performance. The only effect by factor Perceived Environment Uncertainty on Economic Performance is the indirect effect through factor Manufacturing Flexibility and RMMSDM. The total effect of each factor or variable on Economic Performance is indicated in Table 4.5.

Table 4.5. The total effect of variables on economic performance [Swamidass and Newell, 1987].

Variables	Direct Effect	Indirect Effect	Total Effect
A	Not significant	(0.33x0.53) - (0.31x0.36) = 0.04	0.04
B	0.53	0	0.53
C	0.36	0	0.36

The strengths of the Path Analytic Method are twofold:

1. By introducing the disturbance variables, a researcher can isolate the variables of interest and study the effects of selected variables on the variables.
2. Indirect, as well as direct, effects of variables on other variables can be identified.

However, the formula used to compute the indirect effect as shown in Table 4.5 is questionable since the effect of the variables were scored using different scales. The effects of 'Manufacturing Flexibility' and 'Economic Performance' variables were scored using ten-point scale system while the effects of 'Perceived Environmental Uncertainty' and 'The Role of Manufacturing Managers in Strategic Decision Making' variables were scored using five-point scale system. Therefore, the effects of the first two variables cannot be added to the effects of the last two variables.

4.5.3 The Analytic Hierarchy Process

Rangone (1996) used the Analytic Hierarchy Process to measure and compare the performance of four factories supporting manufacturing strategy. The hierarchical structure of the manufacturing strategy performance is indicated by Figure 4.12.

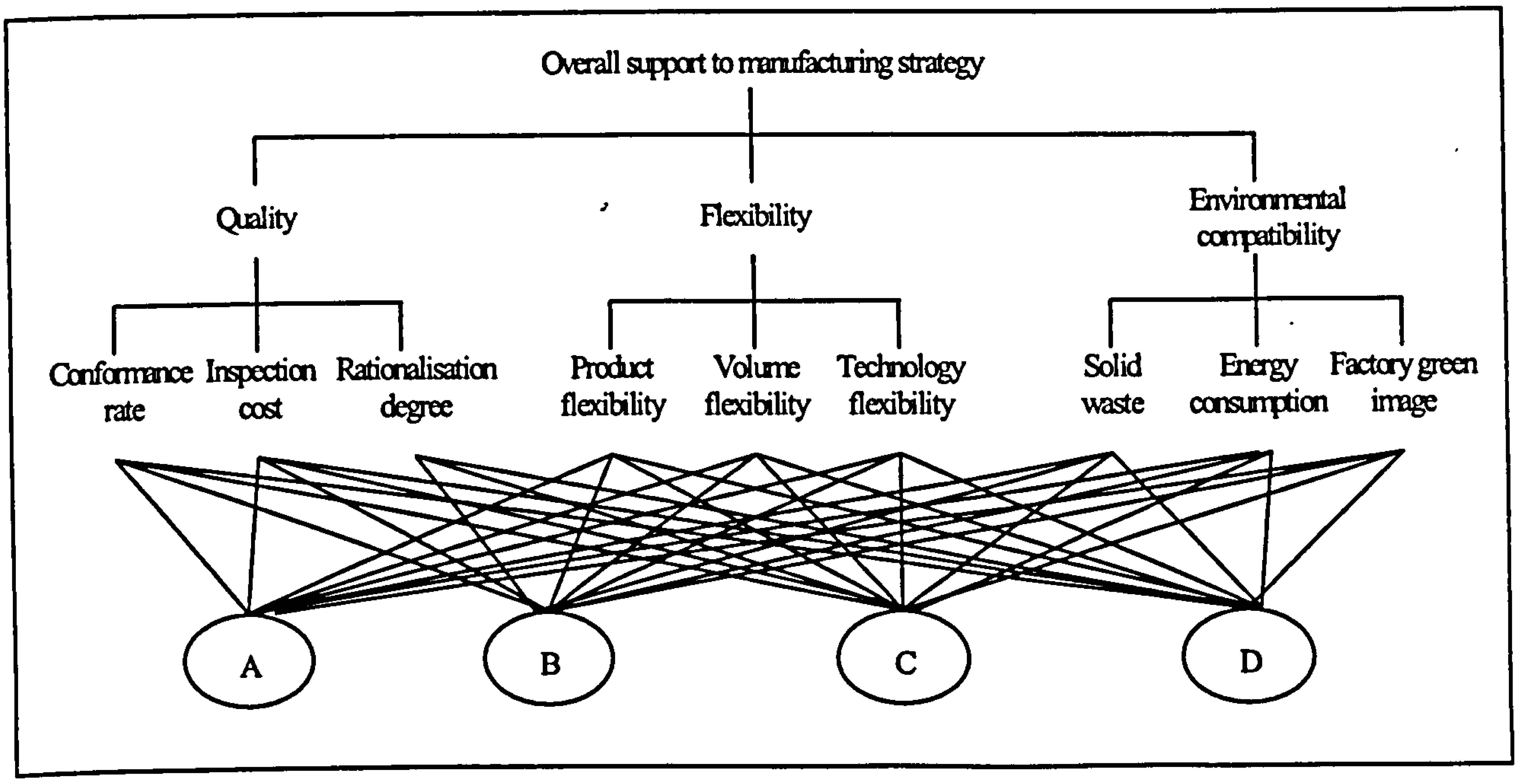


Figure 4.12. The manufacturing strategy performance hierarchy [Rangone, 1996].

Managers were asked to complete pair-wise comparison questionnaires. For each pair of criteria or factors in the same level, their effect on the factor from the next higher level was compared. A ratio scale lying between one (equally important) and nine (absolutely more important) was assigned for each comparison depending on the subjective judgement of the managers. Then eigenvector theory was used to derive the weights of the effects of factors on performance. The results of a pair-wise comparison questionnaire to assess the effect of quality, flexibility and environmental compatibility on overall support to manufacturing strategy is indicated by Table 4.6.

Table 4.6. Pair-wise comparison [Rangone, 1996].

Factors	**Quality**	**Flexibility**	**Environmental compatibility**	**Weights**
Quality	1	7	3	0.682
Flexibility	1/7	1	1/2	0.103
Environmental compatibility	1/3	2	1	0.215

The same procedure was repeated to level II and III. At the final step, the composition process was carried out to calculate the effect of each factory on overall support to the manufacturing strategy performance. The results are indicated by Table 4.7.

Table 4.7. The effect of factories on overall support to manufacturing strategy performance [Rangone, 1996].

Factory	**A**	**B**	**C**	**D**
The effect	0.194	0.279	0.192	0.335
Ranking	4	2	3	1

Finally, Rangone (1996) pointed out that to be successful in applying the AHP for a performance measurement system, the following critical assumptions should be considered carefully:

- the manufacturing departments to be compared should be homogenous in terms of manufacturing competitive priorities and performance measures;
- competitive priorities and performance measures should be independent, not redundant and additive;
- the pair-wise comparisons made by managers should be fairly consistent;
- the 1-9 ratio scale should allow the relative importance of competitive priorities and performance measures to be expressed well.

The similar work was also reported by Lee et al (1995) which used the AHP to structure hierarchically and prioritise the effect of factors on business objectives.

4.5.4 Multi-Criteria Decision Analysis Models

Performance measurement involves multi-dimensional factors, which can be measured in pounds, percentage of defects, time, or number of new products to be introduced per year. Some factors, for example management commitment and company culture, are even more difficult to measure. Aggregating and prioritising the effects of factors on performance needs a procedure for facilitating value trade off between multi-dimensional measures. In operation research discipline this subject is covered by ***Multi-Criteria Methods.***

Multi-Criteria methods consist of several models which can be classified further as indicated by Figure 4.13 [Zimmermann and Gutsche, 1991; Von Winterfeldt and Edwards, 1986; Belton, 1986].

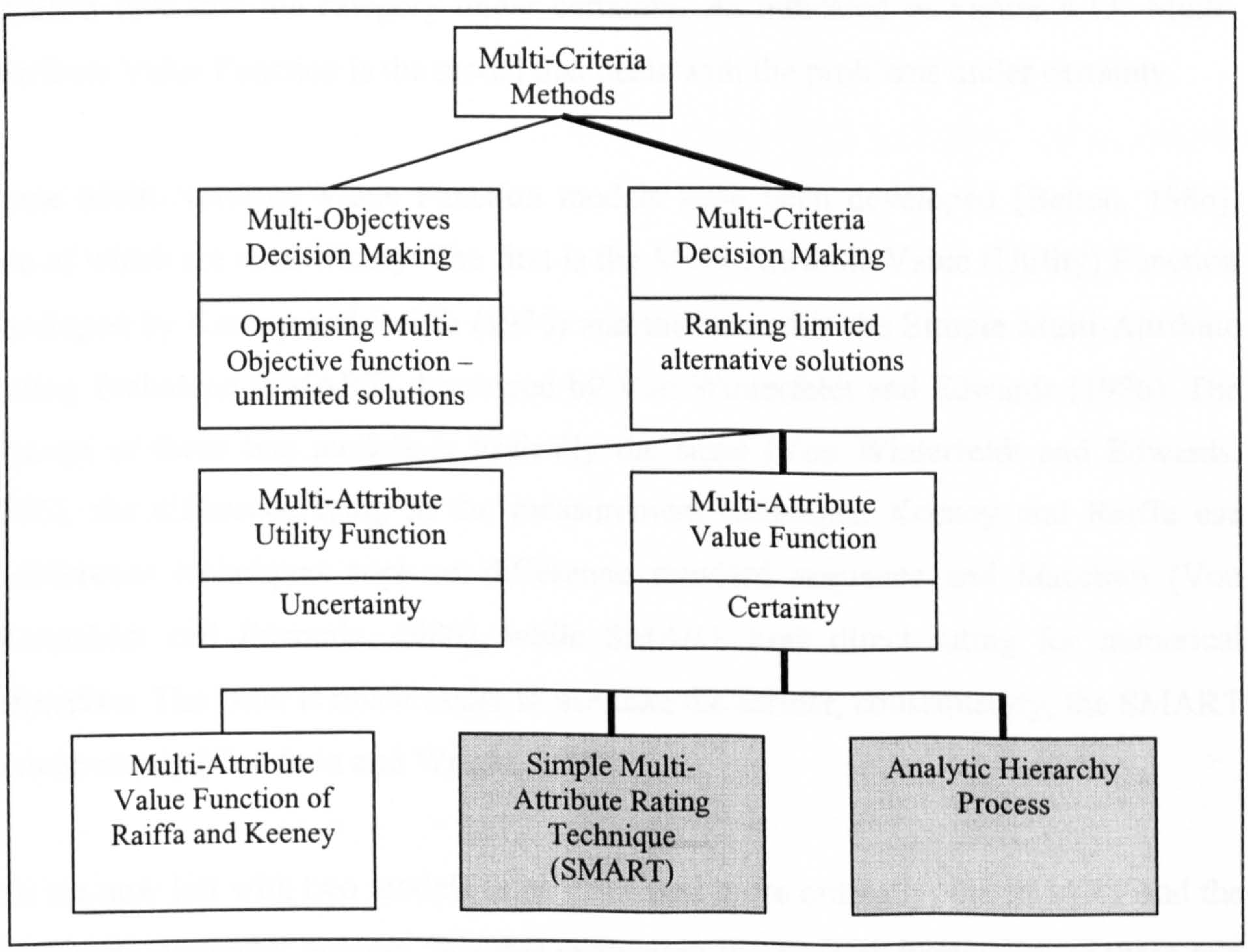


Figure 4.13. Classification of multi-criteria methods.

Firstly, Multi-Criteria methods can be classified based on the objective of the study and the number of alternatives. If the objective of the study is to find an optimal solution from unlimited feasible solutions as in a linear programming problem, then the model falls into category Multi-Objective Decision Making. On the other hand, if the problem is to rank limited alternatives, the problem is categorised as Multi-Criteria Decision Making. Prioritisation of performance measures falls into the latter category.

Multi-Criteria Decision Making can be classified further based on the consequences of the decision or action. If the decision-maker can predict the consequences of his decision or action with certainty, the problem is categorised as Decision-Making Under Certainty. Otherwise, the problem is Decision-Making Under Uncertainty.

In performance measurement systems the effects of factors on performance, whether they have a positive or negative effect, can be identified in advance. Consequently, the problem falls into the category under certainty. As indicated in Figure 4.13, Multi-Attribute Value Function is the model that deals with the problems under certainty.

Some Multi-Attribute Value Function models have been developed [Belton, 1986], two of which are used widely. The first is the Multi-Attribute Value (Utility) Function developed by Keeney and Raiffa (1976) and the second is the Simple Multi-Attribute Rating Technique (SMART) developed by Von Winterfeldt and Edwards (1986). The concept of these two models is basically the same [Von Winterfeldt and Edwards, 1986], the difference lying in the measurement technique. Keeney and Raiffa use indifference techniques such as difference standard sequence and bisection [Von Winterfeldt and Edwards, 1986], while SMART uses direct rating for numerical estimation. The latter is much easier to use than the former, consequently, the SMART is used widely [Goodwin and Wright, 1998].

We are now left with two models to be evaluated more critically, the SMART and the Analytical Hierarchy Process. For this evaluation the general framework of these two models will be reviewed.

The Differences between the SMART and the Analytic Hierarchy Process

Solving multi-attribute problems using SMART involves the following stages [Goodwin and Wright, 1998]:

1. Identify the decision-maker (or decision-makers).
2. Identify alternative courses of action.
3. Identify attributes which are relevant to the decision problem.
4. For each attribute, assign values to measure the performance of the alternatives on that attribute.
5. Determine a weight or priority of each attribute.
6. For each alternative, take a weighted average of the values assigned to that alternative.
7. Make a provisional decision.
8. Perform a sensitivity analysis.

If the Analytic Hierarchy Process is used, the process will be carried out as follows [Saaty and Kearns, 1985]:

1. Define the problem and determine the overall objective.
2. Structure the hierarchy from the top (management objectives) through the intermediate levels (criteria), to the lowest level (alternatives).
3. Construct a set of pair-wise comparison matrices for each lower level; one matrix for each element in the level immediately above.
4. Compute the priority using eigenvector equation.
5. Check the consistency of the judgement and modify if necessary.
6. Calculate the overall priority vector.
7. Check the consistency of the whole hierarchy and modify if necessary.

Even although the terminology used is different, the general steps of the two methods for solving the problem are quite similar. Both methods involve problem definition, identifying alternatives, identifying attributes or criteria, computing the score of each alternative on each attribute, computing overall score of each alternative and making a decision.

However, the SMART and AHP also have fundamental differences in some areas [Belton, 1986; Von Winterfeldt and Edwards, 1986; Saaty, 1980; Goodwin and Wright, 1998] as indicated in Table 4.8.

The AHP uses the pair-wise comparison technique and assigns a ratio scale of between 1 (equally important) and 9 (absolutely more important) both for assessing the score of the alternative and the weights of criteria. This method is very simple and easy to understand. However, it has been criticised [Belton, 1986] as it is very difficult for a decision-maker to interpret the questions posed. Consequently, the results may not be accurate [Belton, 1983; Belton, 1986; Dyer, 1990].

Table 4.8. The fundamental differences between SMART and AHP.

Area	SMART	AHP	Remark
Assessment of alternative's score	Scale: Interval Method: Direct rating [Von Winterfeldt and Edwards, 1986; Goodwin and Wright, 1998]	Scale: Ratio (1 – 9) Method: Pair-wise comparison [Saaty, 1980]	AHP is simpler SMART is more accurate [Belton, 1986]
Assessment of weights of criteria	Swing technique [Von Winterfeldt and Edwards, 1986; Goodwin and Wright, 1998]	Scale: Ratio (1-9) Method: Pair-wise comparison [Saaty, 1980]	AHP is simpler SMART is more accurate [Belton, 1986]
Consistency check of judgements	Does not have formal procedure	Inconsistency Index [Saaty, 1980]	AHP is better

The SMART uses different methods for assessing the score of the alternative and for assessing the weights of criteria. For assessing the score of the alternative on a particular criteria the SMART uses the direct rating technique [Von Winterfeldt and Edwards, 1986; Goodwin and Wright, 1998]. The direct rating technique requires the specification of two arbitrary end points of the interval scale [Von Winterfeldt and Edwards, 1986; Belton, 1986]. These points represent the worst and the best achievements of the alternative. Generally, a scale of 0 to 100 is used. The score for each alternative is then directly rated by that scale.

For assessing the weights of criteria the SMART uses the swing technique. In this technique the decision-maker is asked to compare the degree of importance of the change (or swing) of a criteria from least preferred to most preferred, to the change of another criteria from least preferred to most preferred. Managers, for example, may believe that the change of quality criteria from lowest to highest is 1.5 times more important than the change of cost criteria from highest cost to lowest.

It is clear that both methods used by the SMART for assessing the score (direct rating) of an alternative on a criterion and for assessing the weights of criteria (swing technique) are more difficult than the pair-wise comparison questionnaire used by the AHP. However, some authors reported that the SMART is extremely robust [Watson and Buede, 1987].

Experimental research has been reported comparing multi-criteria methods [Schoemaker and Waid, 1982; Zapatero et al, 1997]. Schoemaker and Waid (1982) conducted an experiment on college admissions to compare the weight produced by and the predictive ability of, five different approaches, the approaches being multiple linear and non-linear regression, direct decomposed tradeoffs as proposed by Keeney and Raiffa (1976), AHP, straightforward allocation of 100 importance points and unit weighting. Subjects were asked to evaluate hypothetical college applicants on the basis of verbal scholastic aptitude (VSAT), quantitative scholastic aptitude (QSAT), high school cumulative average (CUM) and extra curricular activity (EC). Even though the results of the research did not prove the existence of the best method, the subjective perception of the respondents showed that AHP was the least difficult and most trustworthy compared to the direct tradeoffs (another name of multi-attribute value function) and Multiple Regression methods as indicated in Table 4.9.

Table 4.9. Comparison of the degree of difficulty and trustworthiness of AHP, direct tradeoffs and multiple regression [Schoemaker and Waid, 1982].

Mental Difficulty of the Method						Trustworthiness in Capturing Preferences			
			Percentage					Percentage	
	Mean	SD	Most Difficult	Least Difficult		Mean	SD	Best Capture	Least Capture
MR	4.42	0.84	78 %	6 %		2.78	1.38	21 %	32 %
DT	3.08	1.18	17 %	36 %		3.02	1.46	39 %	35 %
AH	2.33	1.04	6 %	58 %		3.33	1.22	40 %	33 %
1 = least difficult 5 = most difficult						1 = least trustworthy 2 = most trustworthy			

More recent research work by Zapatero et al (1997) evaluated six multi-attribute decision support software packages in terms of user-friendliness, confidence in the procedure, users' confidence in the results and time to reach decision. The software evaluated were Criterium, ExpertChoice, which are both based on AHP [Saaty, 1980]; Logical Decision, which is based on multi-attribute utility theory [Keeney and Raiffa, 1976]; VIMDA, which is based on the visual reference direction approach [Korhonen, 1988]; VISA, which is based on multi-attribute value function [Belton, 1990]; and the spreadsheet package, Quatro Pro.

Twenty-four college faculty members participated in the research and they used the software repeatedly to analyse semi-structured multi-attribute problems. The results are summarised as follows [Zapatero et al, 1997]:

1. VISA and ExpertChoice were ranked the highest out of six tools.
2. ExpertChoice and VISA had the highest factor scores for user-friendliness.
3. VISA and ExpertChoice had the highest factor scores for confidence in the procedure.

4. Criterium and VISA required the least time for decision-makers to reach a decision.

For confidence in solution criteria, ExpertChoice was ranked second, while VISA was ranked sixth. However, this criteria is not statistically significant [Zapatero et al, 1997].

As has been presented earlier there are seven toos that can be used to prioritising or quantifying the effects of factors on performance. These methods are:

- ✓ Pair-comparison.
- ✓ Graphical.
- ✓ Simultaneous comparison.
- ✓ Path analytic method.
- ✓ Analytic hierarchy process (AHP).
- ✓ Utility function.
- ✓ Simple multi-attribute rating techniques (SMART).

The characteristics of the tools that can be used for prioritising or quantifying the effects of factors on performance are indicated in Table 4.10. All seven tools facilitate the quantification of the effect of factors on performance and also can accommodate the consolidation of performance measures into a single performance indicator. The pair-comparison, graphical and simultaneous comparison, models proposed by Globerson (1985), are very simple and easy to implement. However, those toolss are very intuitive and have no theoretical background. Consequently, their accuracy is questionable.

In contrast, the Path Analytic Model [Swamidass and Newell, 1987] is a very powerful tool for quantifying the effects of factors on performance, including the interaction effect. However, like many other statistical tools, it is very complicated and requires a large amount of data. While this method is commonly used by researchers, it is unlikely that managers would use this tool for performance measurement systems in their daily work.

Table 4.10. The characteristics of the methods for quantifying the effects of factors on performance.

	Criteria of selection					
	Facilitate the identification and quantification of the effect of factor on performance	Facilitates the consolidation of performance measures	Accommodates interaction effect	Simple	Accurate	Easily implemented
Pair-comparison	* * *	* *	-	* * *	*	* * *
Graphical	* * *	* *	-	* * *	*	* * *
Simultaneous comparison	* * *	* *	-	* * *	*	* * *
Path analytic method	* * *	* *	* * *	-	* * *	-
Analytic hierarchy process	* * *	* *	* *	* *	* *	* *
Utility function	* * *	* *	* *	*	* * *	*
SMART	* * *	* *	* *	*	* * *	*

Legend:

- \- does not fulfil the criteria of selection
- * weakly fulfils the criteria of selection
- * * fulfils the criteria of selection
- * * * strongly fulfils the criteria of selection

The Utility Function and SMART methods have similar characteristics with the path analytic method except that they do not accommodate the interaction effects. The analytic hierarchy process seems to have balanced characteristics of simplicity and accuracy. However, the analytic hierarchy process proposed by Rangone (1996) did not take into account the interaction effects.

In this research the analytic hierarchy process has been selected. However, it will be modified to accommodate the interaction effect. How the researcher dealt with this problem will be explained in the next part of the thesis.

Since the AHP has been selected as the model to be used for prioritising performance measures, it is important to elaborate the underlying theory in more detail.

4.6 Basic Theory of the Analytic Hierarchy Process

The aim of this sub-chapter is to provide a general theoretical background of the Analytic Hierarchy Process without necessarily going into details of the mathematical aspect of the model. This sub-chapter is mainly extracted from the work of Saaty (1980). The controversy and the variant of the model will also be presented.

Supposing a manager has to decide on ranking the effects of factors - cost, quality, delivery and flexibility - on business performance. Such a task is not easy, since cost, quality, delivery and flexibility factors are measured in different dimensions. To deal with this problem the Analytic Hierarchy Process uses relative measurement based on the manager's judgement in the form of ratio scales to derive the relative effects of factors on performance and the quantified judgement is elicited through pair-wise comparison questionnaires.

Pair-wise Comparison Matrix

Let $\mathbf{F}_1, \mathbf{F}_2, \ldots, \mathbf{F}_n$ be a set of factors. The quantified judgements on pair of factors $\mathbf{F}_i$, $\mathbf{F}_j$ are represented by n-by-n matrix

$$\mathbf{A} = (\mathbf{a}_{ij}), \quad i, j = 1, 2, \ldots, n$$

The matrix **A** is called pair-wise comparison matrix.

The entries of $\mathbf{a}_{ij}$ are defined by the following entry rules.

Rule 1. If $\mathbf{a}_{ij} = \alpha$, then $\mathbf{a}_{ji} = 1/\alpha$, $\alpha \neq 0$

Rule 2. If $\mathbf{F}_i$ is judged to be of equal relative importance as $\mathbf{F}_j$, the $\mathbf{a}_{ij} = 1$, $\mathbf{a}_{ji} = 1$; in particular, $\mathbf{a}_{ii} = 1$ for all i.

Thus the pair-wise comparison matrix **A** has the form of

$$\mathbf{A} = \begin{bmatrix} 1 & \mathbf{a}_{12} & \cdots & \mathbf{a}_{1n} \\ 1/\mathbf{a}_{12} & 1 & \cdots & \mathbf{a}_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ 1/\mathbf{a}_{in} & 1/\mathbf{a}_{2n} & \cdots & 1 \end{bmatrix}$$

Since $\mathbf{a}_{ij} = 1/\mathbf{a}_{ji}$ the matrix A is reciprocal. If $\mathbf{a}_{ik} = \mathbf{a}_{ij}.\ \mathbf{a}_{jk}$ for all i,j,k then the matrix **A** is called consistent.

An example of a consistent, reciprocal pair-wise comparison matrix is the one which is constructed based on exact measurement. For example there are three stones X, Y and

Z which are 2 lb., 3 lb. and 5 lb. in weights respectively. Comparing those three stones in pairs generates a consistent reciprocal matrix **A** below.

$$\mathbf{A} = \begin{bmatrix} 1 & 2/3 & 2/5 \\ 3/2 & 1 & 3/5 \\ 5/2 & 5/3 & 1 \end{bmatrix}$$

The pair-wise comparison matrix **A** has captured the manager's perception of the relative effects of factors on performance. Therefore, the priority of factors affecting performance can be derived from the pair-wise comparison matrix **A**. The Analytic Hierarchy Process uses Perron-Frobenius eigenvectors theory to derive the priority of factors affecting performance from pair-wise comparison matrix [Saaty, 1980].

Eigenvalue and Eigenvector

Let $\mathbf{w}_1, \mathbf{w}_2, \ldots, \mathbf{w}_n$ are the weights derived from an exact measurement. Then

$$\boxed{\mathbf{a}_{ij} = \frac{\mathbf{w}_i}{\mathbf{w}_j}} \qquad i, j = 1, 2, \ldots.., n \qquad (4\text{-}2)$$

and thus

$$\mathbf{a}_{ij}\,\mathbf{a}_{jk} = \frac{\mathbf{w}_i}{\mathbf{w}_j} \cdot \frac{\mathbf{w}_j}{\mathbf{w}_k} = \mathbf{a}_{ik}$$

Also,

$$\mathbf{a}_{ji} = \frac{\mathbf{w}_j}{\mathbf{w}_i} = \frac{1}{\mathbf{w}_i / \mathbf{w}_j} = \frac{1}{\mathbf{a}_{ij}}$$

Let us consider a simultaneous linear equation

$$
\begin{aligned}
\mathbf{a}_{11}\,\mathbf{x}_1 + \mathbf{a}_{12}\,\mathbf{x}_2 + \ldots + \mathbf{a}_{1n}\,\mathbf{x}_n &= \mathbf{y}_1 \\
\mathbf{a}_{21}\,\mathbf{x}_1 + \mathbf{a}_{22}\,\mathbf{x}_2 + \ldots + \mathbf{a}_{2n}\,\mathbf{x}_n &= \mathbf{y}_2 \\
\vdots \qquad\qquad\qquad & \quad \vdots \\
\mathbf{a}_{n1}\,\mathbf{x}_1 + \mathbf{a}_{n2}\,\mathbf{x}_2 + \ldots + \mathbf{a}_{nn}\,\mathbf{x}_n &= \mathbf{y}_n
\end{aligned}
$$

The equation can be written in matrix and vector forms as follow:

$$
\begin{bmatrix}
\mathbf{a}_{11} & \mathbf{a}_{12} & \ldots & \mathbf{a}_{1n} \\
\mathbf{a}_{21} & \mathbf{a}_{22} & \ldots & \mathbf{a}_{2n} \\
\vdots & & & \\
\mathbf{a}_{n1} & \mathbf{a}_{n2} & \ldots & \mathbf{a}_{nn}
\end{bmatrix}
\begin{bmatrix}
\mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_n
\end{bmatrix}
=
\begin{bmatrix}
\mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_n
\end{bmatrix}
$$

or

$$\sum_{j=1}^{n} \mathbf{a}_{ij}\,\mathbf{x}_j = \mathbf{y}_i \qquad \text{for } i = 1, \ldots, n$$

The shorthand notation of the equation is

$$\mathbf{A\,X} = \mathbf{Y}$$

where : **A** is m x n matrix.

X and **Y** are column vectors.

From the equation (4-2) we obtain

$$\mathbf{a}_{ij}\,\frac{\mathbf{w}_j}{\mathbf{w}_i} = 1 \qquad \text{for } i,j = 1, \ldots, n$$

and consequently

$$\sum_{j=1}^{n} \mathbf{a}_{ij}\, \mathbf{w}_j\, \frac{1}{\mathbf{w}_i} = \mathrm{n} \qquad \text{for } i = 1, \ldots, \mathrm{n}$$

or

$$\sum_{j=1}^{n} \mathbf{a}_{ij}\, \mathbf{w}_j = \mathrm{n}\ \mathbf{w}_i \qquad \text{for } i = 1, \ldots, \mathrm{n}$$

which is equivalent to

$$\boxed{\mathbf{A\ w = n\ w}} \qquad (4\text{-}3)$$

In linear algebra **w** is called an eigenvector of **A** with eigenvalue of **n**. When written fully the equation will be

$$\begin{bmatrix} \frac{\mathbf{w}_1}{\mathbf{w}_1} & \frac{\mathbf{w}_1}{\mathbf{w}_2} & \cdots & \frac{\mathbf{w}_1}{\mathbf{w}_n} \\ \frac{\mathbf{w}_2}{\mathbf{w}_1} & \frac{\mathbf{w}_2}{\mathbf{w}_2} & \cdots & \frac{\mathbf{w}_2}{\mathbf{w}_n} \\ \vdots & \vdots & & \vdots \\ \frac{\mathbf{w}_n}{\mathbf{w}_1} & \frac{\mathbf{w}_n}{\mathbf{w}_2} & \cdots & \frac{\mathbf{w}_n}{\mathbf{w}_n} \end{bmatrix} \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \vdots \\ \mathbf{w}_n \end{bmatrix} = \mathbf{n} \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \vdots \\ \mathbf{w}_n \end{bmatrix}$$

Computation of Eigenvalue and Eigenvector

In practice $\mathbf{a}_{ij}$ are not derived from exact measurement, but based on subjective judgements. Consequently, $\mathbf{a}_{ij}$ will deviate from ideal ratio $\mathbf{w}_i/\mathbf{w}_j$ and equation (4-3) will no longer hold.

Suppose that $\lambda_1, \lambda_2, \ldots, \lambda_n$ are eigenvalues of $\mathbf{A}$, therefore they satisfy equation

$$\mathbf{A}\,\mathbf{X} = \lambda\,\mathbf{X}$$

If $\mathbf{a}_{ii} = 1$ for all i, then

$$\sum_{i=1}^{n} \lambda_i = \mathbf{n}$$

If matrix $\mathbf{A}$ is consistent, the equation (4-3) is held and all the eigenvalues are zero, except one which has the largest value of $\mathbf{n}$. The small changes of the entries $\mathbf{a}_{ij}$ of a consistent matrix $\mathbf{A}$ will change the eigenvalues by small amounts. Combining this results will be found that if the diagonal consistent matrix $\mathbf{A}$ is one, then a small deviation of $\mathbf{a}_{ij}$ will keep the largest eigenvalue λ_{max} close to $\mathbf{n}$ and the remaining eigenvalues close to zero [Saaty, 1994]. Therefore, for pair-wise comparison matrix $\mathbf{A}$ which is derived from subjective judgement, in order to find the priority vector, we must find the vector $\mathbf{w}$ which satisfy

$$\mathbf{A}\,\mathbf{w} = \lambda_{max}\,\mathbf{w} \tag{4-4}$$

The eigenvector $\mathbf{w}$ derived from equation (4-4) is not unique. Normalisation is carried out to ensure the uniqueness of $\mathbf{w}$ by setting

$$\alpha = \sum_{i=1}^{n} \mathbf{w}_i \tag{4-5}$$

and replacing $\mathbf{w}$ by $(1/\alpha)\,\mathbf{w}$. This makes

$$\sum_{i=1}^{n} \mathbf{w}_i = 1$$

Let us consider equation (4-4)

$$\mathbf{A}\,\mathbf{w} = \lambda_{max}\ \mathbf{w}$$

The equation can be transformed into

$$\mathbf{A}\,\mathbf{w} - \lambda_{max}\ \mathbf{w} = \mathbf{0}$$

$$\boxed{(\mathbf{A} - \mathbf{I}\,\lambda_{max})\,\mathbf{w} = \mathbf{0}} \qquad (4\text{-}6)$$

where $\mathbf{I}$ is an identity matrix, $\mathbf{w}$ would be the eigenvector of $\mathbf{A}$ and λ_{max} would be the corresponding maximum eigenvalue if there is a nontrivial (nonzero) solution of equation (4-6). Nontrivial solution of equation (4-6) exists if matrix $\mathbf{A} - \mathbf{I}\,\lambda_{max}$ is singular, i.e. its determinant $|\mathbf{A} - \mathbf{I}\,\lambda_{max}|$ is zero.

For example the eigenvalue and eigenvectors of the pair-wise comparison matrix of stones X, Y and Z can be computed as follows

$$\mathbf{A} = \begin{bmatrix} 1 & 2/3 & 2/5 \\ 3/2 & 1 & 3/5 \\ 5/2 & 5/3 & 1 \end{bmatrix} \ ; \ \mathbf{I} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$|\mathbf{A} - \mathbf{I}\,\lambda| = \begin{vmatrix} 1-\lambda & 2/3 & 2/5 \\ 3/2 & 1-\lambda & 3/5 \\ 5/2 & 5/3 & 1-\lambda \end{vmatrix} = \mathbf{0}$$

This leads to an $\mathbf{n}^{th}$ degree of polynomial in λ as follows

$\lambda^2 (\lambda - 3) = 0$

The solution of this polynomial is

$$\lambda_1 = 0, \lambda_2 = 0, \lambda_3 = \lambda_{max} = 3$$

It is clear that if the matrix **A** is consistent then all the eigenvalues will be zero, except one λ_{max} equal to **n**.

The eigenvector or priority will be derived as follows:
From equation (4-4), $\mathbf{A}\,\mathbf{w} = \lambda_{max}\,\mathbf{w}$,

$$\mathbf{A} = \begin{bmatrix} 1 & 2/3 & 2/5 \\ 3/2 & 1 & 3/5 \\ 5/2 & 5/3 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \mathbf{w}_3 \end{bmatrix} = 3 \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \mathbf{w}_3 \end{bmatrix}$$

$$1\,\mathbf{w}_1 + 2/3\,\mathbf{w}_2 + 2/5\,\mathbf{w}_3 = 3\,\mathbf{w}_1$$
$$3/2\,\mathbf{w}_1 + 1\,\mathbf{w}_2 + 3/5\,\mathbf{w}_3 = 3\,\mathbf{w}_2$$
$$5/2\,\mathbf{w}_1 + 5/3\,\mathbf{w}_2 + 1\,\mathbf{w}_3 = 3\,\mathbf{w}_3$$

Since the rank of matrix **A** is a unity, the above equation has multiple solutions of **w** as follows:

$$\mathbf{w}_3 = 5/3\,\mathbf{w}_2 = 5/2\,\mathbf{w}_1$$

Any vectors which satisfy that equation are the eigenvectors of matrix **A** associated to maximum eigenvalue $\lambda_{max} = 3$. Normalisation using equation (4-5) is used to get a unique eigenvector **w**. This will lead to a unique eigenvector (priority)

$$\mathbf{w} = \begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2 \\ \mathbf{w}_1 \end{bmatrix} = \begin{bmatrix} 0.2 \\ 0.3 \\ 0.5 \end{bmatrix}$$

The result conforms with the data that the weights of stones X, Y and Z are 2 lb., 3 lb. and 5 lb. respectively.

If the size of the matrix is large, as in a performance measurement system, the computation of priority using the equations (4-4) and (4-6) will be tedious and time consuming. From matrix theory the eigenvector associated with the principal eigenvalue of A can be obtained using the equation [Saaty and Vargas, 1982].

$$\lim_{k \to \infty} \frac{A^k e}{e^T A^k e} = C w \qquad (4\text{-}7)$$

Where e is the unity column vector, e^T is its transpose and C is a positive constant. In other words the eigenvector associated to the principal eigenvalue is obtained by raising the matrix to arbitrarily large power and dividing the sum of each row by the sum of the elements of the matrix. The computation is terminated if an eigenvector with sufficient accuracy has been produced. This procedure can be carried out easily and quickly using a computer programme.

Analytic Hierarchy Process – The Scale

The Analytic Hierarchy Process uses ratio scale to measure the preference of one factor over another. This scale is derived based on Weber-Fechner's psychophysical law [Saaty, 1980, Saaty 1994].

In 1846 Ernest Heinrich Weber (1795-1878) equationed his law regarding a stimulus of measurable magnitudes. He said that we needed to increase a stimulus S by a minimum amount ΔS to reach a point where our senses can first discriminate between S and S+ ΔS [Saaty, 1994]. The ΔS is called the just noticeable difference. The ratio

$r = \Delta S/S$ does not depend on S. Weber's law states that '*change in sensation is noticed when the stimulus is increased by a constant percentage of stimulus itself*'.

Fechner considered a sequence of just noticeable increasing stimuli [Batschelet, 1973]. He denoted the first noticeable stimuli by S_0. The next just noticeable stimulus is given by

$$S_1 = S_0 + \Delta S_0 = (1+r)\, S_0$$

Similarly

$$S_2 = S_1 + \Delta S_1 = (1+r)\, S_1 = (1+r)^2 S_0 = \alpha^2 S_0$$

In general

$$\boxed{S_n = S_{n-1}\,\alpha = S_0\,\alpha^n} \qquad \text{for } n = 0, 1, \ldots. \qquad (4\text{-}8)$$

or

$$\boxed{n = \frac{(\log S_n - \log S_0)}{\log \alpha}} \qquad (4\text{-}9)$$

The equation (4-9) implies that the corresponding sensations should follow each other in arithmetic sequence at the discrete points at which just noticeable differences occur. By calibrating the stimulus it is possible to have $\log S_0 = 0$ or $S_0 = 1$. This is carried out by comparing one factor with itself. The next noticeable response is due to the stimulus

$$S_1 = S_0\,\alpha = \alpha,$$

$$n_1 = \frac{(\log S_1 - \log S_0)}{\log \alpha} = \frac{\log \alpha - 0}{\log \alpha} = 1$$

$$S_2 = S_0\,\alpha^2$$

$$n_2 = \frac{(\log S_2 - \log S_0)}{\log \alpha} = \frac{\log \alpha^2 - 0}{\log \alpha} = 2$$

Using that method we obtain the sequence 1, 2, 3, ... The Analytic Hierarchy Process sets nine as the upper limit of the scale for the following reasons [Saaty, 1980]:

(1) The qualitative distinctions are meaningful in practice and have an element of precision when items being compared are in the same order of magnitude or close together with regard to the property used to make the comparison.

(2) People's ability to make qualitative distinctions is well represented by five attributes: equal, weak, strong, very strong and absolute. Between adjacent attributes can be used if greater precision is needed. This total number of scales will be nine.

(3) Miller (1956) suggests that the human brain capacity for processing simultaneous information is limited to 7 ± 2.

As a result the AHP uses the ratio scales as indicated in Table 4.11.

Table 4.11. The analytic hierarchy process ratio scale [Saaty, 1980].

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Very strong or demonstrated importance
9	Absolute importance
2, 4, 6 and 8 are used to facilitate compromise between slightly differing judgements.	

Analytic Hierarchy Process - the Consistency of Judgement

The Analytic Hierarchy Process provides an equation to check the consistency of judgement. The equation is developed based on the fact that the small changes in $\mathbf{a}_{ij}$ will bring small changes in λ_{max}. If the pair-wise comparison matrix is consistent then λ_{max} equals $\mathbf{n}$. The more λ_{max} is greater than $\mathbf{n}$, the more judgement is inconsistent. Therefore, the mean deviation of λ_{max} from $\mathbf{n}$, then is called Inconsistency Index, can be used to measure the inconsistency of the judgement. The value of Inconsistency Index can be calculated using the formula (4-10) below.

$$\text{Inconsistency Index} = \frac{\lambda_{max} - \mathbf{n}}{\mathbf{n} - 1} \qquad (4\text{-}10)$$

The value of Inconsistency Index of random judgement called Random Index is used to decide the inconsistency of the judgement. If the ratio of Inconsistency Index of the judgement to Random Index, then is called Inconsistency Ratio as indicated in formula (4-11), is greater than 10 % , the judgement is considered to be inconsistent.

$$\text{Inconsistency ratio} = \frac{\text{Inconsistency Index}}{\text{Random Index}} \qquad (4\text{-}11)$$

The value of Random Index for a different number of factors is indicated in Table 4.12.

Table 4.12. Random Index

n	R.I		n	R.I		n	R.I
1	0.0		6	1.24		11	1.51
2	0.0		7	1.32		12	1.54
3	0.58		8	1.42		13	1.56
4	0.90		9	1.45		14	1.57
5	1.12		10	1.49		15	1.58

Then the inconsistency index of hierarchy can be computed using equation (4-12).

$$II_H = \sum_{j=1}^{h} \sum_{i=1}^{n_{ij+1}} w_{ij}\, \mu_{ij+1} \qquad (4\text{-}12)$$

where: - n_j, $j = 1, 2, \ldots, h$ is the number of elements in the j^{th} level of hierarchy,

- w_{ij} is the composite weight of the i_{th} criterion of the j_{th} level,

- μ_{ij+1} is the consistency index of all elements in the $(j+1)^{st}$ level compared to the i^{th} criterion of the j^{th} level,

n_{ij+1} is the number of elements of the $(j+1)^{st}$ level with respect to the i^{th} criterion of the j^{th} level.

The Composition of the Analytic Hierarchy Process

In the AHP a large problem is decomposed into several smaller problems. The smaller problems are structured in hierarchical fashion. The priority of factors is computed level by level. In the final stage of computation the composition process is carried out to address the original problem. In a particular level, the Analytic Hierarchy Process uses the additive composition equation to compute the priority of factor affecting performance with respect to criteria, as indicated in equation (4-13).

$$w_i^H = \sum_{j=1}^{m} w_{ij} v_j \qquad \text{for } i = 1, 2, \ldots, n \qquad (4\text{-}13)$$

where : - w_i^H is the priority of factor i,

- n is the number of factor,
- m is the number criteria in the particular level,
- w_{ij} is the priority of factor i with respect to criteria j,
- v_j the weights of criteria j.

4.7 The Controversy and Variants of the Analytic Hierarchy Process

The Analytic Hierarchy Process may be the most popular multi-criteria decision analysis model [Zahedi, 1986]. More than 60 applications of the model were published in the years 1990 and 1991 [Murphy, 1993]. However, the Analytic Hierarchy Process is also the most criticised model [Belton and Gear, 1983; Belton and Gear, 1985; Belton, 1986; Dyer, 1990a; Dyer, 1990b]. This sub-chapter will present the areas of criticism of the Analytic Hierarchy Process.

4.7.1 The controversy of the analytic hierarchy process

Belton and Gear (1980, 1985) were the first scholars who criticised the AHP. They used a simple example as depicted in Figure 4.14 to show the inconsistency of the ranking produced by the AHP if an alternative is added or removed.

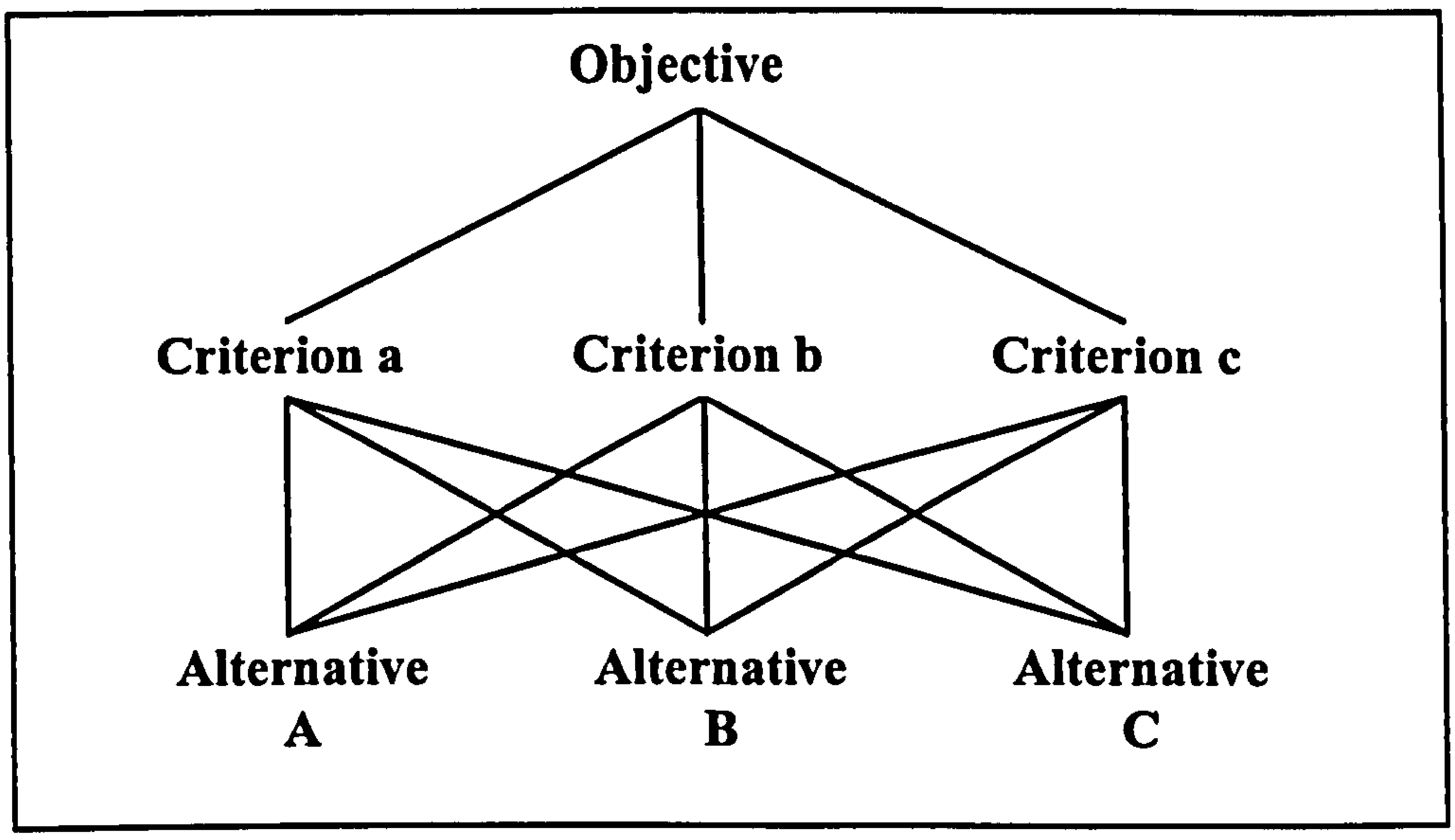


Figure 4.14. Belton and Gear's example.

Supposing the pair-wise comparison matrices and local priorities of each alternative relative to each criterion were as follows:

Criterion a, Criterion b, Criterion c

$$\begin{bmatrix} 1 & 1/9 & 1 \\ 9 & 1 & 9 \\ 1 & 1/9 & 1 \end{bmatrix} = \begin{bmatrix} 1/11 \\ 9/11 \\ 1/11 \end{bmatrix}, \quad \begin{bmatrix} 1 & 9 & 9 \\ 1/9 & 1 & 1 \\ 1/9 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 9/11 \\ 1/11 \\ 1/11 \end{bmatrix}, \quad \begin{bmatrix} 1 & 8/9 & 8 \\ 9/8 & 1 & 9 \\ 1/8 & 1/9 & 1 \end{bmatrix} = \begin{bmatrix} 8/18 \\ 9/18 \\ 1/18 \end{bmatrix}$$

then if each criteria were considered equally important, the vector weight would be (1/3, 1/3, 1/3). The overall priority and the ranking of the alternatives would be:

Ranking	Alternative	Priority
1	B	0.47
2	A	0.45
3	C	0.08

and an additional alternative D, which is in fact a copy of alternative B, is added without changing the initial entries of pair-wise comparison matrix of alternatives A, B and C. The new pair-wise comparison matrices and local priorities of each alternative relative to each criterion would be:

Criterion a

$$\begin{bmatrix} 1 & 1/9 & 1 & 1/9 \\ 9 & 1 & 9 & 1 \\ 1 & 1/9 & 1 & 1/9 \\ 9 & 1 & 9 & 1 \end{bmatrix} = \begin{bmatrix} 1/20 \\ 9/20 \\ 1/20 \\ 9/20 \end{bmatrix},$$

Criterion b

$$\begin{bmatrix} 1 & 9 & 9 & 9 \\ 1/9 & 1 & 1 & 1 \\ 1/9 & 1 & 1 & 1 \\ 1/9 & 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 9/12 \\ 1/12 \\ 1/12 \\ 1/12 \end{bmatrix},$$

Criterion c

$$\begin{bmatrix} 1 & 8/9 & 8 & 8/9 \\ 9/8 & 1 & 9 & 1 \\ 1/8 & 1/9 & 1 & 1/9 \\ 9/8 & 1 & 9 & 1 \end{bmatrix} = \begin{bmatrix} 8/27 \\ 9/27 \\ 1/27 \\ 9/27 \end{bmatrix}$$

Hence, the new overall priority and the ranking of the alternatives would be:

Ranking	Alternative	Priority
1	A	037
2 and 3	B,D	0.29
4	C	0.06

The result shows that the ranking of alternatives A and B is reversed by the addition of a copy of alternative B. Belton and Gear (1980) argued that the sources of rank reversal phenomenon which occurred in that example could be:

1. The normalisation procedure so that the sum of the entries of priority vector is a unity.
2. The concept of criteria weight.

3. The scale and the additive composition equation.

Belton and Gear (1980, 1985) suggested that the normalisation procedures used by the Analytic Hierarchy Process are consistent with the belief that the relative importance of criteria is proportional to the arithmetic mean value of the alternatives relative to each criterion. This was later supported by other authors [Watson and Freeling, 1982; Watson and Freeling, 1983; Schenkerman, 1994; Boucher et al, 1997]. Consequently, the question asked of the manager must be made very clear, i.e. whether the criteria weights associate with the arithmetic mean of the values of alternatives under consideration. Otherwise, the question would be meaningless and lead to an inaccurate solution [Watson and Freeling, 1983; Belton, 1986].

To preserve the ranking, Belton and Gear (1980) proposed different normalisation procedure. Instead of normalising the entries of priority vector so that the sum is a unity, normalisation should be carried out so that the maximum value of the entries of priority vector is equal to one. This procedure is consistent with a definition of weight being the value of a unit on the scale on which the criterion is measured. The scale is determined by the nature of the alternative ranked most highly on it. Consequently, the addition and removal of an alternative to the existing alternative could change the weight of the criterion depending on whether or not the maximum entry of priority vector changed under each criterion.

Under the normalisation method maximum entry is equal to 1, therefore, the previous example can be solved as follows:

Renormalised priority vectors:

Criterion a, Criterion b, Criterion c

$$\begin{bmatrix} 1/9 \\ 1 \\ 1/9 \end{bmatrix}, \begin{bmatrix} 1 \\ 1/9 \\ 1/9 \end{bmatrix}, \begin{bmatrix} 8/9 \\ 1 \\ 1/9 \end{bmatrix}$$

If each criterion is still considered equally important, the overall priority and the ranking of the alternatives are:

Ranking	Alternative	Priority
1	B	19/27
2	A	2/3
3	C	1/9

If alternative D is added, then the renormalised priority vectors are

$$\underset{\text{Criterion a}}{\begin{bmatrix} 1/9 \\ 1 \\ 1/9 \\ 1 \end{bmatrix}}, \quad \underset{\text{Criterion b}}{\begin{bmatrix} 1 \\ 1/9 \\ 1/9 \\ 1/9 \end{bmatrix}}, \quad \underset{\text{Criterion c}}{\begin{bmatrix} 8/9 \\ 1 \\ 1/9 \\ 1 \end{bmatrix}}$$

Since the maximum entries under each criterion are not changed, the weights of the criteria remain the same. The overall priority and the ranking of the alternatives are:

Ranking	Alternative	Priority
1, 2	B, D	2/3
3	A	19/27
4	C	1/9

The ranking is preserved.

Furthermore, Belton (1986) doubted that the 1-9 scales used by the AHP could accommodate the judgement well. For example, if A was four times preferred to B and C was five times preferred to B, then C had to be 25 times preferred to A. The Analytic Hierarchy Process considers C as nine times preferred to A. The additive composition equation used by the AHP is also criticised as a source of rank reversal.

The multiplicative composition equation would be better used to avoid rank reversal [Belton, 1986; Lootsma, 1993].

A similar criticism was also raised by Dyer (1990a, 1990b). He believed that rank reversal is just a symptom of a much more profound problem with the Analytic Hierarchy Process: the method is flawed as a procedure for ranking alternatives since the rankings provided by the AHP are arbitrary.

In responding to those criticisms, Saaty and his proponents defended that:

1. Rank reversal is not always a bad thing. It is natural and has been accepted as a common phenomenon in areas of economy, marketing and human behaviour [Saaty, 1984; Saaty, 1994]. Therefore, rank reversal should not be considered as a weakness of the AHP, but instead, strength, since the AHP can accommodate the natural phenomenon.
2. Rank reversal does occur in Belton and Gear's example because it violates *Axiom 4* of the AHP, which essentially states that when a copy of an alternative is added, new criteria must be added to preserve one's expectations [Harker and Vargas, 1987; Saaty and Takizawa, 1986].
3. Most of problems in multi-criteria decision making show that the weights of criteria are independent to alternatives. Consequently, there is no need to assign the criteria weights dependent on the value of alternatives as proposed by the critics of the AHP. However, if interdependency does occur between criteria and alternatives or between one alternative and another, the AHP system with feedback should be used [Harker and Vargas, 1987; Saaty, 1994; Saaty, 1996].
4. Experience of using the AHP in government, industry and other private organisations has shown that there have been very few complaints from people not understanding what the questionnaires meant. If a problem was complicated then assistance to formulate the problem, organise the criteria and design the questionnaires was required. Two good practical examples usually help people understand the process [Saaty, 1984].
5. Experiments on using the 1-9 scale proved that the scale captures the preference of an individual on homogeneous objects fairly well [Saaty, 1980; Harker and Vargas,

1987]. However, the scale can be altered to suit an individual's needs [Harker and Vargas, 1987]. For example, instead of using a 1, 2, ..., 9 scale, one can use a 1.1, 1.2, ..., 1.9 scale if necessary [Saaty, 1994]. Finally, clustering should be carried out if the objects are of different orders of magnitude.

6. Additive equation is the correct method to be used for the composition process since it is consistent with the decomposition process carried out in breaking the large problem into several smaller problems. For example, if a large object is divided equally into four smaller objects and then each smaller object is divided equally into four smaller-smaller objects, then the last object will be (1/4 x 1/4) smaller than the original object. It is not $(1/4)^{1/4}$ smaller than the original object as implied by the multiplicative equation [Saaty, 1994].

4.7.2 The variants of the analytic hierarchy process

The controversy surrounding the Analytic Hierarchy Process has stimulated people to develop variants of the AHP. The following are a few variants which have often been cited in literature.

The Referenced AHP

Schoner and Wedly (1989) and Schoner et al, (1993) demonstrated that to avoid rank reversal, the vector of criteria weights must reflect a particular interpretation of the relative importance of criteria, i.e. it must reflect the ratio of the sum (or average) of the subjective values of the alternative on criteria. This concept has also been proposed by other authors [Belton and Gear, 1980; Watson and Freeling, 1982; Watson and Freeling, 1983; Schenkerman, 1994; Boucher et al, 1997]. The referenced AHP mathematically can be expressed as:

$$x_j = \frac{T_j}{\sum_{j=1}^{n} \bar{T}_j} = k\,\bar{T}_j \qquad (4\text{-}14)$$

Where:

x_j is the priority of criteria j,

T_j is j^{th} column of T,

$\bar{T}_j$ is the average of T_j.

Basically the Referenced AHP is the same as the conventional AHP except for the question posed to the manager. In Referenced AHP the question should ***refer*** to average values of the objects, for example, *"How many times is the average sound of the two systems more preferred to that of the average price?"*, and not *"How many times is the sound more preferred to the price?"* as proposed by the conventional AHP [Schoner et al, 1997].

Linking Pins

Consider that the vector **W** is the synthesised global priorities of the alternatives. It can be derived from [Saaty, 1986]:

$$\mathbf{W} = \mathbf{A\,S\,x} = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{in} \\ A_{21} & A_{12} & \dots & A_{in} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ A_{m1} & A_{m2} & \dots & A_{mn} \end{bmatrix} \cdot \begin{bmatrix} S_{11} & 0 & \dots & 0 \\ 0 & S_{22} & \dots & 0 \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ 0 & 0 & \dots & S_{nn} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_n \end{bmatrix} \qquad (4\text{-}15)$$

where:

- $\mathbf{A}_{ij} = \dfrac{\mathbf{T}_{ij}}{\mathbf{T}_{*j}}$

- $\mathbf{T}_{ij}$ is a subjective value of alternative i on criterion j measured in ratio scale

- $\mathbf{T}_{*j} = \min\{\mathbf{T}_{1j}, \mathbf{T}_{2j}, \dots, \mathbf{T}_{mj}\}$

- S is a diagonal matrix where each diagonal element $\mathbf{S}_{jj}$ is defined as:

$$\mathbf{S}_{jj} = \frac{1}{\mathbf{e}^T \mathbf{A}^j} = \frac{(\mathbf{T}_{*j})}{\sum_{i=1}^{m} \mathbf{T}_{ij}} = \frac{\mathbf{T}_{*j}}{(\mathrm{m}\,\overline{\mathbf{T}}_j)}$$

where: - e is unity vector,

- e^T is the transpose of e,
- $\overline{T}_j$ is the average subject value of the alternatives under criterion *j*.
- x is the weight of the criteria.

The equation (4-15) can be generalised as:

$$W = A\,S\,x = A\,N\,N\text{-}1\,S\,x = (A\,N)(N^{-1}\,S\,x) = A\,N\,y \tag{4-16}$$

where: $y = N^{-1}\,S\,x$

By selecting a different N for a different normalisation method, the alternative forms for $y = N^{-1}\,S\,x$ are generated, each of which implies a different interpretation of assessing the relative importance of the criteria [Schoner et al, 1993]. If N = S, equation (4-16) reduces to equation (4-14), which is actually the Referenced AHP, the weight of the criteria referring to the average value of the objects. If N = I (identity matrix) the weight of the criteria refers to the minimum value of the objects. Finally, if the diagonal elements of N are set to $n_{jj} = T_{*j} / T_j^*$ where $T_j^* = \max\{T_{1j}, T_{2j}, \ldots, T_{mj}\}$ the weight of the criteria refers to the maximum values of the objects. In conclusion, there is no single interpretation of criteria weight. The interpretation of criteria weight depends on the ***linking pins*** which are used as a basis for comparison. Again, the linking pins model basically is similar to the conventional AHP, with the exception of the questions posed to the decision maker for eliciting the decision maker's judgement on the weight of the criteria. The question must refer to the linking pins entries under the criteria.

Multiplicative AHP

Lootsma (1993, 1997) developed Multiplicative AHP because of criticisms raised to conventional AHP, especially on the fundamental scale, the estimation of the priority and the composition techniques.

In general, the multiplicative AHP works as follows. Alternatives A_j and A_k are compared under the criterion C_i. The preference information (indifference, weak, strict, strong, or very strong preference for one of the two) is collected and converted the verbal statement of decision maker d into a numerical value $r^{(i)}_{jkd}$ on a geometric scale, i.e. on a discrete scale with echelons constituting a series of geometric progression [Lootsma, 1993]. Next, logarithmic regression is used to calculate the single-criterion impact score $w_i(A_j)$, $j = 1, ..., n$, approximating the subjective values of the alternative under criterion Ci.

In calculating the weight of the criteria, the decision maker is asked to state his preference among the criteria (weak, strict, strong or very strong). Judgement is then converted into numerical value on a particular geometric scale. Logarithmic regression is used to calculate normalised weights $w(C_i)$, $i = 1, ..., m$, for the respective criteria. Finally, the overall priority of alternatives is computed using the composition/aggregation equation.

Multiplicative AHP - The Scale

Let us consider a decision maker who evaluates the alternatives under price criterion. In multiplicative AHP it is assume that the decision-maker is only prepared to consider alternatives with prices between a desired lower bound P_{min} and upper bound P_{max}. In order to model the relative preference for alternative A_j respect to A_k in the range (P_{min}, P_{max}) by the grade with the geometric sequence of points

$$P_\mu = P_{min} + (P_{max} - P_{min}) * \frac{2^\mu}{64}, \quad \mu = 0, 1, ..., 6 \tag{4-17}$$

where:

- P_μ is the μth price category.
- μ is order of magnitude (integer).

The value of μ can be computed using the following equation

$$\mu = {}^2\log \{64 * \frac{P_\mu - P_{min}}{P_{max} - P_{min}}\} \tag{4-18}$$

The prices near category P_μ will be considered as belonging to that category. The corresponding verbal statement of the categories will be:

P_0 = cheap

P_2 = somewhat more expensive

P_4 = more expensive

P_6 = much more expensive.

The odd numbered grid points P_1, P_3, P_5 are used if the decision maker hesitates between two adjacent gradations of expensiveness. The even numbered grade points (major grid points) constitute the major grid points of a geometric sequence with progression factor 4. If the odd numbered grid points corresponding to hesitations are also taken into account, the grids constitute a geometric sequence with the progression factor 2.

For two cars A_j and A_k which its prices (criteria C_i) are belong to the categories $P_{i\mu j}$ and $P_{i\mu k}$, the relative preference r_{ijk} for A_j with respect to A_k is expressed by the inverse ratio of the price increment above P_{min} as shown by equation (4-19).

$$r_{ijk} = \frac{P_{\mu ik} - P_{min}}{P_{i\mu j} - P_{min}} = 2^{\mu_{ik} - \mu_{ij}} \qquad (4\text{-}19)$$

Therefore, a car in the price category P_0 is 4 times more desirable than a car in the price category P_2.

If the performance of the alternative under criterion C_i cannot be measured in physical or monetary value, the subjective preference of the decision-maker can be elicited using verbal expression. He would be asked to state whether he is indifferent to two alternatives under a given criterion, or whether he has a weak, definite or strong preference for one of them. Then the numerical estimate r_{ijk} of his relative preference for alternative A_j over alternative A_k under criterion C_i can be set using equation 4-20).

$$R_{ijk} = 2^{\delta_{ijk}} \qquad (4\text{-}20)$$

where δ_{ijk} stands for an integer valued index designating the major gradation of his comparative judgement. Thus, $\delta_{ijk} = 0$ designates indifference, $\delta_{ijk} = \pm 2$ designates weak preference, etc.

Multiplicative AHP - Computation of Priority Vector

The estimated r_{ijk} are bundled into a pair-wise comparison matrix, one for each criterion. Unlike the conventional AHP, in which the priority of alternative on the criteria is computed using eigenvector theory, in the Multiplicative AHP the priority of alternative A_j on the criteria is computed using the geometric mean of the *j*th row in the corresponding pair-wise comparison matrix as indicated by equation (4-21).

$$w_{ij} = \sqrt[n]{\prod_{k=1}^{n} r_{ijk}} \qquad (4\text{-}21)$$

Then the overall priority vector under all criteria is computed using equation (4-22).

$$f_j = \prod_i a_{ij}^{c_i} \qquad (4\text{-}22)$$

where c_i is the weight of criterion *i*.

Multiplicative AHP-The Relative Importance of Criteria

Multiplicative AHP uses a simple geometric sequence of values between 1/16 and 16, with echelons corresponding to indifference, weak, strict, strong and very strong preference. The geometric value, verbal preference and the weight of first criterion (C_f) with respect to the second criterion (C_s) are indicated in Table 4.13.

Table 4.13. Relative importance of criteria in Multiplicative AHP.

Geometric Value	Verbal Judgement	Weights
16	C_f vastly more important than C_s	0.95 and 0.05
8	C_f much more important than C_s	0.90 and 0.10
4	C_f more important than C_s	0.80 and 0.20
2	C_f somewhat more important than C_s	0.66 and 0.33
1	C_f as important as C_s	0.50 and 0.50
1/16	C_f vastly less important than C_s	0.05 and 0.95

4.8 Discussion and Conclusion

As mentioned earlier, performance measurement usually involves a number of factors and personnel from different departments. Eden et al (1983) pointed out that in organisational life the individual is an irrational and subjective person. He or she is involved in complicated social relationships and internal (organisational) political games. Different individuals will interpret a particular situation differently depending on their mental framework and political concerns. Therefore, in performance measurement system, the factors to be measured are often not well defined at the start and uncovering what the real factors to be measured are and their relationship is not always an easy task. This chapter reviewed the tools can be used to identify factors affecting performance. Those tools are repertory grids, mind map, focus group and cognitive map. The cognitive map is selected to be used in this research mainly because of its ability to accommodate the interaction of factors affecting performance.

For structuring the factors hierarchically, structured or tree diagram will be used in this research. By numbering the factors the relationship of the factors affecting performance can be clearly shown. The structured diagram is also widely used in multi-criteria decision analysis to structure the factors hierarchically. Based on these considerations structured diagram is selected to be used in this research.

Since the effect of a factor on performance is different from that of others, it is necessary to assign weights to factors affecting performance to reflect the degree of impacts of the factors on performance. These degrees of impact are important for monitoring and resource allocation purposes [Suwignjo et al, 1997c]. Five models often cited in literature have been used to prioritise the effects of factors on performance. These are pair comparison, graphical, simultaneous comparison techniques [Globerson, 1985], Path Analytic Model [Swamidass and Newell, 1985], Analytic Hierarchy Process [Lee et al, 1985; Rangone, 1996].

The pair comparison, graphical and simultaneous comparison techniques are very straightforward, simple and easy to use as no complicated computation is required. However, these techniques are purely intuitive. No theoretical background is used to justify their validity. As a result, the accuracy of the priorities derived by those techniques cannot be guaranteed and it is no surprise, therefore they are not widely used.

The Path Analytic Model seems to be a very good technique to use to identify the effect of variables on other variables, especially if the variables form a network. Using this technique one can analyse a limited number of variables under study and treat other variables as the disturbance. This process simplifies the problem significantly. Using the Path Analytic Model the direct and indirect effects of variables on other variables can be identified. As in the regression model, the Path Analytic Model provides information on how much the level of other variables will increase or decrease if the level of a particular variable increases/decreases a unit.

Similar to other statistical models, in order to get a good model, sufficient data is required. Usually up to ten lots of data are required to be able to develop a good model. In a performance measurement system, a large number of factors are involved and it could therefore prove to be a difficult task to collect enough data to develop a good model. Moreover, the computation involved in the Path Analytic Model is quite complicated for managers, especially if the number of factors involved is large. A simpler model would be better for managers.

As performance factors are multi-dimensional, a common scale is needed to aggregate the effects of factors on performance. If the number of factors is large, a systematic procedure is required to organise the factors in order that the computation of the effects of the factors on performance can be simplified. The Analytic Hierarchy Process would appear to be the appropriate model to serve such purpose. It has been applied widely, including in the area of performance measurement systems [Lee et al, 1985; Rangone, 1996]. Even though the Analytic Hierarchy Process is subject to criticism, a large number of successful applications of the model to various cases have been reported. Having reviewed the literature on multi-criteria decision analysis models and their applications extensively, the author believes that AHP is the most appropriate model to prioritise performance measures because of its simplicity, it is easily implemented and it is accurate.

Some variants of AHP have been developed including Referenced AHP, Linking Pins AHP and Multiplicative AHP. The Referenced AHP and the Linking Pins AHP only differ from conventional AHP in the way questions are posed, as has been discussed in the previous chapter. The Multiplicative AHP differs quite significantly to the conventional AHP in that the scale, the computation of priority vectors and the composition procedures used by Multiplicative AHP are different to those used by the conventional AHP. However, no single agreement exists among the experts on multi-criteria decision analysis on the validity of this model [Barzilai and Lootsma, 1997; Larichev, 1997; Korhonen, 1997; Vargas, 1997; Lootsma and Barzilai, 1997].

As stated, selecting the most appropriate model for aggregating and quantifying the effects of factors on performance is not an easy task. Perhaps it is worth acting what the editors of the Journal of Multi-Criteria Decision Analysis wrote in their Welcome (1992):

"*We recognise that there are differences, significant differences in the underlying principles, between the various methodologies practised around the world*",

and added:

"*We hope that part of the service the Journal can perform is to debate these differences so that we can learn from each other's strength*".

This hope is parallel to the belief of Costa et al (1997) that:

"*....the different streams of thought in MCDA must not be seen as conflicting, but rather as complementary approaches and sources of new and rich ideas. Under this constructive perspective, the image of the [MCDA as a] hydra with several heads can be replaced by a rocket with several engines ....*"

4.9 Summary

This chapter presents the available methods which can be used to identify factors affecting performance and their relationship, structure them hierarchically and prioritise the effects of factors on performance

The chapter concludes that:

(1) Cognitive maps is an appropriate tool for identifying factors affecting performance and their relationship for several reasons, e.g. it has been proved that cognitive maps can be used to solve management problems, can be used integratedly with multi-criteria decision analysis models and can be used alongside the AHP.

(2) Structured diagram is an appropriate tool for structuring the factors affecting performance hierarchically.

(3) Even although the AHP has suffered from criticism, it is an appropriate method for prioritising and aggregating the effects of factors on performance because of its simplicity and accuracy. The AHP may be theoretically imperfect, but it is acceptable.

The next chapter will discuss the development of a Quantitative Method for a Performance Measurement System. The method uses cognitive maps, structured diagram and the Analytic Hierarchy Process for identifying factors affecting performance, structuring the factors hierarchically and quantifying the effects of factors on performance.

Chapter 5

QUANTITATIVE METHODS FOR PERFORMANCE MEASUREMENT SYSTEMS

"When you can measure what you are speaking about and express it in number, you know something about it... .(otherwise) your knowledge is a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in thought advanced to the stage of science"

(Lord Kelvin, 1824-1907)

5.1 Introduction

As the business environment has been changing enormously in the last decade traditional performance measurement systems have become less relevant and new performance measurement systems, more suited to the new environment, are required. Several new performance measurement systems have been developed to respond to this requirement. Some of them, for example, the Balanced Scorecard [Kaplan and Norton, 1996], the SMART [Cross and Lynch, 1988-1989], the Performance Measurement Questionnaires [Dixon et al, 1990], the Cambridge Model [Neely, 1995] and the Integrated Performance Measurement System [Bititci et al, 1997], provide frameworks for designing new performance measurement systems, while the others such as Performance Measurement for World Class Manufacturing [Maskell, 1991] and Performance Criteria System [Globerson, 1985] provide criteria for developing new performance measurement systems. Table 5.1 shows the summary of the analysis on the existing new performance measurement systems using thirteen attributes, at the end of Chapter 3.

Table 5.1. The summary of the analysis on the existing new performance measurement systems.

Performance measurement model	Attributes											
	Framework	Starting point	Control / Improvement	Prioritisation	Relate to Strategy / Objective	Deployment procedure	Levels of organisation	Stated specific objectives	Review	External Monitor	Timely feedback	Integration	Interaction
Performance Measurement for World Class Manufacturing [Maskell, 1991]	None	None	Both	None	Relate to manufacturing strategy	None	None	As stated in seven common characteristics	Yes	None	Yes	No	No
Performance Criteria System [Globerson, 1985]	Yes	Performance criteria	Both	Yes	Relate to objectives	None	None	As stated in the guidelines	Yes	Yes	Yes	No	No
SMART System [Cross and Lynch, 1988-1989]	Yes	Corporate vision and strategy	Both	Yes	Yes	Yes	Yes	Continually self-adjusted to the future needs of the business	Yes	Partly	No	Yes	No
Performance Measurement Questionnaires [Dixon et al, 1990]	Yes	Improvement areas	Both	Yes	Yes	No	Partly	Linking strategy, actions and measures	Yes	No	No	Yes	No
Balanced Scorecard [Kaplan and Norton, 1996]	Yes	Business strategy	Learning	Partly	Yes	Partly	Partly	Communication, informing and learning system and strategic management technique	Yes	No	Yes	Yes	No

								nique					
Cambridge Model [Neely, 1995]	Yes	Product group	Both	Yes	Yes	No	No	Integrates, closes management loop and considers behavioural implications	Yes	No	Yes	Partly	No
Integrated Performance Measurement System [Bititci et al, 1997]	Yes	*Stakehol*der requirements and external monitors	*Both*	Yes	Relates to objectives	Yes	Yes	Align critical tasks and activities with top-level objectives, facilitates control, drive and maximise improvements	Yes	Yes	Not explicitly stated	Yes	Yes

As has been mentioned in the conclusion of Chapter 3, only the Integrated Performance Measurement System developed at the Centre for Strategic Manufacturing, University of Strathclyde, points out the importance for recognising and modelling interactions of factors affecting performance. A quantitative method for quantifying the effects of factors, including the interaction effects, has been developed. It is named the **Quantitative Method for Performance Measurement System (QMPMS)**.

5.2 The Framework of the Quantitative Method for Performance Measurement System

To identify and quantify the effect of factors on performance a method has been developed named Quantitative Method for Performance Measurement System (QMPMS). As has been mentioned in Chapter 1, the objectives of this method are:

1. To identify and quantify the effects of factors on performance and consolidate them into a single performance indicator.
2. To develop a tool for reducing the number of performance reports.

The are three steps to the Quantitative Method for Performance Measurement System as depicted in Figure 5.1.

5.2.1 Identification of factors affecting performance

Factors affecting performance are any variables which determine the level of achievement of performance. There is no unique answer on "*How many factors should be included in the analysis*?". Different cases with different objectives of study may require different number of factors to be considered in the analysis. However, we can use the general principle which says that *all the important factors should be included in the analysis but at the same time the number of factors is kept as small as possible.*

Factor identification is the most crucial step in QMPMS implementation. Failing to include all the factors affecting performance and identifying their relationship in implementation certainly would cause deterioration of results. In order to explore and identify factors affecting performance and their relationship, the QMPMS uses cognitive maps.

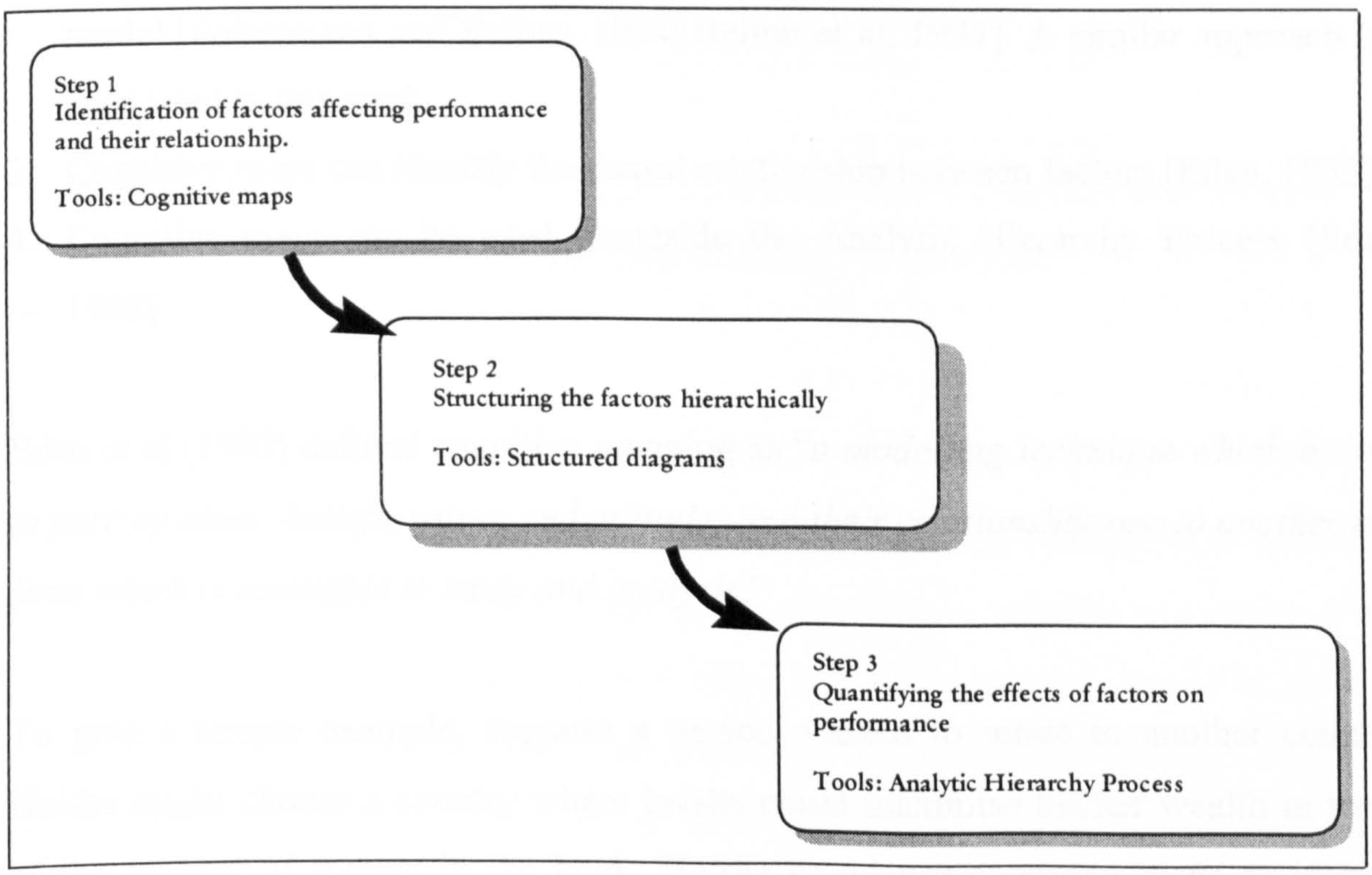


Figure 5.1. The framework of the QMPMS.

As stated in previous chapter, performance measurement usually involves a number of factors and personnel from more than one department. The factors to be measured are often not well defined from the beginning and uncovering what the real factors to be measured are and their relationship is not always an easy task. Eden et al (1983) pointed out that in organisational life the individual is an irrational and subjective person and may be involved in complicated social relationship and/or internal (organisational) political games. Therefore, different individuals will interpret a particular situation differently depending on their mental framework and political concerns. The analysis of the tools carried out in the Chapter 4 concluded that cognitive map would appear to be an effective tool to help identify the factors affecting performance and their relationship. The following support the conclusion:

1. It has been proved that cognitive maps can be used successfully to capture the ideas of decision-makers in solving management problems [Ackermann and Belton, 1994; Belton et al, 1997; Carlson and Walden, 1996].
2. Cognitive maps have been used integratedly with a multi-criteria decision analysis model [Ackermann and Belton, 1994; Belton et al, 1997]. A similar approach has been used in this work.
3. Cognitive maps can identify the causal relationship between factors [Eden, 1983].
4. Cognitive maps can be used alongside the Analytic Hierarchy Process [Eden, 1988].

Eden et al (1983) defined cognitive mapping as "*a modelling technique which intends to portray ideas, beliefs, values and attitudes and their relationship one to another in a form which is amenable to study and analysis.*"

To give a simple example, suppose a person wanted to move to another country. He/she might choose a country where he/she could maximise his/her wealth in terms of the amount of money in the bank. He/she could use cognitive maps to identify factors affecting the amount of his/her money in the bank. Figure 5.2(a) shows the cognitive maps produced. The effect of factors on performance or on other factors is indicated by an arrow.

In general, the effect of a factor on performance, as indicated by Figure 5.2(a), can be classified into:

- Direct (vertical) effect
- Indirect (horizontal) effect
- Self-interaction effect

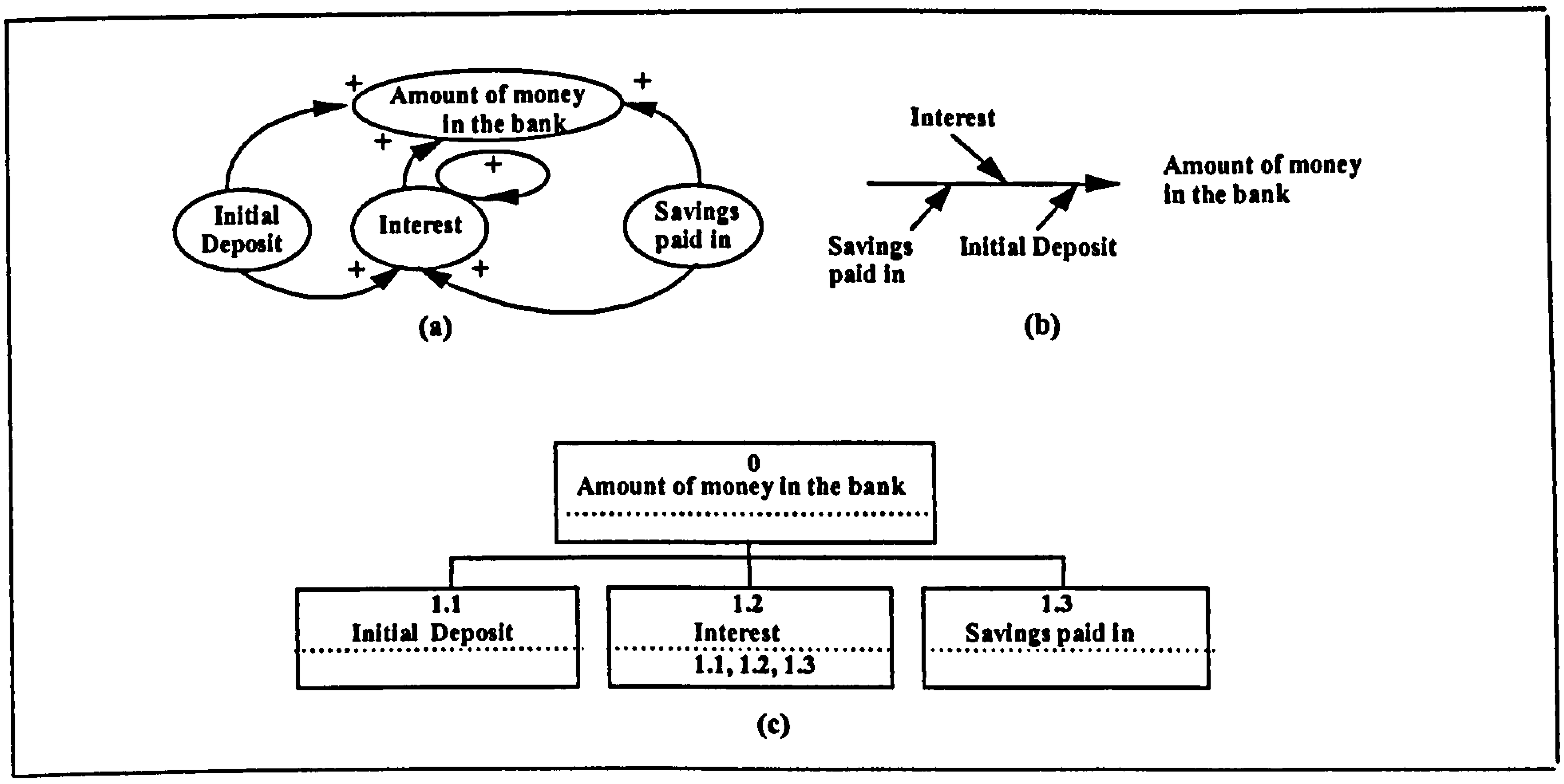


Figure 5.2. (a) Cognitive maps, (b) Cause and effect diagram and (c) Tree diagram of 'amount of money in the bank'.

Direct effect

Direct effect of a factor on performance is an aggregate of all the effects of factors on performance through that factor. Usually direct effect is people's perception about 'effect' of factor on performance. Direct effect of a factor is made up of its inherent effect, its self-interaction effect and indirect effects of other factors through that factor. As indicated by Figure 5.2(a) there are three factors that directly affect 'amount of money in the bank'. The factors are 'initial deposit', 'interest' and 'savings paid in'. Positive signs at the end of the arrows indicate positive effects of the factors.

Indirect effect

In addition to direct or vertical effect, factors 'initial deposit' and 'savings paid in' in Figure 5.2(a) also indirectly affect 'amount of money in the bank' through their effects on other factors within the same level (factor 'interest'). Indirect effect is the effect of a factor on performance through other factors within the same level.

Self-interaction effect

While factors 'initial deposit' and 'savings paid in' indirectly affect 'amount of money in the bank' through their horizontal effects on factor 'interest', factor 'interest' indirectly affects 'amount of money in the bank' through its self-interaction. Self-interaction effect is the effect of a factor on itself. Factor 'interest' in Figure 5.2(a) has self-interaction effect since the amount of money received from interest this month will increase the amount of interest received next month.

5.2.2 Structuring the factors hierarchically

In the first step, the main concern is merely to elaborate on the factors affecting performance and their relationship. No attempt is made to classify factors in the same level into one group. As a result, the hierarchical structure of the factors is not clear. Cause and effect diagrams can be used to identify the hierarchical structure of the factors [Bititci, 1995]. A factor is a member of level 0 if this factor is affected by other factors but it does not affect them, while factors which directly affect factors at a particular level will be the members of the next lower level. As has been shown by the analysis in Chapter 4, a structured diagram or tree diagram can then be used to give a clearer picture of the hierarchical structure. For the money in the bank problem the cause and effect diagram and the tree diagram can be seen in Figure 5.2(b) and 5.2(c). In this tree diagram, the number above each factor indicates the level and the factor's number within that level. For example, the number 1.2 above 'interest' indicates that interest is factor number 2 in level 1, while numbers below the factors indicate interaction relationship of the factors. For example, the numbers 1.1, 1.2, 1.3 below 'interest' indicate that besides affecting 'amount of money in the bank' directly (vertically), the factors also indirectly affect 'amount of money in the bank' through their interaction with 'interest'.

Structuring the factors hierarchically serves to simplify the problem through decomposing a large problem (factor at level 0) into several manageable, smaller problems (factors at lower levels). Analysis will be carried out level by level starting from the highest level down to the lowest level. At the final stage of analysis, the composition process will be carried out to address the top-level problem.

How widely and deeply should the original problem be decomposed? There is no unique answer to this question. However, Keeney and Raiffa (1976) and Keeney (1992) provided the following guidelines on what makes a good hierarchical structure:

- Completeness: the hierarchy includes all the important factors affecting performance.
- Operational: it is meaningful and can be implemented with considerable efforts.
- Decomposable: it allows different parts of the hierarchy to be analysed separately.
- Non-redundancy: no factor's effect on performance is counted twice.
- Minimum size: the number of factors included in the hierarchy is kept as small as possible.
- Understandable: it allows understanding and communication of the problem.
- Measurable: the factors can be measured quite comfortably.

5.2.3 Quantifying the effect of the factors on performance

Finally, the relative effects of the factors (direct, indirect and combined) can be quantified using the Analytic Hierarchy Process (AHP) procedures [Saaty, 1980; Saaty, 1994]. It was concluded in the literature review - Chapter 4 - that even although the AHP may be theoretically imperfect, it is acceptable practically.

The quantification process in AHP is carried out based on the results of pair-wise comparison among factors. For each pair of factors from a particular level, their effect on the factor from the next higher level (direct effect) or on the factor within the same cluster (indirect effect) is compared. A score lying between one (equals important) and nine (absolutely more important) is assigned for each comparison depending on the subjective judgement of the analyst. The result is a pair-wise comparison matrix. The relative effects of the factors on performance can be generated by normalising the eigenvector associated with the maximum eigenvalue of the pair-wise comparison matrix. A computer program package called ExpertChoice (1995) can be used to calculate the effects of factors on performance.

The pair-wise comparison questionnaire and the pair-wise comparison matrix of 'amount of money in the bank' problem described earlier are indicated in Figure 5.3.

Level : 0
Factor : Amount of money in bank.
Sub-factors : Initial deposit, Interest, Saving.

Row	Absolutely	Very Strong	Strong	Weak	Equal	Weak	Strong	Very Strong	Absolutely	Column
1.1 Deposit	-	-	V	-	-	-	-	-	-	1.2 Interest
1.1 Deposit	-	-	-	-	-	-	V	-	-	1.3 Saving
1.2 Interest	-	-	-	-	-	-	-	- V	-	1.3 Saving

(a)

Amount of money in bank	Deposit	Interest	Saving	Priority
Deposit	1	5	1/5	0.212
Interest	1/5	1	1/8	0.062
Saving	5	8	1	0.726

The priority in the table is computed using ExpertChoice software

(b)

Figure 5.3. (a) Pair-wise comparison questionnaire, (b) Pair-wise comparison matrix.

The questions posed would be: "Comparing factor 'A' to 'B', which one has a stronger effect on 'amount of money in the bank'?" and "How strong?". In answering these types of questions suppose someone believes that factor 'deposit' has a stronger effect on 'amount of money in the bank' compared to that of factor 'interest', then the score in the pair-wise comparison matrix is 5. Based on the result of pair-wise comparison questionnaire in Figure 5.3(a), the pair-wise comparison matrix of 'amount of money in the bank' can be constructed as indicated in Figure 5.3(b). Using ExpertChoice software, the relative effect of factors 'initial deposit', 'interest' and 'savings paid in' on 'amount of money in the bank' are 0.212, 0.062 and 0.726 respectively. The effect of factor 'savings paid in' on 'amount of money in the bank' is roughly 3.5 times stronger than the effect of 'initial deposit', while the effect of 'initial deposit' on 'amount of money in the bank' is roughly 3.5 times stronger than the effect of 'interest'.

The combined effects of the factors on performance can be computed by decomposing the direct effects of the factors into two clusters. For example, for factor A at a particular level as indicated in Figure 5.4, the direct effect of factor A on performance can be decomposed into cluster I and cluster II. Cluster I consists of the inherent effect of factor A, while cluster II consists of the self-interaction effect of factor A and the horizontal effects of other factors through factor A. The interaction effect of factor A on performance is made up of the self-interaction effect of factor A and the horizontal effects of factor A through other factors within the same level.

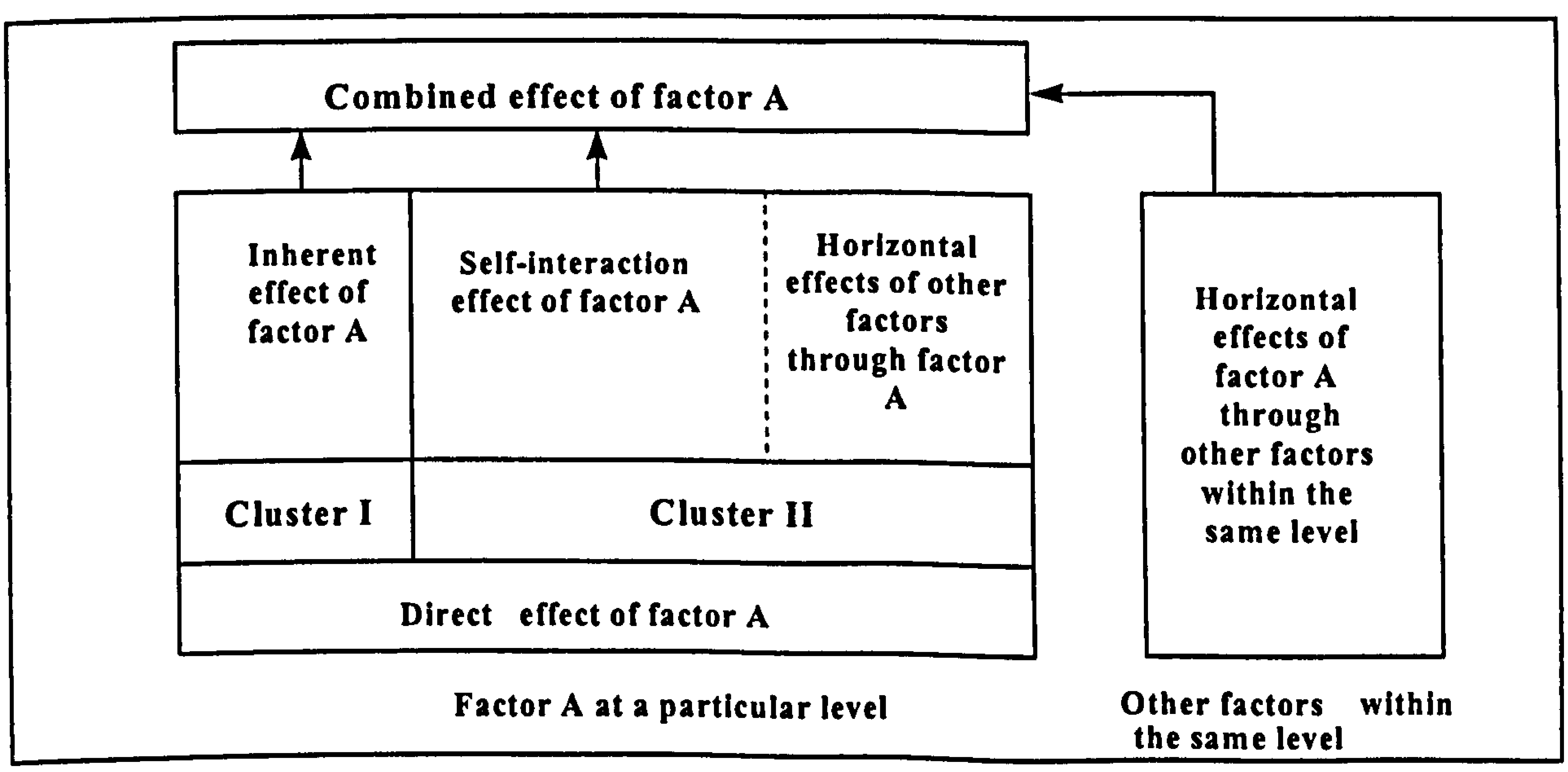


Figure 5.4. The interaction model of the QMPMS.

Finally, the combined effect of factor A on performance is made up of the inherent effect of factor A and the interaction effect of factor A. The decomposition matrices can be generated based on the results of this decomposition process. Summation of the values in a row of the matrix will give the combined effect of a factor. For example, the direct or vertical effect of factor 'interest' on 'amount of money in the bank' can be decomposed into cluster I and cluster II as indicated in Figure 5.5. Using the pair-wise comparison questionnaire as explained earlier, the person believes that cluster I (inherent effect) and cluster II (self interaction effect plus the effect of other factors on 'amount of money in the bank' through factor 'interest') has an equal effect on 'amount of money in the bank'.

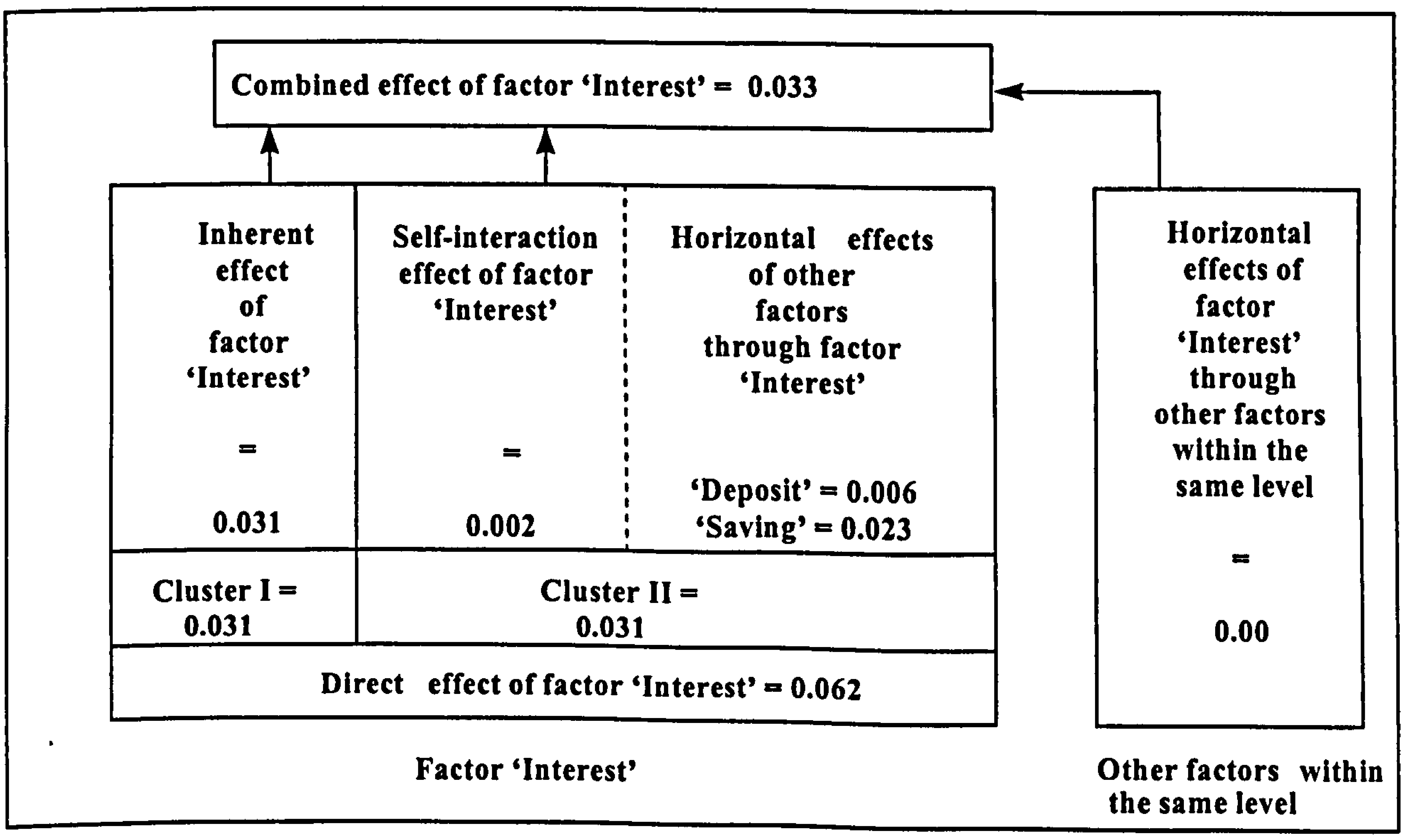


Figure 5.5. The decomposition of the direct effect of factor 'interest'.

The effect of cluster II is then decomposed further to identify the effects of self-interaction of factor 'interest', indirect effect of factor 'initial deposit' and indirect effect of factor 'savings paid in'. Using the same procedure as has been explained earlier to compute the effects of self-interaction of factor 'interest', indirect effect of factor 'initial deposit' and indirect effect of factor 'savings paid in' on 'amount of money in the bank', gives the results 0.002, 0.006 and 0.023 respectively. The combined effect of factor 'interest' on 'amount of money in the bank' (0.033) can then be found by summing up the inherent effect (0.031), self-interaction (0.002) and horizontal effects through other factors of factor 'interest' (0.00). A summary of the computation of combined effects of factors 'initial deposit', 'interest' and 'savings paid in' can be seen in Figure 5.6.

	Direct Effects									Combined Effect
	Initial Deposit = 0.212			Interest = 0.062			Saving = 0.726			
	Cluster I	Cluster II		Cluster I	Cluster II		Cluster I	Cluster II		
	Inherent	Self interaction	Other factors	Inherent	Self interaction	Other factors	Inherent	Self interaction	Other factors	
Initial Deposit	0.212					0.006				0.218
Interest				0.031	0.002					0.033
Saving						0.023	0.726			0.749

Figure 5.6. The computation of combined effects.

5.2.4 The computation of overall performance

Most performance measures of a business are of multi-level hierarchy. Performance measures affect the next higher level factors and the next higher level factors in turn will affect the next-next higher level factors. Through this mechanism, a factor in particular, finally will affect the top-level factor. The effect of a factor on the next higher level factors is called the local priority or local effect, while the effect of a factor on the top-level factors is called global or overall priority. The overall effect of factors on performance can be calculated using the additive composition formula (4-13) as explained in Chapter 4.

Supposing after a preliminary evaluation a person finally came up with only two possibilities, country A and country B, where he/she should move to. To choose which country he/she should move to, he/she must evaluate the effects of each country on the factors affecting 'amount of money in the bank'. Using the same pair-wise comparison questionnaire method, he/she can compute the effect of the countries on 'initial deposit', 'interest' and 'savings paid in' as indicated in Figure 5.7.

Factor : Initial deposit

	Country A	Country B	Priority
Country A	1	1	0.50
Country B	1	1	0.50

Factor : Interest

	Country A	Country B	Priority
Country A	1	1/3	0.25
Country B	3	1	0.75

Factor : Saving

	Country A	Country B	Priority
Country A	1	2	0.666
Country B	1/2	1	0.333

Figure 5.7. The pair-wise comparison matrices of the effects of country A and country B on 'initial deposit', 'interest' and 'savings paid in'.

Finally, in the composition step, the performance of country A and country B can be computed as indicated in Figure 5.8. Since the performance of country A (0.617) is better than the performance of country B (0.383), he/she would probably decide to move to country A.

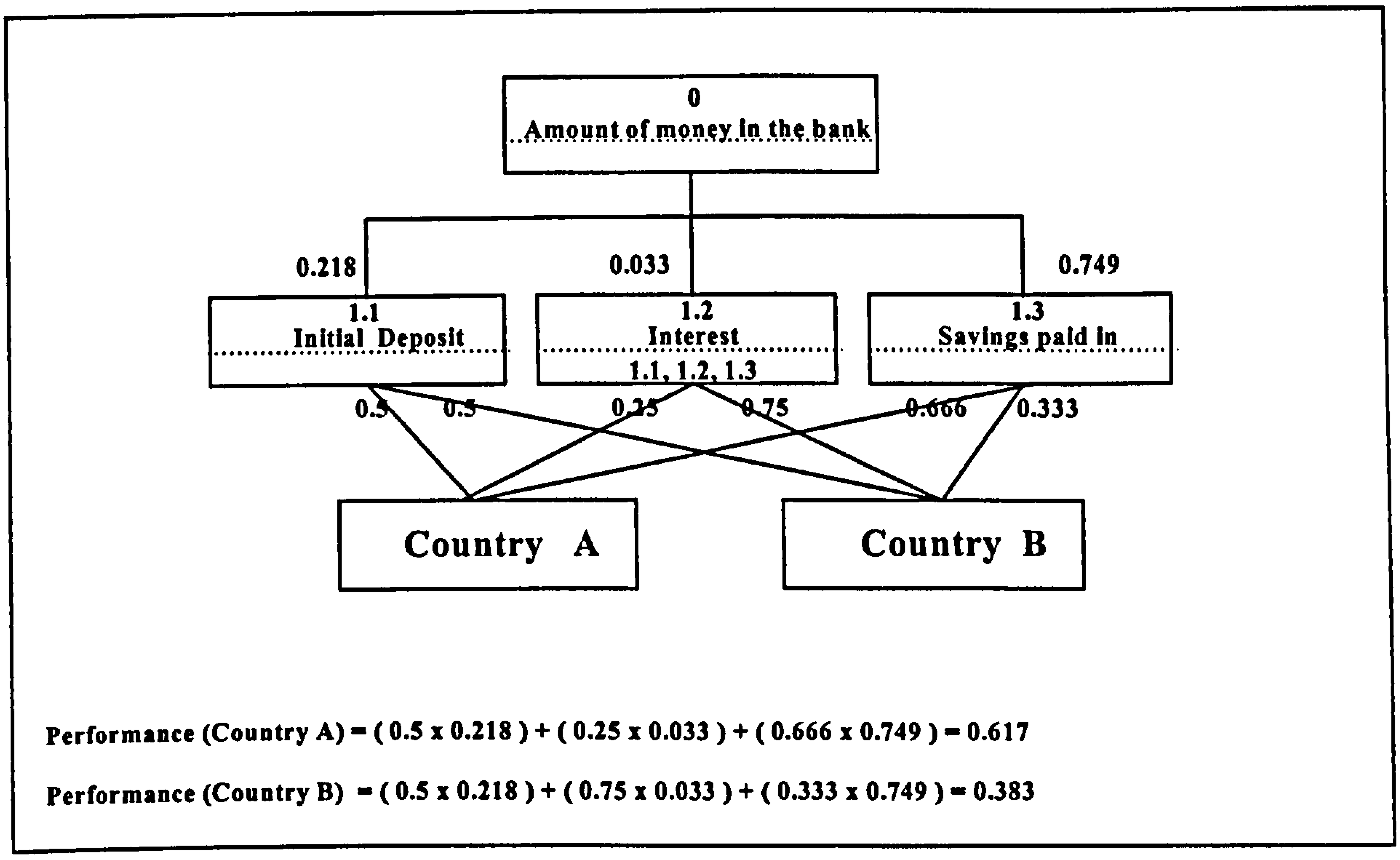


Figure 5.8. The performance of country A and country B on 'amount of money in the bank'.

5.2.5 Sensitivity analysis

The result of the QMPMS is a list of numerical values which represents the relative effect of factors on performance. This value can be used as a main input in management decision-making such as resource allocation, improvement programme development and strategy formulation. As the environment changes frequently, not all the states of factors affecting performance can be identified accurately in advance. As a result, more than one scenario can result. The decision-maker should consider all possible scenarios occurring. This is done through the "what-if" game or sensitivity analysis on the method. This was actually one of the feedback the researcher got from the dissemination of the research in a conference.

The sensitivity analysis of the QMPMS can be carried as follows [Saaty, 1994]. Let **H** be a complete hierarchy with h levels. Let $\mathbf{B}_k$ be the priority matrix of the kth level, k = 1, 2, ….., h. If **W'** is the global priority vector of the pth level with respect to some element in **z** in the (p-1)st level, then the priority vector **W** of the q*th* level (p<q) with respect to **z** is given by the multi-linear form,

$$\mathbf{W} = \mathbf{B}_q\, \mathbf{B}_{q-1} \ldots\ldots \mathbf{B}_{p+1}\, \mathbf{W'} \tag{5-1}$$

Then the global priority vector of the lowest level with respect to the goal is given by,

$$\mathbf{W} = \mathbf{B}_h\, \mathbf{B}_{h-1} \ldots\ldots \mathbf{B}_1\, \mathbf{W'} \tag{5-2}$$

The sensitivity analysis process can be carried out easily and quickly using a software package such as ExpertChoice (1995).

To give a simple example, suppose an engineering company wants to expand its business by introducing a new product line and also wants to construct a new factory to produce the new product line. As the characteristics of the new factory will be influenced by the manufacturing strategy adopted, an analytical evaluation must be carried out to decide what kind of manufacturing strategy should be adopted. This analysis could be carried out using the QMPMS framework.

Manufacturing strategies adopted by companies have a great impact on their internal environment. Different manufacturing strategies require different competitive capabilities [Miller and Roth, 1994; Sweeney and Szwejczewski, 1996a]. To build particular competitive capabilities as required by the adopted manufacturing strategy, companies must employ specific types of machines, tooling, layout, qualified human resources, information flows, system and procedures and technology. The configuration of those entities determines the generic performance of the manufacturing system: cost, quality, delivery and flexibility. Evaluation of alternative manufacturing strategies requires that the performance of the strategies on cost, quality, delivery and flexibility can be quantified and aggregated. This is not a straightforward task, since cost, quality, delivery and flexibility are measured in different dimensions. Cost is measured in pounds, quality may be measured in parts per million (ppm) of critical defects, delivery may be measured by the number of orders missing the due date and flexibility may be measured by the time required for changeover. The QMPMS method could be an effective tool for evaluating manufacturing strategy alternatives.

As the market changes rapidly, selection of manufacturing strategy to be adopted is becoming more difficult. A manufacturing strategy which is being employed successfully today, cannot be guaranteed to bring about the same success story in the future. Consequently, evaluation of alternative manufacturing strategies must take into account market dynamics.

Returning to the hypothetical case example, the company will employ a 'make to order' policy. Based on the generic manufacturing strategy identified by Sweeney and Szwejczewski (1996a, 1996b), two alternative strategies can be adopted by the company depending on the volume of demand. If the demand is low the company should adopt 'Innovator' strategy. However, if the demand is high the company should adopt 'Mass Customiser' strategy. These two strategies require different competitive capabilities. Innovator strategy requires the following competitive capabilities:

- consistent quality,
- rapid product design change,
- improved product performance,
- dependable delivery,

while Mass Customiser strategy requires competitive capabilities of:

- dependable delivery,
- short delivery lead time,
- consistent quality,
- product performance.

The differences between the two groups lie in the elements of the capabilities and their relative positions in the group (ranking). The Innovator strategy primarily stresses on quality and rapid product design change. To have the ability to accommodate rapid product design changes the manufacturing system must be able to shift from one type of product to another very quickly. In other words, the manufacturing system possesses flexibility. The next two competitive capabilities of the Innovator strategy are improved product performance and dependable delivery. Referring to the generic performance of a manufacturing system mentioned earlier, the Innovator must be excellent in quality, flexibility and delivery. Although it is necessary to control cost, but it is not the principal capability of competitiveness.

The Mass Customiser strategy primarily puts stress on dependable delivery and short delivery lead time. Both these competitive capabilities relate to delivery in the generic performance of a manufacturing system. The next two competitive capabilities are consistent quality and product performance, both relating to the quality in the generic performance of a manufacturing system. The ability of the Mass Customiser to win competition is affected much more by performance in delivery and quality rather than performance in flexibility and cost.

The hierarchical structure of the evaluation of the performance of Innovator and Mass Customiser manufacturing strategies can be constructed as indicated in Figure 5.9. The level 0 of the structure is the overall performance of the manufacturing strategies. The performance of the manufacturing strategies depends on the volume of the demand (the scenario) as indicated by level 1 of Figure 5.9. There are three possibilities of the level of demand: low (pessimistic scenario), average (normal scenario) and high (optimistic scenario). Level 2 of the structure is performance criteria. Based on the generic performance of manufacturing strategy the performance of the alternatives can be evaluated based on the criteria cost, quality, delivery and flexibility. Finally, level 3 of the structure is the alternatives.

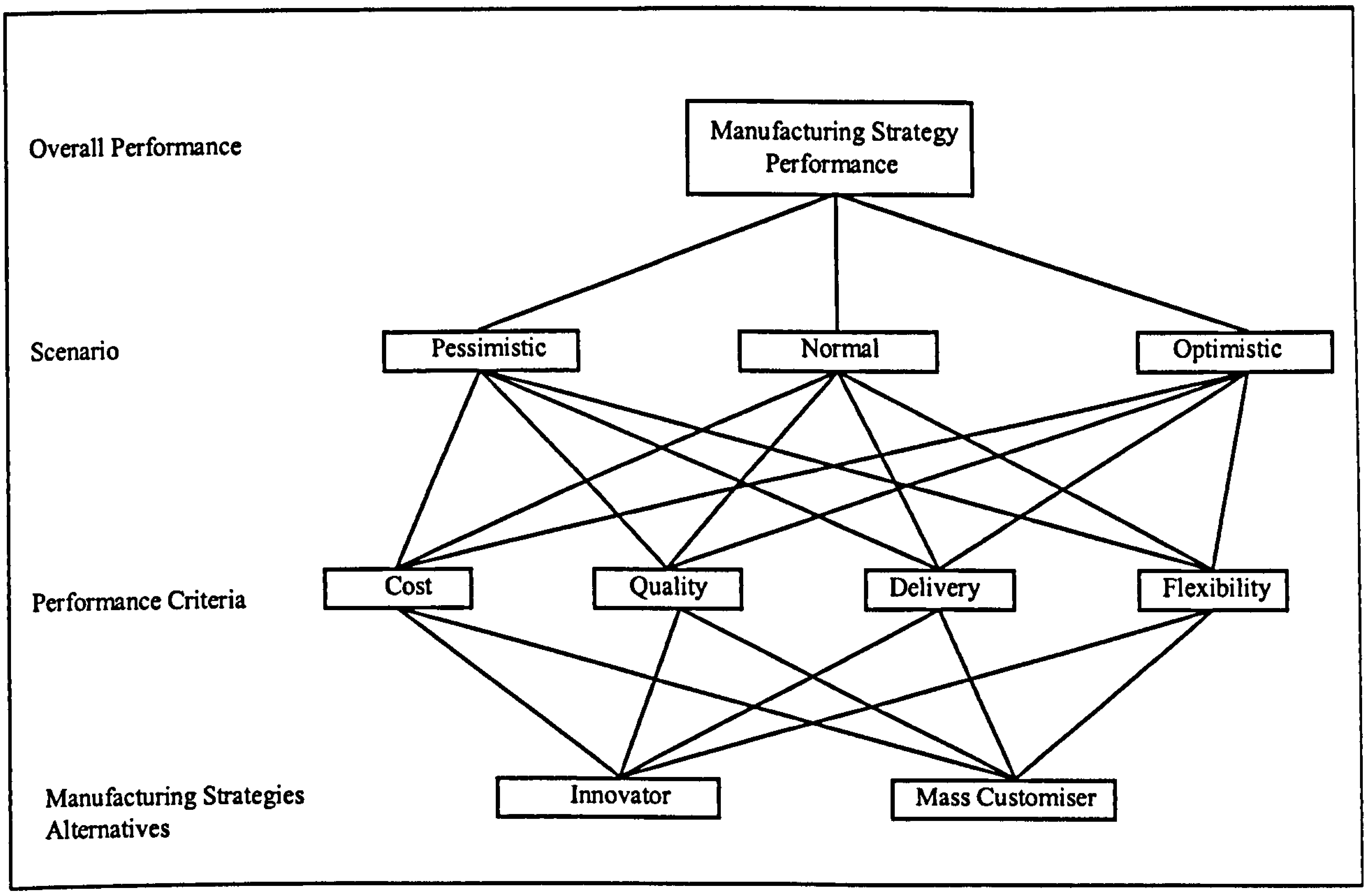


Figure 5.9. Hierarchical structure of manufacturing strategy performance evaluation.

Evaluation of alternative performance is carried out level by level starting from the top level down to the lower levels. The first evaluation assesses the possibilities of scenarios occurring in the planning period. The second evaluation assesses the relative effects of each criterion on performance under a particular scenario.

For example, what are the relative effects of cost, quality, delivery and flexibility on performance if demand is low. The relative effects of each criterion on performance are not necessarily the same under different scenarios. The third evaluation assesses the performance of each alternative on each performance criterion. Finally, the overall performance of each alternative can be computed through the composition process as explained earlier. Using the ExpertChoice (1995) software which is available on the market, the performance of Innovator and Mass Customiser strategies can be evaluated as indicated in Figure 5.10. From the evaluation, it can be seen that the performance of Mass Customiser strategy (0.515) is better than the performance Innovator strategy

(0.485), given that the probability of demand being low, average and high are 0.143, 0.286 and 0.571 respectively.

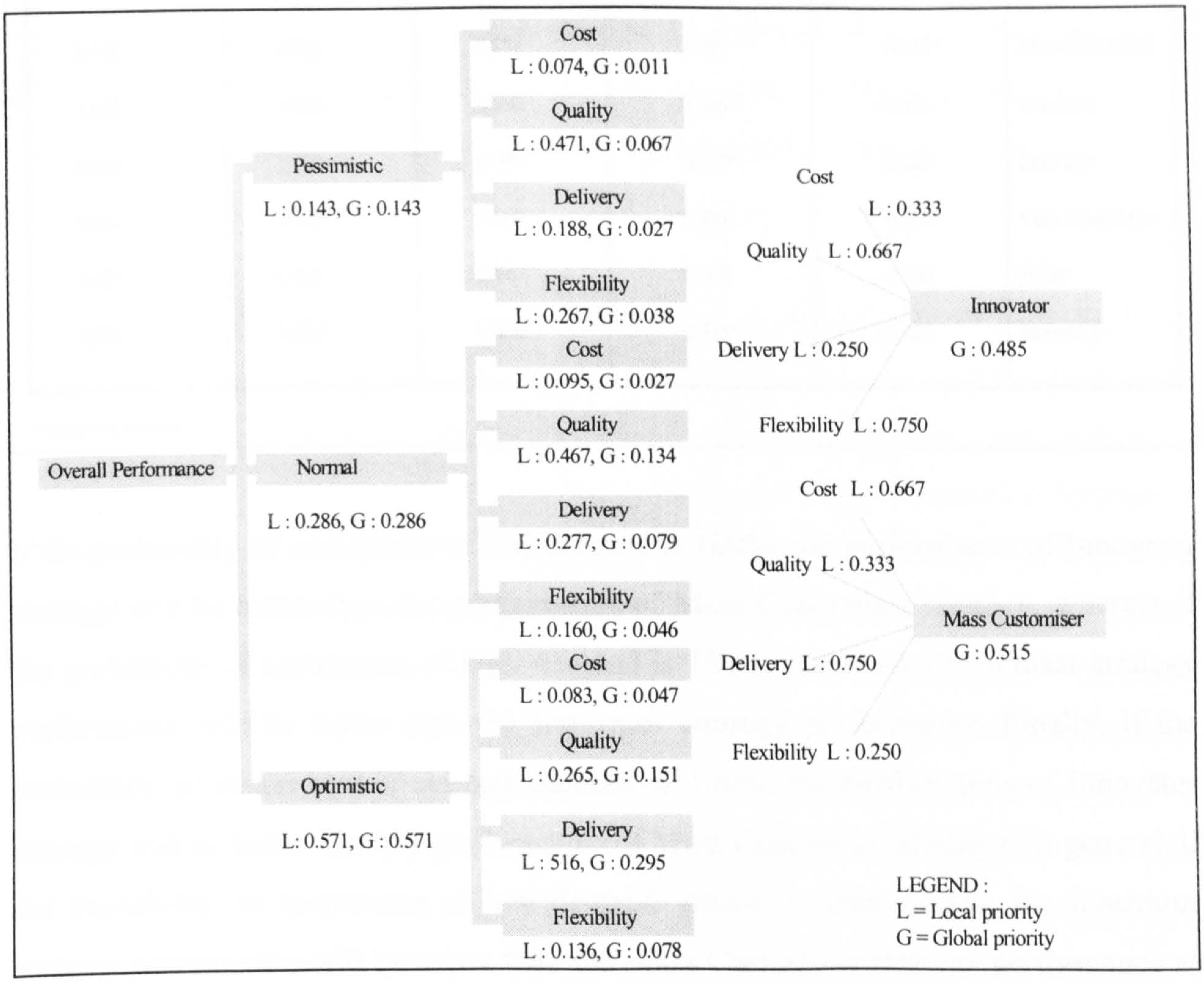


Figure 5.10. Evaluation of Innovator and Mass Customiser manufacturing strategy performance.

The probability of occurrence of low, average and high demand is based on current available information, but may change if more information becomes available. Based on the current judgement, the priority (performance) of Mass Customiser strategy is better than the priority (performance) of Innovator strategy. However, it is important to analyse further how the performance will change if the probability of demand level changes. Using the ExpertChoice software the results of the sensitivity analysis are indicated in Table 5.2.

Table 5.2. Sensitivity analysis of manufacturing strategy performance.

Probability of Pessimistic Scenario	Probability of Normal Scenario	Probability of Optimistic Scenario	Priority of Innovator Strategy	Priority of Mass Customiser Strategy	Strategy to be adopted
0.143	0.286	0.571	0.485	0.515*	Mass Customiser
1.000	0.000	0.000	0.586*	0.414	Innovator
0.000	1.000	0.000	0.533*	0.467	Innovator
0.000	0.000	1.000	0.435	0.565*	Mass Customiser
0.433	0.000	0.567	0.500	0.500	Either
0.530	0.000	0.470	0.515*	0.485	Innovator

* preferred strategy

If the probability of occurrence of low demand is 100%, the performance of Innovator strategy will be better than the performance of Mass Customiser strategy, whereas if the probability of occurrence of high demand is 100%, the Mass Customiser strategy performance will be better than the Innovator strategy performance. Finally, if the probability of occurrence of average demand is 100%, the performance of Innovator strategy will be better than the performance of Mass Customiser strategy. In general, if the probability of occurrence of low demand greater is than 43.3%, the Innovator strategy performance will be better than the Mass Customiser strategy performance as indicated in Table 5.1. Therefore, the decision on which strategy to choose will depend on the probability of the occurrence of low demand. If the probability of low demand is unlikely to exceed 43.3% Mass Customiser strategy must be adopted. Sensitivity analysis can also be carried out on the changes of impacts on performance criteria on performances under different scenarios.

5.3 Consolidating Performance Measures

As has been mentioned earlier in this research work, performance measurement involves a large number of multi-dimensional factors which affect performance. It has been reported that an organisation has used 114 top-level measures consisting of 17 financial measures, 17 customer measures, 19 internal process measures, 35 measures of renewal and development and 26 human resources measures [Meyer, 1998]. It will be extremely difficult for top-level managers to manage those measures and make decisions based on them unless the measures are aggregated or consolidated into a single performance indicator. For this reason, it is extremely important to have a method or procedure which consolidates performance measures into a single performance indicator.

It is widely accepted that consolidating performance measures will be very helpful in decision-making. In their daily work it is common for managers to be faced with more than one alternative. Each alternative decision can lead to difference consequences in various aspects of an organisation. It is also common that no alternative decision is superior to other alternatives in all criteria. Consequently, it will be very difficult for a manager to arrive at the best decision, especially if taking a large number of factors and a large number of criteria into account unless the performance of each alternative can be aggregated or consolidated into a single performance indicator. Unfortunately, at the time writing, there is a belief among practitioners and researchers on performance measurement systems that it is impossible to consolidate multi-dimensional performance measures into a single performance indicator [Clark, 1998].

The QMPMS has been equipped with a procedure for consolidation of performance measures and the consolidation process is very simple. It is carried out by comparing the achievement against target and expressing the results in percentages thus changing all the dimensions of the measures into a single dimension - percentage. As a result, measures can now be aggregated since they are already in the same dimension.

To make the concept clear, let us considers an example consolidating performance measures as indicated in Figure 5.11. The overall performance is affected by two main areas: cost and delivery.

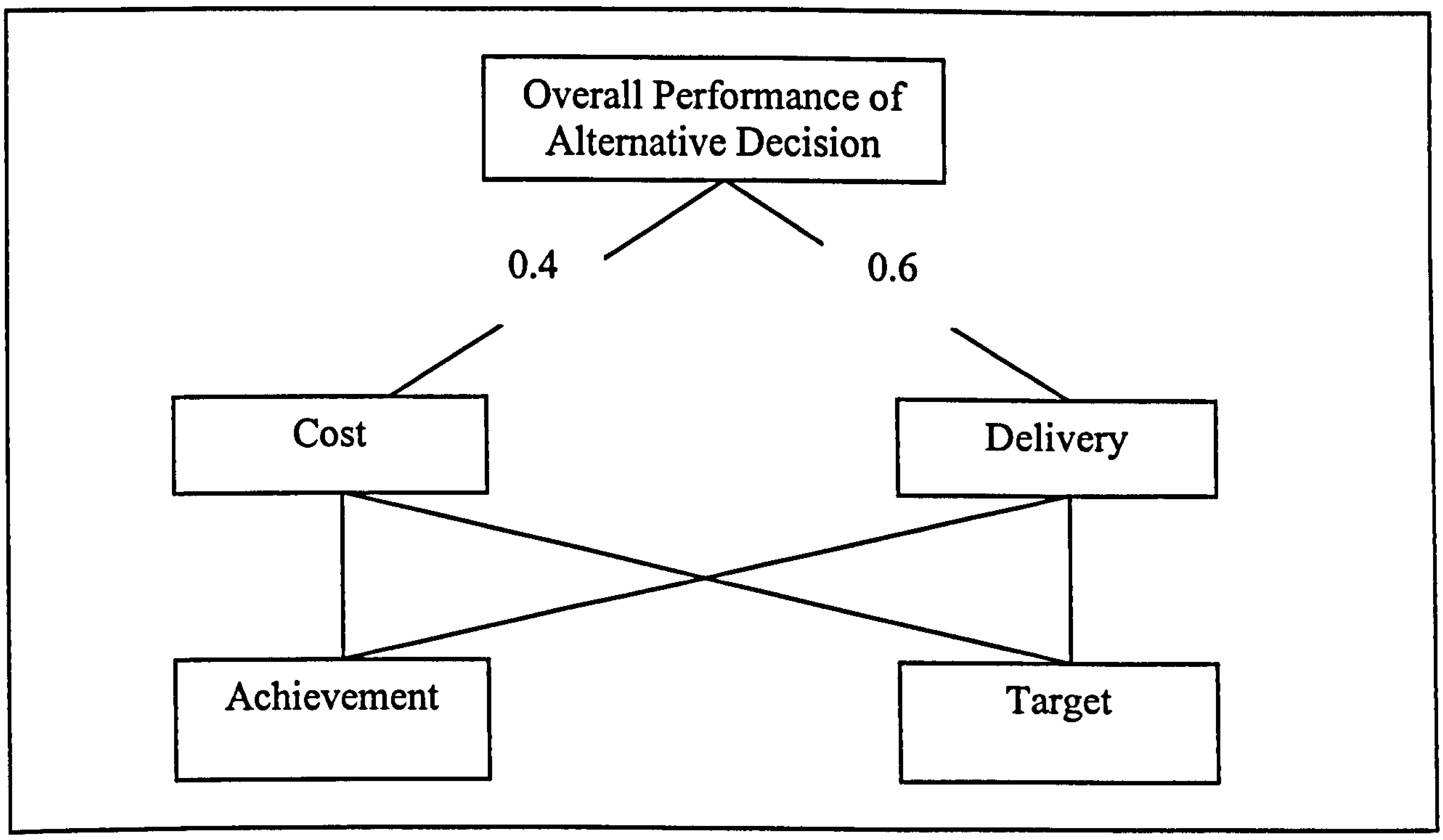


Figure 5.11. An example of consolidation of performance measures.

Suppose the effect of each area on the overall performance has been calculated using the QMPMS. The result indicates that the overall performance is 40% affected by cost and 60% affected by delivery. Furthermore, in the particular period of time, if the achievement in cost is £110,000 while the target cost is £100,000 and the achievement in delivery time is 20 days, while the target delivery is 25 days, the consolidation of performance measures is carried out as follows:

Cost criteria:

Target = £100,000

Achievement = £110,000

Since the higher the cost the less the performance, cost performance is computed as follows:

Cost performance in percent = (1/110,000) / (1/100,000) = 90.91 percent.

Delivery criteria:

Target = 25 days

Achievement = 20 days

Delivery performance in percent = (1/20) / (1/25) = 125 percent.

The overall performance = (0.4 x 90.91%) + (0.6x 125%) = 111.364 percent.

It is clear that the dimensions £ and day can be aggregated and expressed into a single performance indicator percent. This procedure can be implemented very easily using the ExpertChoice software since it has a facility for carrying out this procedure.

Target

Since consolidation process basically is comparing the achievement against the target, the value of the consolidated measure depends on the target used. There are three types of targets that can be used:

1. Absolute target: refers to perfect condition.
2. Potential target: refers to the level which can be achieved if some or all of the constraints can be resolved.
3. Realistic target: refers to the level which can be realistically achieved under the current conditions or available resources.

Realistic targets are reviewed periodically. However, it is quite difficult to compare the realistic performance in one particular period to another, since the realistic targets are different. To solve this problem fixed targets are set. These targets are absolute targets which refer to perfection. Since absolute targets are fixed, comparing two absolute performances of different periods of time is meaningful; consequently, absolute performance can be used to measure the performance of continuous performance programmes. Finally, potential performance can be used to indicate the achievement in resolving the constraints.

5.4 The Extension of the QMPMS to Reduce the Number of Performance Reports

Maskell (1991), as described in Chapter 3, proposed seven common characteristics for the design of performance measurement systems, three being that the new performance measurement system should:

- relate directly to manufacturing strategy,
- vary between companies,
- change over time.

Some people believed that implementing a performance measurement system compatible with the above criteria usually produces unmanageable performance reports [Maskell, 1991]. As reported by Neely et al (1995) an issue for future research on performance measurement would be to develop a technique to reduce the list of possible measures into a manageable set.

A framework as depicted in Figure 5.12 has been developed to reduce the number of performance reports. This framework has been developed based on the extension of the QMPMS method. According to the framework, reduction in performance reports can be achieved through the following steps:

1. Quantification of the effects of factors on performance.

The effects of factors on performance are identified and quantified using the QMPMS method explained earlier. How the method works has been discussed extensively in the previous sub-chapter.

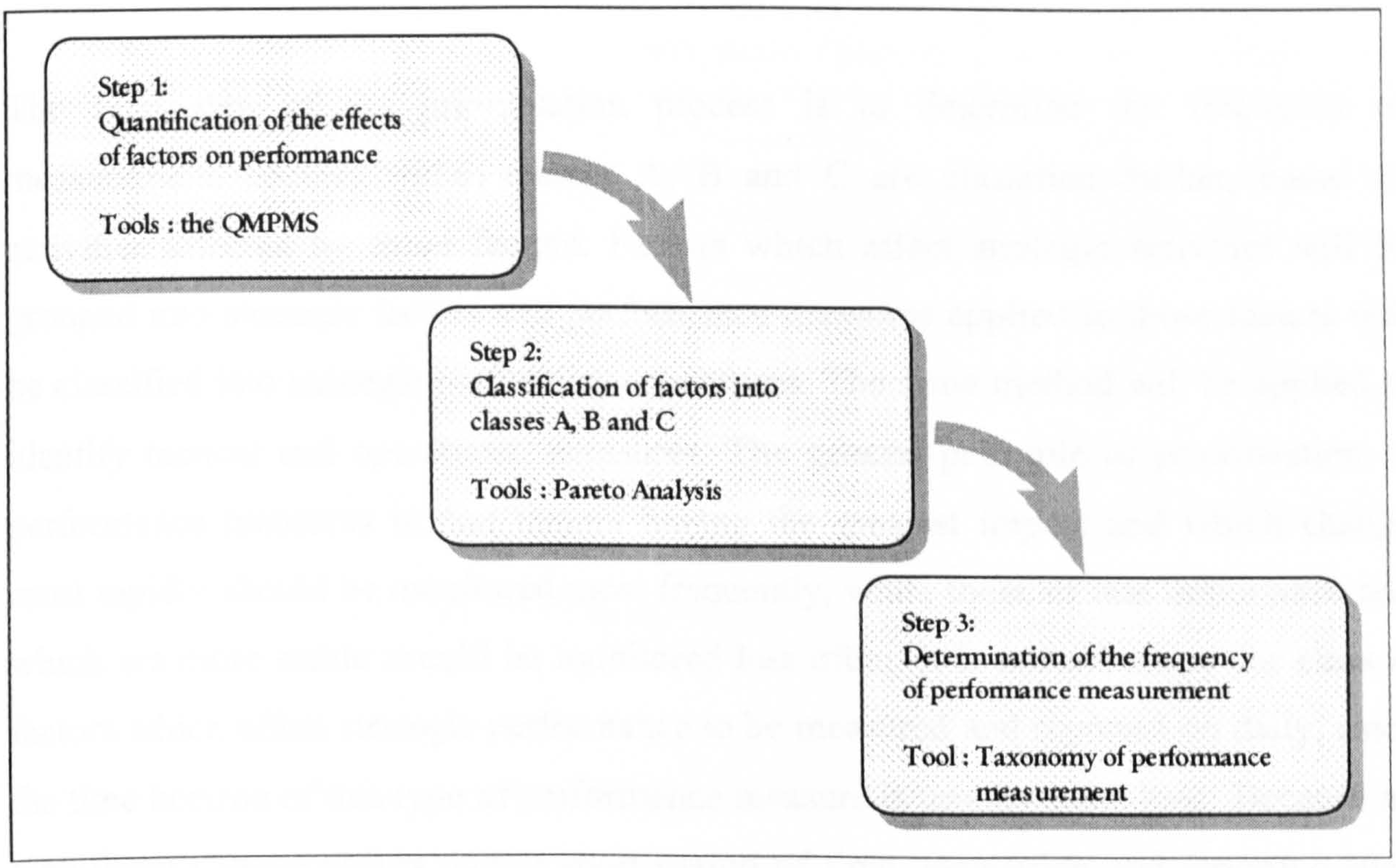


Figure 5.12. Framework to reduce the number of performance reports.

2. Classification of factors into classes A, B and C.

The results of the quantification process are the relative effects of factors on performance. Not all factors have an equal effect on performance. Pareto analysis can be used to classify factors into classes A, B and C, based on their degree of impact on performance. Factors which have the greatest impact on performance, contributing about 75 percent, will be classified as class A. Factors which have the lowest effect on performance, contributing about 5 percent, will be classified as class C. The remaining factors will be classified as class B. The performance measurement process will give the greatest priority to class A factors.

3. *Classification of the factors into categories and determination of performance measurement frequency*

The final step of the prioritisation process is to determine the frequency of measurement. Factors within classes A, B and C are classified further, based on activities affected by those factors. Factors which affect strategic activities will be grouped into strategic factors and performance measures applied to those factors will be classified into strategic performance measures. The same method will be applied to identify tactical and operational measures. The general principle of prioritisation of performance measures is that factors having the greatest impact and which change most rapidly should be monitored most frequently, while those of less importance and which are more stable should be monitored less often. It is not necessary for class A factors which affect strategic performance to be measured and reported on daily, since the time horizon of this type of performance measure is usually quite long. Because no significant change occurs over a short period of time, measuring and reporting such performance measures at short intervals is a waste of time and energy. Also, not all operational performance measures should be measured at short intervals. Operational performance measures which are members of class C can be measured at longer intervals. The performance measurement system gives priority to the most dynamic and highest impact factors.

Taxonomy of performance measurement has been developed as indicated in Figure 5.13. This taxonomy can be used as a general guideline in classifying the performance measures into the categories 'critical', 'intermediate' and 'minor'. The 'intermediate' and 'minor' categories are classified further into 'intermediate I', 'intermediate II' and 'minor I', 'minor II'. These classifications allow the determination of the frequency of performance measurement, as indicated in Figure 5.13. The time frame used in this taxonomy varies between companies as companies producing capital goods use a longer time frame compared to that used by companies producing consumer goods. The application of the method to prioritise performance measurement will be presented in Chapter 6.

		RATE OF CHANGE		
		Operational Performance Measures	**Tactical Performance Measures**	**Strategic Performance Measures**
DEGREE OF IMPACT	A	Critical Continuously to Daily Monitoring	Intermediate I Daily to Weekly Monitoring	Intermediate II Weekly to Monthly Monitoring
	B	Intermediate I Daily to Weekly Monitoring	Intermediate II Weekly to Monthly Monitoring	Minor I Monthly to Quarterly Monitoring
	C	Intermediate II Weekly to Monthly Monitoring	Minor I Monthly to Quarterly Monitoring	Minor II Quarterly to Annually Monitoring

Figure 5.13. The taxonomy of performance measurement.

In the context of performance measurement in strategic change, a similar model has been developed by Feurer and Chaharbaghi (1995). They argue that a constant review of all measures is impractical due to their sheer number. Therefore, it is important to determine the frequency with which measures should be reviewed. For this purpose Feurer and Chaharbaghi (1955) developed the matrix which groups measures into three categories as indicated in Figure 5.14:

1) A-measures which require a high level of attention and should constantly be reviewed.
2) B-measures which require less attention when compared to A-measures.
3) C-measures which require the least attention.

However it is not clear how the classification of low, medium and high importance to perform is carried out.

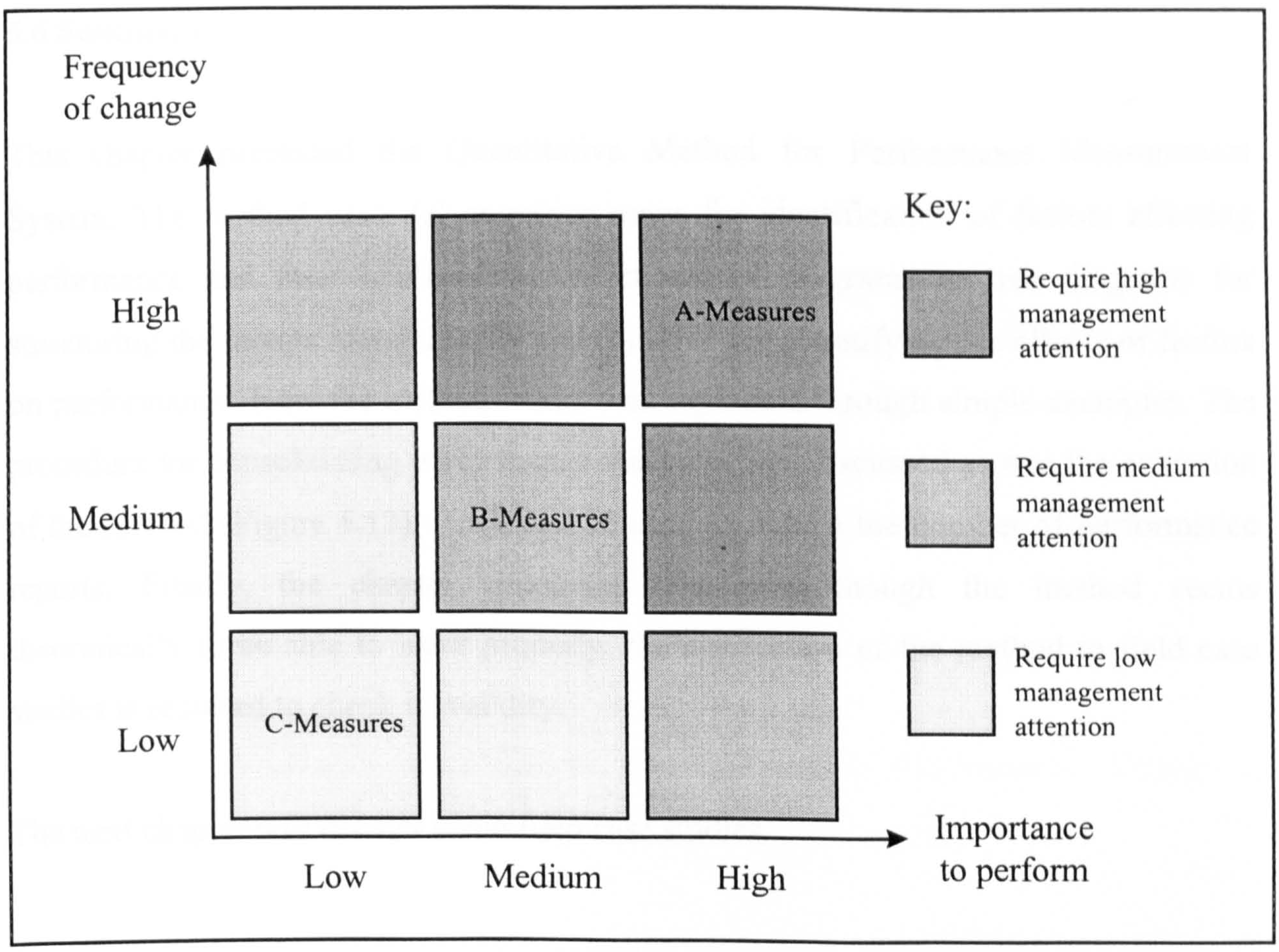


Figure 3.14. ABC-measurement matrix [Feurer and Chaharbaghi, 1995].

5.5 Discussion and Conclusion

A method has been developed for identification of factors affecting performance and their relationship and quantifying their effects on performance. The method uses cognitive maps, structured diagrams and the AHP. Theoretically, the method appears to work properly, since the tools used in the method have been successfully used in management practices as discussed in Chapter 4. However, like all management methods, the quality of the method must not only be judged on the elegance of the underlying theory, but also on how well it can perform in practice. Therefore, the method should be validated by field case studies to test it works. The application of the method to various field case studies will be presented in Chapter 6.

5.6 Summary

This chapter presented the Quantitative Method for Performance Measurement System. The method uses: (a) cognitive maps for identification of factors affecting performance and their relationship, (b) structured diagrams or tree diagrams for structuring the factors hierarchically and (c) AHP for quantifying the effects of factors on performance. How the method works was explained through simple examples. The procedure for consolidating performance measures was discussed as was the extension of the method (Figure 5.13) which can be used to reduce the number of performance reports. Finally, the chapter concluded that even though the method seems theoretically to be able to work properly, the application of the method to field case studies is required to check its validity.

The next chapter will discuss some field case studies.

Chapter 6

CASE STUDIES

6.1 Introduction

As stated in Chapter 2, five questions are addressed in this research. Chapter 5 addressed the first three, inductive questions:

- *How can factors affecting performance and their relationship, especially in performance measurement for improvement, be identified and quantified?*
- *How can the effects of factors on performance be consolidated and expressed in a single performance indicator?*
- *How can the method developed be extended to reduce the number of performance reports?*

This chapter will address the remaining two, deductive questions which are:

- *Is the method valid and can it be applied to real cases?*
- *Is the method stable for a reasonable period of time?*

This chapter will present three case studies. The first will present the use of the Quantitative Method for Performance Measurement System and its extension to method the 'on time delivery' performance of a collaborator company. This case study will be used primarily for the purpose of 'desk' validation of the method, i.e. whether the method can produce the intended output.

The second case study will discuss the experiment for testing the application validity of the Quantitative Method for Performance Measurement System, i.e. whether the output of the QMPMS is close to the actual performance. This case study will also be used to test the stability of the QMPMS.

Finally, the last case study will present the application of the Quantitative Method for Performance Measurement System at the Inland Revenue, Cumbernauld for testing another application validity of the QMPMS, i.e. whether the QMPMS can be applied comfortably to a real case.

6.2 Case Study One: On Time Delivery Performance

6.2.1 The application of the QMPMS to 'on time delivery' performance

In developing the Quantitative Method for Performance Measurement System (QMPMS) the author was mainly influenced by the 'on time delivery' problem of a collaborator company [Bititci, 1995]. The company, J&B Scotland Ltd, is a Scottish-based subsidiary (cost centre) of a major multi-national specialising in the production, bottling, packaging and world-wide distribution of spirits. The operation process of the company was modelled by Bititci (1995) as indicated in Figure 6.1.

The company was faced with the problem of failing to deliver orders on time [Bititci, 1995]. Many factors were, in fact, affecting 'on time delivery' as depicted in Figure 6.2. An important question that had to be addressed was which activities the scarce resources should be deployed to in order to gain maximum improvement to 'on time delivery' performance. To be able to answer this question, one had to know the effect of activities or factors on 'on time delivery performance'. Obviously maximum improvement would be gained if scarce resources were deployed to activities which had the greatest impact on performance.

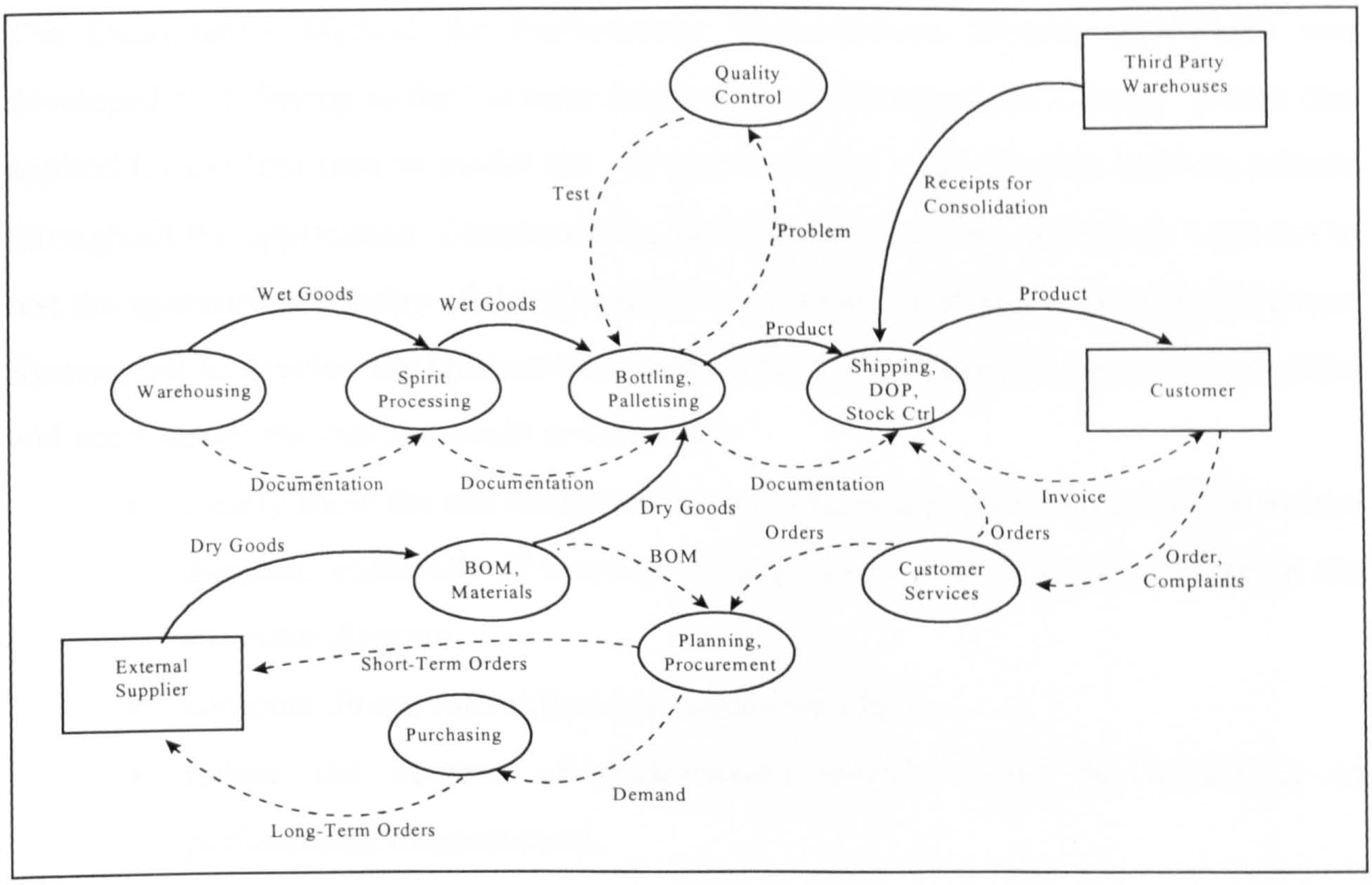


Figure 6.1. Process model of 'on time delivery' performance [Bititci, 1995].

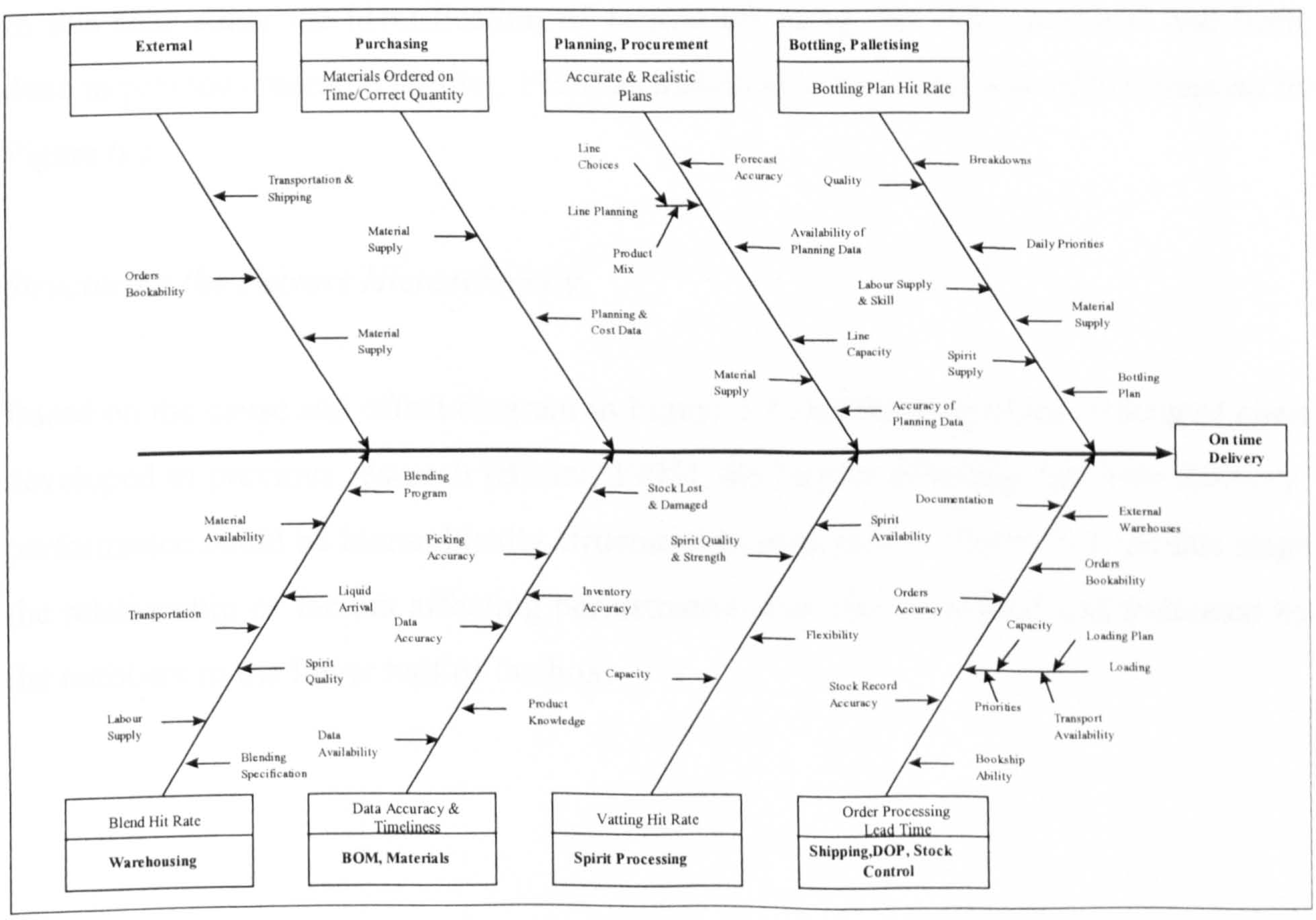


Figure 6.2. Cause and effect diagram of 'on time delivery' problem [Bititci, 1995].

The Quantitative Method for Performance Measurement System (QMPMS) was developed by referring to the 'on time delivery' problem mentioned earlier. It was also applied for the first time to model the 'on time delivery' performance and was refined throughout the application. Consequently, the objectives of the case study were not to test the operational validity of the Quantitative Method for Performance Measurement System, but to develop the Quantitative Method for Performance Measurement System and see whether the method could or could not:

- clearly show the interaction of factors affecting performance using structure diagram, especially if there are a large number of factors included in the structure diagram,
- compute direct, interaction and combined effect,
- reduce the number of performance reports using the taxonomy of performance measurement.

Identification of Factors Affecting Performance

In this case study the identification of factors affecting 'on time delivery' had been done in previous research [Bititci, 1995] as indicated in the cause and effect diagram in Figure 6.2.

Structuring the Factors Hierarchically

Based on the cause and effect diagram in Figure 6.2 and the simplified structured chart developed in previous research [Bititci, 1995], the factors affecting 'on time delivery' performance could be hierarchically structured as indicated in Figure 6.3. At this stage the relationship of factors affecting performance was also identified and indicated by the numbers in the lower half of the box.

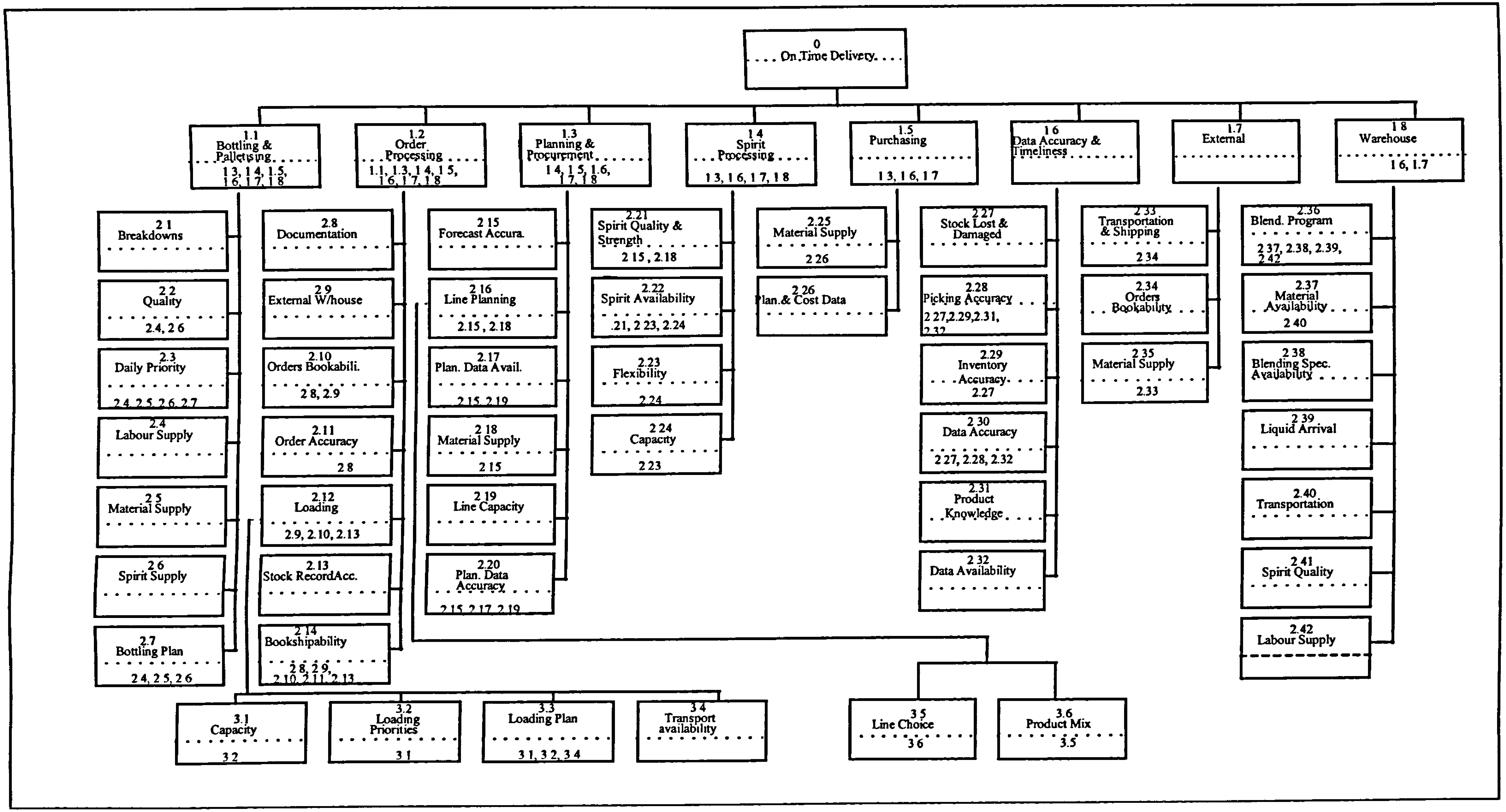


Figure 6.3. Hierarchical structure of 'on time delivery' performance.

For example, for factor number 1.1 'Bottling and Palletising', six factors had an indirect effect on the 'on time delivery' performance through the factor 'Bottling and Palletising'. These factors are:

- factor number 1.3 'Planning and Procurement',
- factor number 1.4 'Spirit Processing',
- factor number 1.5 'Purchasing',
- factor number 1.6 'Data Accuracy and Timeliness',
- factor number 1.7 'External',
- factor number 1.8 'Warehouse'.

Quantifying the Effects of Factors on Performance

To quantify the effects of factors on performance two sets of questionnaires were constructed. The first set of questionnaires was for eliciting judgement on the direct effect of factors on performance. An example of this questionnaire is given in Figure 6.4.

Based on the results of the pair-wise comparison questionnaires, a pair-wise comparison matrix of factors affecting 'on time delivery' could be constructed. An example of the pair-wise comparison matrix of factors directly affecting 'on time delivery' performance is depicted in Figure 6.5. Using the Analytic Hierarchy Process Software, ExpertChoice [1995], the direct effect of level 1 factors on 'on time delivery' performance could be computed and the result is indicated by Figure 6.6.

The direct effect of other factors of the lower hierarchy level on 'on time delivery' performance could be computed using the same method, and these results are given in Appendix A.1. A summary of the direct effect of the lowest hierarchy factors on 'on time delivery' performance is indicated in Table 6.1.

Pair-wise Comparison Questionnaire
'on time Delivery'
(Direct Effect)

Level : 0
Factors : On Time Delivery
Sub-factors: Bottling & Palletising, Order Processing, Planning & Procurement, Spirit Processing, Purchasing, Data Accuracy & Timeliness, External, Warehouse
Question: "*Comparing factor in the 'row' column to factor in the 'column' column, which one has a stronger effect on On Time Delivery?*" and "*How strong?*"

Row	Absolutely	Very Strong	Strong	Weak	Equal	Weak	Strong	Very Strong	Absolutely	Column
1.1 Bottling & Palletising			■							1.2 Order Processing
1.1 Bottling & Palletising					■					1.3 Planning & Procurement
1.1 Bottling & Palletising					■					1.4 Spirit Processing
1.1 Bottling & Palletising				■						1.5 Purchasing
1.1 Bottling & Palletising			■							1.6 Data Accuracy & Timeliness
1.1 Bottling & Palletising				■						1.7 External
1.1 Bottling & Palletising					■					1.8 Warehouse

Figure 6.4. An example of pair-wise comparison questionnaires of the direct effect of factors on performance.

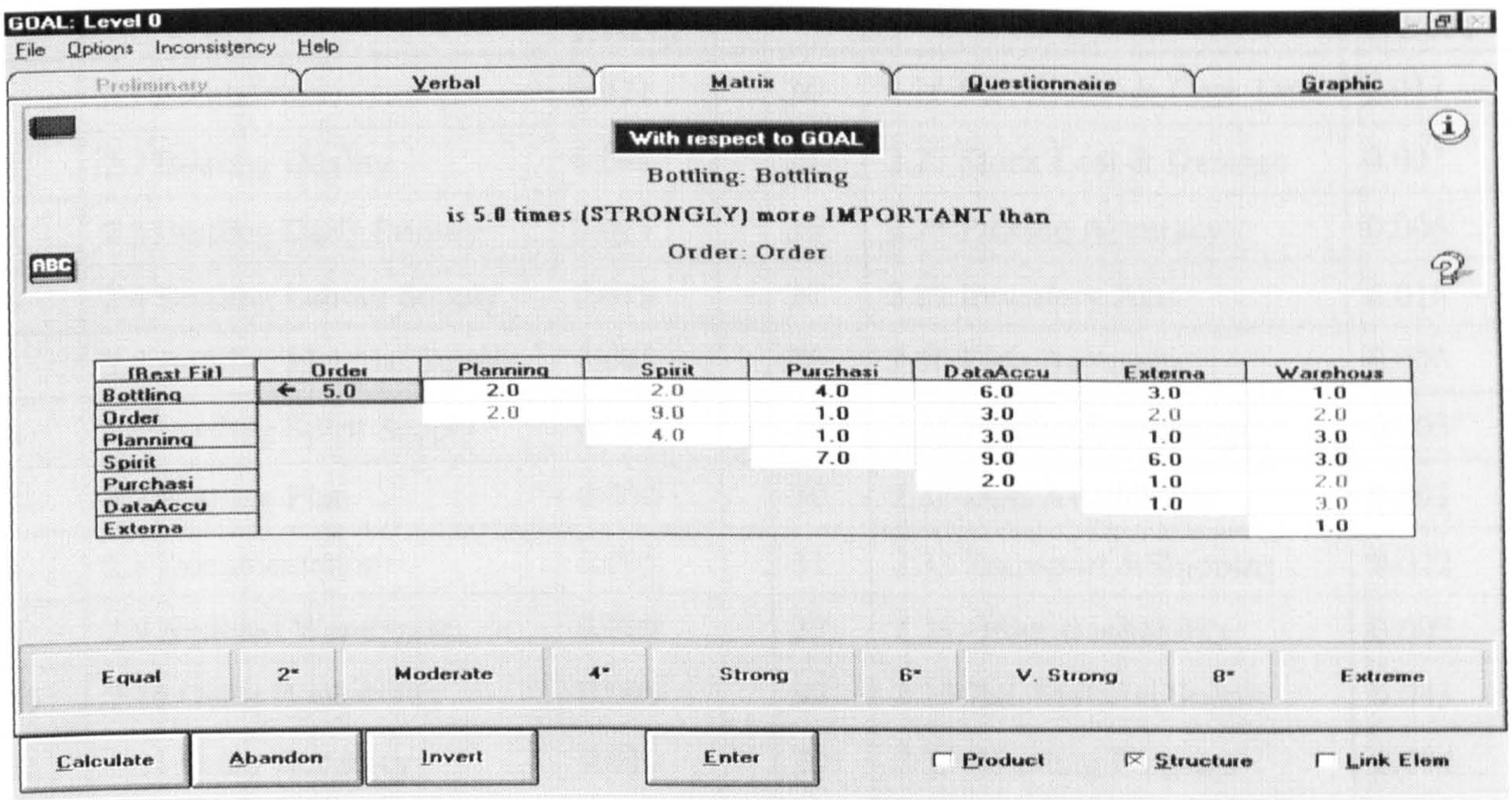


Figure 6.5. Pair-wise comparison matrix of factors affecting 'on time delivery'.

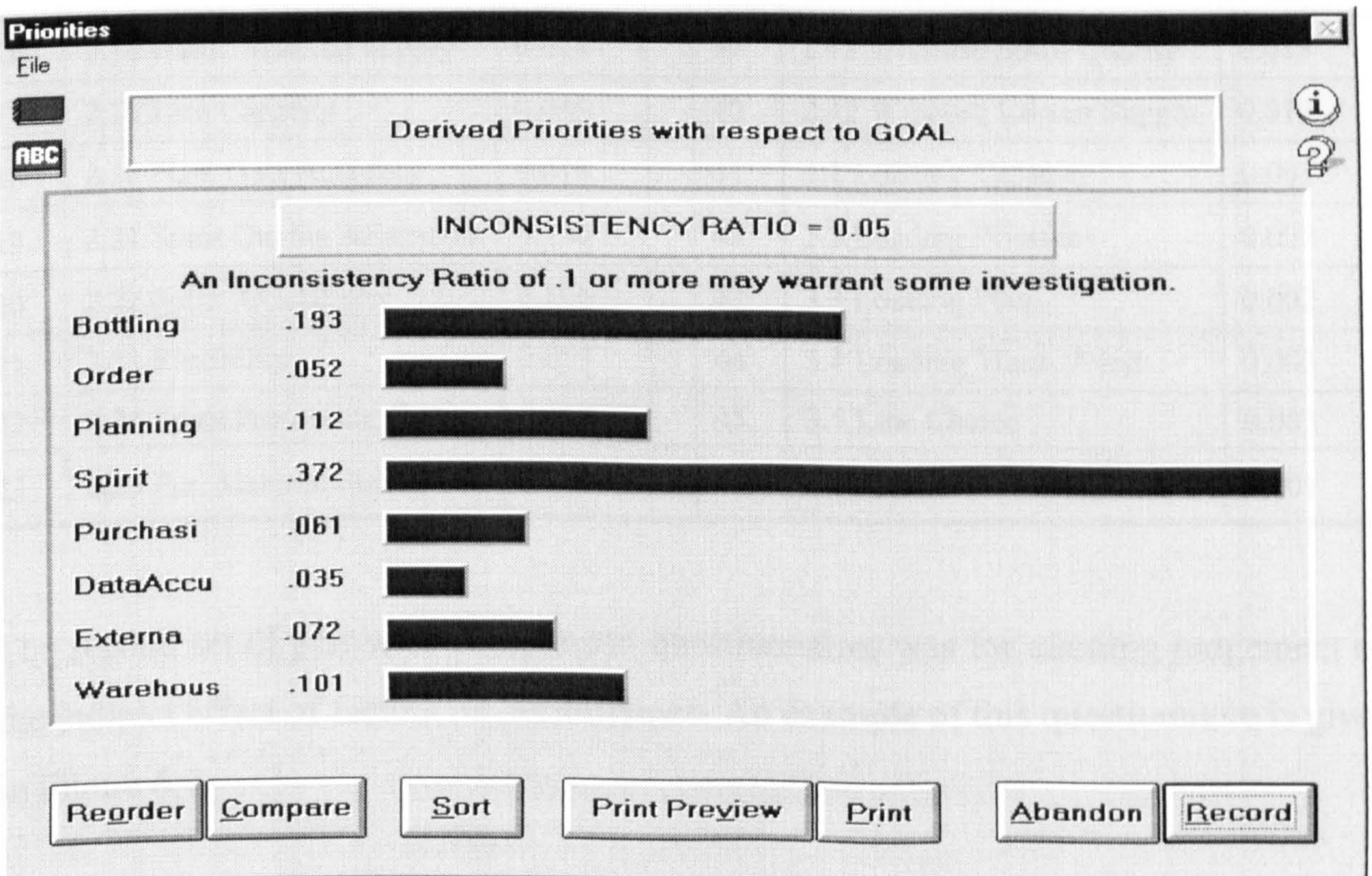


Figure 6.6. The effect of factors level 1 on 'on time delivery' performance.

Table 6.1. Direct effect of factors on 'on time delivery' performance.

No	Factor	Direct Effect		No	Factor	Direct Effect
1	2.1 Breakdown	0.021		24	2.26 Pur. Plann..& Cost Data	0.012
2	2.2 Bottling Quality	0.041		25	2.27 Stock Lost & Damage	0.003
3	2.3 Bottling Daily Priority	0.021		26	2.28 Picking Accuracy	0.006
4	2.4 Bottling Labour Supply	0.019		27	2.29 Inventory Acc.	0.016
5	2.5 Bottling Material Supply	0.043		28	2.30 Data Accuracy	0.006
6	2.6 Bottling Spirit Supply	0.044		29	2.31 Product Knowledge	0.003
7	2.7 Bottling Plan	0.004		30	2.32 Data Availability	0.003
8	2.8 Documentation	0.005		31	2.33 Transport &Shipping	0.022
9	2.9 External Warehouse	0.009		32	2.34 Order Bookability	0.007
10	2.10 Order Bookability	0.005		33	2.35 Ext. Material Supply	0.043
11	2.11 Order Accuracy	0.010		34	2.36 Blending Program	0.004
12	2.13 Stock Record Accuracy	0.005		35	2.37 W/h M'rial Availability	0.021
13	2.14 Bookshipability	0.005		36	2.38 Blend.Spec. Avail.	0.005
14	2.15 Forecast Accuracy	0.007		37	2.39 Liquid Arrival	0.020
15	2.17 Planning Data Avail.	0.013		38	2.40 Transportation	0.015
16	2.18 Plann. Material Supply	0.024		39	2.41 W/house Spirit Quality	0.018
17	2.19 Line Capacity	0.049		40	2.42 W/house Labour Supply	0.019
18	2.20 Plan. Data Accuracy	0.013		41	3.1 Loading Capacity	0.007
19	2.21 Spirit Quality &Strength	0.106		42	3.2 Loading Priorities	0.002
20	2.22 Spirit Availability	0.106		43	3.3 Loading Plan	0.002
21	2.23 Flexibility	0.053		44	3.4 Loading Trans. Avail.	0.003
22	2.24 Spirit Processing Capa.	0.106		45	3.5 Line Choice	0.003
23	2.25 Pur. Material Supply	0.049		46	3.6 Product Mix	0.001

The second set of pair-wise comparison questionnaires was for eliciting judgement on the indirect effect of factors on performance. An example of this questionnaire is given in Figure 6.7.

The combined effect of factors affecting 'on time delivery' could be computed based on the interaction model which was developed and presented in Chapter 5, Figure 5.4.

Pair-wise Comparison Questionnaire
'on time Delivery'
(Indirect Effect)

Level : 1
Factors : Bottling & Palletising
Sub-factors : Planning & Procurement, Spirit Processing, Purchasing, Data Accuracy & Timeliness, External, Warehouse

Question: "*Comparing factor in the 'row' column to factor in the 'column' column, which one has a stronger effect on On Time Delivery?*" and "*How strong?*"

Row	**Absolutely**	**Very Strong**	**Strong**	**Weak**	**Equal**	**Weak**	**Strong**	**Very Strong**	**Absolutely**	**Column**
Cluster I										Cluster II
1.3 Planning & Procurement										1.4 Spirit Processing
1.3 Planning & Procurement										1.5 Purchasing
1.3 Planning & Procurement										1.6 Data Accuracy & Timeliness
1.3 Planning & Procurement										1.7 External
1.3 Planning & Procurement										1.8 Warehouse

Figure 6.7. An example of pair-wise comparison questionnaires on the indirect effect of factors on performance.

Based on the results of the pair-wise comparison questionnaires on the indirect effect of factors affecting performance, the pair-wise comparison matrix could be developed. An example of the pair-wise comparison matrix of factors indirectly affecting 'on time delivery' performance through factors 'Bottling & Palletising' is indicated in Figure 6.8.

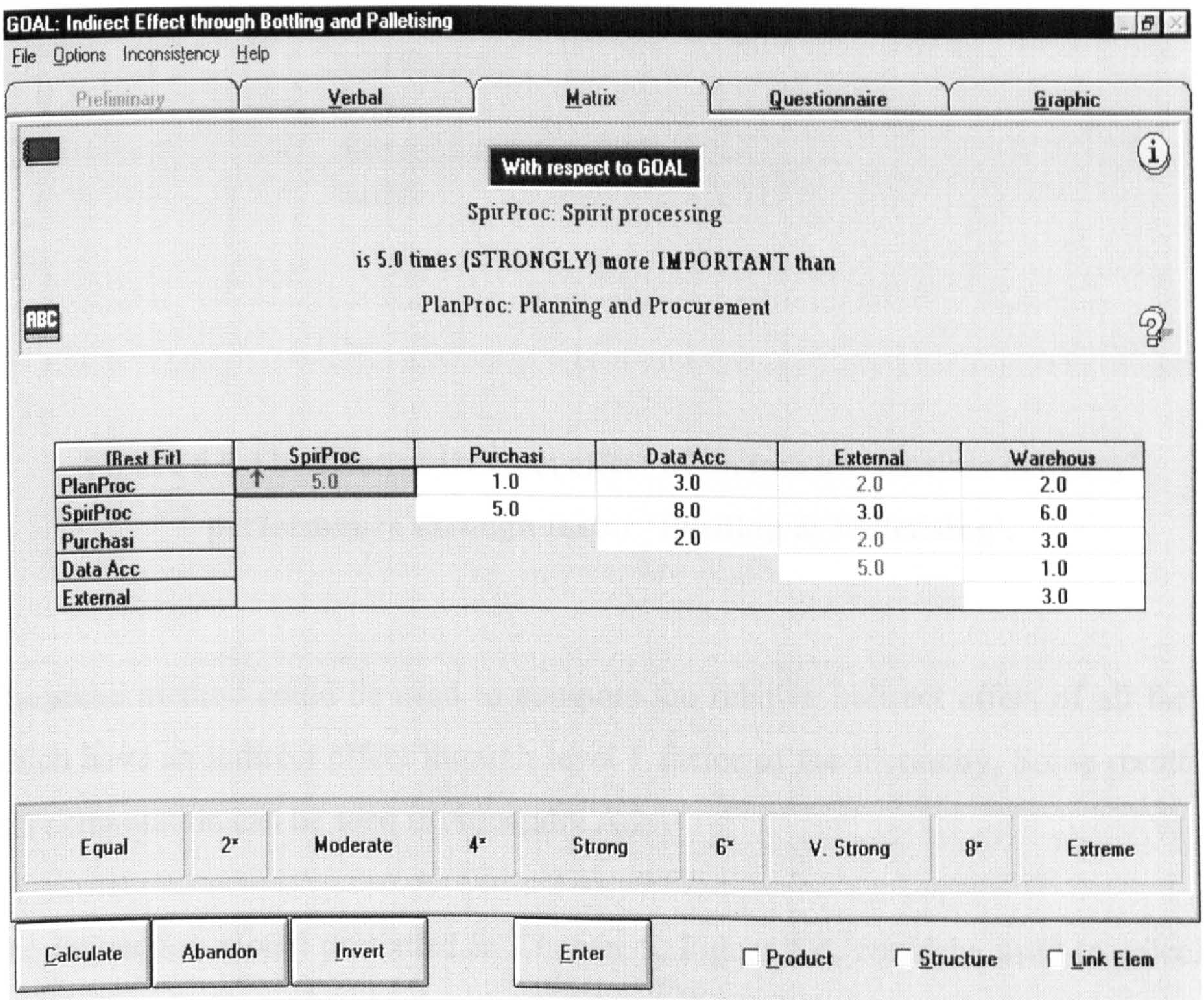


Figure 6.8. Pair-wise comparison matrix of factors indirectly affecting 'on time delivery' performance through factor 'Bottling & Palletising'.

The relative indirect effect of factors 'Planning & Procurement', 'Spirit Processing', 'Purchasing', 'Data Accuracy', 'External' and 'Warehousing' on 'on time delivery' performance through factor 'Bottling & Palletising' is indicated in Figure 6.9.

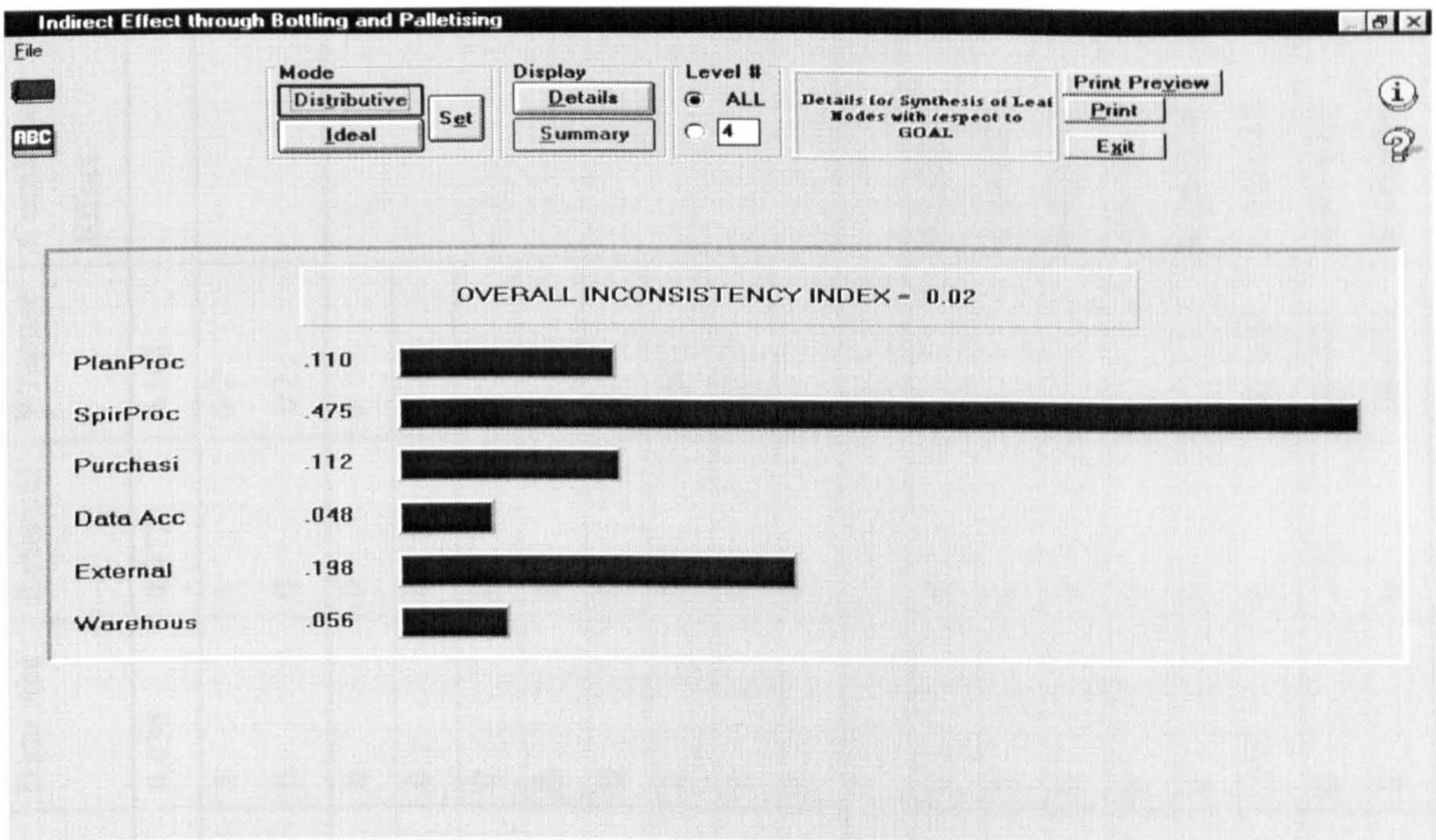


Figure 6.9 The relative indirect effect of factors on 'on time delivery' performance through factor 'Bottling & Palletising'.

The same method could be used to compute the relative indirect effect of all factors which have an indirect effect through level 1 factor of the hierarchy. Some results of this computation can be seen in Appendix A.2.

The interaction model presented in Chapter 5, Figure 5.6, could be used to calculate the combined effect of factors on performance. Table 6.2 shows the calculation of the combined effect of level 1 factors on 'on time delivery' performance.

As explained in Chapter 5, Cluster I consists of the inherent effect of a factor, while Cluster II consists of the self-interaction effect of a factor and the indirect effects of other factors from the same level through that factor. For factor 'Bottling and Palletising', for example, the direct effect is 0.193 as indicated in Figure 6.6. The decision-maker believed that the effect of Cluster I on the direct effect was 7 times more than the effect of Cluster II on the direct effect. Consequently, the effect of Cluster II is 1/8 x 0.193 = 0.024125.

Table 6.2. Computation of combined effect of level 1 factors.

Factors of Level 1		Bottling	Ord.Proc	Plan&Pro	Spirit Proc	Purchas	Data Acc	External	W/house	Combined Effect
Direct Effect		0.193	0.052	0.112	0.372	0.061	0.035	0.072	0.101	
Cluster I		7/8	8/9	8/9	7/8	7/8	1	1	6/7	
Cluster II		1/8	1/9	1/9	1/8	1/8	0	0	1/7	
Relative Contribution on Cluster II	Bottling	0	0.166	0	0	0	0	0	0	
	Ord.Proc	0	0	0	0	0	0	0	0	
	Plan&Pro	0.110	0.092	0	0.436	0.326	0	0	0	
	Spirit Proc.	0.475	0.462	0.074	0	0	0	0	0	
	Purchas	0.112	0.090	0.214	0	0	0	0	0	
	Data Acc	0.048	0.050	0.438	0.097	0.070	0	0	0.667	
	External	0.198	0.051	0.200	0.218	0.604	0	0	0.333	
	W/house	0.056	0.090	0.074	0.250	0	0	0	0	
Inherent Effect and Indirect Effect	Bottling	.168875	.000958	0	0	0	0	0	0	0.169833
	Ord.Proc	0	.046222	0	0	0	0	0	0	0.046222
	Plan&Pro	.002658	.000530	.099555	.020273	.002486	0	0	0	0.125502
	Spirit Proc.	.011459	.002668	.000921	.325500	0	0	0	0	0.340548
	Purchas	.002702	.000520	.002663	0	.053375	0	0	0	0.059260
	Data Acc	.001158	.000288	.005451	.004509	.000534	.035	0	.009624	0.056564
	External	.004777	.000294	.002489	.010135	.004605	0	.072	.004805	0.099105
	W/house	.001351	.000520	.000921	.011623	0	0	0	.086571	0.100986

From the pair-wise comparison questionnaires for indirect effect, the relative effects of factors which have an indirect effect through factor 'Bottling and Palletising' have been computed as follows as indicated in Figure 6.9:

- Planning and Procurement = 0.110
- Spirit Processing = 0.475
- Purchasing = 0.112
- Data Accuracy = 0.048
- External = 0.198
- Warehousing = 0.056

The values of relative indirect effects of level 1 factors are listed in Table 6.2 under the heading **Relative Contribution on Cluster II.**

The value of the Relative Contribution on Cluster II determines the indirect effect of each factor on performance. For factor 'Bottling and Palletising' the indirect effect of factors 'Planning and Procurement', 'Spirit Processing', 'Purchasing', 'Data Accuracy', 'External' and 'Warehousing' can be computed as follows:

- Planning and Procurement = 0.110 x 0.024125 = 0.002658
- Spirit Processing = 0.475 x 0.024125 = 0.011459
- Purchasing = 0.112 x 0.024125 = 0.002702
- Data Accuracy = 0.048 x 0.024125 = 0.001158
- External = 0.198 x 0.024125 = 0.004777
- Warehousing = 0.056 x 0.024125 = 0.001351

These values are listed in Table 6.2 under the heading **Inherent Effect and Indirect Effect.**

The inherent effect of a factor is computed by multiplying the relative effect of Cluster I by its direct effect. For example, for factor 'Bottling and Palletising', its inherent effect is 7/8 x 0.193 = 0.168875. The combined effect of a factor is then calculated by summing up its inherent effect and all the indirect effects of other factors through this factor.

For example, the combined effect of factor 'Planning and Procurement' is 0.002658 + 0.000530 + 0.099555 + 0.020273 + 0.002486 = 0.125502. A summary of the combined effect of the lowest level factors on 'on time delivery' performance is indicated in Table 6.3.

Table 6.3. Combined effect of factors on 'on time delivery' performance.

No	Factor	Comb. Effect		No	Factor	Comb. Effect
1	2.1 Breakdown	0.018384		24	2.26 Pur. P.&C. Data	0.005515
2	2.2 Bottling Quality	0.004094		25	2.27 Stock Lost&Dam.	0.032747
3	2.3 Bott. Daily Priority	0.008511		26	2.28 Picking Accuracy	0.012926
4	2.4 Bott. Labour Supply	0.004273		27	2.29 Inventory Acc.	0.053559
5	2.5 Bott. Material Supply	0.003682		28	2.30 Data Accuracy	0.003543
6	2.6 Bott. Spirit Supply	0.013012		29	2.31 Product Knowledge	0.018573
7	2.7 Bottling Plan	0.013474		30	2.32 Data Availability	0.004819
8	2.8 Documentation	0.025123		31	2.33 Transport&Shipping	0.019714
9	2.9 External Warehouse	0.056574		32	2.34 Order Bookability	0.017619
10	2.10 Order Bookability	0.031695		33	2.35 Ext.M'rial Supply	0.017240
11	2.11 Order Accuracy	0.013206		34	2.36 Blending Program	0.018421
12	2.13 Stock Rec. Accur.	0.110253		35	2.37 W/h M'rial Availabi.	0.018969
13	2.14 Bookshipability	0.083525		36	2.38 Blend.Spec. Avail.	0.038598
14	2.15 Forecast Accuracy	0.055600		37	2.39 Liquid Arrival	0.043142
15	2.17 Plan. Data Avail.	0.091679		38	2.40 Transportation	0.004437
16	2.18 Plan. M'rial Supply	0.043894		39	2.41 W/h Spirit Quality	0.005686
17	2.19 Line Capacity	0.015450		40	2.42 W/h Labour Supply	0.009259
18	2.20 Plan. Data Accuracy	0.007538		41	3.1 Loading Capacity	0.004910
19	2.21 Spirit Qual.&Str'th	0.007883		42	3.2 Loading Priorities	0.002324
20	2.22 Spirit Availability	0.023253		43	3.3 Loading Plan	0.001701
21	2.23 Flexibility	0.015764		44	3.4 Loading Trans. Avail.	0.002150
22	2.24 Spirit Proc. Capa.	0.007886		45	3.5 Line Choice	0.003426
23	2.25 Pur. M'rial Supply	0.004742		46	3.6 Product Mix	0.001230

6.2.2 Reducing the number of performance reports

As presented in Chapter 5, the QMPMS has been extended to reduce the number of performance reports. In general, a reduction in the number of performance reports could be carried out by:

1. Identifying the effect of factors on performance.
2. Classifying the factors into class A, B, or C using Pareto Analysis.
3. Classifying the factors into categories critical, intermediate and minor and determining the frequency of reporting.

For 'on time delivery' performance, a reduction of the number of performance reports was carried out as follows:

1. Identifying the effects of factors on performance

Identification of the effects of factors affecting 'on time delivery' performance was carried out and the results are indicated in Table 6.3.

2. Classifying the factors into class A, B, or C

Using Pareto Analysis, factors affecting 'on time delivery' performance can be classified into classes A, B, or C as indicated in column five of Table 6.4. Since class A factors contribute 78.37 percent of the total effect on 'on time delivery' performance, measurement and reporting should be prioritised into factors which are members of this class.

3. Classifying the factors into categories critical, intermediate and minor and determining the frequency of reporting

Frequency of measurement is not only determined by the class of factor. The rate of change also determines the frequency of measurement and reporting as explained in Chapter 5.

Table 6.4. Classification of factors affecting 'on time delivery' performance into A, B, or C classes.

No	Factor	Ranked Combined Effect	Cumulative Combined Effect	Class	Category	Measurement Frequency
1	2.21 Spirit Qual.&Str'th	0.110253	0.110253	A	Critical	Every 4 hours
2	2.24 Spirit Proc. Capa.	0.091679	0.201932	A	Intermediate I	Weekly
3	2.22 Spirit Availability	0.083525	0.285457	A	Critical	Daily
4	2.19 Line Capacity	0.056574	0.342031	A	Critical	Daily
5	2.23 Flexibility	0.055600	0.397631	A	Critical	Daily
6	2.35 Ext.M'rial Supply	0.053559	0.451190	A	Critical	Daily
7	2.25 Pur. M'rial Supply	0.043894	0.495084	A	Critical	Daily
8	2.6 Bott. Spirit Supply	0.043142	0.538226	A	Critical	Every 4 hours
9	2.5 Bott. Material Supply	0.038598	0.576824	A	Critical	Daily
10	2.33 Transport&Shipping	0.032747	0.609571	A	Critical	Daily
11	2.2 Bottling Quality	0.031695	0.641265	A	Critical	Every hour
12	2.18 Plan. M'rial Supply	0.025123	0.666388	A	Critical	Daily
13	2.29 Inventory Acc.	0.023253	0.689641	A	Critical	Daily
14	2.39 Liquid Arrival	0.019714	0.709355	A	Critical	Every 4 hours
15	2.42 W/h Labour Supply	0.018969	0.728325	A	Critical	Daily
16	2.37 W/h M'rial Availabi.	0.018573	0.746898	A	Critical	Daily
17	2.41 W/h Spirit Quality	0.018421	0.765319	A	Critical	Daily
18	2.1 Breakdown	0.018384	0.783703	A	Intermediate II	As occured
19	2.4 Bott. Labour Supply	0.017619	0.801323	B	Intermediate I	Weekly
20	2.40 Transportation	0.017240	0.818563	B	Intermediate I	Weekly
21	2.3 Bott. Daily Priority	0.015764	0.834326	B	Intermediate I	Weekly
22	2.26 Pur. P.&C. Data	0.015450	0.849776	B	Intermediate I	Weekly
23	2.17 Plan. Data Avail.	0.013474	0.863250	B	Intermediate I	Weekly
24	2.20 Plan. Data Accuracy	0.013206	0.876455	B	Intermediate I	Weekly
25	2.15 Forecast Accuracy	0.013012	0.889467	B	Intermediate I	Weekly
26	2.34 Order Bookability	0.012926	0.902393	B	Intermediate I	Weekly
27	2.9 External Warehouse	0.009259	0.911652	B	Intermediate I	Weekly
28	2.11 Order Accuracy	0.008511	0.920163	B	Intermediate I	Weekly
29	2.30 Data Accuracy	0.007886	0.928049	B	Intermediate I	Weekly
30	2.28 Picking Accuracy	0.007883	0.935931	B	Intermediate I	Weekly
31	2.27 Stock Lost&Dam.	0.007538	0.943469	B	Intermediate I	Weekly
32	2.8 Documentation	0.005686	0.949155	B	Intermediate I	Weekly
33	2.32 Data Availability	0.005515	0.954670	C	Minor I	Monthly
34	3.1 Loading Capacity	0.004910	0.959580	C	Minor I	Monthly
35	2.38 Blend.Spec. Avail.	0.004819	0.964399	C	Minor I	Monthly
36	2.31 Product Knowledge	0.004742	0.969140	C	Minor I	Monthly
37	2.7 Bottling Plan	0.004437	0.973578	C	Minor I	Monthly
38	2.13 Stock Rec. Accur.	0.004273	0.977851	C	Minor I	Monthly
39	2.10 Order Bookability	0.004094	0.981945	C	Minor I	Monthly
40	2.14 Bookshipability	0.003682	0.985627	C	Minor I	Monthly
41	2.36 Blending Program	0.003543	0.989170	C	Minor I	Monthly
42	3.5 Line Choice	0.003426	0.992596	C	Minor I	Monthly
43	3.2 Loading Priorities	0.002324	0.994919	C	Minor I	Monthly
44	3.4 Loading Trans. Avail.	0.002150	0.997069	C	Minor I	Monthly
45	3.3 Loading Plan	0.001701	0.998770	C	Minor I	Monthly
46	3.6 Product Mix	0.001230	1	C	Minor I	Monthly

The greater the rate of changes of a factor, the more frequent measurement and reporting on this factor should be carried out. Factors that are members of class A and which change most frequently, are classified into the 'critical' category. This category is measured and reported on most frequently. The categories and frequency of measurement of 'on time delivery' performance are indicated in columns six and seven of Table 6.4. Using this method the number of performance reports can be reduced significantly.

6.2.3 Discussion and conclusion of case study one

A quantitative method for a performance measurement system with an example of the application and its extensions have been presented. The application of the method to 'on time delivery' performance at J&B Scotland Ltd. resulted the following findings:

1. The interaction of factors affecting performance can be clearly shown using a structured diagram or tree diagram. By numbering the factors as indicated by Figure 6.3 the indirect effect of factors on performance through other factors within the same level could be clearly indicated.
2. The QMPMS can be used to compute the direct, the interaction and the combined effect of the factors on performance. Using the method developed, the effects of multi-dimensional factors on performance can be aggregated into a single dimensionless unit (priority). This enables managers to determine the level of impact of factors on performance and allows them to focus on performance improvement. The identification of the interaction effect of factors affecting performance goes one step forward in helping to understand the dynamic behaviour of factors affecting performance.
3. The number of performance reports can be reduced using the taxonomy of performance measurement developed. Using this method, performance measures can be classified. Critical performance measures should be measured at shorter intervals, while non-critical performance measures should be measured at longer

intervals. As a result, the number of performance reports can be minimised and performance improvement programmes can be focused on the critical measures.

It may seem that the technique used in the QMPMS method for quantifying the effects of factors on performance (AHP) is very intuitive, subjective and very difficult to use in practice. However, through a careful explanation of the concept of the method, it has been found that the method can be understood and implemented quite comfortably. Moreover, in performance measurement systems a large number of multi-dimensional factors can affect performance. Integrating those multi-dimensional effects into a single unit can only be done through subjective, individual or group judgement. It is impossible to have objective measurement and a scale system for each different dimension of measurement which would facilitate an objective value trade-off between different measures. For example, how could we develop an objective measurement and scale to measure management commitment? How could we quantify objectively value trade-off between management commitment and percentage of rejects? These types of measurement definitely do not exist. In fact, subjective measurement is the only concept that is widely accepted in Multi-Criteria Decision Analysis to deal with multi-criteria problems.

Since the QMPMS uses subjective measurement, results may not be very accurate. However, this problem could be overcome by using group judgement rather than individual judgement and this would reduce the subjectivity of the judgement. The accuracy of the QMPMS could also be improved through experience. Saaty (1984) suggested that with the help of two practical experiences in using accurate judgement could normally be made.

Some potential problems might be encountered in applying the QMPMS method. The first would probably be hesitation on the part of managers to complete the pair-wise comparison questionnaires, particularly if the method was to be applied to model performance improvement as shown by the 'on time delivery' problem. Performance improvement usually involves identification and quantification of a large number of factors affecting performance. Consequently, the number of pair-wise comparison questionnaires would be enormous and their completion would be exhausting and time-consuming. However, this problem could be eliminated through decomposing the model into several smaller models. Each smaller model could then be distributed to a group of people responsible for filling in the questionnaires. The use of interactive software, such as ExpertChoice (1995), would make implementation of the method much easier.

The second problem of the QMPMS application would be getting a single judgement on pair-wise comparison if more than one person was involved in filling in the questionnaires. Even though Saaty (1994) provided a formula for computing the priority of group judgement using geometric mean, getting consensus among members of a group in filling in the score in the pair-wise comparison matrices appears much better than just using geometric means. Much discussion may be required to elaborate on the real situation before a general consensus of the judgement of a particular problem can be achieved. Cognitive mapping is also an effective method which could be used to elaborate on the problem.

Furthermore, if companies operate in a dynamic environment, performance measurement is consequently a dynamic process. This means that performance measures will change over time and vary between companies. In a particular company, performance measures that are critical today and measured on a short interval basis, could change after a period of time and become trivial performance measures measured quarterly. These changes could be as a result of a performance improvement programme, or because the internal and/or external environments of the company had changed. It is important to recognise these changes as early as possible in order that the priority of the performance measurement system can be changed accordingly. However, changes in some factors up to a certain level would have no significant effect on performance measurement and the current performance measurement system would not need to be changed. To deal with this problem it seems a 'sensitivity analysis' on the method is required.

The application of the QMPMS on 'on time delivery' problem at J&B Scotland Ltd. was a 'desk experiment'. We could not learn about the applicability, validity and stability of the QMPMS. To be able to identify the applicability, validity and stability of the QMPMS real case studies should be carried out.

Table 6.5 shows the summary of the case study 1.

6.3 Case Study Two: Validation of the QMPMS

6.3.1 Validation concept

To test the validity of the QMPMS the following concept was adopted:

1. The direction of changes of the QMPMS is the same as the direction of changes of the actual data. For example, if the actual data at a particular period of time indicated the occurrence of performance improvement, the QMPMS should also show the same occurrence.
2. The lesser the difference of the relative changes of the QMPMS from the relative changes of the actual data, the more the QMPMS is valid.

To implement this concept, the following steps were carried out:

1. A case for experiment was selected.
2. The QMPMS model of the selected case was developed.
3. Related data was collected.
4. The relative change of performance of two successive periods of the selected cased was computed.
5. The relative changes computed using the QMPMS to the relative changes of the actual data in pairs was compared.
6. The results using graphics, descriptive and inference statistical methods were analysed.
7. Conclusions were drawn.

Table 6.5. The summary of the case study 1.

Case study 1: J&B Scotland Ltd.		
What we want to learn	**Case study process**	**What we can learn / findings**
1. Can the interaction of factors affecting performance be clearly displayed using a structured diagram, especially if there are a large number of factors affecting performance? 2. Can the direct effect, interaction effect and combined effect of the factors affecting performance be computed using the method developed (QMPMS)? 3. Can the taxonomy of performance measures developed be used to reduce the number of performance reports?	Using the data of previous research [Bititci, 1995], a "desk study" (to differentiate with field a case study) was carried out. The method developed (QMPMS) was used to: ✓ identify the relationship (including the interaction) of factors affecting performance, ✓ compute the direct, interaction and combined effect, ✓ classify the factors affecting performance into categories "critical", "intermediate" and "minor" to reduce the number of performance reports.	Positive aspects: This case study shows that theoretically / numerically (to contrast with the results of a field case study) the method developed: 1. can clearly show the relationships of factors effecting performance (including the interaction) even though there are 56 factors included in the structure, (Contribution 1) 2. can compute the direct, interaction and combined effect of the factors on performance, (Contribution 1) 3. can reduce the number of performance reports by reporting critical factors most frequently and minor factors least frequently. (Contribution 3) Negative aspects: Since this case study is a 'desk experiment' we can not learn about the applicability, validity, and stability of the method developed (QMPMS). To be able to identify the applicability, validity and stability of the method (QMPMS) real case studies should be carried out.

6.3.2 The validation experiment

A. The selection of the case and the development of the QMPMS model

The validity of the QMPMS was carried out through the application of the QMPMS to model 'Total production cost per unit' at a collaborator company - 'Seagate Distribution (UK) Ltd'. 'Seagate Distribution (UK) Ltd' is part of the 'Seagate Corporation' which specialises in the manufacture and distribution of disk and tape drives for the electronics industry. 'Seagate Distribution (UK) Ltd' configures the company's product to the customer specification before delivery to the customer.

The selection of the case and the development of the QMPMS model were carried out as follows. Firstly, the research team conducted a presentation to the general manager of 'Seagate Distribution (UK) Ltd' to explain the objective of the research and the concept of the QMPMS. It was very critical at this stage to make clear to management the concept of the pair-wise comparison questionnaires used by the method, which asked the following questions: "Comparing factor A to B, which one has a stronger effect on performance?" and "How strong?" After the presentation the research team asked the company's manager to think about a problem that might be selected for a case study and advised that the selection of the case study and the development of the model could be discussed at a future meeting.

At a following meeting the research team and the general manager discussed the selection of a case study and agreed to select 'Total production cost per unit' because the availability of information related to this. The research team asked the manager to identify factors affecting 'Total production cost per unit' and their relationship. It was important at this point to ensure that it was the manager's thoughts concerning factors affecting 'Total production cost per unit' and their relationships which were mapped. The results are indicated in Figure 6.10.

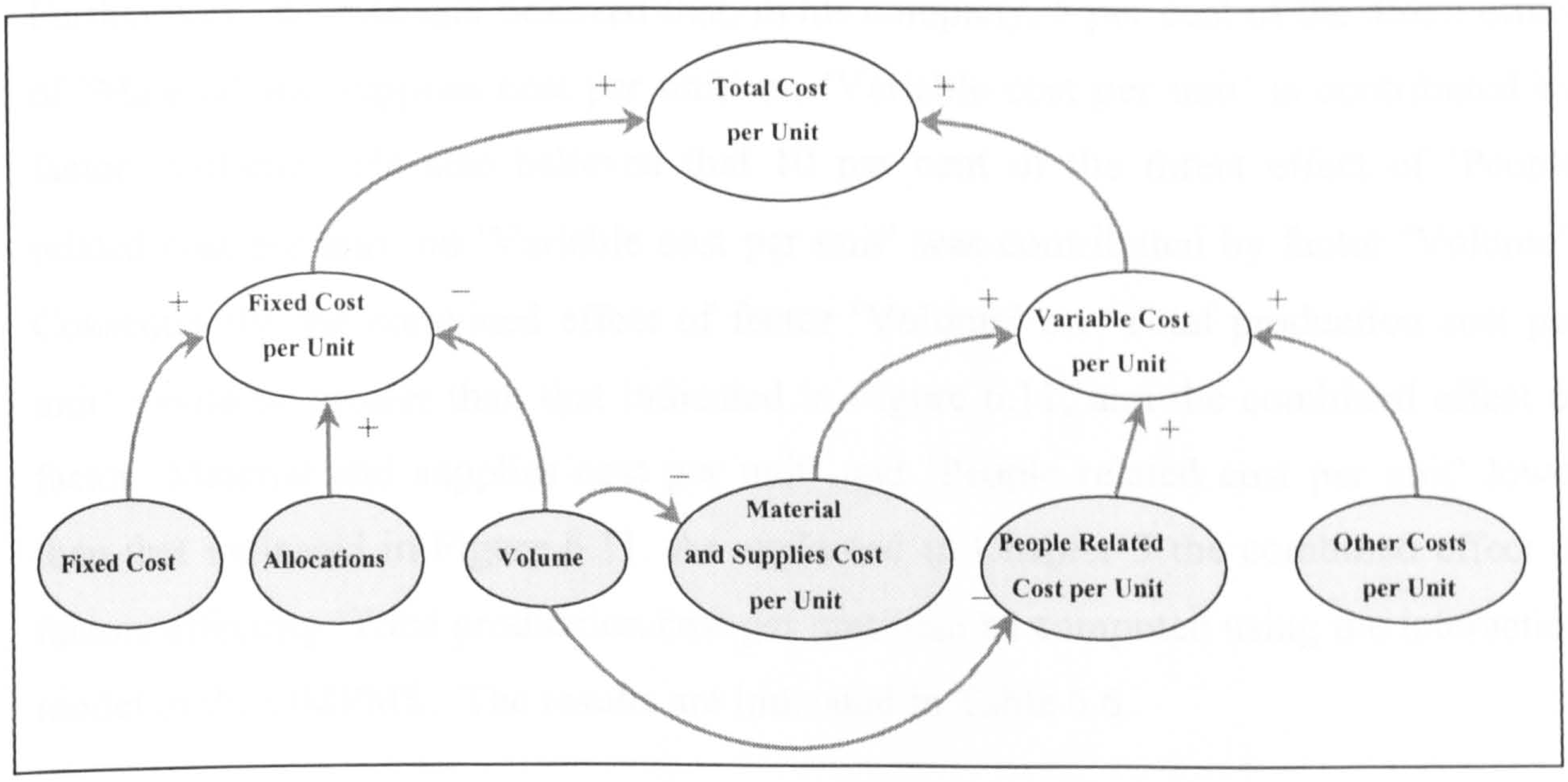


Figure 6.10. Factors affecting 'Total production cost per unit' and their relationship.

The manager's judgement on the effects of factors on 'Total production cost per unit' was elicited by the use ExpertChoice. The direct effect of factors on 'Total production cost per unit' is indicated in Figure 6.11.

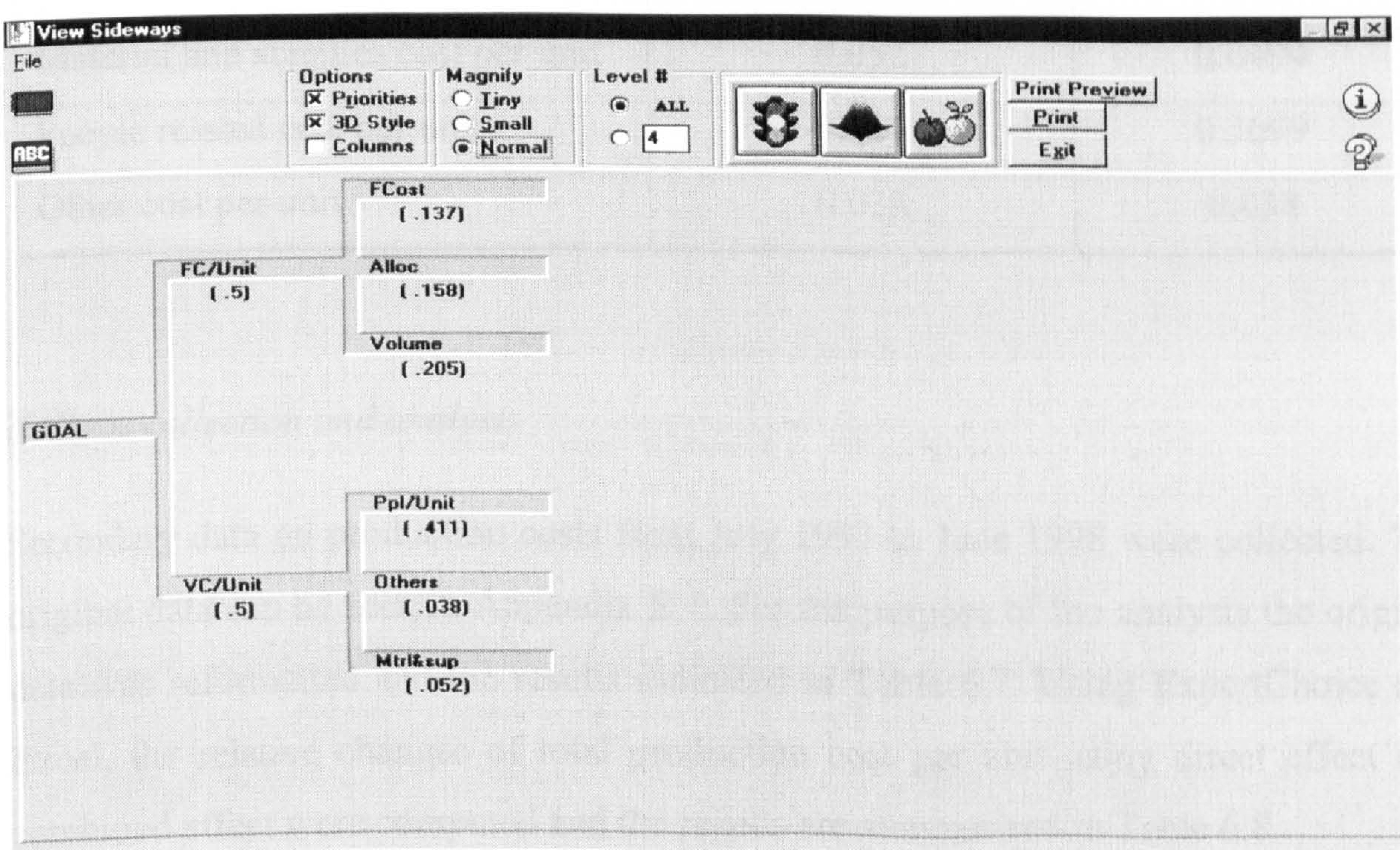


Figure 6.11. Direct effect of factors affecting 'Total production cost per unit'.

Furthermore, the manager believed that, in his company, 5 per cent of the direct effect of 'Material and supplies cost per unit' on 'Variable cost per unit' is contributed by factor 'Volume'. He also believed that 10 per cent of the direct effect of 'People related cost per unit' on 'Variable cost per unit' was contributed by factor 'Volume'. Consequently, the combined effect of factor 'Volume' on 'Total production cost per unit' would be greater than that indicated in Figure 6.11, and the combined effect of factor 'Material and supplies cost per unit' and 'People related cost per unit' lower than that indicated in Figure 6.11. As explained in Chapter 5 the combined effect of factors affecting 'Total production cost per unit' can be computed using the interaction model of the QMPMS. The results are indicated in Table 6.6.

Table 6.6. Combined effect of factors affecting 'Total production cost per unit'.

Factor	Direct Effect	Combined Effect
Fixed cost per unit	0.500	0.500
Variable cost per unit	0.500	0.500
Fixed cost	0.137	0.137
Allocations	0.158	0.158
Volume	0.205	0.2487
Material and supplies cost per unit	0.052	0.0494
People related cost per unit	0.411	0.3699
Other cost per unit	0.038	0.038

B. Data collection and analysis

Secondary data on production costs from July 1997 to June 1998 were collected. The original data can be seen in Appendix B 1. For the purpose of the analysis the original data was reformatted and the results indicated in Table 6.7. Using ExpertChoice and Excel, the relative changes of total production cost per unit using direct effect and combined effect were computed and the results are summarised in Table 6.8.

Table 6.7. Total production cost per unit from July 1997 to December 1997.

	Jul97	Aug97	Sep97	Oct97	Nov97	Dec97
A.1 Fixed Cost:						
Fixed cost - Brewser (Building)	9849	12012	11014	10740	15163	16153
Fixed cost - YB (Building)	0	0	0	0	18691	5102
Administration (People)	19185.36	25016.55	19131.34	16329.589	21003.98	16732.33
Traffic (V-based)	5721.878	12220.45	5773.501	3834.1465	6484.343	4804.928
Total	34756.24	49249	35918.84	30903.735	61342.33	42792.26
A.2 Allocations (V.based)	36126	47111	51872	41502	42717	49787
A.3 Volume	27498	41614	41823	42492	52313	44447
A. Fixed Cost per Unit	**2.57772**	**2.31557**	**2.0991**	**1.703985**	**1.98917**	**2.08291**
B.1 Material & Supply per Unit	0.23118	0.105181	0	0	0.231854	0.0859
B.2 Total People Related Cost	3.224957	2.681431	2.043351	2.3535352	2.659762	2.647105
B.2.1 People Related Cost Per Unit	1.992581	1.816144	1.404682	1.7327497	1.964502	2.020294
B.2.2 Warehouse (people)	1.232376	0.865287	0.638669	0.6207856	0.69526	0.626811
B.3 Other Cost per Unit	0	0	0	0	0	0.019349
B. Variable Cost per Unit	**3.45614**	**2.78661**	**2.04335**	**2.353535**	**2.89162**	**2.75235**
Total Cost per Unit	**6.03386**	**5.10218**	**4.14245**	**4.05752**	**4.88078**	**4.83527**

Table 6.7. Total production cost per unit from January 1998 to June 1998.

	Jan98	Feb98	Mar98	Apr98	May98	Jun98
A.1 Fixed Cost:						
Fixed cost-Brewser (Building]	14466	14549	15921	15073	14767	11587
Fixed cost - YB (Building)	9196	9261	9510	9020	10819	16402
Administration (People)	13523.92	9951.292	15514.42	3526.634	12423.12	16852.89
Traffic (V-based)	3755.809	5433.344	5151.462	1055.4371	3780.208	4813.155
Total	40941.73	39194.64	46096.89	28675.071	41789.33	49655.05
A.2 Allocations (V.based)	39444	43504	54058	54097	47179	57106
A.3 Volume	15737	18028	40766	6397	24629	30542
A. Fixed Cost per Unit	**5.10807**	**4.58723**	**2.45682**	**12.9392**	**3.61234**	**3.49555**
B.1 Material & Supply per Unit	0.253416	0.356889	0.211868	0.6546819	0	0.133521
B.2 Total People Related Cost	2.797782	2.678759	2.186079	1.584564	2.420407	2.519788
B.2.1 People Related Cost Per Unit	1.589248	1.740071	1.547957	0.6904799	1.606034	1.739572
B.2.2 Warehouse (people)	1.208534	0.938688	0.638122	0.8940841	0.814373	0.780216
B.3 Other Cost per Unit	0.129694	0.006878	0.072242	0.042833	0.075561	0.082346
B. Variable Cost per Unit	**3.18089**	**3.04253**	**2.47019**	**2.282079**	**2.49597**	**2.73565**
Total Cost per Unit	**8.28896**	**7.62976**	**4.92701**	**15.22128**	**6.10831**	**6.2312**

Table 6.8. Relative changes of 'Total production cost per unit'.

Period	Direct Effect (per cent)	Combine Effect (per cent)
July – August 1997	89.810	89.062
August – September 1997	78.434	79.723
September – October 1997	100.107	99.459
October - November 1997	123.302	120.925
November – December 1997	103.763	89.990
December 1997 – January 1998	133.271	120.975
January – February 1998	91.855	90.695
February – March 1998	86.290	73.151
March – April 1998	115.012	117.062
April – May 1998	88.593	75.339
May-June 1998	114.535	104.083

The relative change of total production cost per unit at successive period of times is calculated as follows:

$$\text{Relative change}_{(\text{July-August})} = (\text{Total production cost per unit}_{(\text{August})} / \text{Total production cost per unit}_{(\text{July})}) \times 100\ \%$$

To analyse the data three techniques were used: mean percentage of deviation, graphical, and Wilcoxon Matched-Pair Test.

Mean percentage of deviation (MPD)

Mean percentage of deviation (MPD) indicates, in average, how far the QMPMS differs from the actual condition. The less the MPD, the less the QMPMS differs from the actual condition, and the more the QMPMS is valid. Table 6.9 shows the MPDs of the QMPMS from the actual data for both direct and combined effect.

Table 6.9. Mean percentage of deviation for both direct and combined effect.

Period	Relative change (percent)			Percentage Deviation	
	Actual	Direct	Combined	Direct	Combined
July – Aug'97	84,577	89.810	89.062	6.187	5.302
Aug – Sept'97	81.176	78.434	79.723	3.377	1.789
Sept – Oct'97	98.067	100.107*)	99.459	2.081	1.420
Oct – Nov'97	120.197	123.302	120.925	2.583	0.605
Nov – Dec'97	99.190	103.763*)	89.990	4.621	9.265
Dec'97 – Jan'98	171.281	133.271	120.975	22.191	29.370
Jan – Feb'98	92.038	91.855	90.695	0.198	1.458
Feb – March'98	64.613	86.290	73.151	33.549	13.214
March – Apl '98	308.722	115.012	117.062	62.745	62.081
April – May '98	40.144	88.593	75.339	120.686	87.671
May - June'98	101.964	114.535	104.083	12.329	2.079

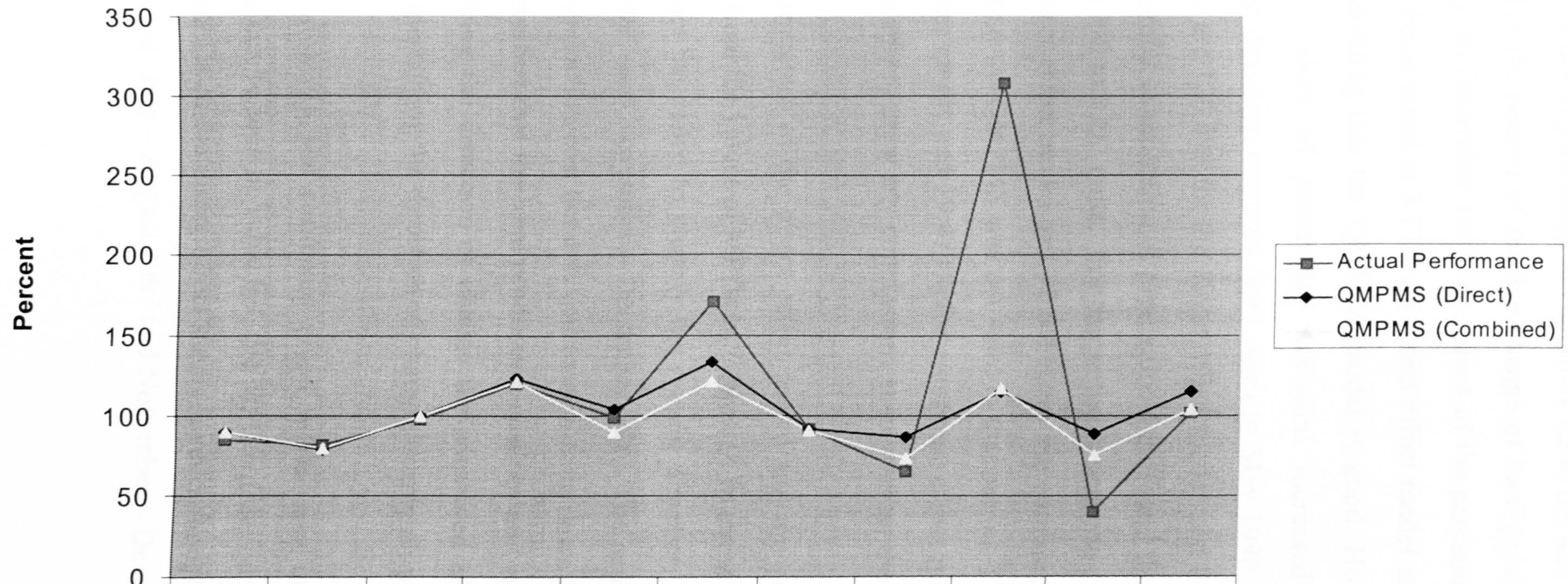
*) the model failed to identify the direction of change

Direct Effect:	**Combined Effect:**
MPD (July - Dec'97) = 3.77%	MPD (July - Dec'97) = 3.67%
MPD (Dec'97 – June'98) = 41.95%	MPD (Dec'97 – June'98) = 32.645%
MPD (July'97 – June'98) = 24.59%	MPD (July'97 – June'98) = 19.478%

The graphics of relative changes

To get a clearer picture of the QMPMS relative changes from the actual relative changes, the relative changes of the QMPMS and the actual data are presented in graphical form as indicated in Figure 6.12.

Relative Change of Total Production Cost per Unit



	A97	S97	O97	N97	D97	J98	F98	M98	A98	M98	J98
Actual Performance	84.5771	81.1765	98.0676	120.197	99.1803	171.281	92.0386	64.6134	308.722	40.1445	101.964
QMPMS (Direct)	89.810	78.434	100.107	123.302	103.763	133.271	91.855	86.290	115.012	88.593	114.535
QMPMS (Combined)	89.062	79.723	99.459	120.925	89.990	120.975	90.695	73.151	117.062	75.339	104.083

Period

Figure 6.12. The relative change the QMPMS and the actual data.

From the values of percentage deviation in Table 6.9 and the graphics in Figure 6.12, it is clear that the pattern of relative change of total production cost per unit changed. From July to December 1997 the values of the percentage deviation are quite small, the MPD being equal to 3.77% for direct effect model and 3.67% for combined effect model indicating that the QMPMS model is good. However, from January to June 1998 the values of percentage deviation increased significantly. The greatest percentage deviation occurred from April to May 1998. In that period the percentage deviations are 120.686 for the direct effect model and 87.671 for the combined effect model. Careful examination of production data found that the volume dropped sharply in April 1998 to 6397 units. For the period January to June 1998 the MPD is 41.95% for the direct effect model and 32.645% for the combined effect model. It is therefore apparent that the QMPMS was not valid in that period. The overall MPD is 24.59% for direct effect model and 19.478% for combined effect model. These values appear too high to be able to draw any conclusions as to whether the QMPMS is valid or not.

The performances of the direct effect model and the combined effect model can be analysed from the values of MPDs in Table 6.9. In terms of the direction of change, the direct effect has failed to identify the correct direction in two periods, September – October 1997 and November – December 1997. The actual performance indicated that the total production cost per unit decreased during those periods, while the direct effect model identified that the total production cost per unit increased during those periods. In identifying the direction of change the combined effect model performed better, correctly identifying the direction of changes during all periods.

In terms of MPD, the combined effect model also outperformed the direct effect model. As can be seen in Table 6.9, the MPDs of the combined effect model are better than the MPDs of the direct effect model, even although the difference is quite small for the periods July – August 1997 and November – December 1997.

Statistical test

As explained in Chapter 2 that the **Wilcoxon Matched-Pairs** test was used to test the validity of the QMPMS. To show how this statistical test was carried out, the validity of the direct effect model over the period July 1997 to June 1998 has been used as an example.

1. Define the statistical hypothesis:

   Since the hypothesis is that the QMPMS is a valid method, the null and alternative hypotheses can be defined as follows:

   H_0: d = 0 (There is no difference between the QMPMS and actual data)

   H_A: d ≠ 0 (There is a difference between the QMPMS and actual data)

   The null hypothesis is rejected only if the data strongly indicates that the deviation is significantly large.

2. Find the difference score of each pair (d_i).

No.	1	2	3	4	5	6	7	8	9	10	11
d_i	+ 5.233	- 2.742	+ 2.040	+ 3.105	+ 4.583	- 38.01	- 0.182	+ 21.67	- 193.7	+ 48.44	+ 12.57

3. Rank the order of the differences from smallest to largest regardless of the signs.

No.	1	2	3	4	5	6	7	8	9	10	11
d_i	0.182	2.040	2.742	3.105	4.583	5.233	12.57	21.67	38.01	48.44	193.7

4. Add the actual signs of the differences to the rank values.

No.	1	2	3	4	5	6	7	8	9	10	11
d_i	- 0.182	+ 2.040	- 2.742	+ 3.105	+ 4.583	+ 5.233	+ 12.57	+ 21.67	– 38.01	+ 48.44	- 193.7

5. Calculate the test statistic T, which is defined as the sum of the ranks with the less frequent sign.

   Negative sign is the less frequent, so the test statistic test T is = 1 + 3 + 9 + 11 = 24.

6. Find critical value T from the statistical table for particular significance level and number of pairs.

   For this experiment 95% of significant level was chosen and the number of pairs is 11. From the statistical table for Wilcoxon Matched-Pairs Test in Appendix B2, the value of statistical test T is 11.

7. Make decision to accept or reject the null hypothesis.

   The null hypothesis is rejected if test statistic T is greater than the critical value T. Since the test statistic T is greater than the critical value of T, reject the null hypothesis. In other words the test has failed to prove that the performance of the QMPMS is the same as the performance of the actual data. The conclusion is that the direct effect model of the QMPMS is invalid.

Using the same procedure the statistical test T of the combined effect model was computed and the value is 34. Since the value is greater than 11, the combined effect model of the QMPMS is also invalid.

6.3.3 Discussion and conclusion of case study two

In this case study the general manager of Seagate Distribution (UK) did not feel it was difficult to understand the operational (not theoretical) concept of the QMPMS. Through the explanation of the concept of the QMPMS given by the researchers during the presentations and meeting the general manager could understand the QMPMS quite easily. It was also found that the general manager wanted to include the interaction effect in the model. He agreed that in the current dynamic environment the interaction of factors affecting performance is becoming important to be examined.

The accuracy of the QMPMS is good. From July to December 1997 the values of the percentage deviation are quite small, the MPD being equal to 3.77% for direct effect model and 3.67% for combined effect model indicating that the QMPMS method is good. However, from January to June 1998 the values of percentage deviation increased significantly. The greatest percentage deviation occurred from April to May 1998 i.e. 120.686 for the direct effect model and 87.671 for the combined effect model. This happened because the volume dropped sharply in April 1998 to 6397 units. As can be seen from Table 6.9 and the graph in Figure 6.12, the pattern of the relative change of total production cost per unit changed significantly from January 1998. In that period volume started to decrease. The lowest level of volume occurred in April 1998 with a total production of 6397 units. Clarification of this situation to management of 'Seagate Distribution (UK) Ltd' revealed that since January 1998 the company had suffered by losing its market share to its competitor, the worst loss occurring in April 1998. In other words, the business environment had changed in 1998 and such changes to the external and internal environment certainly needed a change of model.

As the company loses its market share, increasing demand and production volume becomes a much more important factor than ever before. If demand and production volume are low, many resources lie idle making the fixed cost per unit high. Thus the effect of fixed cost per unit to total production cost per unit becomes more important than the effect of variable cost per unit. Consequently, the model should be modified to accommodate the change of production volume.

Basically, two types of modification to the model can be done. Firstly, no other factor emerged on the model and in this case modification can be carried out by modifying the effect of factors on total production cost per unit through filling new pair-wise comparison questionnaires. The second modification occurs if new factors emerge on the model. For this situation the model must be rebuilt by introducing new factors to the model and filling the pair-wise comparison questionnaires for the new model.

In this experiment, the author discussed the situation with the manager of 'Seagate Distribution (UK) Ltd' who explained that in 1998 demand was low as a result of the company losing its market share to its competitor, hence production was low. It was agreed that the model should be modified to adapt to the changes in the environment. However, the manager believed that rather than modify the effects of factors on performance, introducing another factor (flexibility) into the model would be more appropriate. Based on his evaluation of the market situation, he believed that the demand and production volume could be increased if the flexibility of the manufacturing system was improved. Unfortunately, the company still has no clear idea how flexibility will be improved or how to measure it and is currently trying to define this. Consequently, a new model incorporating the flexibility factor cannot be developed as yet.

In was also found in this case study that the different of the accuracy of the direct effect (do not take into account interaction effect) and the combined effect (take into account interaction effect) was small. The MPD of the direct effect was 3.77 %, while the MPD of the combined effect was 3.67 %. However, this phenomenon could not be generalised for all cases.

The stability of the QMPMS can also be examined from Figures 6.12. The figures show that the QMPMS method was quite stable from July to December 1997. However, as production volume decreased from January 1998 the model seemed to be unstable as indicated by the large difference in the performance of the QMPMS model to the actual performance as indicated in Figure 6.12.

In conclusion, the results of the validity testing of the QMPMS in this experiment can be summarised as follows:

- The method developed (QMPMS) can be used to identify the factors affecting performance and their interaction and quantify the effect (including interaction effect) of the factors on performance.
- The general manager did not feel difficult in understanding the operational (not theoretical) concept of the methods developed (QMPMS).
- The general manager wanted to include the interaction effect in the model.
- In this case, within the period of July 1997 to December 1997 the accuracy of the method (QMPMS) was good (Mean Percentage Deviation was less than 4 %).
- In this case the different of the accuracy of the direct model and the combined model was small. The MPD of the direct effect was 3.77 %, while the MPD of the combined effect was 3.67 %. However, this phenomenon can not be generalised for all cases.
- In this case the method (QMPMS) was stable within the period of July 1997 to December 1997. However, as the environment changed, the system should be modified to accommodate the changes.

Table 6.10 shows the summary of the case study two.

Table 6.10. The summary of the case study 2.

Case study 2: Seagate Distribution (UK)		
What we want to learn	**Case study process**	**What we can learn / findings**
1. Can the method developed (QMPMS) be used to identify factors affecting performance, their interaction and quantify the effect of the factors (including the interaction effect) on performance? 2. Can manager understand easily the concept of the method (cognitive maps, structured diagrams, pair-wise comparison questionnaires, priority, direct effect, interaction effect and combined effect)? 3. Is the method developed (QMPMS) accurate? 4. Is the method developed (QMPMS) applicable to real cases? 5. Is the method developed (QMPMS) stable for a reasonable period of time?	1. A two-hour meeting with the general manager was carried out to explain the objectives of the experiment and the concept of the method (QMPMS). At the end of the meeting, the researchers asked the general manager to think about the case can be used in this research. 2. In the second meeting (two weeks after the first meeting) the general manager decided to use "Total production cost per unit" as the case study, because "Total production cost per unit" was an important issue at that time and all the related information was documented well. The researchers helped the general manager to identify the factors affecting "Total production cost per unit" and their interaction. The general manager was guided to fill in pair-wise comparison questionnaires. The results of the computation of the effects of the factors on "Total production cost per unit", based on the pair-wise comparison filled in, were shown to the general managers to check whether he agreed with the results. If he did not agree with the results, the general manager was asked to modify his judgement. In this research, the general manager was not happy with the results of the first pair-wise comparison. However, he was happy with the second. The researchers were then supplied by the general manager 12 months (from July 1997 to June 1998) reports on "Total production cost per unit". 3. The researchers computed the relative change of "Total production cost per unit" from the previous period to the next period using the	<u>Positive aspects:</u> It was found in this experiment that: 1. The method developed (QMPMS) could be used to identify factors affecting performance, their interaction and quantify the effect of the factors (including interaction effect) on performance. (Contribution 1) 2. The general manager did not feel difficult to understand the operational (not theoretical) concept of the method developed (QMPMS). (Contribution 7) 3. The general manager wanted to include the interaction effect in the model. (Contribution 4) 4. In this case, within the period of July 1997 to December 1997, the accuracy of the method (QMPMS) was good (Mean Percentage Deviation was less than 4 %). (Contribution 9) 5. In this case the different of the accuracy of the direct effect (did not take into account the interaction effect) and the combined effect (took into account the interaction effect) was small. The MPD of the direct effect was 3.77 %, while the MPD of the combined effect was 3.67 %). However, this phenomenon can not be generalised for all cases. (Contribution 9) 6. In this case the method (QMPMS) was stable within the period of July 1997 to December 1997. However, as the environment changes, the model should be updated to accommodate the changes. (Contribution 10) <u>Negative aspects:</u> 1. In this case, the problem was very simple and

	3. The researchers computed the relative change of "Total production cost per unit" from the previous period to the next period using the method developed in this research (QMPMS). The results were compared to the relative change of the actual "Total production cost per unit" data. 4. The results of the experiment were communicated to the general manager using e-mail and telephone. 5. The results of the experiments are: ✓ The general manager was happy with the output of the method (QMPMS). ✓ The general manager agreed that started on December 1998, the "Total production cost per unit" was up as a result of the fall of the production volume. ✓ The general manager agreed that starting from January 1998 to June 1998, the model no longer represented the current environment. ✓ The general manager did not agree to alter the pair-wise comparison to adapt to the changes of the environment. He would like to include a new factor "flexibility" in the model. However, at that moment the company did not have any idea on what type of flexibility should be used and what factors affect the flexibility. Consequently, a new model, which includes flexibility factor could not be built yet.	<u>Negative aspects:</u> 1. In this case, the problem was very simple and clearly understood by the general manager. At the period of the research carried out, "Total production per unit" was an important issue for the company. It was monitored and reported monthly. The general manager knew exactly the problem. Only six factors (lowest level) involved in the problem and the structure of the problem was clearly defined. Consequently, the accuracy of the method (QMPMS) could be mostly determined by the simplicity of the problem. The method (QMPMS) should also be tested to a larger problem. 2. As the environment changed, the model seemed no longer valid. The general manager wanted to add new factors relates to flexibility in the model. However, the company did not have any idea on what type of flexibility should be used and what factors affect the flexibility. Therefore, a new model could not be developed.

6.4 Case Study Three: Prioritisation and Consolidation of Performance Measures at Inland Revenue, Cumbernauld

6.4.1 Background of the case study

In the middle of 1997 the Inland Revenue, Cumbernauld agreed to take part in a pilot exercise of the application of performance measurement systems developed at the Centre for Strategic Manufacturing, University of Strathclyde. It was found that in this case study Inland Revenue, Cumbernauld had the objectives:

1. To audit the Inland Revenue's performance measurement system against the Reference Model of Integrated Performance Measurement System.
2. To prioritise the Inland Revenue's performance measures and consolidate them into a single performance indicator. This was actually in line with what had been highlighted by Michael Heseltine in 1996 concerning the need to provide a single performance indicator for the Civil Service, something that the Inland Revenue, Cumbernauld wanted to implement.

In line with the second objective, a new research problem, hypothesis and objective related to the consolidation of performance measures into a single performance indicator were added to the current research problems, hypotheses and objectives to form the final research problems, hypotheses and objectives as follows:

Final research problems:

1. Identifying factors affecting performance.
2. Identifying the interaction between the factors affecting performance.
3. Quantifying the effects of the factors on performance.
4. Reducing the number of performance reports.
5. Consolidating performance measures into a single performance indicator.

Final research hypotheses:

1. A quantitative method for a performance measurement system can be developed. The method can be used for:
   - ✓ identifying factors affecting performance and their relationship,
   - ✓ quantifying the effect of the factors on performance.
   - ✓ consolidating performance measures into a single performance indicator.
2. The method is valid and can be applied to real cases.
3. The method developed can help managers to reduce the number of performance reports.
4. The method is stable for a reasonable period of time.

Final research objectives:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship, quantify the effect of the factors on performance and consolidate them into a single performance indicator.
2. To carry out experiments for testing the validity, applicability and stability of the method developed.
3. To develop a method for reducing the number of performance reports.

Table 6.11 shows the summary of the case study three.

6.4.2 Auditing the Inland Revenue, Cumbernauld's performance measurement system

A series of meetings was carried out by the University of Strathclyde's research team with Inland Revenue senior managers to audit and consolidate the Inland Revenue, Cumbernauld's performance measurement system. The results of the audit are as follows [Suwignjo et al, 1998]:

1. There was confusion between Business Processes and Functions.
2. There was an absence of Business Process focused measures.

Table 6.11. The summary of the case study 3.

Case study 3: Inland Revenue, Cumbernuld		
What we want to learn	**Case study process**	**What we can learn / findings**
At the beginning of the implementation, we wanted to learn about: 1. Can the method developed (QMPMS) be easily understood and implemented? As the implementation progressed we also wanted to learn about: 2. Can the method developed for consolidating performance measures into a single performance indicator be applied to a real case? 3. Can the application concept (to differentiate with theoretical concept) be transferred to other people easily? 4. What are the benefits of implementing the method developed (QMPMS) for managers?	1. In the middle of 1997, a two-hour presentation and discussion was carried out in front of an audience consisted about 50 top and middle managers at Inland Revenue, Cumbernauld. The objectives of the presentation were to explain the objectives of the study and the concept of the method developed (QMPMS). At the end of the discussion session, it was found that the Inland Revenue, Cumbernauld has, for a long time, wanted to have a single performance indicator for the performance of each business process and overall office. This was in line with Michael Heseltine's concern of the need of Civic Service to have a single performance indicator. As a result, the issue of consolidating performance measures into a single performance indicator was added to the research problems, hypotheses and objectives and a method to address this issue was developed. (Contribution 2) 2. A two-hour meeting was carried out by the researchers with three senior managers to understand the operations of Inland Revenue, Cumbernauld and how the operations were organised. 3. The researchers faced a problem in understanding the specific terms used in tax office. A senior manager of the Inland Revenue, Cumbernauld was appointed as a counter part to work intensively with the researchers. 4. The researchers were supplied with 1995/1996 performance reports to be used as the case. The researchers constructed the 1995/1995 performance reports using the method developed (QMPMS). Two two-hour meetings with the counter part were carried out to discuss the construction of the 1995/1996 performance reports using the method developed. 5. A two-hour presentation and discussion was carried in front of an audience consisted of 40 senior and middle managers at the Inland Revenue, Cumbernauld to show and discuss the results of the construction of the 1995/1996 performance reports. At the end of the presentation the Inland Revenue, Cumbernauld decided to implement the method developed (QMPMS). The facilitators from the Inland Revenue, Cumbernuld were appointed to facilitate the implementation of the method (QMPMS). The facilitators were trained by the researchers on the implementation concept of the method (QMPMS). 6. A two-day training was carried out in 11-12 August 1998 to train the facilitators. The content of the training included:	<u>Positive aspects:</u> 1. The management of the Inland Revenue, Cumbernauld believed that it is good for the office to have a single performance indicator for each business process and overall office performance. (part of Contribution 2) 2. The Inland Revenue, Cumbernauld could understand and implement the method developed (QMPMS) easily. (Contribution 7) 3. The method used to consolidate performance measures into a single performance indicator worked properly. (Contribution 2) 4. The application concept of the method developed could be transferred successfully through a two-day training. (Contribution 8) 5. Implementing the method developed (QMPMS) led to better understanding of the nature of the business. (Contribution 5) 6. Better understanding of the nature of the business has led the Inland Revenue, Cumbernauld to be able to rationalise their performance measurement system. (Contribution 6) 7. The Inland Revenue, Cumbernauld did not want to include interaction effect in the performance measurement model. (Contribution 4) 8. The success of the implementation of the method at Inland Revenue, Cumbernuld might be because of: - Inland Revenue, Cumbernuld has been for a long time wanted to have the QMPMS-like method. - The Inland Revenue, Cumbernuld felt that they owned the model because they built the model themselves. (Contribution 11) <u>Negative aspects:</u> The researchers feel that there is no negative aspect of this case study.

the method (QMPMS).

6. A two-day training was carried out in 11-12 August 1998 to train the facilitators. The content of the training included:
   - ✓ The concept of cognitive maps.
   - ✓ The concepts of the direct effect, interaction effect and combined effect.
   - ✓ Structuring the factors affecting performance hierarchically.
   - ✓ The concept of pair-wise comparisons.
   - ✓ The concept of computing priority from the results of the pair-wise comparison.
   - ✓ Computing the effect of the factors on performance using the ExpertChoice software.
   - ✓ Writing performance reports using excel based on the outputs of the ExpertChoice.
   - ✓ The concept of consolidation of performance measures into a single performance indicator.
   - ✓ At the end of the training the researcher guided the trainees to construct a performance model of the Inland Revenue, Cumbernauld for financial year 1996/1997.

   It was found that during the training, the trainees captured the implementation concept of the method (QMPMS) very well. This was clearly indicated by the fact that the trainees needed only very little assistance from the researchers for constructing the performance measurement model for the financial year 1996/1997. Consequently, the researchers were very confident that the facilitators would be able to facilitate the implementation of the QMPMS at the Inland Revenue – Cumbernauld successfully.
7. The facilitators helped Inland Revenue – Cumbernauld to implement the method (QMPMS) for financial year 1998/1999. Through out the implementation the Inland Revenue, Cumbernauld refined the model which finally rationalised their business process from six business processes using 130 performance measures down to three business processes using 20 measures. In that period the researchers kept in touch with Inland Revenue – Cumbernauld through telephone communication.
8. In the third week of April 1999 a meeting was carried out involving the researchers and the people from the Inland Revenue, Cumbernauld. The objective of the meeting was to discuss the implementation of the method (QMPMS) for the financial year 1998/1999 and the review of the system, which has been carried out by the Inland Revenue, Cumbernauld at the first week of April 1999. The Inland Revenue, Cumbernauld decided to continue to implement the QMPMS for the financial year 1999/2000 and reported the performance more frequently, from quarterly for financial year 1998/1999 to monthly for financial year 1999/2000.

3. There were a lot of detail measures at activity levels, but nothing to measure the performance of each Business Process.
4. Similarly, there were no means of measuring the overall performance of the office.
5. A lot of detail measures existed, some possibly irrelevant, i.e. insignificant to strategic and operational objectives.

The audit recommended the need to redefine the business structure and measuring the performance of each business process and the overall office.

In response to the recommendation, the structure of the business was changed. Before the audit the office was structured based on division as indicated in Figure 6.13(a). However, this structure made the office unable to focus on business processes - the processes that really add value. To eliminate this weakness the office was restructured as indicated in Figure 6.13(b). The new structure, based on business processes, allows the office to focus on processes that really add value to the business; consequently, performance measurement and control of the business processes are become more effective.

6.4.3 Prioritisation of the Inland Revenue, Cumbernauld's performance measures

Having restructured the office based on business processes as recommended the next step was the prioritisation of the Inland Revenue's performance measures. The objectives of the prioritisation were threefold:

1. To identify the relationship between measures.
2. To identify the effect of factors on business process performance and overall office performance.
3. To enable the consolidation of performance measures and expressed them into a single performance indicator.

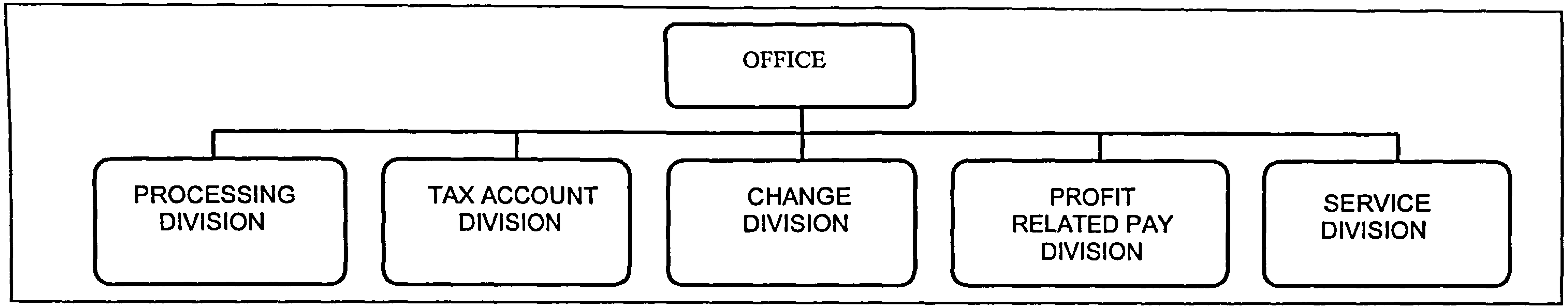


Figure 6.13(a). The structure of the Inland Revenue, Cumbernauld before Audit.

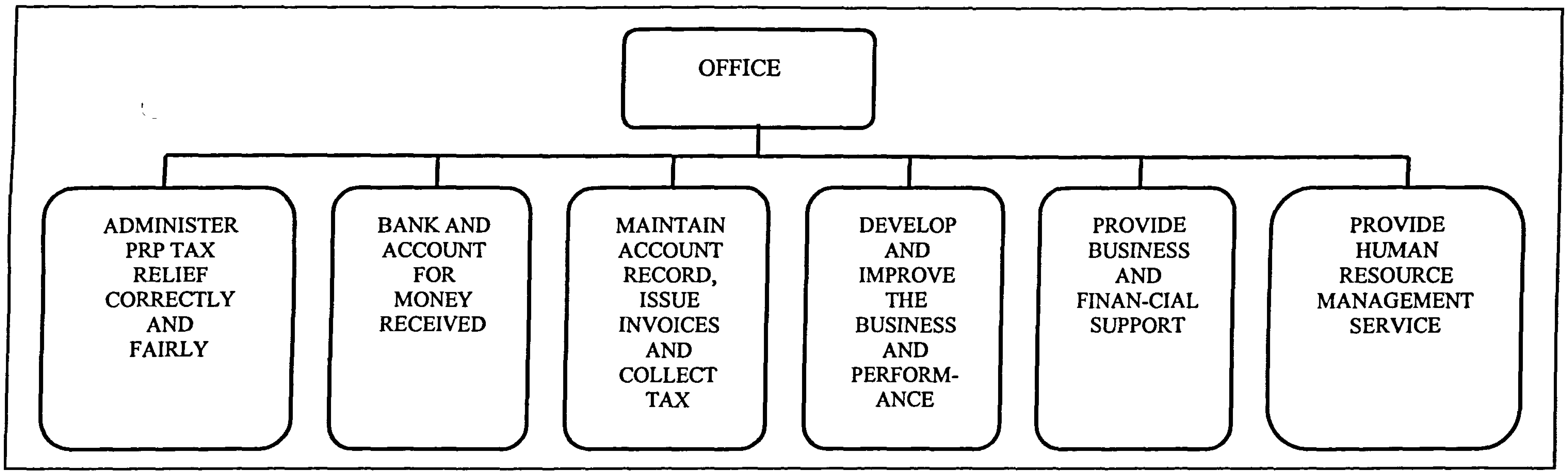


Figure 6.13(b). The structure of Inland Revenue, Cumbernauld after audit.

As explained in Chapter 5, the prioritisation process using the QMPMS is carried out in three stages. These stages are: identify factors affecting performance, structure the factors hierarchically and quantify the effect of factors on performance.

The identification of factors affecting performance was done by the Inland Revenue's staff involved in this project who also did the early stage structuring of the hierarchical factors. For the financial year 1996/1997 130 measures were used by the Inland Revenue to measure the performance of its business processes and the overall office as indicated in Appendix C.1. The measures affecting business processes are grouped into two areas: Key Business Results and Other Operational and Quality Results as indicated in Figure 6.14.

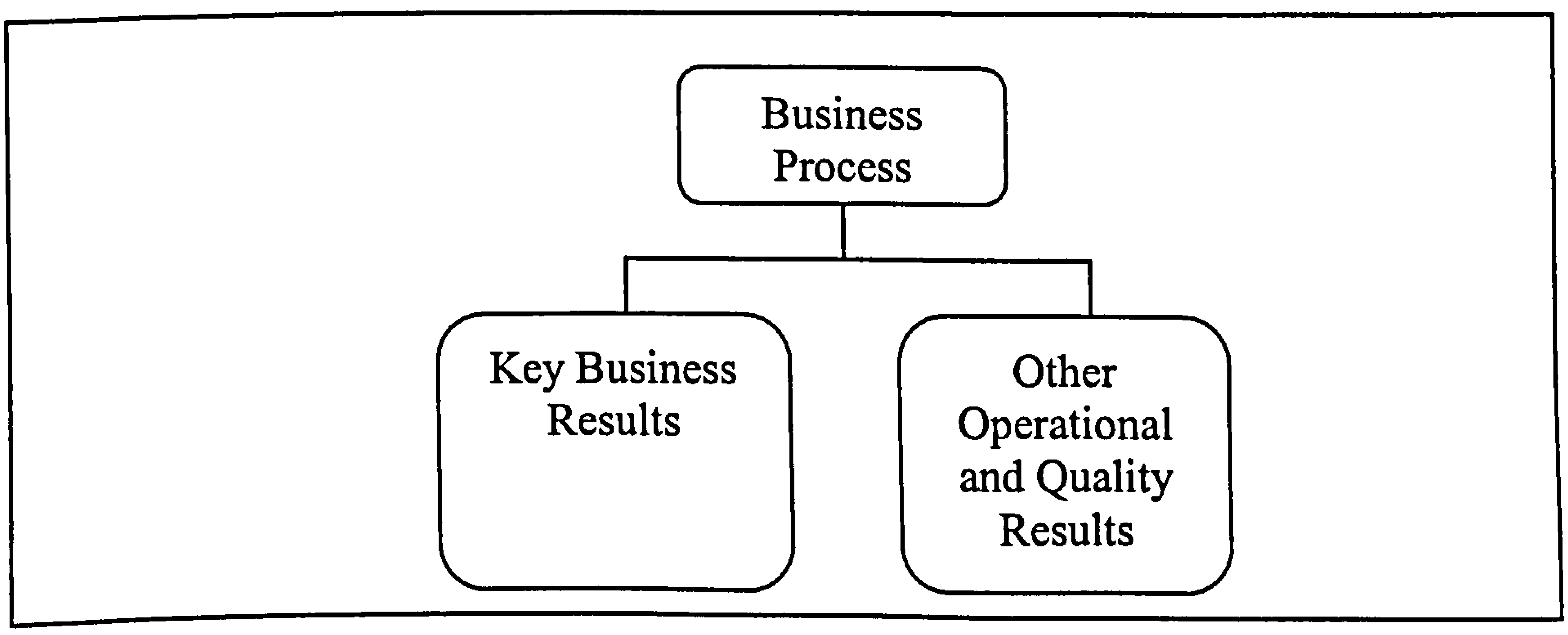


Figure 6.14. The grouping of performance measures at the Inland Revenue, Cumbernauld.

A minor problem faced in structuring the factors hierarchically was that some of the business processes had so many performance measures under a particular area. Since the Analytical Hierarchy Process limits the maximum number of factors of each group or cluster to nine, sub-grouping of performance measures had to be done. For example Business Process **Maintain Accounting Record, Issue Invoices, and Collect Tax** has 43 measures under the **Other Operational and Quality Results** area. Consequently, sub-grouping or clustering had to be carried to split the measures into sub-groups of

Accuracy, Timeliness, Quantity and **Speed.** With the help of ExpertChoice software Inland Revenue's performance measures can be structured as depicted in Figure 6.15.

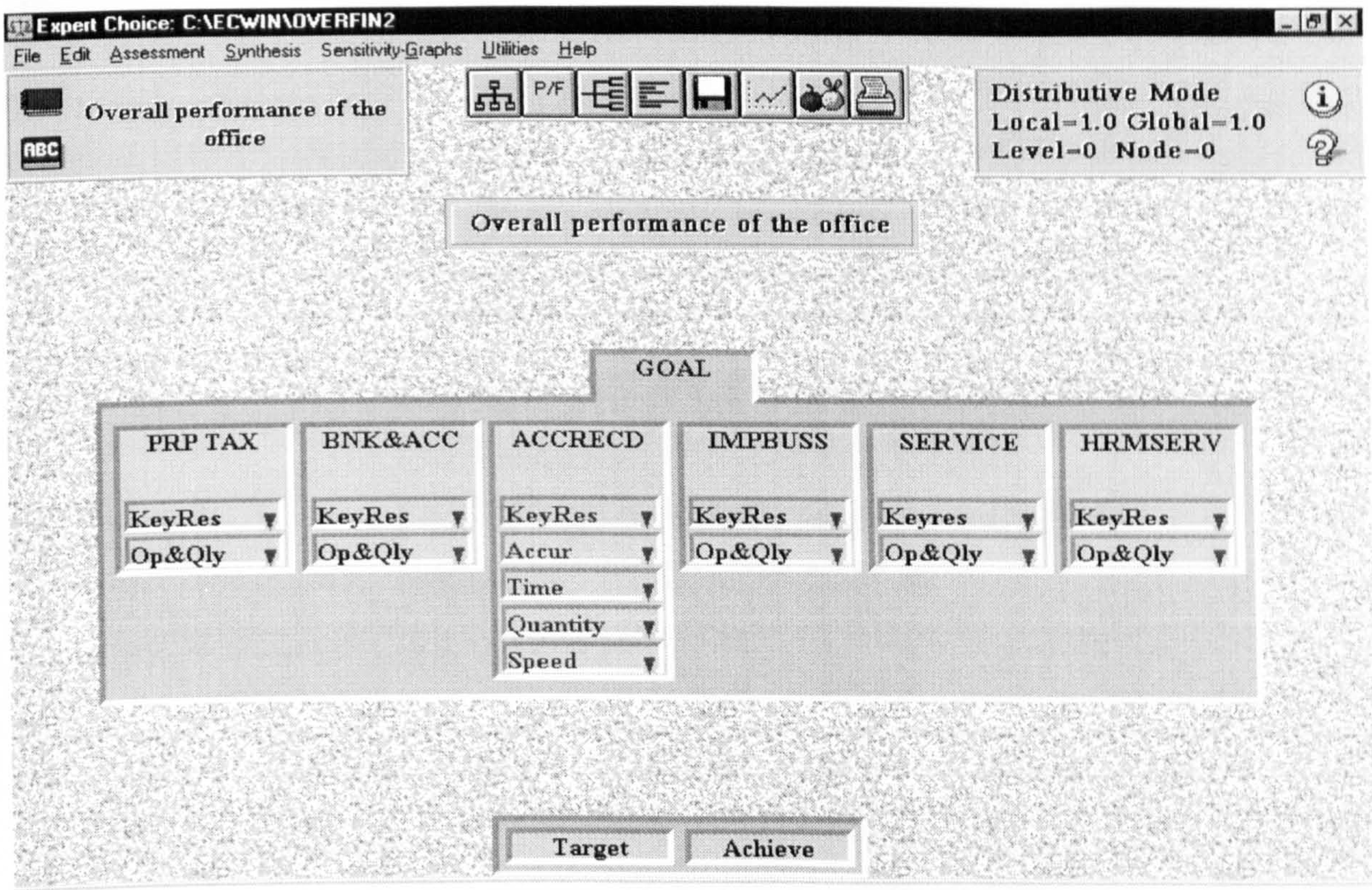


Figure 6.15. The hierarchical structure of the Inland Revenue, Cumbernauld's performance measures.

Inland Revenue managers were asked to fill pair-wise comparison questionnaires. Based on the pair-wise comparison, the effect of factors on performance was calculated with the help of ExpertChoice software. An example of the effect of each business process on overall performance is depicted in Figure 6.16. The results of the computation of the effects of all factors affecting performance can be seen in Appendix C.2.

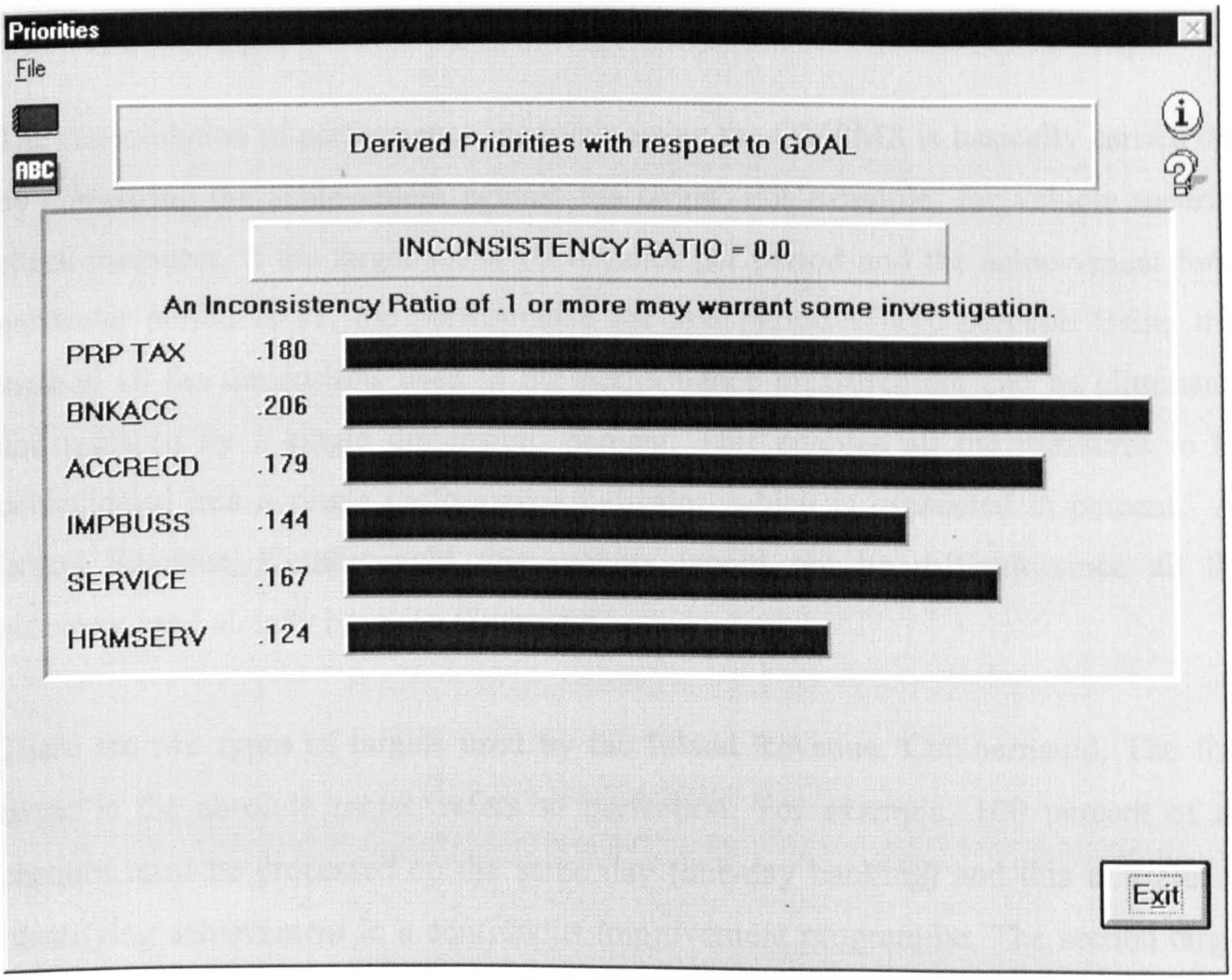


Figure 6.16. The effect of business processes on overall office performance.

It is clear from Figure 6.16 that Inland Revenue managers believe that Business Process **Bank and Account Money Received** is the most important business process since it was the highest impact on overall office performance.

6.4.4 Consolidation of Inland Revenue, Cumbernauld's performance measures

For quite a long time the Inland Revenue, Cumbernauld has wanted a single performance indicator to measure the performance of each business process and the overall office. As the Inland Revenue, Cumbernauld employs so many performance indicators which are not structured systematically this requirement is becoming more important. As a result of this structure it is very difficult for managers to get information on the aggregate performance of each business process and the overall office.

The consolidation of performance measures using the QMPMS is basically carried out by comparing the achievement against the target. For example, for vehicle security check measures, if the target set is 10 vehicles per period and the achievement for a particular period is 11, the performance for that period is 110 percent. Using this method all the dimensions used in the performance measurement can be eliminated and replaced by a single dimension: percent. This enables all the measures to be consolidated into a single performance indicator, which is expressed in percent. At Inland Revenue, Cumbernauld this process would not be difficult since all the measures used already have the targets set.

There are two types of targets used by the Inland Revenue, Cumbernauld. The first target is the absolute target, refers to perfection. For example, 100 percent of all cheques must be processed on the same day (one-day banking) and this is useful in identifying achievement in a continuous improvement programme. The second target is realistic target refers to the level which can be realistically achieved using the available resources. For example, 92 percent of overpayments must be dealt with within 2 months. Since the consolidation process basically is the comparison of achievement against target, consequently the value of the consolidated indicator depends on the target set.

Using the ExpertChoice software, the consolidated performance report for financial year 1996/1997 relative to the absolute target is indicated in Figure 6.17. The value produced by the ExpertChoice software indicated the relative value of achievement and target and the summation of these values is one. To convert to a 100 percent scale, the following calculation is required:

Consolidated overall performance = (0.488 / 0.512) x 100 percent = 95.3 percent.

In other words, relative to perfection, the performance of the office is 4,7% below the target.

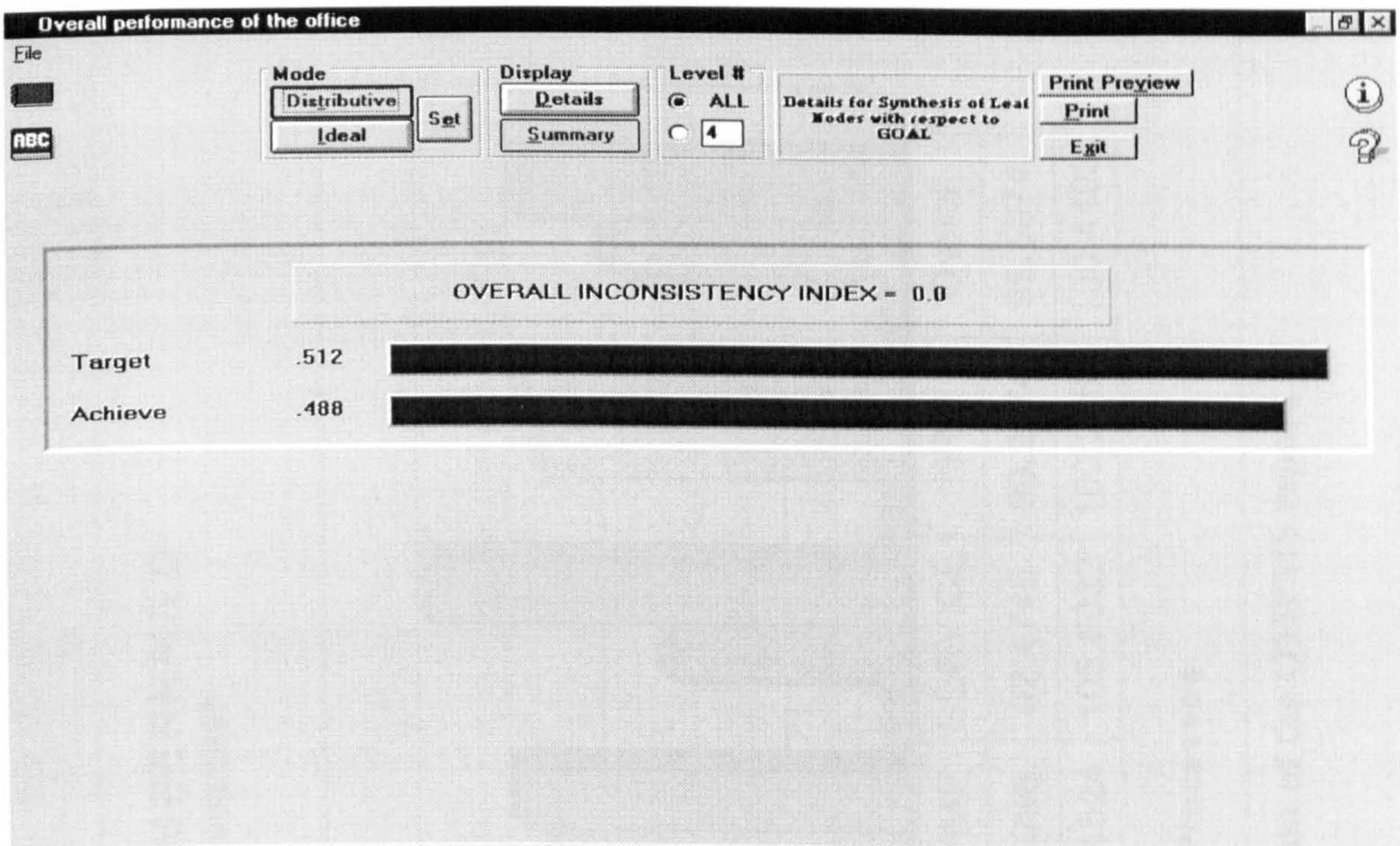
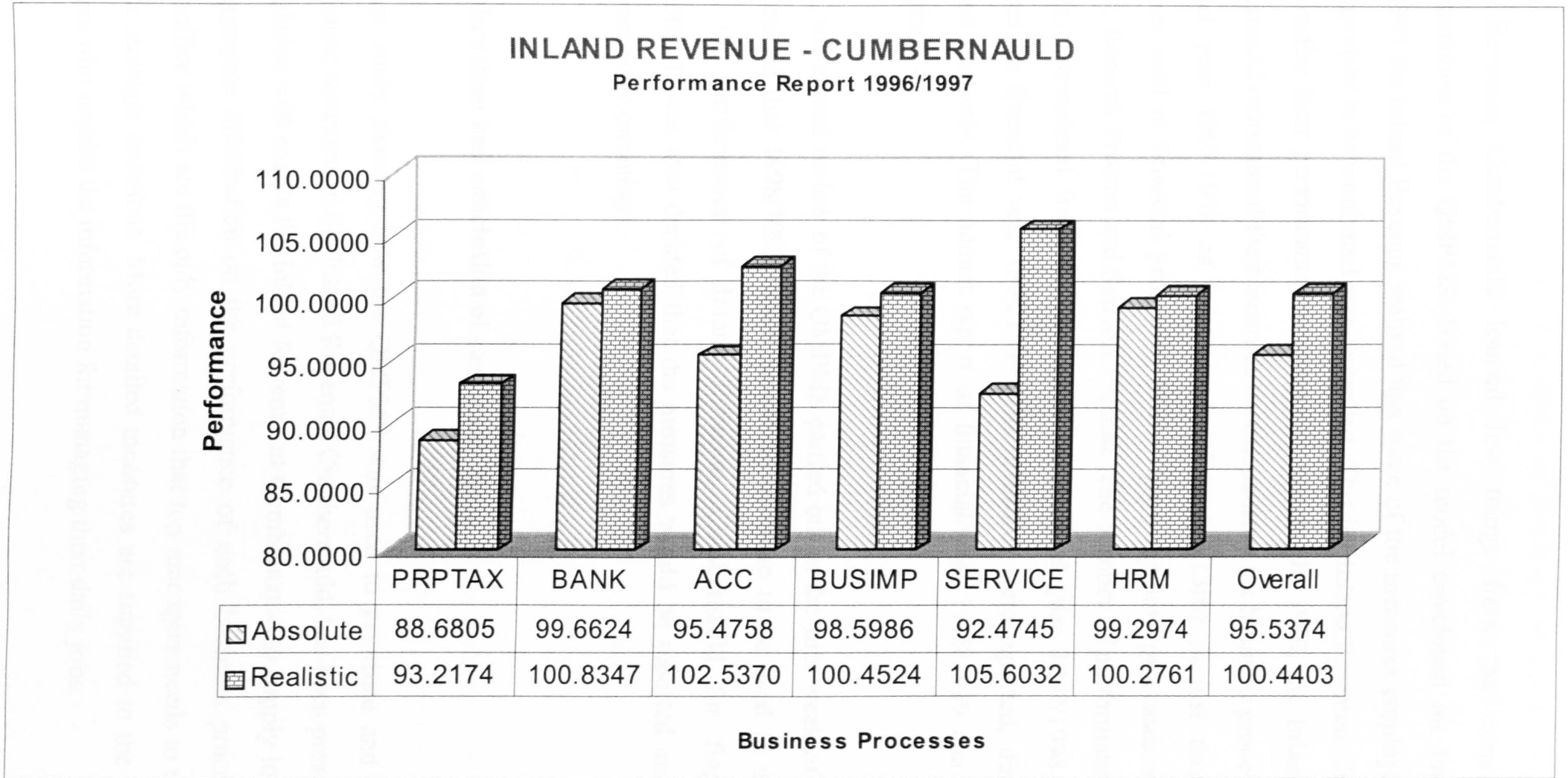


Figure 6.17. The consolidated performance of the overall office.

The same method could be used to calculate the consolidated performances of the business processes. The consolidated performance of some business processes can be seen in Appendix C.3.

Another important strength of ExpertChoice is that the output of the model can be exported to spreadsheet file. Using this utility, the QMPMS can be integrated with other information system modules in the organisation. Using Excel the reports can be presented in graphical form as depicted in Figure 6.18.



	PRPTAX	BANK	ACC	BUSIMP	SERVICE	HRM	Overall
Absolute	88.6805	99.6624	95.4758	98.5986	92.4745	99.2974	95.5374
Realistic	93.2174	100.8347	102.5370	100.4524	105.6032	100.2761	100.4403

Figure 6.18. Graphical presentation of the QMPMS report.

6.4.5 The review of the QMPMS at Inland Revenue, Cumbernauld

Inland Revenue, Cumbernauld learned few things from the exercise of the implementation of the QMPMS. Based on the model developed for financial year 1997/1998 the Inland Revenue realised that some of the measures employed were not very important to be monitored and controlled. This led Inland Revenue, Cumbernauld to rationalise their performance measurement system. In 1998, the Inland Revenue, Cumbernauld rationalised their business processes from six business processes used in financial year 1997/1998 as indicated by Figure 6.13(b) to just three business processes used in financial year 1998/1999. Those business processes are Banking Process, Records Process and Support Process. The number of performance measures was also rationalised from 130 measures in financial year 1997/1998 to just 20 measures for financial year 1998/1999. The measures were reported, discussed and reviewed quarterly. The annual report of financial year 1998/1999 can be seen in Appendix C.4.

Finally, the annual review of the QMPMS carried out in the first week of April 1999 have decided that 1998/1999 model would be continue to be used to monitor and control the performance of Inland Revenue, Cumbernauld for financial year 1999/2000. It was also decided that the measures would be reported and discussed more frequently (monthly).

6.4.6 Discussion and conclusion of case study three

The case study showing how the QMPMS was used to prioritise and consolidate performance measures at the Inland Revenue, Cumbernauld, has been presented. This consolidation will enable the Inland Revenue at Cumbernauld to supply top managers with aggregate information on the performance of each business process and the overall office which are the only information that top managers needs to enable them to make strategic decisions. More detailed measures are supplied to the lower level managers who require the information for managing their daily jobs.

The QMPMS, through this case study, has shown a different perspective on the nature of performance measures to that highlighted by Professor Bruce H. Clark of North Eastern University in his keynote speech at the International Conference on Performance Measurement in Cambridge 1998. He stated that:

"*Measuring of marketing performance has become increasingly multi-dimensional in nature (e.g. Bhargava et a., 1994; Dunn, Norburn, and Briley, 1994), reflecting the wisdom that performance cannot be summarised in a single measure. A problem arises in that many of these measures appear to be correlated with or related to one another (e.g. Selnes, 1993). Distinct constructs can be extracted by statistical techniques, but these seem unlikely to be part of everyday management. More generally, it is unclear whether management is interested in elegant multi-dimensional schemes. The challenge is to present management with a handful of measures that are simple enough to be useable but comprehensive enough to be accurate.*"

Furthermore he stated that:

"*Assuming a reasonable set of measures is available, it will be important to measure performance at different levels of the firm's organisation. ....*"

Even though Professor Clark's statements related to marketing performance measurement, they are also valid for performance measurement in general.

The QMPMS, using the method of comparing achievement against target, has proved that multi-dimensional measures can be consolidated into a single performance indicator, thus overcoming one very important problem in performance measurement system which most people have been sceptical about. The consolidation of performance measures is a very important aspect in a performance measurement system since it will allow decisions relating to performance appraisal, resource allocation and designing of an incentive system to be made.

The QMPMS is also easily implemented. Even although the basic concept of the Analytic Hierarchy Process, the multi-criteria decision analysis model used by the QMPMS, is quite complicated, to implement this method is very simple. What managers should do is just to fill in the pair-wise comparison questionnaires but if the number of factors involved in performance measurement is large, the task of filling in the questionnaires can be quite tedious. However, by using the interactive software available on the market, the task is made easier. The implementation of the QMPMS, in fact, becomes much easier because of the availability of the spreadsheet program developed in this research. What users need to do is merely to enter the achievement of each measure to the program.

Another method which could be used to make the application easier would be to delegate the task of filling in the questionnaires to several groups of people from the lower level hierarchy, e.g. a group of people with the best knowledge, experience, or information could be given responsibility filling in the questionnaires. This would make the group feel as if they owned the measures and it is likely that implementation would be more successful.

How to get accurate judgements when comparing the effect of a pair of factors on performance may present a problem in the application. As mentioned in Chapter 5, two good practical experiences would result in accurate judgements and the subjectivity of judgements could also be reduced using group decision-makers.

While the general manager of the Seagate Distribution (UK) wanted to consider the interaction effect of factors affecting performance, the managers of Inland Revenue, Cumbernauld did not want to consider the interaction effect of factors affecting performance in his model. The managers of Inland Revenue, Cumbernauld were quite happy with the results of the direct effect model. This might be because at that moment Inland Revenue, Cumbernauld employed a large number of performance measures and wanted to use the QMPMS for monitor and control purposes.

The implementation of the QMPMS enabled the Inland Revenue, Cumbernauld to rationalise their performance measurement system. For financial year 1997/1998 Inland Revenue, Cumbernauld employed six business processes with 130 measures. In 1998 Inland Revenue, Cumbernauld rationalised their performance measurement system to just three business processes with 20 measures. It seemed that the implementation of the QMPMS has led the managers of Inland Revenue, Cumbernauld to have better understanding of the nature of their business. The followings might be the reasons why by implementing the QMPMS the managers of Inland Revenue, Cumbernauld could better understand the nature of their business:

- ✓ When a group of people of Inland Revenue, Cumbernauld involved in filling pair-wise comparison questionnaires each member of the group might have different opinion on the effect of factor on performance. Intensive discussion occurred between the member of the group. Each member explained his/her opinion and why did it so. This led to better understanding of the other people's tasks, constraints, and objectives.
- ✓ Using the QMPMS the performance of activities, business processes and business units can be reported in a single performance indicator. Then the review of the performance reports examined why some units of organisation did not perform well, while the others did. This gave a clear picture on how well each unit of organisation performed and why did it so. The QMPMS provides a viewing glass to managers to see the performance of an organisation.

In this case study the researcher trained three staffs of the Inland Revenue, Cumbernauld about the concept of the QMPMS and how to implement it. The content of the training can be seen in the summary of the case study in Table 6.11. It was found during the training that they did not have a problem in understanding the implementation concept of the QMPMS. The implementation concept of the QMPMS can be transferred easily to the staffs of Inland Revenue, Cumbernauld through training. The staffs in turn facilitated the implementation of the QMPMS at Inland Revenue, Cumbernauld. It was also found in this case study that the implementation of the QMPMS at Inland Revenue, Cumbernauld did not require a lot of efforts, time and resources.

The implementation of the QMPMS at Inland Revenue, Cumbernauld could be considered as successful. Inland Revenue, Cumbernauld' managers were very happy with the results of the QMPMS and decided to continue to use the model for financial year 1999/2000. The success of the implementations could be because of:

- Inland Revenue - Cumbernauld has been for a long time wanted to have the QMPMS-like method. It was discovered in the implementation of the QMPMS at Inland Revenue, Cumbernauld that the Inland Revenue has been for a long time wanted to have a single performance indicator for each business process and overall office. This was in line with Michael Heseltine's concern of the need of Civic Service to have a single performance indicator.
- The people of the Inland Revenue - Cumbernauld felt that they owned the model because they built the system themselves. In this case study the researchers trained three staffs of Inland Revenue – Cumbernauld on the concept of the model and how to implement it. The people from the Inland Revenue – Cumbernauld then developed their performance model themselves. Since they developed the model themselves they felt that they owned the model.

Based on the above discussions, the conclusions of the implementation of the QMPMS at Inland Revenue, Cumbernauld can be summarised as follows:

1. The QMPMS provided the Inland Revenue, Cumbernauld the method for consolidating performance measures into a single performance indicator.
2. The managers of Inland Revenue, Cumbernauld did not want to consider the interaction effect of the factors affecting performance in their model.
3. The QMPMS can be easily understood and implemented.
4. The implementation concept of the QMPMS can be easily transferred to other people through training.
5. The implementation of the QMPMS led the Inland Revenue, Cumbernauld to understand better the nature of their business.
6. The implementation of the QMPMS enabled the Inland Revenue, Cumbernauld to rationalise their performance measurement system.

7. The need of the QMPMS-like method and the ownership of the model made the implementation of the QMPMS at Inland Revenue, Cumbernauld successful.

6.5 Conclusions

To test the validity, stability and applicability of the QMPMS, three case studies have been carried out in the research.

The first case study objective was to test whether the QMPMS could produce the intended output or not. Through modelling the 'on time delivery' performance of a spirit company, the experiment showed that the intended output of the QMPMS model could be generated. The quantitative effects of factors affecting the 'on time delivery' performance, including the direct effect and the combined effect, could be identified using the QMPMS and the experiment also found that the QMPMS could be extended to reduce the number of performance reports.

The second case study objective was to test the validity and stability of the QMPMS method. This experiment was carried out through the implementation of the QMPMS to method the 'Total production cost per unit' of an electronics company. The experiment showed that the QMPMS was a valid method as indicated by the small value of mean percentage of deviation (MPD) of the QMPMS performance from the actual performance. However, the QMPMS should be modified if the external and/or internal environment of the organisation change. The experiment also found that the QMPMS was quite stable for a period of six months. Of course, the stability of a performance measurement system will vary from company to company.

The third case study objective was to test the applicability of the QMPMS. Through the implementation of the QMPMS to prioritise and consolidate performance measures at the Inland Revenue, Cumbernauld, it has been proved that the method can be applied comfortably. By implementing the QMPMS, Inland Revenue, Cumbernauld could understand better the nature of their business and enabled them to rationalise their performance measurement system.

6.6 Summary

This chapter presented three experiments for testing the validity, applicability and stability of the QMPMS. The experiments were carried out by implementing the QMPMS in three different collaborator companies.

The first experiment was to model the 'on time delivery performance' at a spirit company for testing whether or not the QMPMS could produce the intended outputs.

The second experiment, implementing the QMPMS to model the 'Total production cost per unit' of an electronics company, was carried out to test the validity and stability of the QMPMS.

Finally, the third experiment was carried out by implementing the QMPMS at the Inland Revenue, Cumbernauld to prioritise and consolidate performance measures.

Chapter 7 will present the discussion, conclusion and further research.

Chapter 7

CONCLUSIONS AND FURTHER WORK

As has been mentioned earlier in Chapter 1 the objectives of this research are as follows:

1. To develop a quantitative method that can identify the factors affecting performance and their relationship, quantify the effect of the factors on performance and consolidate them into a single performance indicator.
2. To carry out experiments for testing the validity, applicability and stability of the method developed.
3. To develop a method for reducing the number of performance reports.

The following have made the achievement of the above objectives more difficult:

✓ Performance measurement may involve a large number of multi-dimensional factors affecting performance and personnel from various departments. As pointed out by Eden et al (1983) that in organisational life the individual is an irrational and subjective person. He or she involves in complicated social relationships and internal (organisational) political games. Therefore, different individuals will interpret a particular situation differently depending on their mental framework and political concerns. This makes the identification of the factors affecting performance and their relationship more difficult.

✓ Factors affecting performance are multi-dimensional. Some of them may be difficult to measure. Therefore, quantifying the effects of the factors on performance and consolidating them into a single performance indicator are difficult tasks.

✓ To test the validity, stability and applicability of the method developed some case studies are required. To persuade company's managers so that they agree to implement the method seriously at their company for a reasonable period of time is not an easy task. Most companies are very reluctant to allocate additional resources for the implementation of a new method except where they see the potential benefits of the implementation.

Chapters 5 and 6 have presented the development of the methods (the QMPMS and the taxonomy of performance measurement) to achieve the research objectives. The objectives of this chapter are:

- to draw conclusions from the research,
- to highlight the research contribution to performance measurement knowledge,
- to present potential research as a continuation of this research.

7.1 Conclusions

Discussions and conclusions on the important findings of this research have been presented in previous chapters, in particular Chapters 5 and 6. However, this sub-chapter will consolidate them based on the research questions.

Research Question 1:
How can factors affecting performance and their relationship, especially in performance measurement for improvement, be identified and quantified?

To answer this question a quantitative method for performance measurement system (QMPMS) was developed. The development of the method was presented in Chapter 5. The method uses the following tools:

1. Cognitive maps for identifying factors affecting performance and their relationship.
2. Structured diagrams for structuring the factors hierarchically.

3. Analytic hierarchy process for quantifying the effect of the factors on performance.

The selection of the tools used in the method was explained in Chapter 4.

In a dynamic environment the interdependency of factors affecting performance is more eminent. Consequently, it is important to understand the interaction of factors affecting performance, and the QMPMS can be a good method for this purpose. Using the QMPMS, both the direct effect and the interaction effects of a factor on other factors can be identified and quantified, which will lead to a better understanding of the relationship between factors affecting performance.

The QMPMS can help decision making in allocating resource for improving performance. In order to gain maximum improvement, it is important that resources are allocated to activities which have the highest effect on performance and, by using the QMPMS, activities which have the highest impact on performance can be identified.

The biggest problem in implementing the QMPMS is to get consensus amongst managers on pair-wise comparison questionnaires. As performance measurement may involve many people who carry out different functions, completing pair-wise comparison questionnaires will usually also involve a group of people and getting consensus amongst the members of a group can be very difficult and time consuming. Experience gained from the implementation of the QMPMS at the Inland Revenue, Cumbernauld, showed that, intensive discussion amongst the member of the group usually occurs when a group of people involve in completing pair-wise comparison questionnaires. In the discussion each member of the group may explain what are his/her tasks, the objectives and the constraints of the tasks. Each member of the group can learn about each other's tasks, objectives, constraints, and understand better the nature of the company's business. This can make consensus amongst the member of the group more easily achieved. If consensus cannot be achieved, the group decision-making model of the Analytic Hierarchy Process can be used.

Research Question 2:

How can the effects of factors on performance be consolidated and expressed in a single performance indicator?

This question was addressed in Chapter 5.

As mentioned earlier, a performance measurement system involves a large number of factors affecting performance. The factors are multi-dimensional. It is important to aggregate or consolidate the measures and express them in a single performance indicator. As a result, management are only supplied with a limited number of consolidated performance reports, this saving time in analysing reports. Consolidating performance measures into a single performance indicator also makes it easier for decisions to be made.

The method for consolidating performance measures used in this research is very simple. For each performance measure, the achievement is compared to its target. If the achievement meets the target exactly, the value of performance indicator is 100 and is computed using this formula:

$$\text{Performance Indicator} = (\text{Achievement} / \text{Target}) \times 100$$

If there is more than one measure, the composition process of the AHP is used to consolidate the measures.

Nowadays, consolidation of performance measures is an important issue. As the internal and external environments of an organisation become more dynamic, there is a tendency for an organisation to use many performance measures to control its operations. It is important that they are consolidated into a single performance indicator representing the performance of a business process or business unit. Using this method managers are only supplied with a limited number of aggregated performance indicators. However, managers should avoid practising 'management by number'. Any suspicious data should be investigated to uncover the real situation.

Research Question 3:
How can the method developed be extended to reduce the number of performance reports?

This question was addressed in Chapters 5 and 6.

Neely et al (1995) identified one of the challenges of performance measurement systems, i.e. how to reduce the number of performance reports. A taxonomy of performance measurement has been developed in this research that can be used to classify the factors affecting performance into the categories 'critical', 'intermediate' and 'minor' and to determine the frequency of measurement of each category of measure. Measurement and reporting of performance measures should be prioritised to critical measures. Using this method the number of performance reports can be reduced significantly. As indicates in the first case study in Chapter 6, out of 46 performance measures, only 16 needed to be measured on a daily basis (or less), and the remainder measured either on a weekly or monthly basis.

Performance measurement is dynamic in nature. If the environment changes, the category of measure may change. A measure which currently falls into a critical category, may, in the future, change to other categories. Consequently, it is important to carry out a periodic review of performance measurement systems. Using this method, any required changes can be identified immediately.

Research Question 4:
Is the QMPMS valid and can it be applied comfortably to real cases?

This question was addressed in Chapter 6.

Chapter 6 of this work presents experiments to test the validity, stability and applicability of the QMPMS. The results of the experiments show that the validity and applicability of the method are quite good, even though the statistical test did not prove that. The researcher considers that due to the size of the sample is too small the use of the statistical test in this experiment is not appropriate. On the other hand, the mean percentage of deviation of the QMPMS performance from the actual performance is quite low - less than 4 percent. However, the QMPMS must be modified if the business environment of the organisation changes. The experiment at an electronics company which is presented in Chapter 6 showed that the business environment of the company changed in January 1998. In this context, it is important to be able to identify quickly when the environment changes and modify the QMPMS immediately.

The validity of the QMPMS cannot be tested using regression analysis, since the concepts of the QMPMS and regression analysis are different. The concept of the QMPMS takes into account the importance of criticality of the independent variables, while regression analysis does not. Consequently, we can not use the regression analysis to explore the robustness of the QMPMS.

In the experiment carried out in this research the validity of the QMPMS is quite good, perhaps because the problem (production cost per unit) was simple and the relationship of the factor was very clear. In the author's opinion the case selected benefited well from the performance of the QMPMS. The author also believes that in other cases the QMPMS will perform well so long as the managers have a good understanding of the nature of the problems and are experienced in using the QMPMS. However, it is true to say that the QMPMS should be tested on other cases to identify its validity.

The applicability of the QMPMS has also been tested by implementing the method to prioritise and consolidate performance measures at the Inland Revenue, Cumbernauld. It was found that the QMPMS is easy to understand and implement. The facts that the Inland Revenue, Cumbernauld can implement the QMPMS successfully without significant assistance from the researcher and the managers of Inland Revenue, Cumbernauld feel very happy with the results of the implementation prove that the QMPMS is applicable to real cases.

Research Question 5:
Is the QMPMS stable for a reasonable period of time?

This question was addressed in Chapter 6.

The experiment carried out at the electronics company found that the QMPMS seemed to be stable for a six month period of time. However, as demand decreased significantly, the method did not perform well and modification was necessary.

The stability of the QMPMS differs from company to company, i.e. a company which operates in a rapid changing environment will have a less stable performance measurement system compared to that of a company which operates in a slow changing environment. Therefore, it is necessary to identify the pattern of changes over past periods in order to be able to make appropriate adjustments to the performance measurement system. How to handle this problem will be addressed in the next research on the review of a performance measurement system.

It is important here, based on the findings from the research undertaken, to address the critical assumptions proposed by Rangone (1996) which have been presented in page 123 of this thesis. Rangone pointed out that to be successful in applying the AHP for performance measurement system, the following assumption should be considered carefully:

1. The manufacturing departments to be compared should be homogenous in terms of manufacturing competitive priorities and performance measures.
2. Competitive priorities and performance measures should be independent, not redundant and additive.
3. The pair-wise comparisons made by managers should be fairly consistent.

4. The 1-9 ratio scale should allow the relative importance of competitive priorities and performance measures to be expressed well.

The first assumption basically states that people should compare the similar objects. People cannot compare apple to orange. The author agrees with this assumption. It is important, when comparing the performance of two or more companies, to make sure that the companies are similar. In the context of the QMPMS, it is important when setting a target considering the performance of the best practice or the main competitor in that business.

The author does not fully agree with the second assumption which states that performance measures should be independent, not redundant and additive. It is true that when identifying the measures it is important to make sure the measures are redundant and additive. These are the principal assumptions of the AHP. However, when business environment is becoming dynamic the measures are no longer independent. The interactions between measures occur. The experiment carried out at Seagate Distribution (UK) found that there were interactions between factors 'Volume', 'Material and supplies cost per unit' and 'People related cost per unit' in affecting 'Total production cost per unit'. One of the objectives of this research is actually identifying and quantifying the interaction of factors affecting performance.

The author agrees with the last two assumptions. These are also the principal assumptions of the AHP. The pair-wise comparison made by managers should be fairly consistent. To deal with this issue the AHP is equipped with a method for checking and improving the consistency of the judgements. Saaty (1994) pointed out that if the 1-9 ratio scale could not express the relative important of the measures, grouping the measures should be done.

Research Method

Another important aspect which needs to be highlighted is the design of the research method used in this work. As stated by Easterby-Smith et al (1991) no single research method or strategy is ideal for all types of research. Consequently, acquiring knowledge and skill to be able to select the most appropriate research method is one of the most important outcomes of conducting management research [Buchanan, 1990].

In carrying out this research the author used the framework for selecting a research method proposed by Buckley (1976) as indicated in Figure 2.3 of Chapter 2. This framework systematically guide the researcher in selecting the appropriate research technique to be used. This technique is identified based on the following factors:

- Type of research questions
- Research mode
- Research strategy
- Research domain

The selection of the research technique used in this research is based on a systematic framework, not on intuition. This will reduce the errors in selecting the research methodology.

Finally, the conclusions can be summarised as follows:

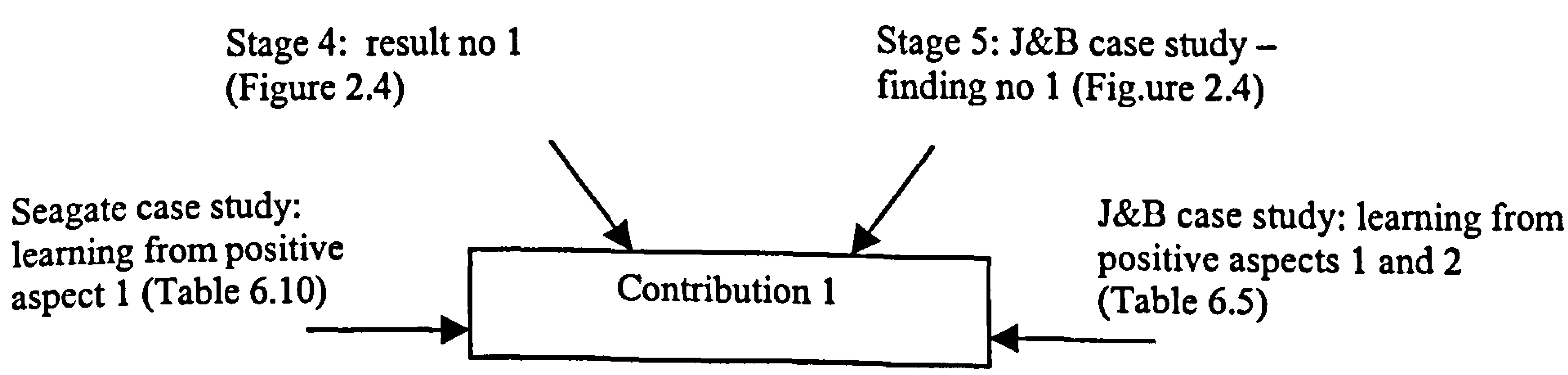
1. The QMPMS developed in this research can be used to identify factors affecting performance and their relationship, and quantify the effect of factors on performance (research question 1).
2. By comparing the achievement against the target and using the composition process of the AHP, the multi-dimensional measures can be consolidated into a single performance indicator (research question 2).
3. Using the taxonomy of performance measurement developed in this research, the number of performance reports can be reduced significantly (research question 3).
4. The experiments carried out in this research found that the validity, stability and applicability of the QMPMS are quite good (research question 4 and 5).
5. A performance measurement system is dynamic in nature. Consequently, it must be reviewed periodically and adapted to suit changes in the business environment.

7.2 Research Contribution to the Knowledge of Performance Measurement Systems.

The contributions this research has made to knowledge, especially to knowledge of performance measurement systems has been explained in the previous chapters. The followings are the summary of the contributions and where the contributions are presented in the thesis.

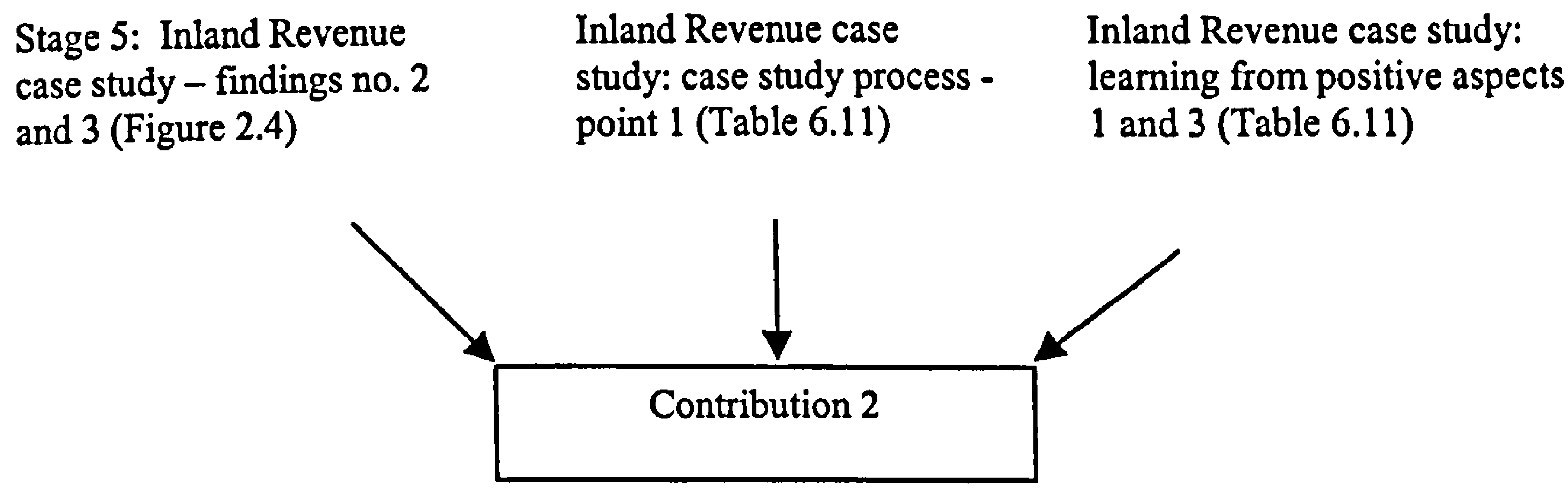
Contribution 1: Provide a method for computing the interaction effect of factors on performance.

A method has been developed in this research for computing the interaction effect of factors on performance. The computation of the interaction effect of factors on performance is carried out using a series of pair-wise comparisons, the same method used to compute the direct effect of factors on performance. Since the computation of the interaction effect is based on judgements this method does not require a lot of data. However, its accuracy depends on the accuracy of the input judgements.



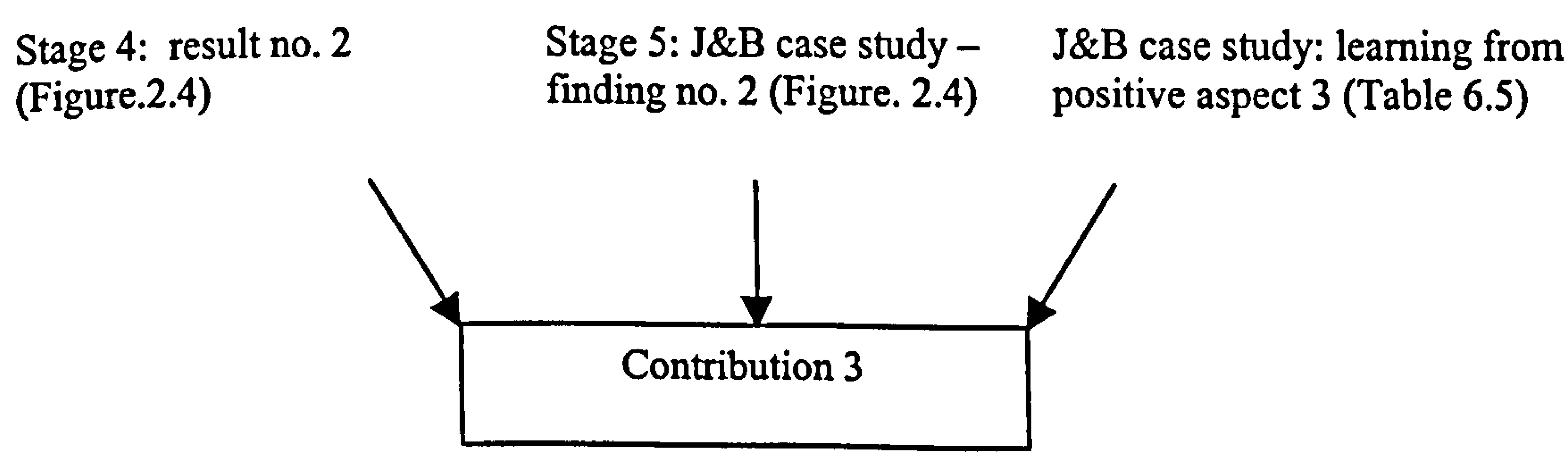
Contribution 2: Provide a method for consolidating performance measures into a single performance indicator.

Factors affecting performance are multi-dimensional. It will be very good if those multi-dimensional factors can be consolidated into a single performance indicator. A method has been developed in this research to consolidate performance measures by comparing the achievement to its target. Consequently, the meaning of the consolidated measures depend on the target used.



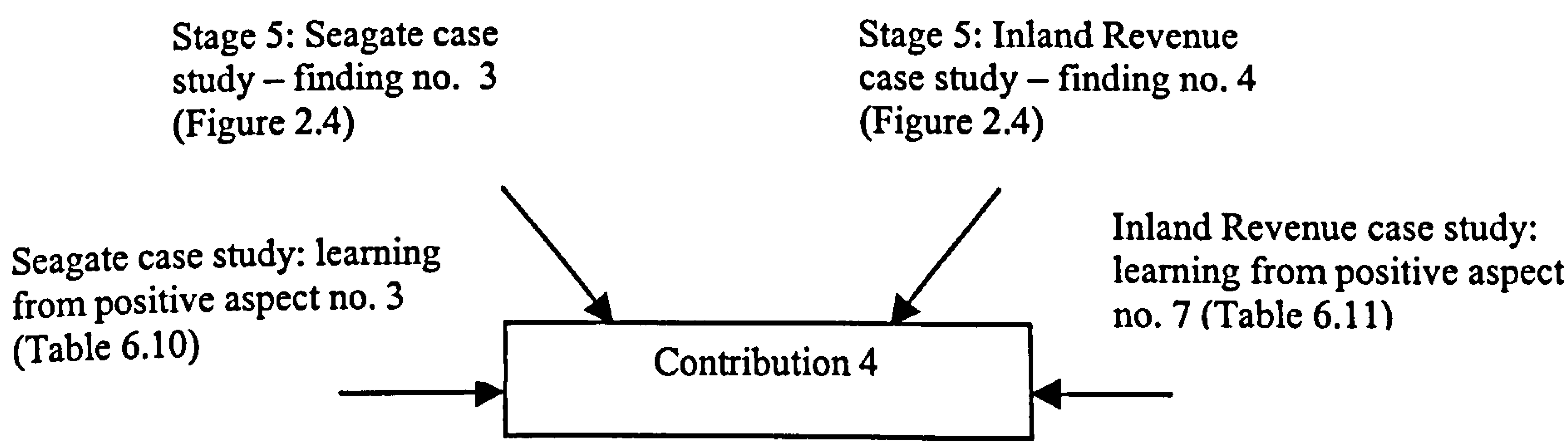
<u>Contribution 3: Develop a taxonomy of performance measurement for reducing the number of performance reports.</u>

In this taxonomy performance measures are classified into categories critical, intermediate and minor depend on their effect on performance and their rate of changes. Critical measures should be measured most frequently while minor measures could be measured least frequently.



<u>Contribution 4: Taking into account interaction effect seems more important in performance measurement for improvement than that in performance measurement system for monitoring and control.</u>

When conducting case studies, the concept of interaction effect was explained both to people of Inland Revenue – Cumbernauld and Seagate Distribution (UK). While manager at Seagate Distribution (UK) (just the general manager involved in this case study) wanted to take into account the interaction effect in the method, managers at the Inland Revenue (4 managers) did not want to take into account the interaction effect in their model. It could be because the Inland Revenue wanted to use the model for monitoring and control purposes, while Seagate Distribution (UK) wanted to use the model for improvement, monitoring and control purposes. In performance measurement for improvement the subject under investigation is usually in critical condition (under performed), and therefore, a detailed analysis of what factor affecting performance is important.

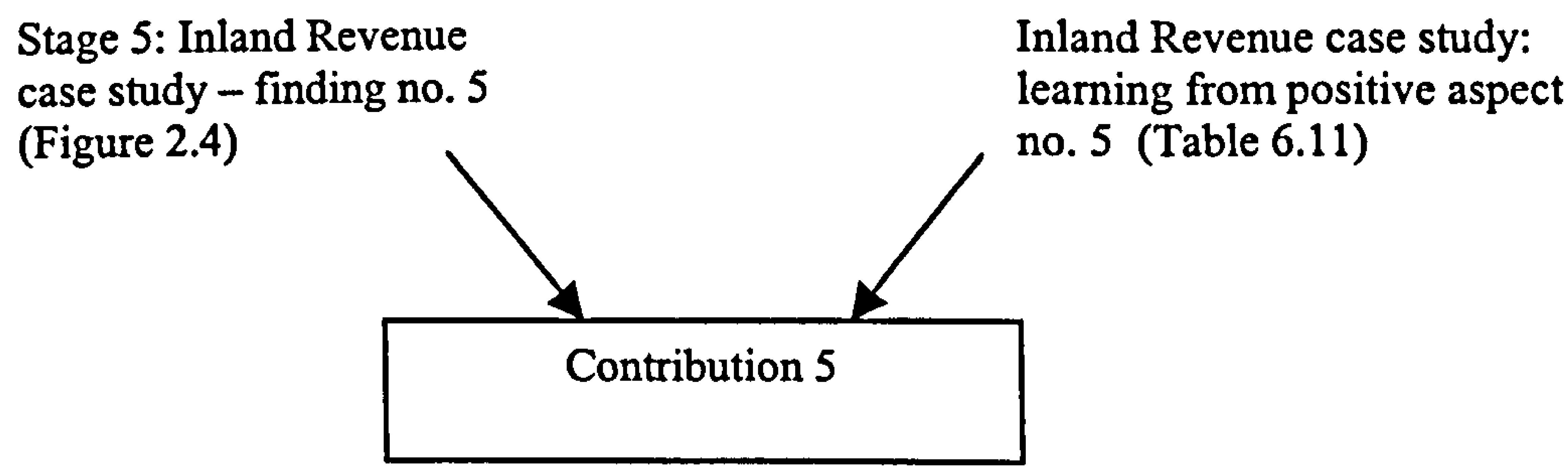


Contribution 5: Implementing the QMPMS leads to better understanding of the nature of the business.

Better understanding of the nature of the business may be achieved because of the following reasons:

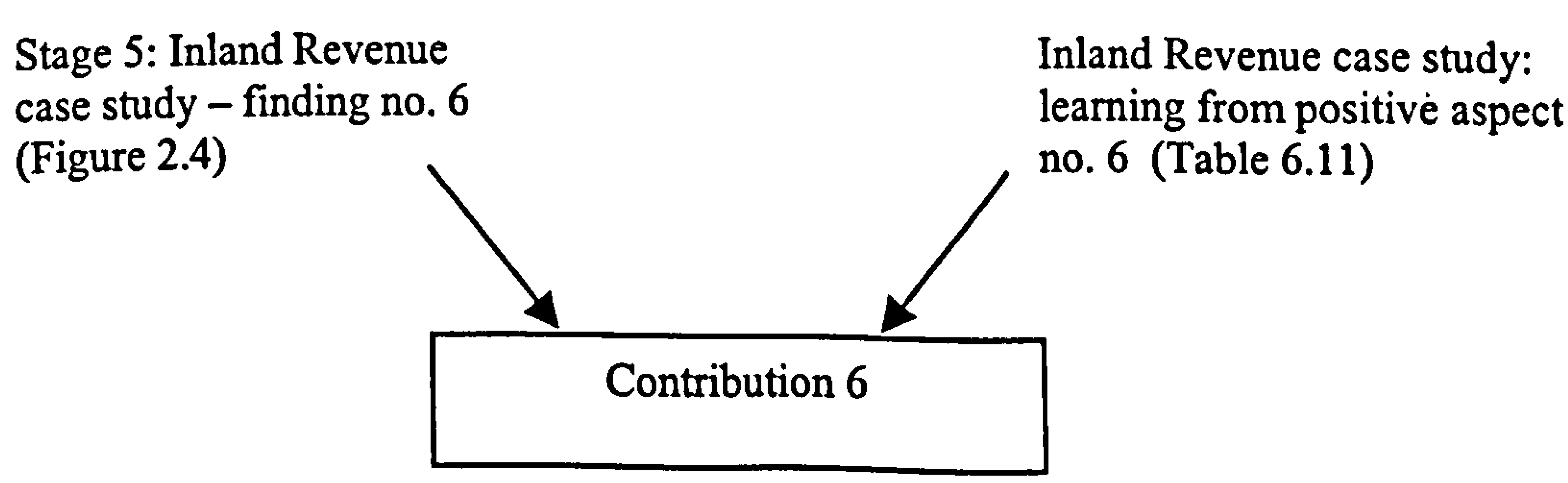
- ✓ When a group of people involve in filling pair-wise comparison questionnaires each member of the group may have different opinion about the effect of factors on performance. Intensive discussion may occur between the member of the group. Each member will explain what is her/his opinion and why does it so. This will lead to better understanding of other people's tasks, constraints, and objectives. (Chapter 6: Inland Revenue case study)
- ✓ Using the QMPMS the performance of activities, business processes and business units can be reported in a single performance indicator. Then the periodic review of performance reports will examine why some units of

organisation were not performing well, while the others were. This will give a clear picture on how well each unit of the organisation is performing and why it so. The QMPMS provides a viewing glass to managers to see the performance of an organisation.



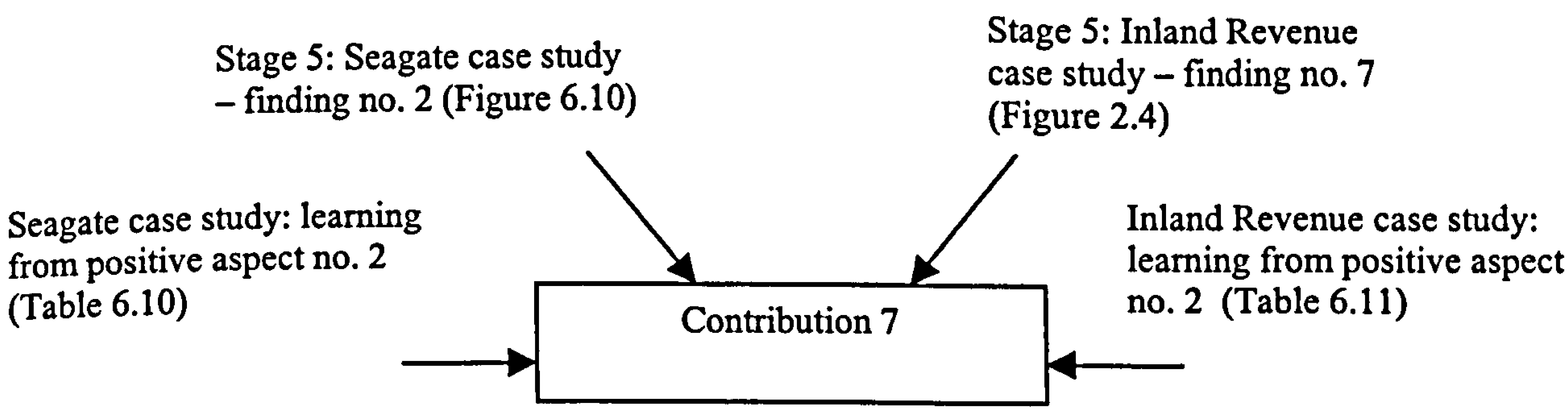
Contribution 6: Better understanding of the nature of the business enable an organisation to rationalise the number of performance measures into a manageable set.

A years experience of implementing the QMPMS managers at Inland Revenue – Cumbernauld quite confidently decided that some of the measures currently monitored and controlled were considered not really had significant effect on performance and consequently should be dropped from the performance measurement system. Until the end of the financial year 1997/1998 the Inland Revenue – Cumbernauld used a total of 130 measures to monitor and controlled their six business processes. Starting from the financial year 1998/1989 they cut down their business processes to three business processes and used 20 measures to monitor and control their performance.



Contribution 7: The QMPMS can be easily understood and implemented.

The experiences of implementing the QMPMS shows that people from Inland Revenue - Cumbernauld and Seagate Distribution (UK) had no problem in understanding the concept of the QMPMS and implementing the method.

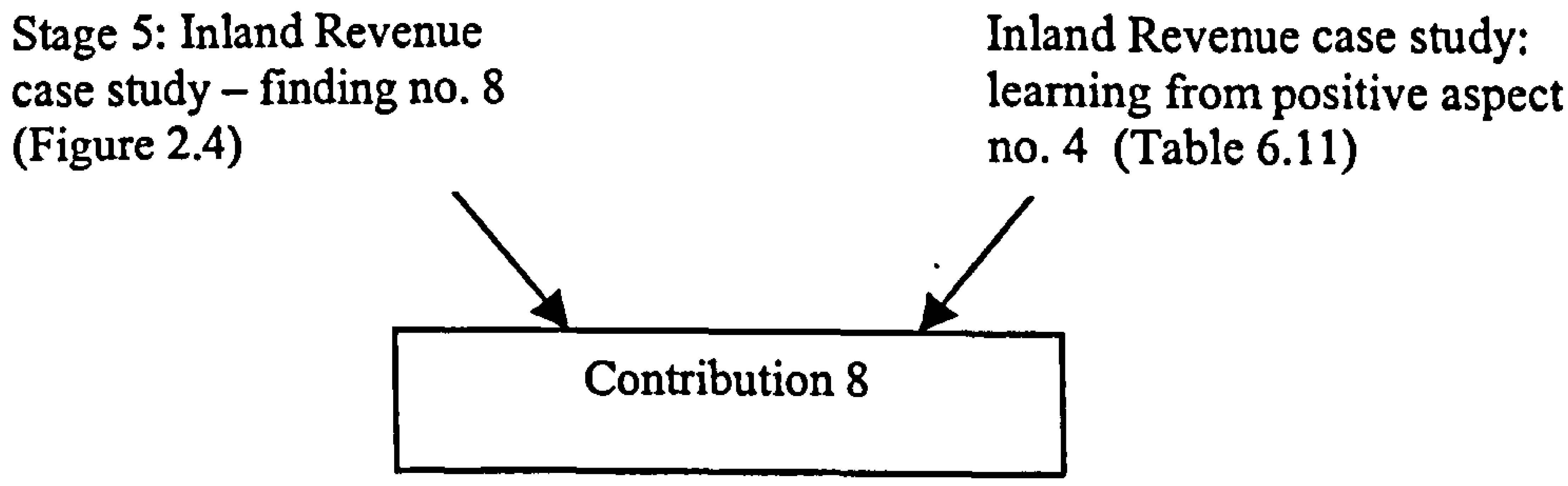


Contribution 8: The implementation concept of the QMPMS can be transferred to other people quite easily through training.

In the implementation of the QMPMS at Inland Revenue – Cumbernauld, a manager (project manager) of Inland Revenue – Cumbernauld has been appointed to work together with the researchers from the Centre for Strategic Manufacturing – University of Strathclyde (CSM) from the beginning of the project. To facilitate the implementation of the QMPMS, three people were trained for two days. The content of the training covered:

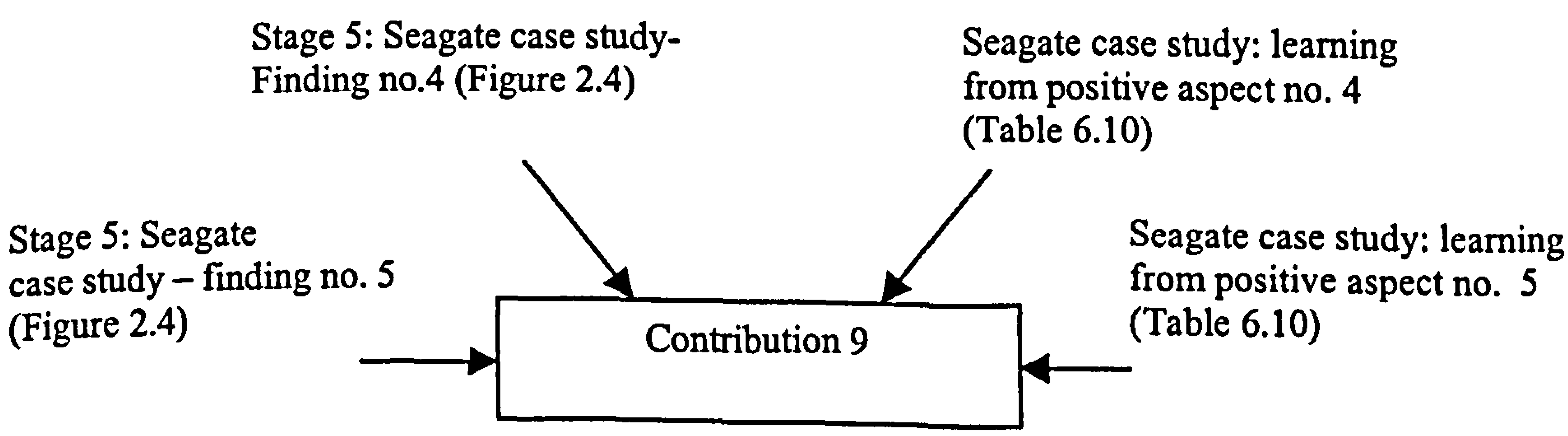
- ✓ the concept of the QMPMS,
- ✓ how to use the ExpertChoice software,
- ✓ building performance measurement model using the QMPMS and the ExpertChoice software,
- ✓ facilitating them to build the performance model of Inland Revenue – Cumbernauld for the financial year 1996/1997 (a copy of the training material will be included in the Appendices of the thesis).

At the end of the training the trainees felt quite confident that they will be able to facilitate the implementation of the QMPMS at Inland Revenue – Cumbernauld for the financial year 1997/1998. The fact that the Inland Revenue – Cumbernauld now has successfully built and implemented the QMPMS without any assistance from the CSM suggests that they have already had implementation expertise in the QMPMS.



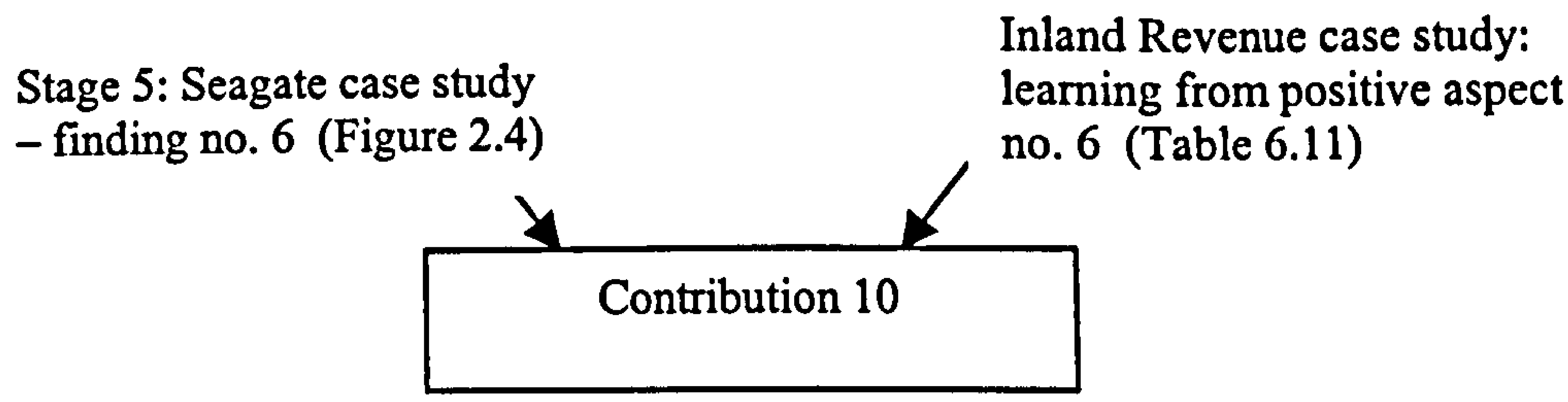
Contribution 9: The accuracy of the QMPMS is good.

The experiment at Seagate shows that for the periods of July 1997 to December 1997 the accuracy of the QMPMS is good. The mean percentage of deviation of the relative change is 3.77 % for the direct effect model and 3.67 % for the combined effect model. In this case the accuracy of the direct effect model is not significantly different from the accuracy of the combined effect model. However, it is too early to generalise that the accuracy of the methods developed (QMPMS) is good for all cases.



Contribution 10: The QMPMS is stable for a considerable period of time.

The experiment at Seagate shows that the QMPMS is stable from the period of July 1997 to December 1997. When the environment significantly changes the QMPMS should be modified to adapt to the changes.



Contribution 11: The need and the ownership of the model have increased success in implementation of the model.

The following may be the reasons why the implementation of the methods at Inland Revenue - Cumbernauld is successful:

- Inland Revenue - Cumbernauld has, for a long time, wanted to have the QMPMS-like method. It was discovered in the experiment that Inland Revenue, Cumbernauld wanted to have a single performance indicator for each business process and overall office. This was in line with Michael Heseltine's concern of the need of Civil Service to have a single performance indicator.
- The Inland Revenue - Cumbernauld feel that they own the model because they built the system themselves. In this case study the researchers trained three staffs of Inland Revenue – Cumbernauld about the concept of the methods and how to implement them. People from Inland Revenue – Cumbernauld then developed their performance model themselves. Since they developed the model themselves they feel that they own the model.

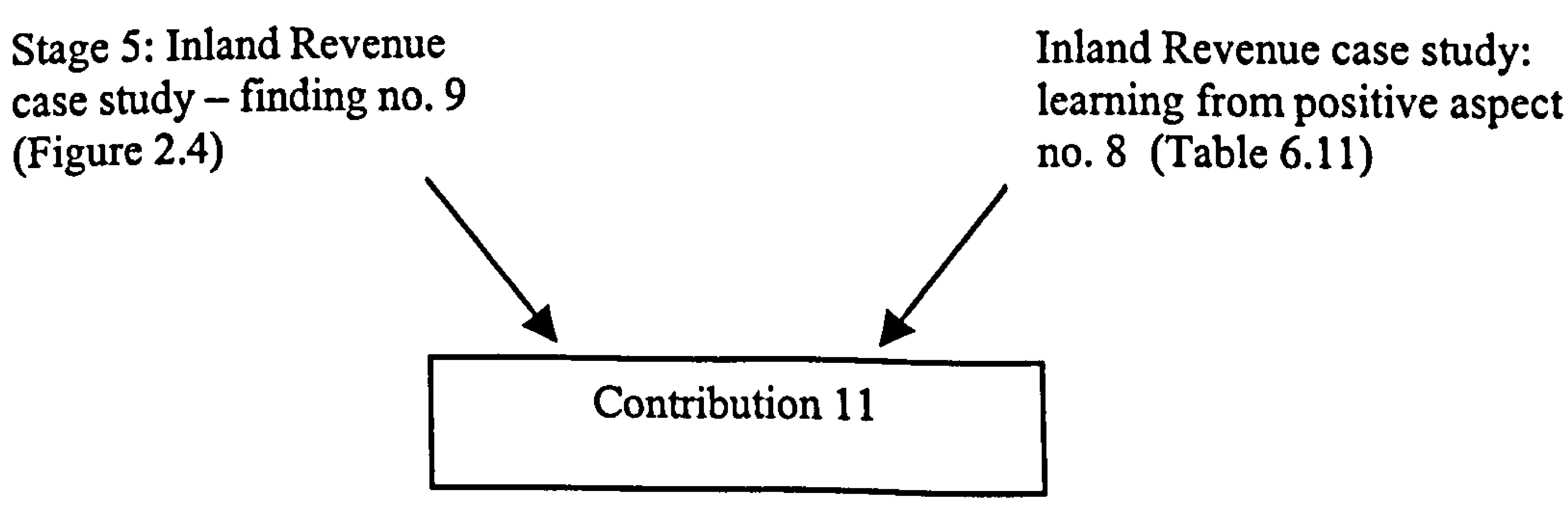


Figure 7.1 shows the contributions of this research has made to the knowledge of performance measurement systems. In Figure 7.1 the contributions are indicated by the grey boxes.

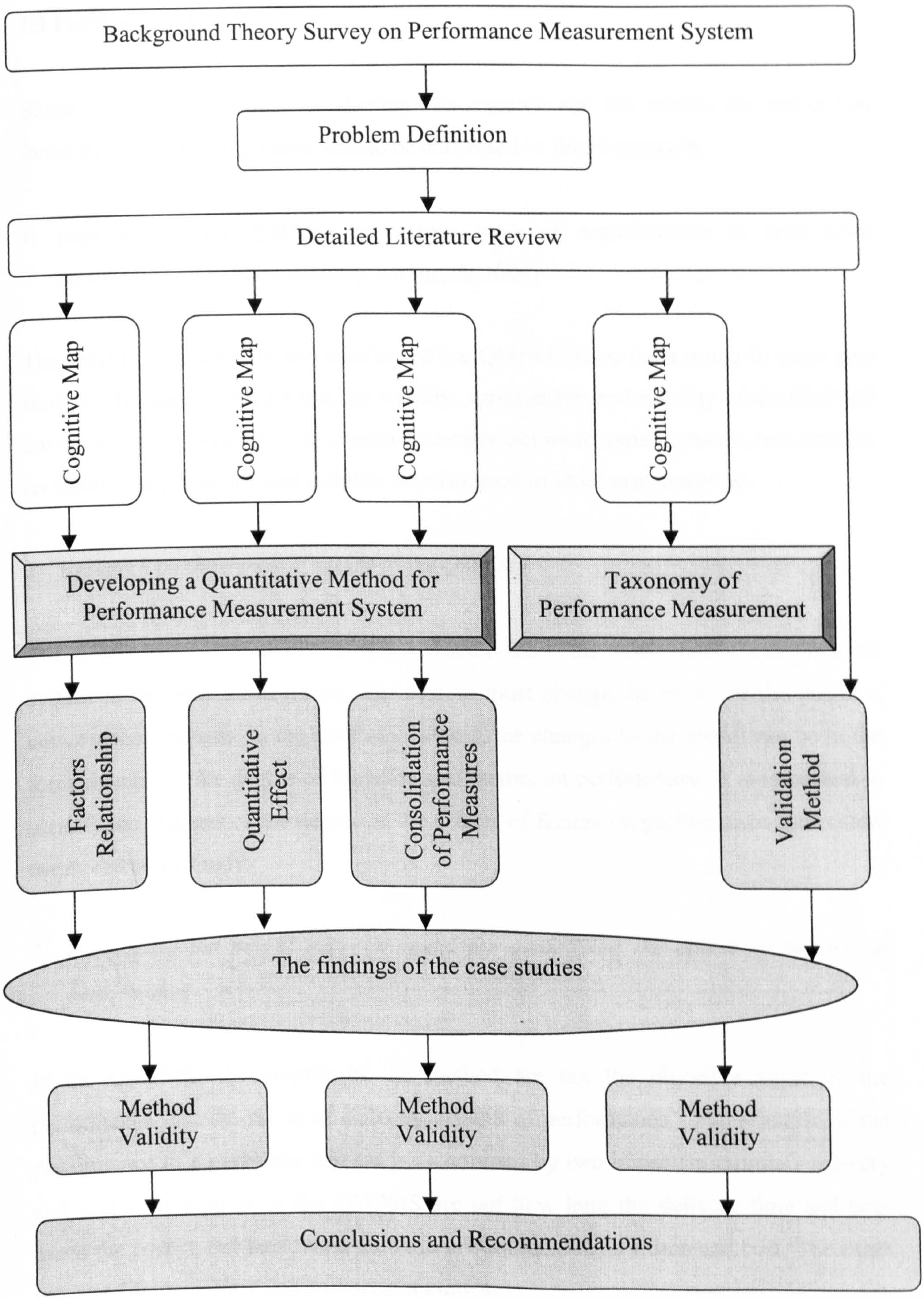


Figure 7.1. Research contribution to the knowledge of performance measurement.

7.3 Further Work

Based on experience whilst conducting this research and the results, the author has found that the following issues should be addressed in future research.

1. *Implementing the QMPMS to various types of organisations to gain more information on validity, stability and applicability*

The validity, applicability and stability of the QMPMS have been tested in three case studies. The results indicate that the validity, applicability and stability of the QMPMS are quite good. However, it is important to carry out more experiments to test whether its validity, applicability and stability are also good in other organisations.

2. *Research on the dynamic nature of the QMPMS*

The experiments carried out in this research show the performance measurement system to be dynamic in nature. The system must change, however, as the business environment changes. In the QMPMS context, the changes to the model can be in the form changes of the degree of the effects of factors on performance. It is important to identify the changes of the degree of the effects of factors on performance and review the model accordingly.

3. *Developing the neural network model for quantifying the effects of factors on performance*

In the QMPMS, the outputs of the method are not the objective value of the performance, but the ratios of different criteria of performance. For example, if the performance of a particular process is determined by two important criteria - delivery and cost - the outputs of the QMPMS are not how long the delivery time and how much the cost is, but how much the ratio is between delivery time and cost. The exact values of delivery time and cost are not known.

Further research can be carried out using the neural network model to identify the exact (not ratio) effect of factors on performance. Using the model, the effect of the addition of more unit resources to particular areas on financial and non-financial performance can be identified.

4. *Assessing the appropriateness of the weightings of the European Foundation of Quality Management model*

The EFQM model assigns the weights of factors affecting business performance as indicated in Figure 7.2. Further research can be carried out to test the appropriateness of the weights for particular types of industries. The QMPMS method and the neural network model can be used to test the EFQM's appropriateness.

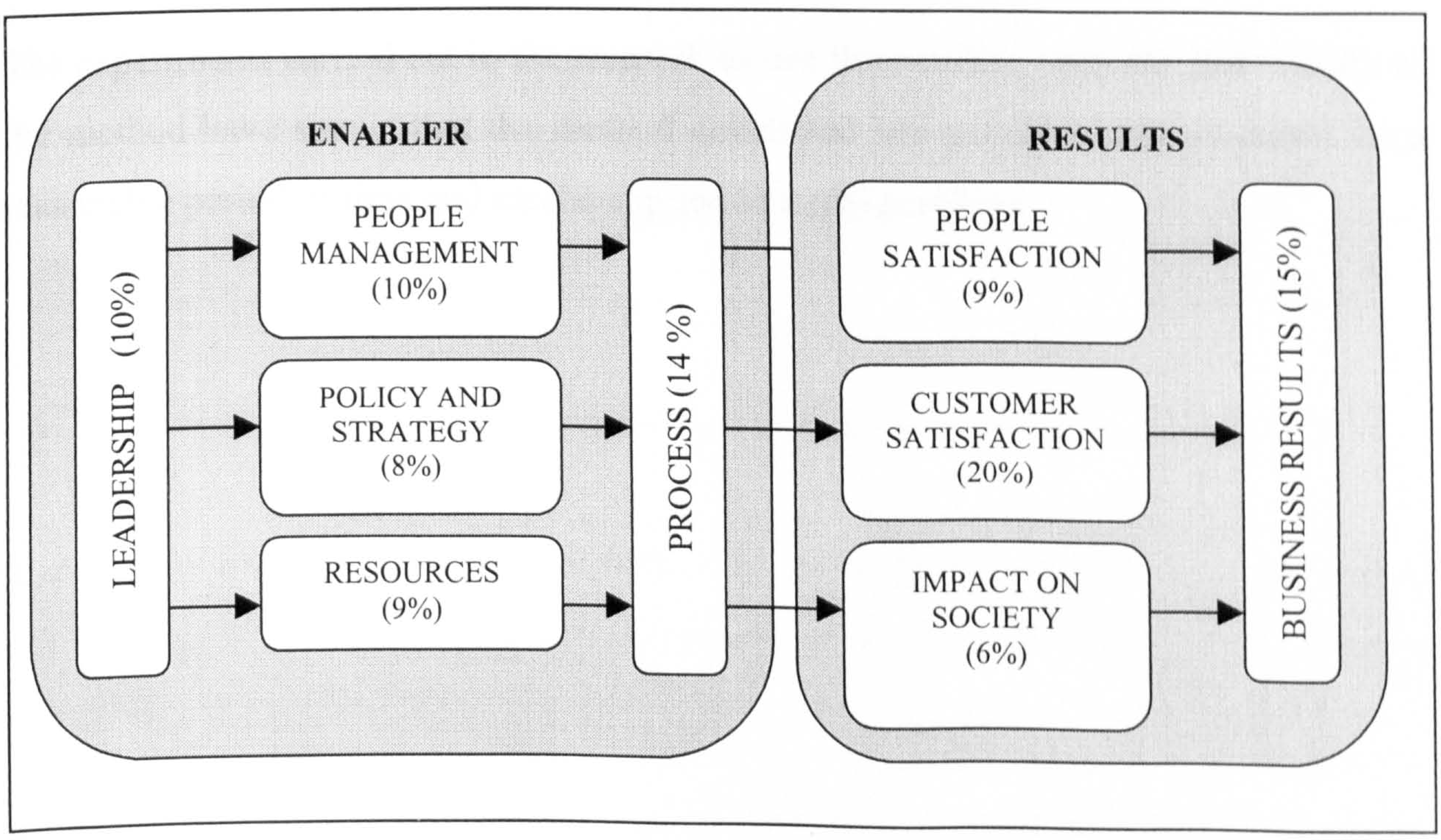


Figure 7.2. European Foundation of Quality Management.

7.4 Closing Remarks

This thesis presents the research on developing quantitative methods for performance measurement systems. The methods developed in the research can be used to identify factors affecting performance, to quantify their effects, to consolidate performance measures and to reduce the number of performance reports.

Following a review of the literature on performance measurement systems and quantification of the effect of factors on performance, the author found that no model has been developed which identifies and quantifies the interaction of factors affecting performance. The author also reviewed, in-depth, the multi-criteria decision analysis model, especially the analytic hierarchy process and from this review proposed a quantitative method for performance measurement systems using cognitive maps, structured diagrams and the analytic hierarchy process.

The experiments carried out in the research to test the validity, stability and validity of the method have shown that the method developed has good validity, is stable for a reasonable period of time and can be applied to a real problem.

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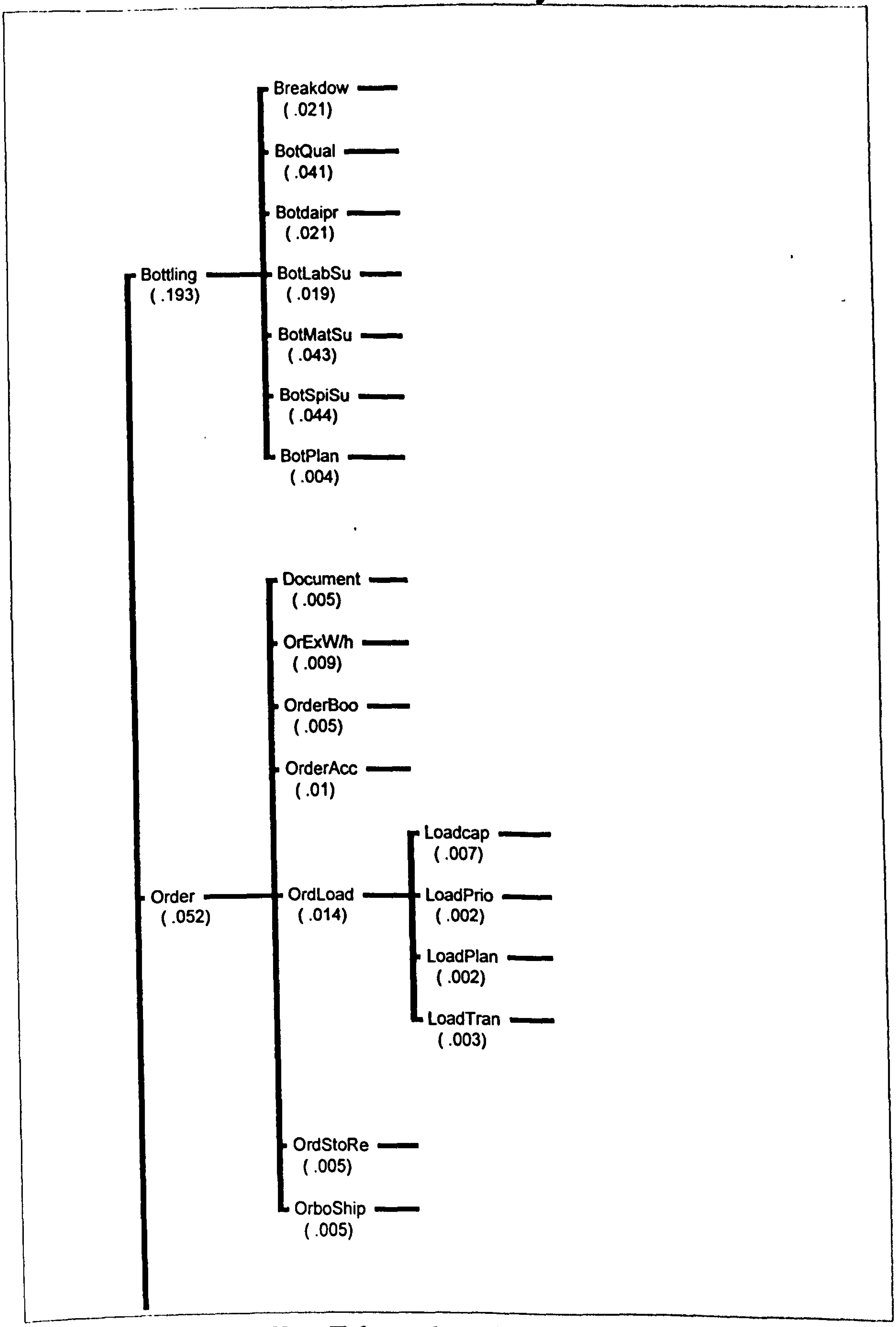
APPENDIX A.1

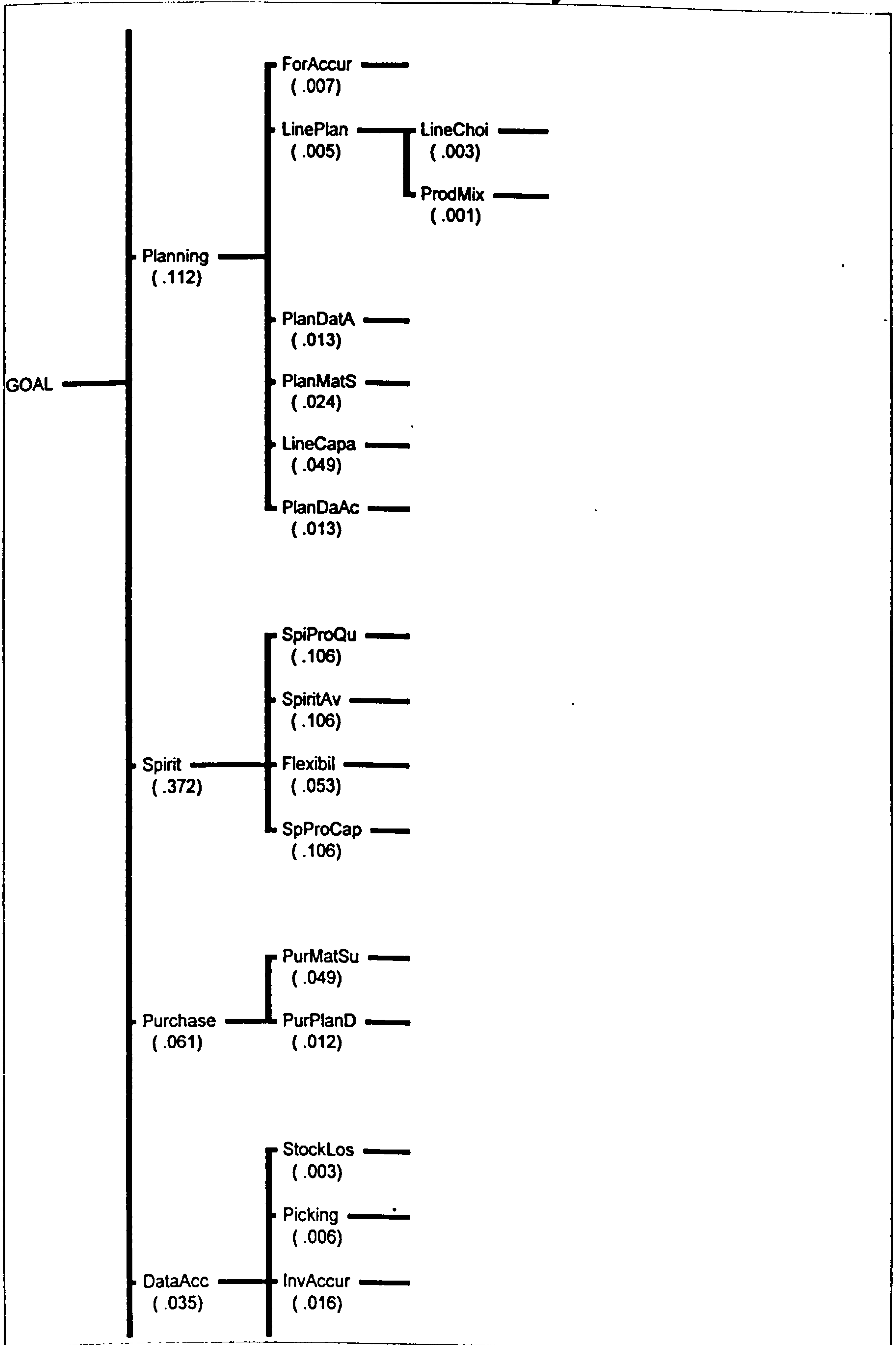
The Direct Effect of Factors on 'On time delivery' Performance

On Time Delivery



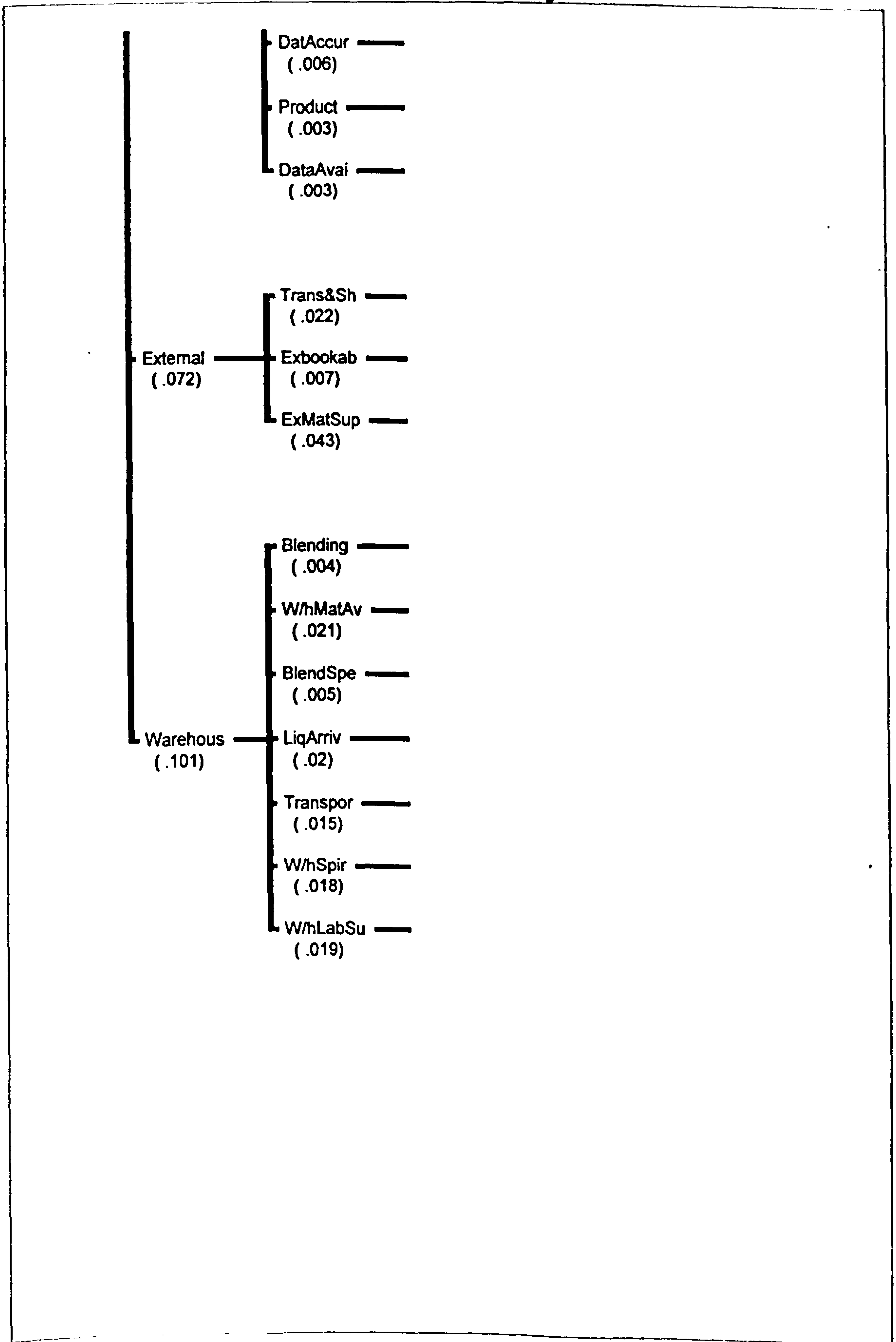
For Educational Use Only

On Time Delivery



For Educational Use Only

On Time Delivery



For Educational Use Only

On Time Delivery

Synthesis of Leaf Nodes with respect to GOAL

Distributive Mode

Abbreviation	Definition
GOAL	
BlendSpe	Blending Spec availability
Blending	Blending program
BotLabSu	Bottling Labour Supply
BotMatSu	Bottling Material Supply
BotPlan	Bottling Plan
BotQual	Bottling Quality
BotSpiSu	Bottling Spirit Supply
Botdaipr	Bottling daily priority
Bottling	Bottling & Palletising
Breakdow	Bottling Breakdowns
DatAccur	Data accuracy
DataAcc	Data Accuracy & Timeliness
DataAvai	Data availability
Document	Documentation
ExMatSup	External material supply
Exbookab	External orders bookability
External	External
Flexibil	Flexibility
ForAccur	Planning & Procurement forecast accuracy
InvAccur	Inventory accuracy
LineCapa	Line capacity
LineChoi	Line choice
LinePlan	Line Planning
LiqArriv	Liquid arrival
LoadPlan	Loading plan
LoadPrio	Loading priority
LoadTran	Loading transport availability
Loadcap	Loading capacity
OrExW/h	Order Procesiing External warehouse
OrboShip	Order processing bookshipability
OrdLoad	Order processing loading
OrdStoRe	Order processing stock record accuracy
Order	Order processing
OrderAcc	Oder accuracy
OrderBoo	Order processing bookability
Picking	Picking accuracy
PlanDaAc	Planning data accuracy

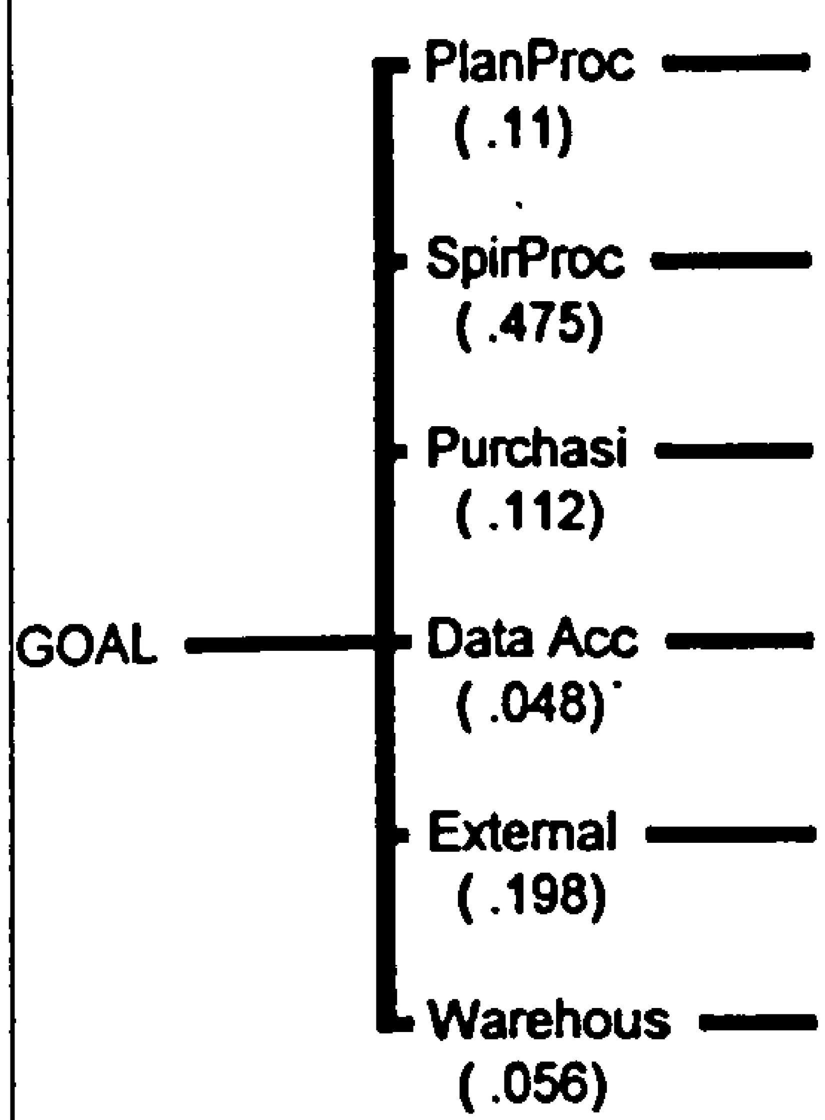
For Educational Use Only

PlanDatA	Planning data availability
PlanMatS	Planning & Procurement material supply
Planning	Planning & Procurement
ProdMix	Product mixed
Product	Product knowledge
PurMatSu	Purchasing material supply
PurPlanD	Purchasing planning & cost data
Purchase	Purchasing
SpProCap	Spitit Processing capacity
SpiProQu	Spirit processing quality
Spirit	Spirit processing
SpiritAv	Spirit Availability
StockLos	Stock lost & damaged
Trans&Sh	Transportation & shipping
Transpor	Transportation
W/hLabSu	Warehouse labour supply
W/hMatAv	Warehouse material availability
W/hSpir	Warehouse spirit quality
Warehous	Warehouse

APPENDIX A.2

The Indirect Effect of Level 1 Factors on 'On time delivery' Performance

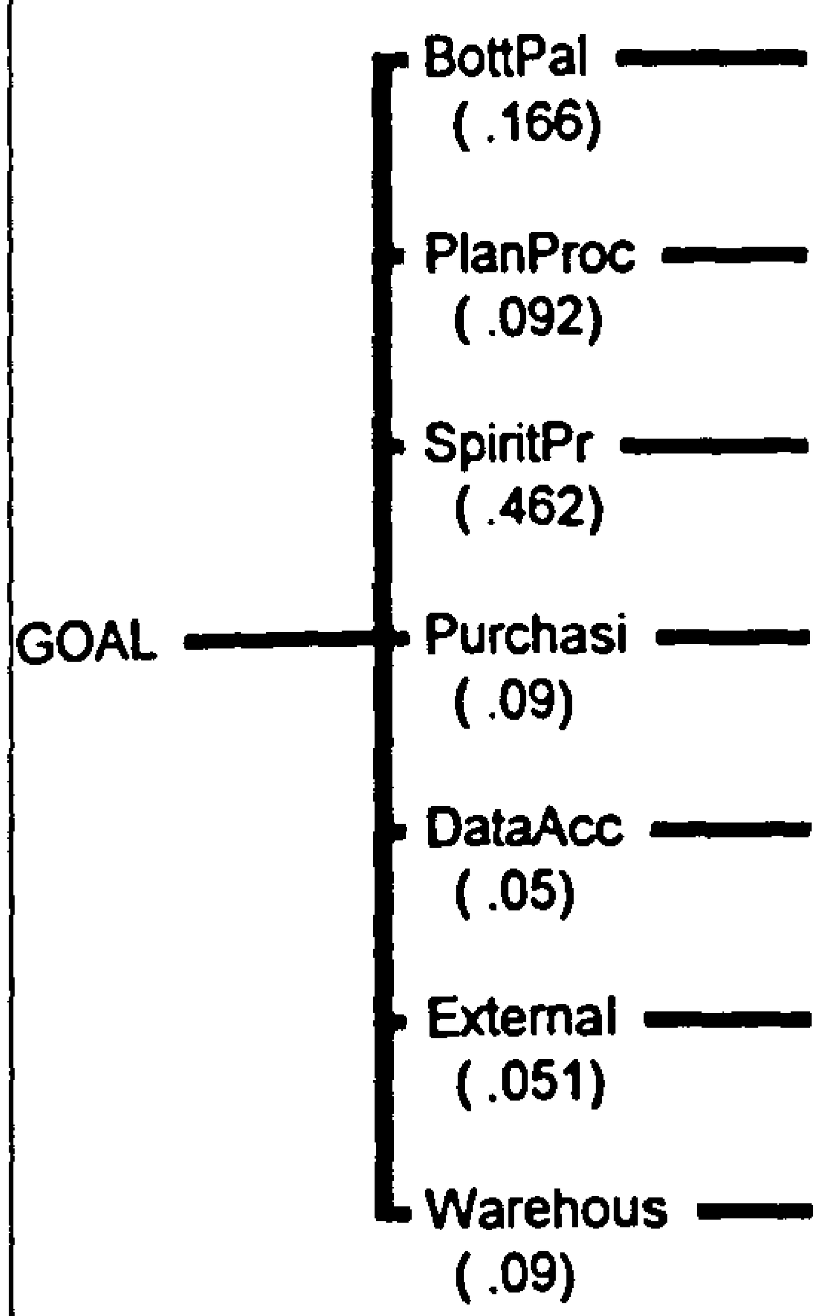
Indirect Effect through Bottling and Palletising



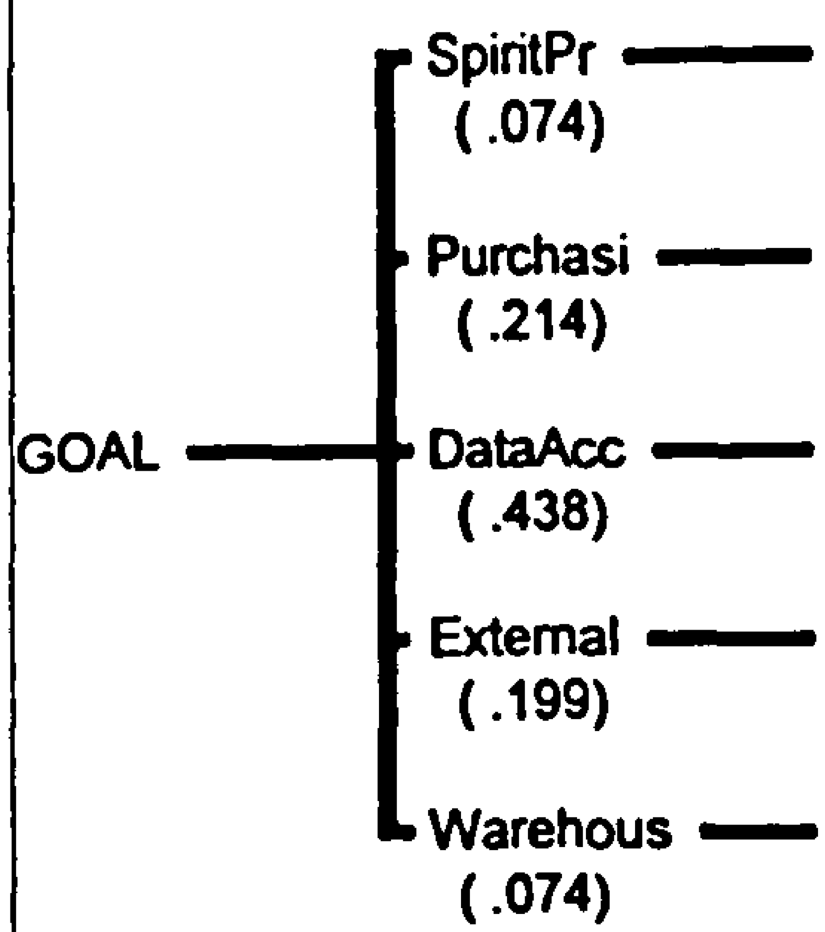
Abbreviation	Definition
GOAL	
Data Acc	Data accuracy
External	External
PlanProc	Planning and Procurement
Purchasi	Purchasing
SpirProc	Spirit processing
Warehous	Warehousing

For Educational Use Only

Indirect effect through order processing

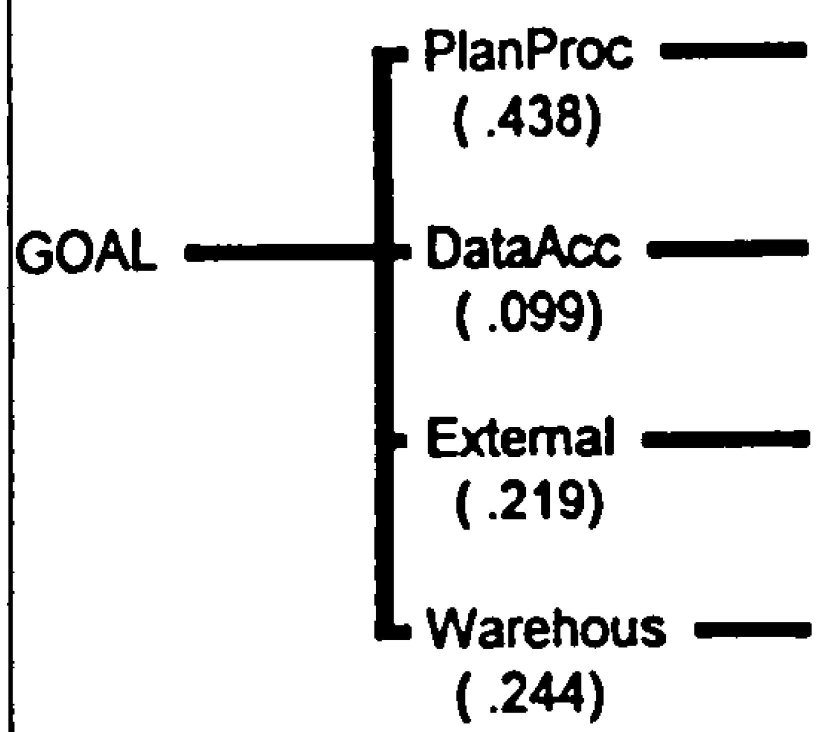


Abbreviation	Definition
GOAL	
BottPal	Bottling&Palletising
DataAcc	Data Accuracy
External	External
PlanProc	Planning and Procurement
Purchasi	Purchasing
SpiritPr	Spirit Procesing
Warehous	Warehousing



Abbreviation	Definition
GOAL	
DataAcc	Data accuracy
External	External
Purchasi	Purchasing
SpiritPr	Spirit processing
Warehous	Warehouse

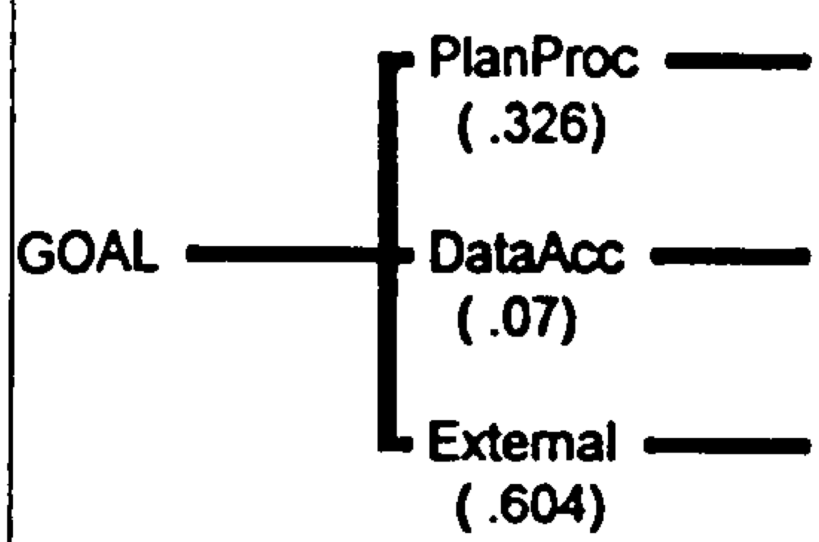
Spirit processing



Abbreviation	Definition
GOAL	
DataAcc	Data Accuracy
External	Warehouse
PlanProc	Planning and Procurement
Warehous	Warehousing

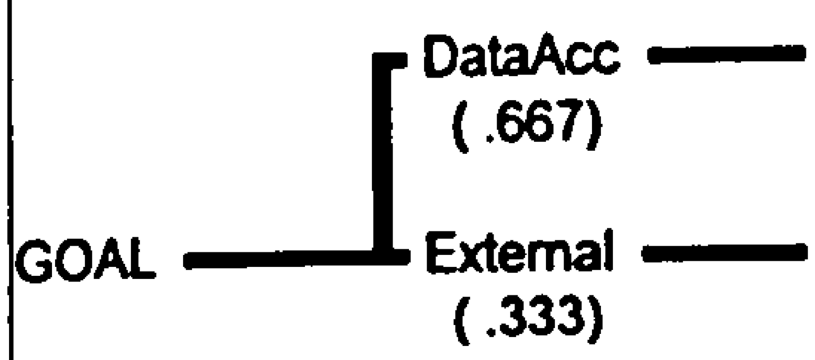
For Educational Use Only

Purhasing



Abbreviation	Definition
GOAL	
DataAcc	data Accuracy
External	External
PlanProc	Planning & Procurement

Warehousing



Abbreviation	Definition
GOAL	
DataAcc	Data Accuracy
External	External

APPENDIX B.1

The Original Data of Total Production Cost per Unit

FY98 DISC COST PER UNIT ANALYSIS

			Jul-97	Aug-97	Sep-97	Q1/98	Oct-97	Nov-97	Dec-97	Q2/98	Jan-98	Feb-98	Mar-98	Q3/98	YTD
People Related Costs			69,206	93,732	111,877	274,815	112,487	153,411	142,773	408,671	64,430			64,430	747 916
Materials/Supplies			6,357	4,377	0	10,734	0	12,129	3,818	15,947	3 988			3,988	30 669
Other Costs			0	0	0	0	0	0	860	860	2,041			2 041	2 901
Fixed Costs	Brewster		9,849	12,012	11,014	32,875	10,740	15,163	16,153	42,056	14,466			14,466	89 397
Fixed Costs	YB							18,691	5,102	23,793	9,196			9,196	32 989
[redacted]			88,412	110,121	122,891	318,424	[redacted]	100,284	168,706	401,327	84,121	[illegible]	0	84,121	893,872
Allocations	Quality		20,638	25,505	28,496	74,639	23,386	24,054	29,640	77,080	21,101			21,101	172 820
	Occupancy		8,988	12,689	13,976	35,653	13,239	12,705	13,323	39,267	11,605			11,605	86 525
	G&A		6,500	8,917	9,400	24,817	4,877	5,958	6,824	17 659	6,739			6,739	49 215
	Allocations Total	B	36,126	47,111	51,872	135,109	41,502	42,717	49,787	134,006	39,444	0	0	39,444	308 560
[redacted]			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1,212,432
Administration	Planning & Scheduling		12,264	16,717	16,472	45,453	13,858	15,011	15,118	43,988	14,110			14,110	103,551
	Order Administration		10,885	15,181	16,575	42,641	11,844	9,623	11,386	32,853	9,252			9,252	84,746
	Administration Total	D	23,149	31,898	33,047	88,094	25,703	24,634	26,504	76,841	23,362	0	0	23,362	188 297
Value Add & Rework Costs		E	144,687	189,130	207,810	541,627	190,432	266,745	244,997	702,174	186,927	0	0	186,927	1,400,729
Shipping	Traffic		6,904	15,582	9,973	32,459	6,035	7,605	7,611	21,251	6,488			6,488	60 198
	Warehouse		40 889	45,913	46,140	132,942	41,520	42,657	44,130	128,307	32 854			32 854	294 103
	Shipping Total	F	47 793	61,495	56,113	165,401	47,955	50,262	51,741	149,558	39,342	0	0	39,342	354 301
[redacted]			192,460	260,826	283,823	707,028	[redacted]	317,807	296,738	851,732	196,269	[illegible]	0	196,269	1,765,030
UNITS BUILT		H	27,498	41,614	41,823	110,935	42,492	52,313	44,447	139,252	15,737			15,737	265,924
[redacted]			$8.03	$6.10	$4.14	$4.97	[redacted]	$4.88	$4.84	$4.62	$8.29	[illegible]	[illegible]	$8.29	$4.96
OPERATIONAL CPU BUILT		(A-Z)/H	$2 58	$2 21	$1 67	$2 10	$1 99	$2 84	$2 60	$2 51	$3 48			$3 48	$2 39
UNITS CONFIGURED		I	5,681	11,447	30,421	47,549	24,391	9,041	25,957	59,389	11,448			11,448	118,386
[redacted]			$4.86	$3.36	$2.98	$3.27	[redacted]	$6.82	$3.15	$3.62	$6.76	[illegible]	[illegible]	$6.76	$3 84
TOTAL OPERATIONAL COSTS PER UNIT CONFIGURED		Z/I	$2 54	$1 59	$1 75	$1 80	$1.59	$5 60	$2 04	$2 40	$3 44			$3 44	$2 26
UNITS SHIPPED (excl. Hub)		J	28,269	75,090	85,659	189,018	71,128	91,814	94,826	257,867				0	448,585
TOTAL COST PER UNIT SHIPPED		G/J	$6 81	$3 34	$3 08	$3 74	$3 35	$3 46	$3 13	$3 31	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$3 93
TOTAL OPERATIONAL COST PER UNIT SHIPPED		(A+F)/J	$4 71	$2 29	$2 09	$2 56	$2 40	$2 73	$2 32	$2 49	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$2 82
REWORK COSTS TOTAL (incl config alloc ref AA below)		Y	26,561	38,303	90 673	155,537	65,575	61,679	81,825	209,078	65,826			65 826	430 441
REWORK COSTS EXCLUDING ALLOCATIONS		Z	14,414	18,155	53,129	85,698	38,859	50,642	52,977	142,478	39,420			39 420	267 596
	UNITS BUILT		27,498	41,614	41,823	110,935	42,492	52,313	44,447	139,252	15,737	0	0	15,737	265 924
	UNITS CONFIGURED		5,681	11,447	30,421	47,549	24,391	9,041	25,957	59 389	11,448	0	0	11,448	118 386
			33,179	53,061	72,244	158,484	66,883	61 354	70 404	198 641	27,185	0	0	27,185	384 310
			17%	22%	42%	30%	36%	15%	37%	30%	42%			42%	31%
	CONFIG ALLOC OF ADMIN & SHIPPING	AA	12,147	20,148	37,544	69 839	26,716	11 037	28 848	66,600	26 406			26 406	162 845

FY98 DISC COST PER UNIT ANALYSIS

			Q1/98	Q2/98	Jan-98	Feb-98	Mar-98	Q3/98	Apr-98	May-98	Jun-98	Q4/98	Y.T.D.
√ People Related Costs DIRECT LABOUR (V)			274,815	408,671	64,430	78,674	142,274	285,378	84,087	91,166	95,169	270,422	1,239,286
√ Materials/Supplies			10,734	15,947	3,988	6,434	8,637	19,059	4,188	0	4,078	8,266	54,006
√ Other Costs			0	860	2,041	124	2,945	5,110	274	1,861	2,515	4,650	10,620
Fixed Costs	Brewster BUILDING		32,875	42,056	14,466	14,549	15,921	44,936	15,073	14,767	11,587	41,426	161,293
Fixed Costs	YB BUILDING			23,793	9,196	9,261	9,610	27,967	9,020	10,819	16,402	36,242	88,002
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,443,207
√ Allocations	Quality	VOLUME BASED FIXED COST	74,639	77,080	21,101	22,038	27,039	70,177	28,181	19,711	26,402	74,294	296,191
	Occupancy		35,653	39,267	11,605	13,809	16,773	42,187	18,510	19,700	20,361	58,571	175,678
	G&A		24,817	17,659	6,739	7,657	10,246	24,642	7,406	7,768	10,344	25,518	92,636
	Allocations Total	B	135,109	134,006	39,444	43,504	54,058	137,006	54,097	47,179	57,106	158,383	564,505
			[illegible]										2,137,712
√ Administration	Planning & Scheduling	FIXED COSTS (PEOPLE)	45,453	43,988	14,110	12,098	17,576	43,784	15,292	15,508	21,469	52,269	185,494
	Order Administration		42,641	32,853	9,252	8,807	11,107	29,166	10,400	7,766	11,749	29,915	134,575
	Administration Total	D	88,094	76,841	23,362	20,905	28,683	72,950	25,692	23,274	33,218	82,184	320,069
Value Add & Rework Costs		E	641,627	702,174	166,927	173,481	262,028	592,406	192,432	189,066	220,076	601,573	2,437,781
Shipping	√ Traffic — FIXED COST BASED ON VOLUME		32,459	21,251	6,488	11,414	9,524	27,426	7,689	7,062	9,487	24,258	105,394
VARIABLE (PEOPLE)	Warehouse		132,942	128,307	32,854	35,550	48,094	116,498	41,667	37,576	46,969	126,212	503,959
	Shipping Total	F	165,401	149,558	39,342	46,964	57,618	143,924	49,356	44,658	56,456	150,470	609,353
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3,047,134
UNITS BUILT		H	110,935	139,252	15,737	18,028	40,766	74,531	6,397	24,629	30,542	61,568	386,286
→			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$8.44
OPERATIONAL CPU BUILT		(A-Z)/H	$2.10	$2.51	$3.48	$3.42	$2.58	$2.97	$6.04	$2.97	$3.08	$3.34	$2.61
UNITS CONFIGURED		I	47,549	59,389	11,448	19,844	34,602	65,894	40,206	21,512	29,658	91,376	264,208
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$3.58
TOTAL OPERATIONAL COSTS PER UNIT CONFIGURED		Z/I	$1.80	$2.40	$3.44	$2.38	$2.14	$2.44	$1.84	$2.12	$1.21	$1.70	$2.06
UNITS SHIPPED (excl. Hub)		J	189,018	267,667	62,472	71,128	122,994	246,594	48,492	67,886	105,338	221,716	914,895
TOTAL COST PER UNIT SHIPPED		G/J	$3.74	$3.31	$3.74	$3.10	$2.60	$2.99	$4.99	$3.44	$2.63	$3.39	$3.33
TOTAL OPERATIONAL COST PER UNIT SHIPPED		(A+F)/J	$2.56	$2.49	$2.54	$2.19	$1.93	$2.13	$3.34	$2.41	$1.77	$2.31	$2.36

		Q1/98	Q2/98	Jan-98	Feb-98	Mar-98	Q3/98	Apr-98	May-98	Jun-98	Q4/98	Y.T.D.
REWORK COSTS TOTAL (incl config alloc.ref AA below)	Y	155,537	209,078	65,826	82,866	118,791	267,483	144,416	83,282	86,218	313,916	946,014
REWORK COSTS EXCLUDING ALLOCATIONS	Z	85,698	142,478	39,420	47,304	~~74,037~~ 79170	160,751	~~73,664~~ 79670	~~45,677~~ 51611	~~35,707~~ 42039	155,362	544,289
UNITS BUILT		110,935	139,252	15,737	18,028	40,766	74,531	6,397	24,629	30,542	61,568	386,286
UNITS CONFIGURED		47,549	59,389	11,448	19,844	34,602	65,894	40,206	21,512	29,658	91,376	264,208
		158,484	198,641	27,185	37,872	75,368	140,425	46,603	46,141	60,200	152,944	650,494
		30%	30%	42%	52%	46%	47%	86%	47%	49%	60%	41%
CONFIG ALLOC OF ADMIN & SHIPPING	AA	69,839	66,600	26,406	35,562	39,621	101,589	64,746	31,671	44,179	140,597	378,624

APPENDIX B.2

Statistical Table for the Wilcoxon Matched-Pair Test

N	Level of Significance for One-Tailed Test		
	.025	.01	.005
	Level of Significance for Two-Tailed Test		
	.05	.02	.01
6	0	—	—
7	2	0	—
8	4	2	0
9	6	3	2
10	8	5	3
11	11	7	5
12	14	10	7
13	17	13	10
14	21	16	13
15	25	20	16
16	30	24	20
17	35	28	23
18	40	33	28
19	46	38	32
20	52	43	38
21	59	49	43
22	66	56	49
23	73	62	55
24	81	69	61
25	89	77	68

Source: Adapted from Table I of F. Wilcoxon, *Some Rapid Approximate Statistical Procedures* (New York: American Cyanamid Company, 1949), p. 13, with the kind permission of the publisher.

APPENDIX C.1

Performance Measures of Inland Revenue - Cumbernauld

AOC - Financial Year 1996/97

Critical Process	Ranking	Related Key Business Results	Target %	Achievement %	Other Related Operational & Quality Objectives	Target %	Achieved %	Notes
Administer PRP tax relief correctly & fairly	2	PRP Schemes - Workload 130885	-	-	Quality - Dealing With:-			
		Annual Returns % received within 60 days of due date Ø	85	83.10	Completed Applications	97	96.5	Ø Workload = 7355
		Live Schemes -Rules Examined	5	6.83	Annuals Returns	97	99.5	
		Profit & Loss Accounts Examined	2	1.70	Scheme Rules	97	96.9	
		Cases passed to Employer Compliance Unit for Visits	250 cases	124 cases	Compliance	97	77.6	
		Applications Processed Before Their Start Date Received More Than 5 Days Before Start Date	98	100	Recovery & Bankruptcy	97	67.5	
		Applications Processed Before Start Date Received Less Than 5 Days Before Start Date	95	100	General Enquiries	97	95.3	
		Annual Returns (workload 8061) Examined with 28 days	85	89.29				
Bank and Account for money received	1	Ø Cheque Banking > £10,000 Day 1 Banking	100	100	Quality D. 2 S			ØWorkload 6,884,500
		Ø 99% of all cheques Day 1 Banking	99.2	99.19	Processing cheques received with payslip	98.5	99.1	
					Processing cheques received without a payslip	95	97.5	
					Processing cheques to retaining account	95	99.7	800,000 Range
					Dealing with post-dated cheques and any accompanying time to pay requests	96	97.9	Book 16
					Returning incorrectly completed cheques	98.5	99.1	Book 17
Maintain Accounting records, issue invoices and collect Tax, National Insurance & Interest	2	Assessed Taxes Coll. Balance			Dealing With Non-Payment Computer Input Ø	80	98.34	Ø Workload = 617804
		Overpayments (workload 289041) Dealt With Within 2 Months	92	93.41	Dealing With Objections to interest charges			
		Manual Charges (workload 118876) Dealt With Within 7 Days	97	99.38	Non-File Cases cleared within 4 weeks	95	99.21	Workload = 1882

AOC - Financial Year 1996/97

Critical Process	Ranking	Related Key Business Results	Target %	Achievement %	Other Related Operational & Quality Objectives	Target %	Achieved %	Notes
Maintain Accounting records, issue invoices and collect Tax, National Insurance & Interest (continued)		Customer Services			File Cases cleared within 12 weeks	94	98.43	
		Dealing With Post and Computer Output - All Areas - (Workload = 3529517) Within 28 Days	90	98.49	Dealing With Overpayments, Unassessed taxes	95	98.08	Workload = 145667
		Dealing With Telephone Calls Within 15 Seconds - All Areas*	90	90.34	Dealing With Network Unit Book 19 Cases Ø	94	85.75	Workload = 22431 Ø Workload = 1510835*
					Time To Pay Unit - Dealing With:			
					Arrangements Within 10 Working Days	98	99.91	Workload = 50949
					Cancelled Arrangements (21 days)	98	100	Workload = 8636
					Quality Measures (See Schedule 'A' attached)			
					Dealing With Complaints - Chairman & Ministerial Dealt With Within 10 Days	100	100	Workload = 11
					Handling Complaints - Revenue Adjudicator, Dealt With Within 10 Days	100	100	Workload = 4
					Network Unit Charges			
					N.U. 1 (Basis 42,000) % Processed Within 2 days	97	83	
					N.U. 2 (Basis 72,000) % Processed Within 2 days	97	88	
					Processing Nil Payslips Within 4 Days (Basis 0.6m)	99.2	100	
					Achieving Reconciliation Of Bank Statements (Basis 171)	98	100	
					Issuing Payable Orders Within 3 Days (Basis 80,000)	98.8	99.6	
					Clearing Exceptions & Rejections Within 5 Days (Basis 250,000)	98.8	100	
					Dealing With Dishonoured Cheques & BLAs (Basis 55,700)	98	100	Various Time Frames

AOC - Financial Year 1996/97

Critical Process	Ranking	Related Key Business Results	Target %	Achievement %	Other Related Operational & Quality Objectives	Target %	Achieved %	Notes
Maintain Accounting records, issue invoices and collect Tax, National Insurance & Interest (continued)					Dealing With Network Unit Payments (Basis 50,000)			
					Posting Payments On Day Of Receipt	98	86	
					Notifying Payments In Advance Of Inv. Setts to L.C. Within 5 Days	94	86	
					RFI			
					Contain Average Number Of Cases On Monthly Listing To No More Than:			
					Tax/NIC	475 cases	530 cases *fail*	
					Interest	225 cases	256 cases *fail*	
					ACT/IT-CP Outstanding Non-Zero			
					Contain Average Number Of Cases On Monthly List To No More Than	275 cases	242 cases	
					Tracing Unemployment Benefit Details For Tax Districts (Basis 1.3m Forms)	98.8	99.20	
Develop and Improve The Business And Performance Levels	4	Publish 1996/97 Comms Plan By 30-05-96	30-05-96	100 (Met)	Desktop Publishing			
		Publish 1995/96 Annual Report By 30-09-96	30-09-96	100 (Met)	Project Work Turned Round Within 20 Days	98	100	
					Priority Targets Agreed With Customer	98	100	
					Introducing New/Amended Letters Forms			
					- 10 Days	98	100	
					- Urgents	98	100	
					Carry Out Management Security Checks	100	100	
					Results Of Surveys: Customer Satisfaction Levels Achieved			
					Network Offices Survey	-	100	

AOC - Financial Year 1996/97

Critical Process	Ranking	Related Key Business Results	Target %	Achievement %	Other Related Operational & Quality Objectives	Target %	Achieved %	Notes
Develop and Improve The Business And Performance Levels (continued)					Telephone Callers Survey	-	97.5	
					Internal Communications Survey	-	65	
					Personal Callers Survey	-	100	
					Correspondence Survey	-	91	
Provide Business And Financial Support Services					Quality & Services			
		Callers (Workload 1585) seen within 10 Minutes of Arrival	95	100	Security: Patrols Carried Out Accurately	99	100	
					Typing: Documents Typed Accurately	97	98.4	
					Porters: Tasks Dealt With Accurately	99	100	
		Cost Efficiency - Achieve Savings From All Contracted Services	4.8	13.1	Messengers: Tasks Dealt With Accurately	99	100	
					Paperkeepers: Items Handled Correctly	98	99.8	
		Customer Services			Postal Services: Items Dealt With Accurately & Timeously	99	99.3	
		Post Distribution Service: Distributed Within Time Frames Ø	98	100	Central Records: Requests Dealt With Accurately & Timeously	99	100	Ø Workload 2.9 million
	3	Post Out Service*						* Workload 8.9 million
		Residual Post Next Day Delivery	98	99.9	Machinery and Equipment - Action Within 1 Day of Fault Report	100	100	
		Despatch Security Listings	100	100	Valeting etc - Official Cars	100	100	
		All Other Outgoing Post	98	100	Masterfile Interrogations	100	100	
		Handling Typing Work			Tax District Reorganisations	100	100	
		Treasury Typing Units Workload = 305384	98	100	Budget Work	100	99.9	
		Standard Typing Work - Workload included in 305384	98	92.7	Management Information Systems	100	99.9	
		Filing & Retrieving Clerical Records (Workload 38612)			Security Checks - Contractor's Vehicles	*10	*10	*= Number Checked
		- Internal Post Requests	98	99.9	Maintaining Switchboard Services	100	100	Various Targets

AOC - Financial Year 1996/97

Critical Process	Ranking	Related Key Business Results	Target %	Achievement %	Other Related Operational & Quality Objectives	Target %	Achieved %	Notes
Provide Business And Financial Support Services (continued)		- External Post Requests	98	100	Providing Postal Photocopying and Fax Services			
		- Counter Requests	98	100	Tracing Items Day 1	98	100	
		- Delivery to 107 Points	100	100	Misdirecteds etc Dealt With Day 1	98	100	
		- Porterage Service	100	100	PRPU Packs Compiled Within 24 Hours	98	100	
		Dealing With Urgent Requisitions ØØ Dealing With Other Requisitions ØØ	100 100	100 99.6	Dealing With Urgent Photocopy Immediately	100	100	ØØ Workload 3348 Orders
		Complete 90% Of Workstation Replacement Programme By 31-03-97	90	96	Dealing With Standard Photocopy Within 4 Hours	98	100	
					Dealing With Fax Notificiations Timeously	99	100	
Provide Human Resource Management Services	5	Recruit and Staff The Office to Meet Manpower Requirements	97	97.4	Presentation Of In-House Courses	90	97.8	
		Publish Strategic Training and Development Plan By 01-04-96 And Meet All Targets By 31-03-97	100 (Met)	100 (Met)	Give Trainees At Least 21 Days Notice Of A Course	100	100	
		Publish Equal Opps Plan By 01-04-96 And Meet All Targets	100 (Met)	100 (Met)	Confirm Skills Centre Bookings Within 5 Days	100	100	
					Deal With Pay Enquiries Within 1 Day	100	100	
					Deal With Special Leave Applications Within 5 Days	100	100	
					Offer At Least 100 Work Experience Placements	100	100	
					Offer To Visit At Least 7 Local Secondary Schools By 31 March 1997	100	100	
					Issue Work Experience Package To Schools At Least 7 Days Before TUD Date.	100	100	
					Conduct Career Interviews Within 2 Weeks Of Request	100	100	
					Arrange Workstation Visits Within 2 Days Of Request.	100	100	

AOC - Financial Year 1996/97

Critical Process	Ranking	Related Key Business Results	Target %	Achievement %	Other Related Operational & Quality Objectives	Target %	Achieved %	Notes
Provide Human Resource Management Services (continued)					Ensure Reports of Ergonomic Visits Are Sent to Personnel Services Within 14 Days Of Final Visit.	100	100	
					Ensure Dataspan Training Courses Are Delivered In Accordance With Training Profiles.	100	10 0	

QUALITY IMPROVEMENT MEASURES (QIMS)

RESULTS 1/4/96 TO 31/3/97

QIM TITLE	ACCURACY		TIMEOUSNESS	
	TARGET	ACHIEVED	TARGET	ACHIEVED
OAS	95%	97%	90%	93%
INTEREST	95%	96%	90%	87%
REPAYMENTS	95%	95%	95%	93%
GENERAL ENQUIRIES	95%	97%	95%	97%
SUSPENSIONS	97%	97%	98%	98%
BROCS	98%	99%	96%	98%
NUMERIC RFI	97%	96%	93%	93%
CT61/ONZ	95%	96%	95%	97%
TIME TO PAY:JUNE 96	95%	98%	97%	99%
TUBS:NOV 96	NO TARGET	96%	99%	100%

LMB. F/Y 96/97
: BREAKDOWN OF MANPOWER & COST BY CRITICAL PROCESS

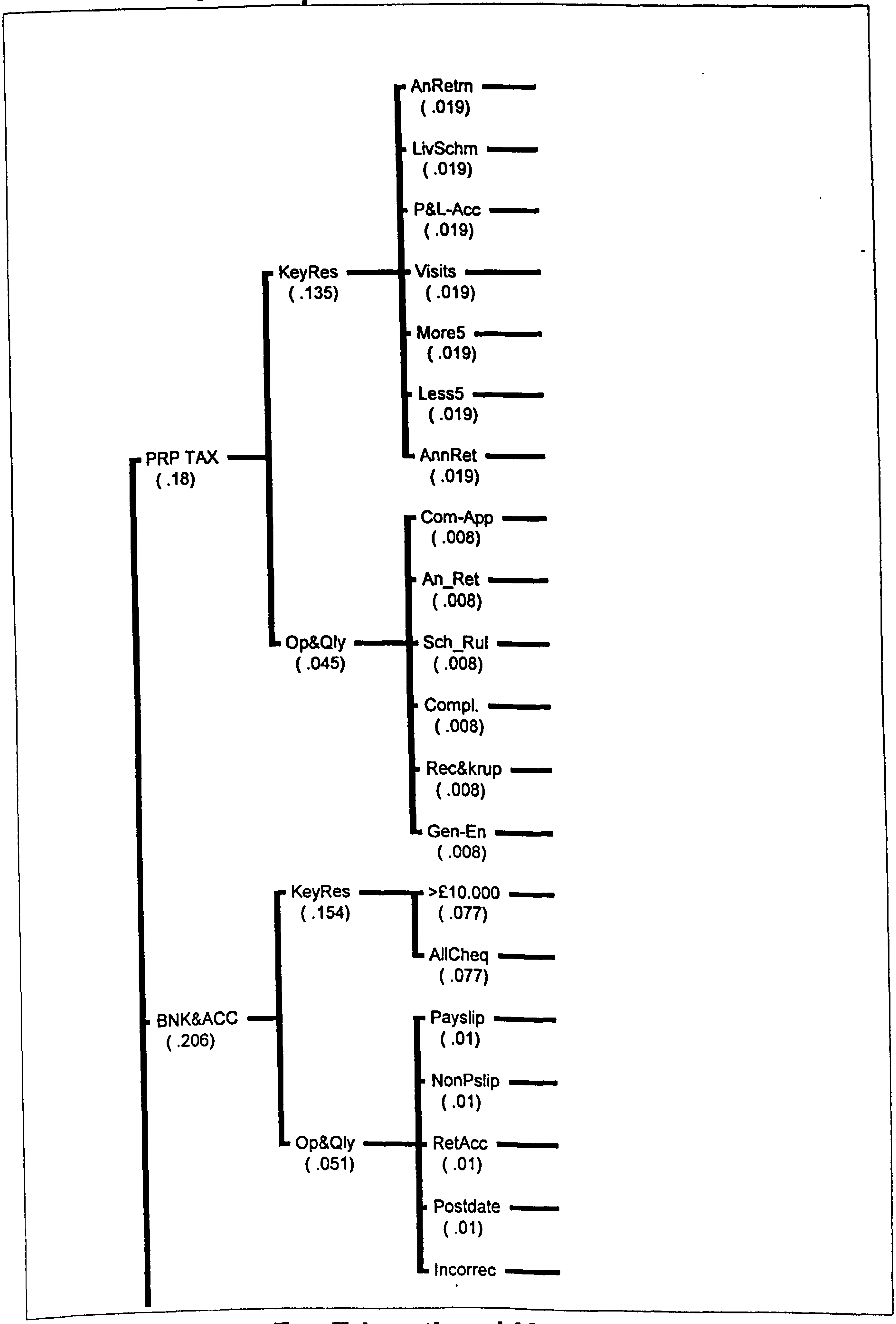
PROCESS	WORK AREA	MANPOWER (m/y)	COSTS (£) PAYBILL	ACCOM	ORC	TOTAL
Administer PRP Tax Relief correctly & fairly	PRPU	35.18	£673,345	£70,345	£23,278	£766,968
	Snr Management	3.61	£112,450	£10,075	£6,011	£128,536
	TOTAL	38.79	£785,795	£80,420	£29,289	£895,504
Bank and account for money collected	ARPE	37.77	£593,911	£94,037	£25,596	£713,544
	IPT	101.33	£1,477,533	£198,614	£61,283	£1,737,430
	PCK	9.22	£136,726	£21,648	£5,893	£164,267
	GIRO	15.33	£244,556	£31,059	£10,934	£286,549
	NPB/E&R	9.61	£142,608	£18,112	£6,376	£167,096
	Repayments	7.58	£126,878	£16,114	£5,673	£148,665
	Bank Rec	4.54	£67,371	£8,557	£3,012	£78,940
	Book 18	13.58	£201,521	£25,594	£9,010	£236,125
	MAPS	5.30	£78,650	£9,989	£3,517	£92,156
	117's	4.50	£66,778	£8,481	£2,986	£78,245
	Snr Management	3.61	£112,450	£10,075	£6,011	£128,536
	TOTAL	212.37	£3,248,982	£442,280	£140,291	£3,831,553
Maintain accounting records, issue invoices to collect Tax, National Insurance and Interest	TA Div (excl TUBS)	381.61	£5,915,285	£547,033	£238,228	£6,700,546
	TUBS	18.81	£290,355	£19,411	£9,303	£319,069
	MACRO	44.24	£715,974	£81,494	£30,274	£827,742
	PAYE EoY Pens	17.23	£297,265	£42,962	£11,126	£351,353
	NRL	11.16	£196,525	£15,943	£7,767	£220,235
	Complaints	5.08	£113,676	£10,248	£3,687	£127,611
	Direct Debits	4.68	£69,449	£8,820	£3,105	£81,374
	IRU	4.33	£92,106	£10,423	£2,092	£104,621
	Snr Management	3.61	£112,450	£10,075	£6,011	£128,536
	TOTAL	490.75	£7,803,085	£746,409	£311,593	£8,861,087
Develop & Improve the business and performance levels	Surveys	2.57	£62,517	£5,186	£1,866	£69,569
	Building Services	5.30	£100,466	£176,249	£9,449	£286,165
	BDD (excl Finance)	30.35	£651,854	£72,149	£28,344	£752,347
	Snr Management	3.61	£112,450	£10,075	£6,011	£128,536
	TOTAL	41.83	£927,287	£263,659	£45,671	£1,236,617
Provide business & financial support services	Building Services	9.20	£174,395	£305,941	£16,403	£496,738
	Finance Team	4.70	£113,954	£12,685	£4,363	£131,002
	CBS	97.16	£1,549,090	£141,174	£42,312	£1,732,576
	Snr Management	3.61	£112,450	£10,075	£6,011	£128,536
	TOTAL	114.67	£1,949,889	£469,875	£69,089	£2,488,853
Provide Human Resource management services	TDG	11.38	£225,195	£29,144	£7,884	£262,223
	Personnel	8.08	£196,609	£80,078	£8,597	£285,284
	Snr Management	3.61	£112,450	£10,075	£6,011	£128,536
	TOTAL	23.07	£534,254	£119,297	£22,492	£676,043
	GRAND TOTAL	921.49	£15,249,292	£2,121,940	£618,426	* £17,989,658

NOTE:-
* = Excludes Postage and Stationery & Printing – handled by EDS but costs borne by AO Cumbernauld

APPENDIX C.2

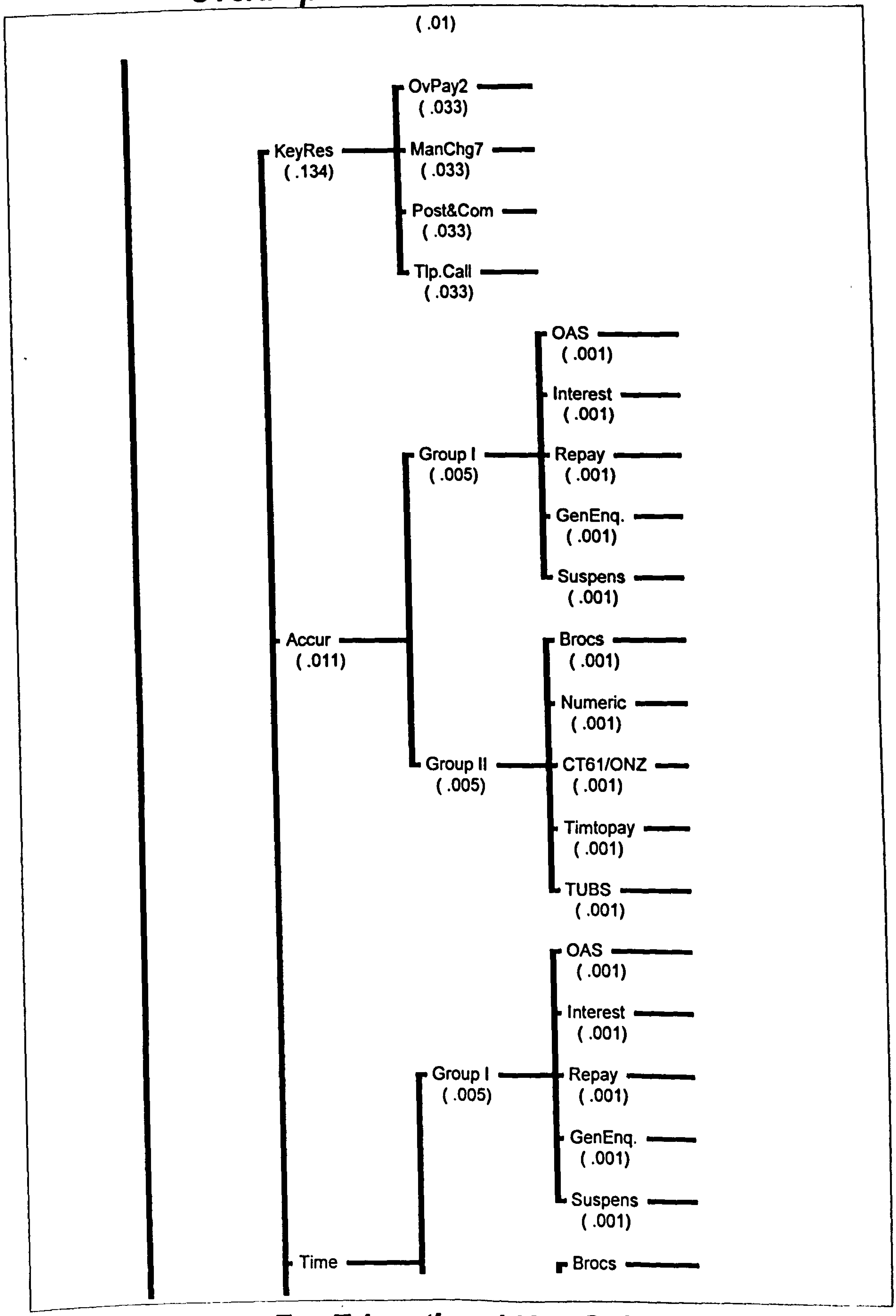
The Effect of Factors on Performance of Inland Revenue - Cumbernauld

Overall performance of the office

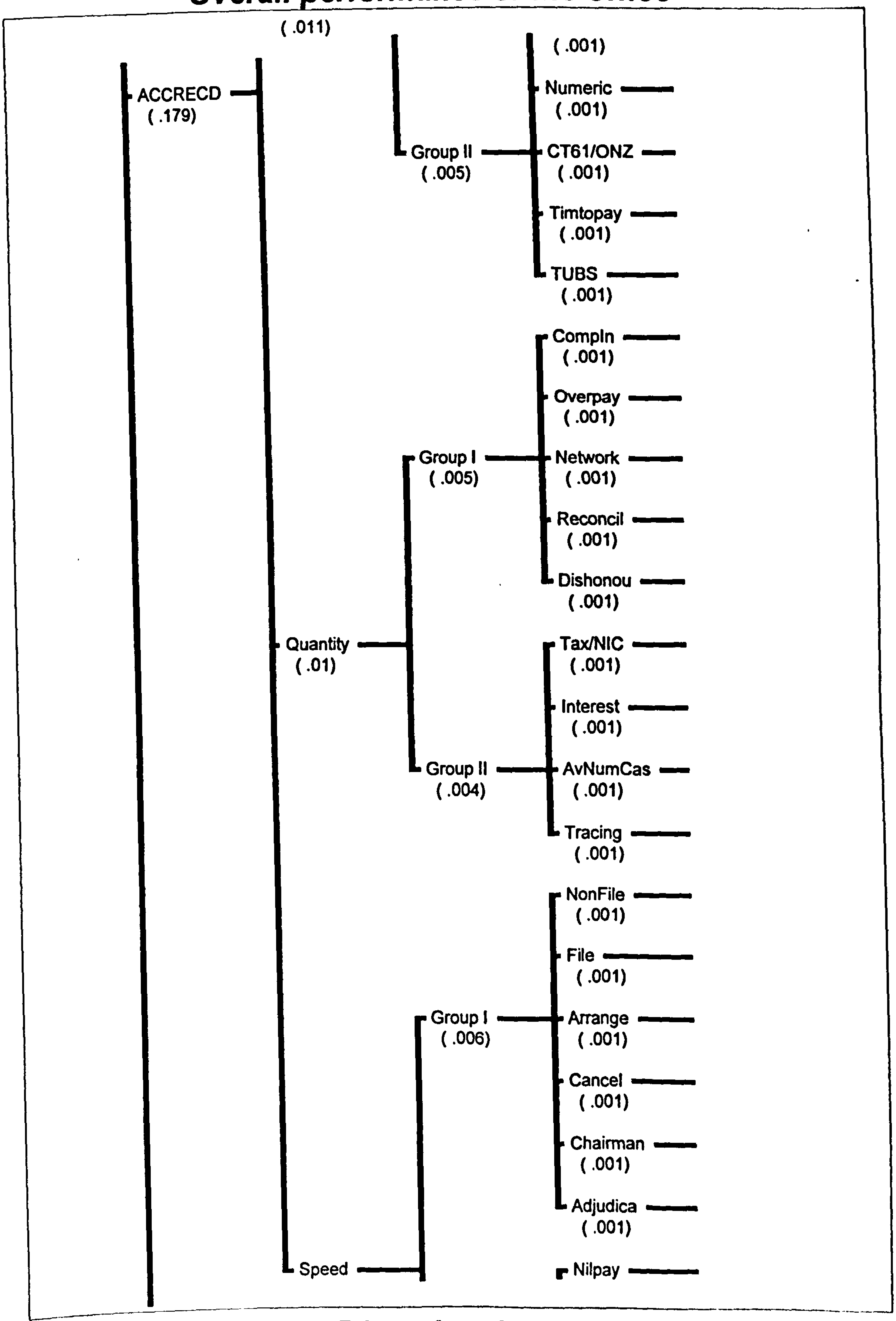


For Educational Use Only

Overall performance of the office



Overall performance of the office



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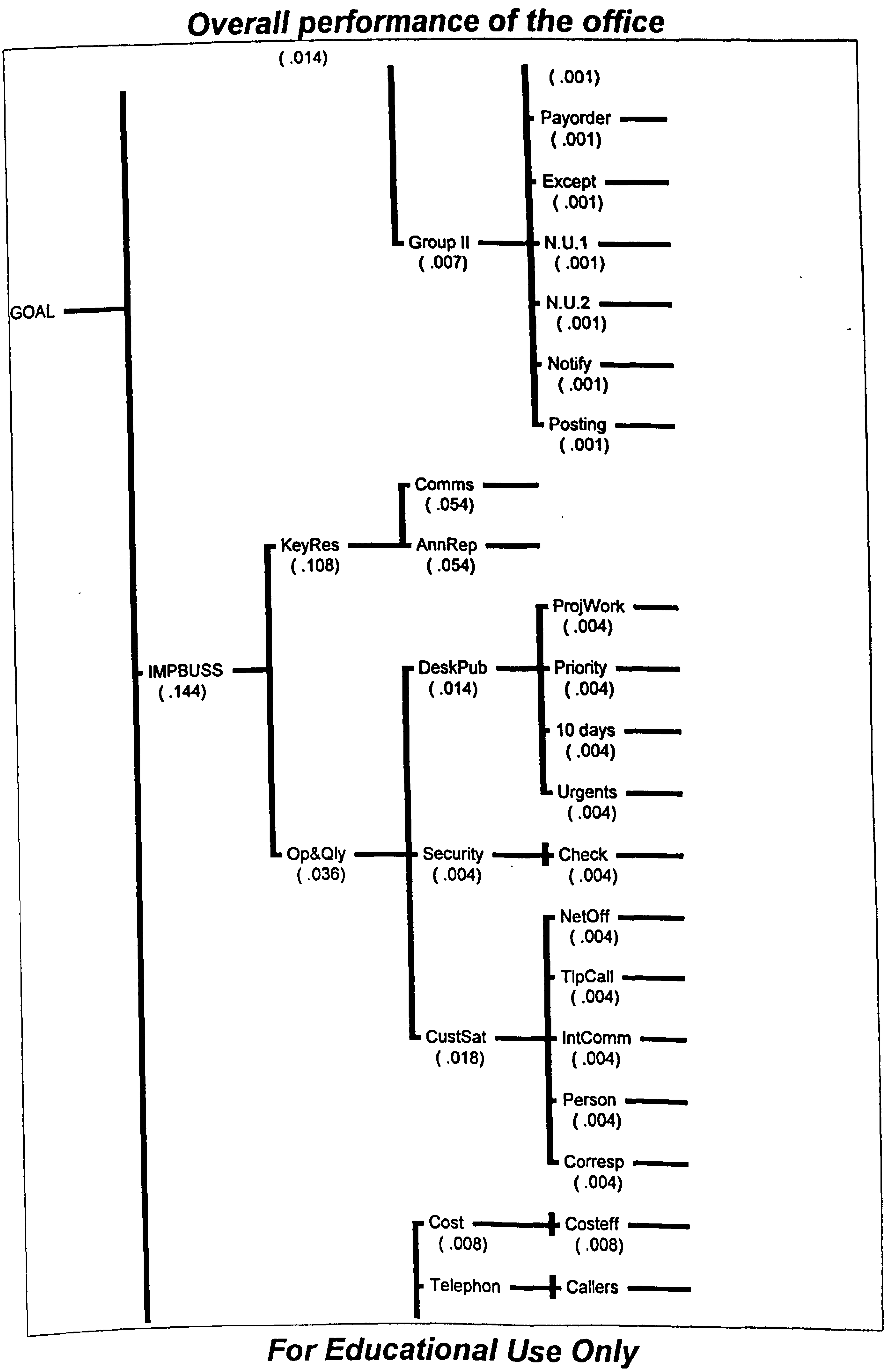
Overall performance of the office
(.014)
(.001)
Payorder
(.001)
Except
(.001)
Group II
(.007)
N.U.1
(.001)
GOAL
N.U.2
(.001)
Notify
(.001)
Posting
(.001)
Comms
(.054)
KeyRes
(.108)
AnnRep
(.054)
ProjWork
(.004)
IMPBUSS
(.144)
DeskPub
(.014)
Priority
(.004)
10 days
(.004)
Urgents
(.004)
Op&Qly
(.036)
Security
(.004)
Check
(.004)
NetOff
(.004)
TlpCall
(.004)
CustSat
(.018)
IntComm
(.004)
Person
(.004)
Corresp
(.004)
Cost
(.008)
Costeff
(.008)
Telephon
Callers
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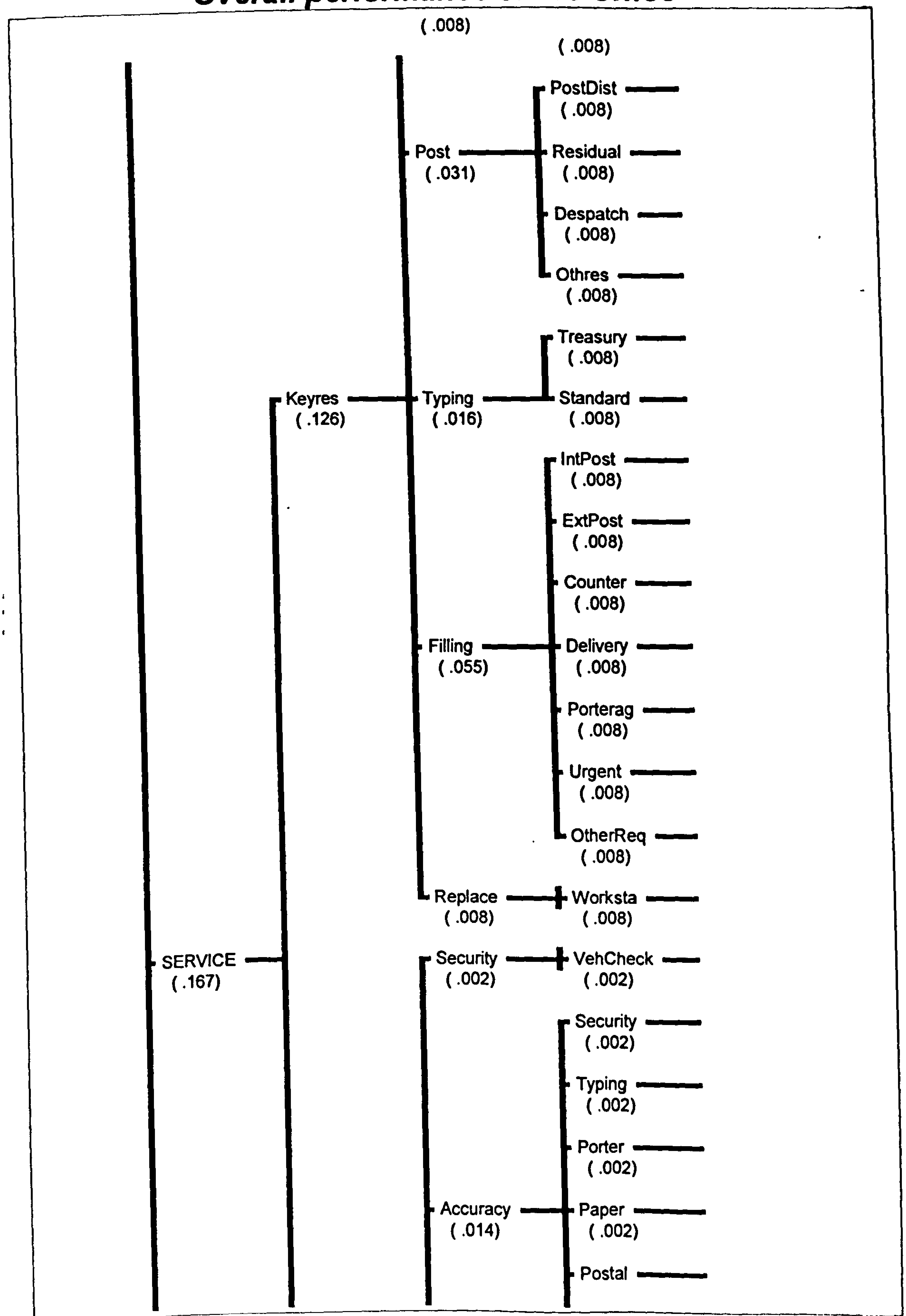
Overall performance of the office



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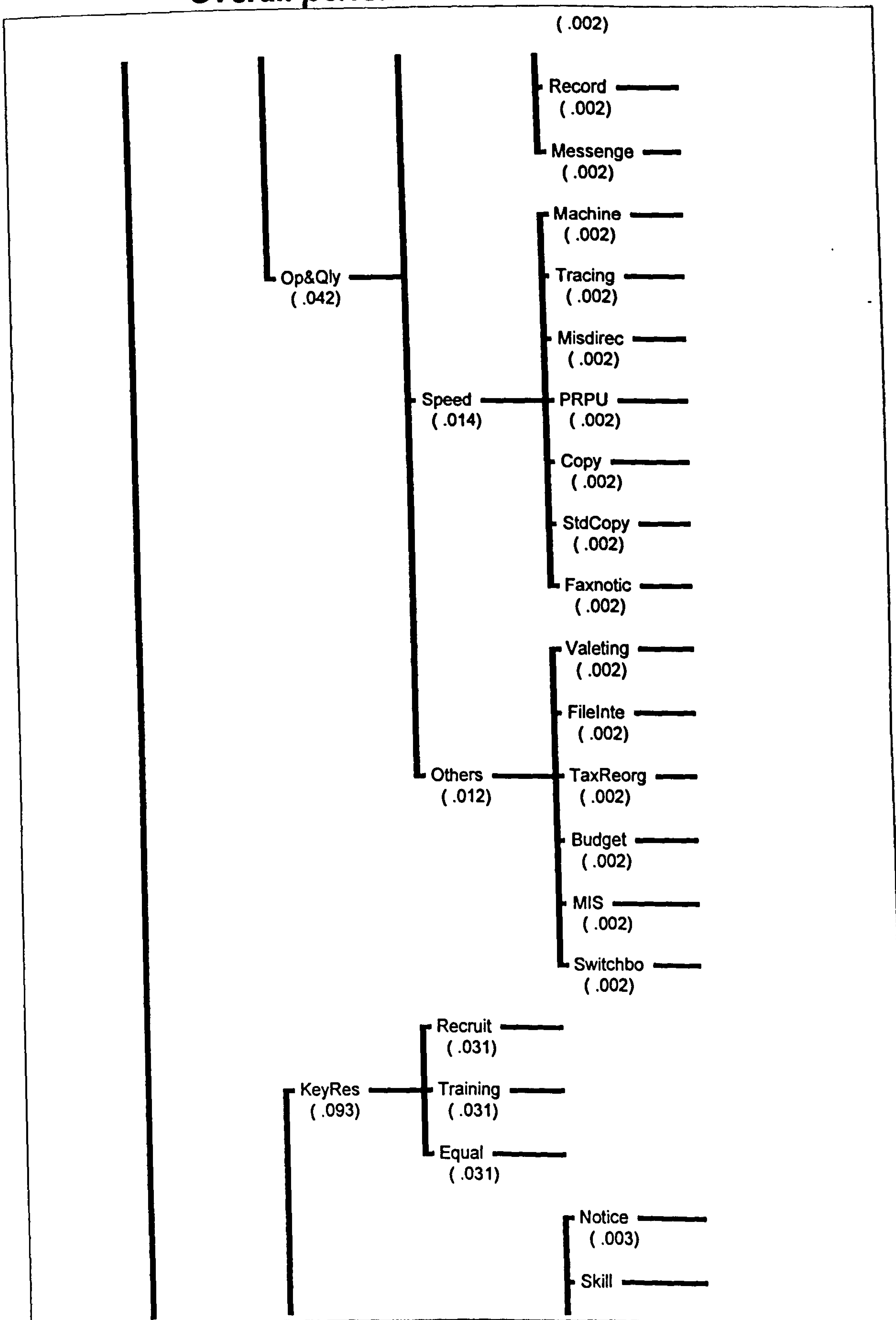
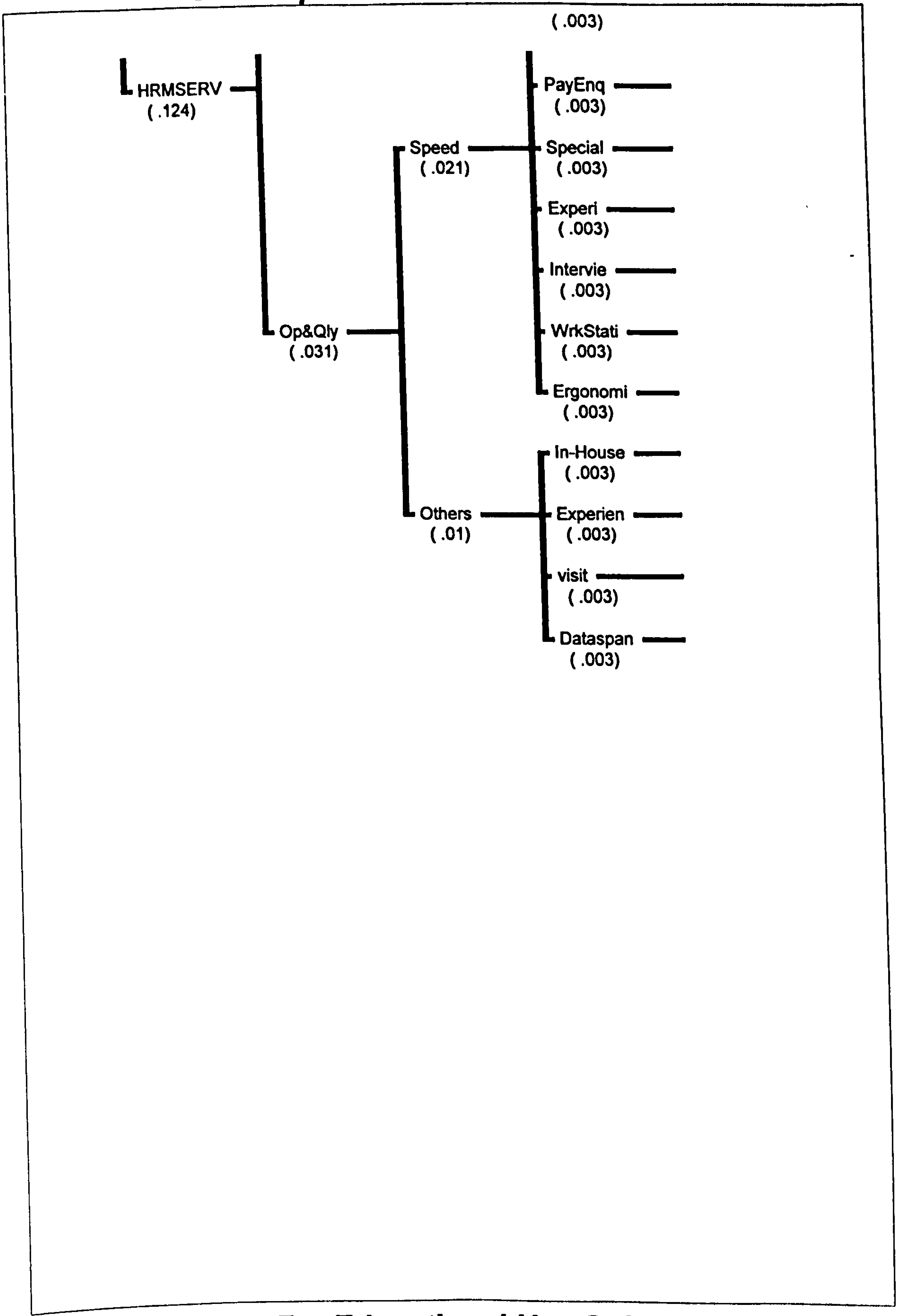
Overall performance of the office



Overall performance of the office



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Overall performance of the office

Synthesis of Leaf Nodes with respect to GOAL
Distributive Mode

Abbreviation	Definition
GOAL	
10 days	Introducing new/amended letters form-10 days
>£10.000	Cheque banking >£10,000 day 1 banking
ACCRECD	Maintain accounting records, issue invoices and collect tax&NII
Accur	Measures relate to accuracy
Accuracy	
Achieve	Achievement
Adjudica	Handling complaints-revenue adjudicator, dealt with within 10 day
AllCheq	99% of all cheques day 1 banking
AnRetrn	Annual return % received within 60 days of due date
An_Ret	
AnnRep	Publish 1995/1998 annual report by 30-09-96
AnnRet	Annual return examined with 28 days
Arrange	Arrangement within 10 working days
AvNumCas	Contain average number of cases on monthly list to no more than
BNK&ACC	Bank and Account for money received
Brocs	Brocs
Budget	Budget work
CT61/ONZ	CT61/ONZ
Callers	Callers (workload 15850) seen within 10 minutes of arrival
Cancel	Cancelled arrangement (21 days)
Chairman	Dealing with complaints-Chaiman&Ministerial dealt with within 10
Check	Carry out management security checks
Com-App	
Comms	Publish 1996/1997 comms plan by 30-05-96
Compln	Dealing with non-payment computer input
Compl.	
Copy	Dealing with urgent photocopy immediately
Corresp	Correspondence survey
Cost	
Costeff	Cost efficiency-achieve savings from all contracted services
Counter	Counter request
CustSat	Results of survey: customer satisfaction level
Dataspan	
Delivery	Delivery to 107 points
DeskPub	Desktop Publishing
Despatch	
Dishonou	Dealing with dishonoured cheques&BLAs (basis 55,700)

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Overall performance of the office

Equal	Publish equal opps plan by 01-04-96 and meet all targets
Ergonomi	Ensure reports of ergonomic visits are sent to personnel service
Except	Clearing exception & rejection within 5 days (Basis 250,000).
Experi	Offer at least 100 work experience placements
Experien	
ExtPost	External post request
Faxnotic	Dealing with fax notification timeously
File	File cases cleared within 12 weeks
FileInte	Masterfile interogations
Filling	
Gen-En	
GenEnq.	General enquiries
Group I	
Group II	
HRMSERV	Provide Human Resource Management Services
IMPBUSS	Develop and Improve The Business and Performance Levels
In-House	
Incorrec	Returning incorrectly completed cheques
IntComm	Internal communication survey
IntPost	Internal post request
Interest	Interest
Intervie	Conduct career interviews within 2 weeks of request
KeyRes	Key Business Results
Keyres	Key Business Results
Less5	Application processed before start date received<5days before
LivSchm	Live scheme-rules examined
MIS	Management information system
Machine	Machinery and equipment-action within 1 day of fault report
ManChg7	Manual charges (workload 118876) dealt with within 7 days
Messenge	Messengers: tasks dealt with accurately
Misdirec	Misdirected etc. dealt with day 1
More5	Application processed before their start date received>5days befo
N.U.1	N.U.1 (Basis 42,000) % processed within 2 days
N.U.2	N.U.2 (Basis 72,000) % processed within 2 days
NetOff	Network office survey
Network	Dealing with network unit book 19 cases
Nilpay	Processing nil payslips within 4 days
NonFile	Non-files cases cleared within 4 weeks
NonPslip	Processing cheques received without a payslip
Notice	Give trainees at least 21 days notice of a course
Notify	Notifying payments in advance of Inv.Stts to L.C within 5 days
Numeric	Numeric RFI
OAS	OAS
Op&Qly	Other related operational & quality objectives
OtherReq	Dealing with other requisition
Others	
Othres	
OvPay2	Over payment workload 289041 dealt with within 2 months
Overpay	Dealing with overpayment, unassessed taxes

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Overall performance of the office

P&L-Acc	Profit&lost account examined
PRP TAX	Administer PRP tax relief correctly and fairly
PRPU	PRPU oacks compiled within 24 hours
Paper	Paperkeepers: items handled correctly
PayEnq	Deal with pay enquiries within 1 day
Payorder	Issuing payable orders within 3 days (Basis 80,000)
Payslip	Processing cheques received with payslip
Person	Personal callers survey
Porter	Porters: tasks dealt with accurately
Porterag	Porterage service
Post	Post
Post&Com	Dealing with post&computer output-all areas-within 28 days
PostDist	Post distribution service: Distributed within time frames
Postal	Postal service: items dealt with accurately&Timeously
Postdate	Dealing with post-dated cheques and any accomp. time to pay req.
Posting	Posting payments on day of received
Priority	Priority targets agreed with customers
ProjWork	Project work turned round within 20 days
Quantity	Measures relate to quantity
Rec&krup	
Reconcil	Achieving reconciliation of bank statements
Record	Central records: requests dealt with accurately&timeously
Recruit	Recruit and staff the office to meet manpower requirements
Repay	Repayments
Replace	
Residual	Residual post next day delivery
RetAcc	Processing cheques to retaining account
SERVICE	Provide Business and Financial Support Services
Sch_Rul	
Security	Carryout management security checkd
Skill	Confirm skills centre booking within 5 days
Special	Deal with special leave applications within 5 days
Speed	Measures relate to speed
Standard	Standard typing work (workload included in 305384)
StdCopy	Dealing with standard photocopy within 4 houus
Suspens	Suspensions
Switchbo	Maintaining switchboard services
TUBS	TUBS:NOV 96
Target	Target
Tax/NIC	Tax/NIC
TaxReorg	Tax district reorganisation
Telephon	
Time	Measures relate to time
Timtopay	Time to pay: June 96
Tlp.Call	Dealing with telephone calls within 15 seconds-all areas
TlpCall	Telephone caller survey
Tracing	Tracing unemployement benefit details for tax district (Basis 1.3
Training	Publish strategic training and development plan by 01-04-96
Treasury	Treasury typing units (workload 305384)

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Overall performance of the office

Typing	Handling typing works
Urgent	Dealing with urgent requisition
Urgents	Introducing new/amended letters forms: urgents
Valeting	Valeting etc-official cars
VehCheck	Security checks-contractors' vehicles
Visits	Cases passed to employer compliance unit for visit
Worksta	Complete 90% of workstation replacement programmes 31-03-97
WrkStati	Arrange workstation visits within 2 days of request
visit	

APPENDIX C.3

Performance of Business Processes and Overall Office of Inland Revenue – Cumbernauld

(Absolute Performance)

Overall performance of the office

Synthesis of Leaf Nodes with respect to PRP TAX
Distributive Mode

Abbreviation	Definition
Target	Target
Achieve	Achievement

Overall performance of the office

Synthesis of Leaf Nodes with respect to BNK&ACC

Distributive Mode

Abbreviation	Definition
Target	Target
Achieve	Achievement

Overall performance of the office

Synthesis of Leaf Nodes with respect to ACCRECD
Distributive Mode

Abbreviation	Definition
Target	Target
Achieve	Achievement

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Overall performance of the office

Synthesis of Leaf Nodes with respect to IMPBUSS
Distributive Mode

Abbreviation	Definition
Target	Target
Achieve	Achievement

Overall performance of the office

Synthesis of Leaf Nodes with respect to SERVICE
Distributive Mode

Abbreviation	Definition
Target	Target
Achieve	Achievement

Overall performance of the office

Synthesis of Leaf Nodes with respect to HRMSERV
Distributive Mode

Abbreviation	Definition
Target	Target
Achieve	Achievement

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Overall performance of the office

Synthesis of Leaf Nodes with respect to GOAL
Distributive Mode
OVERALL INCONSISTENCY INDEX = 0.0

Abbreviation	Definition
Target	Target
Achieve	Achievement

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APPENDIX C.4

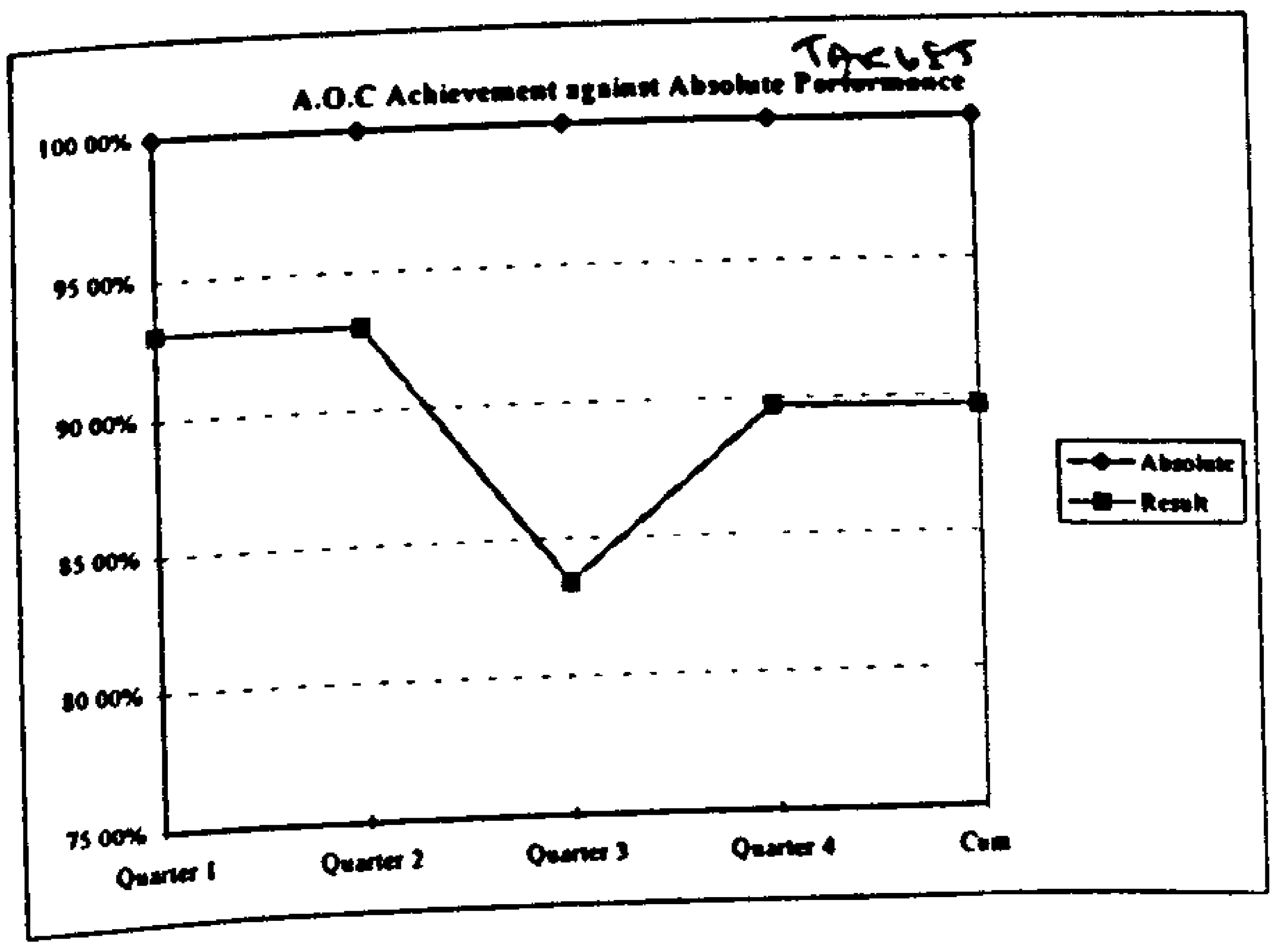
The Annual Performance Reports for Financial Year 1998/1999

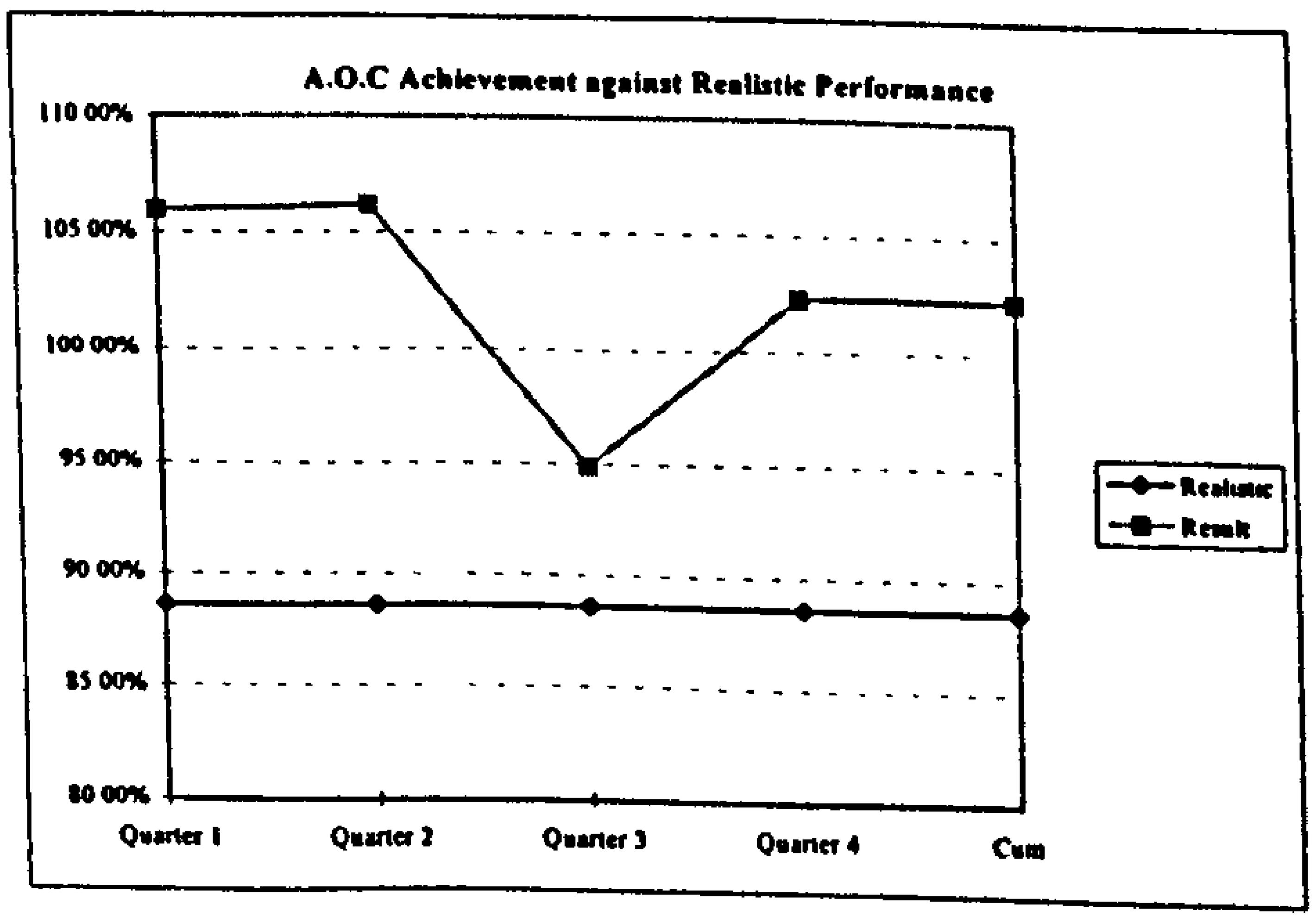
A.O CUMBERNAULD PERFORMANCE MEASUREMENT SYSTEM 1998/99
OFFICE SUMMARY

Office Summary - Overall Performance

		Achievement -				
		Quarter 1 Result	Quarter 2 Result	Quarter 3 Result	Quarter 4 Result	Cumulative Result
Banking Process -						
Achievement against Absolute Performance TARGET	Target	100.0%	94.2%	93.7%	83.9%	91.4%	90.7%
Achievement against Realistic Performance	Target	88.9%	107.0%	106.7%	95.3%	104.1%	103.3%
Records Process -						
Achievement against Absolute Performance	Target	100.0%	91.2%	87.5%	80.5%	77.4%	84.3%
Achievement against Realistic Performance	Target	88.6%	103.6%	99.5%	91.2%	87.8%	95.7%
Support Process -						
Achievement against Absolute Performance	Target	100.0%	87.1%	94.2%	82.8%	91.0%	87.5%
Achievement against Realistic Performance	Target	86.8%	100.9%	109.6%	95.9%	105.5%	101.7%
A.O.Cumbernauld Combined -						
Achievement against Absolute Performance	Target	100.0%	93.1%	93.0%	83.4%	89.7%	89.6%
Achievement against Realistic Performance	Target	88.6%	105.9%	106.2%	94.9%	102.3%	102.3%

Office Summary - Graphs





Office Summary - Notes

1. The A.O.Cumbernauld Performance Measurement System is based on the principle that it has three critical processes.
2. These "processes" are Banking, Records & Support Services.
3. The Board has decided for the purpose of this model that Banking is seven times more important than Records & Support, which are considered of equal importance.
4. Each Process has various sub processes which are explained more fully on their respective reports.

A.O CUMBERNAULD PERFORMANCE MEASUREMENT SYSTEM 1998/99

PROCESS - BANKING

Banking Process - Key Results

	Absolute Target	Realistic Target	Quarter 1 Result	Quarter 2 Result	Quarter 3 Result	Quarter 4 Result	Cumulative Result
Customer Service -							
1. Cheques > £10,000 banked Day 1.	100.0%	100.0%	98.4%	100.0%	100.0%	93.5%	98.0%
2. 99% of all cheques banked Day 1.	100.0%	99.2%	100.0%	100.0%	100.0%	93.5%	98.4%
Quality Improvement -							
1. % of all Q.I.M questions answered positively.	100.0%	97.0%	99.8%	99.7%	98.2%	98.5%	99.5%
Cost Efficiency -							
1. Fixed Unit Costs.	100.0%	70.0%	75.0%	81.3%	58.1%	87.9%	75.7%
2. Variable Unit Costs	100.0%	70.0%	196.6%	89.8%	70.6%	54.3%	80.5%

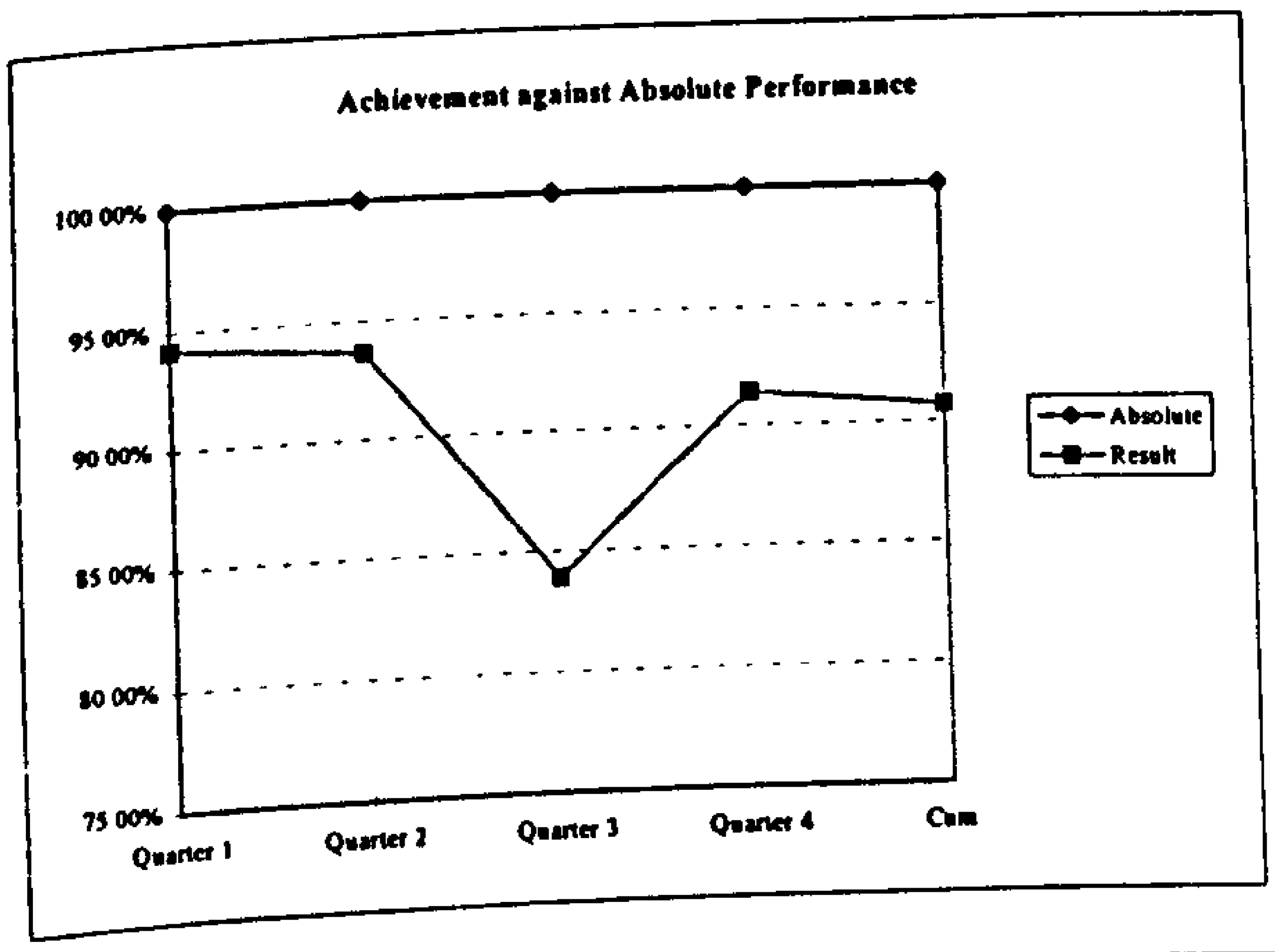
Banking Process - Overall Performance

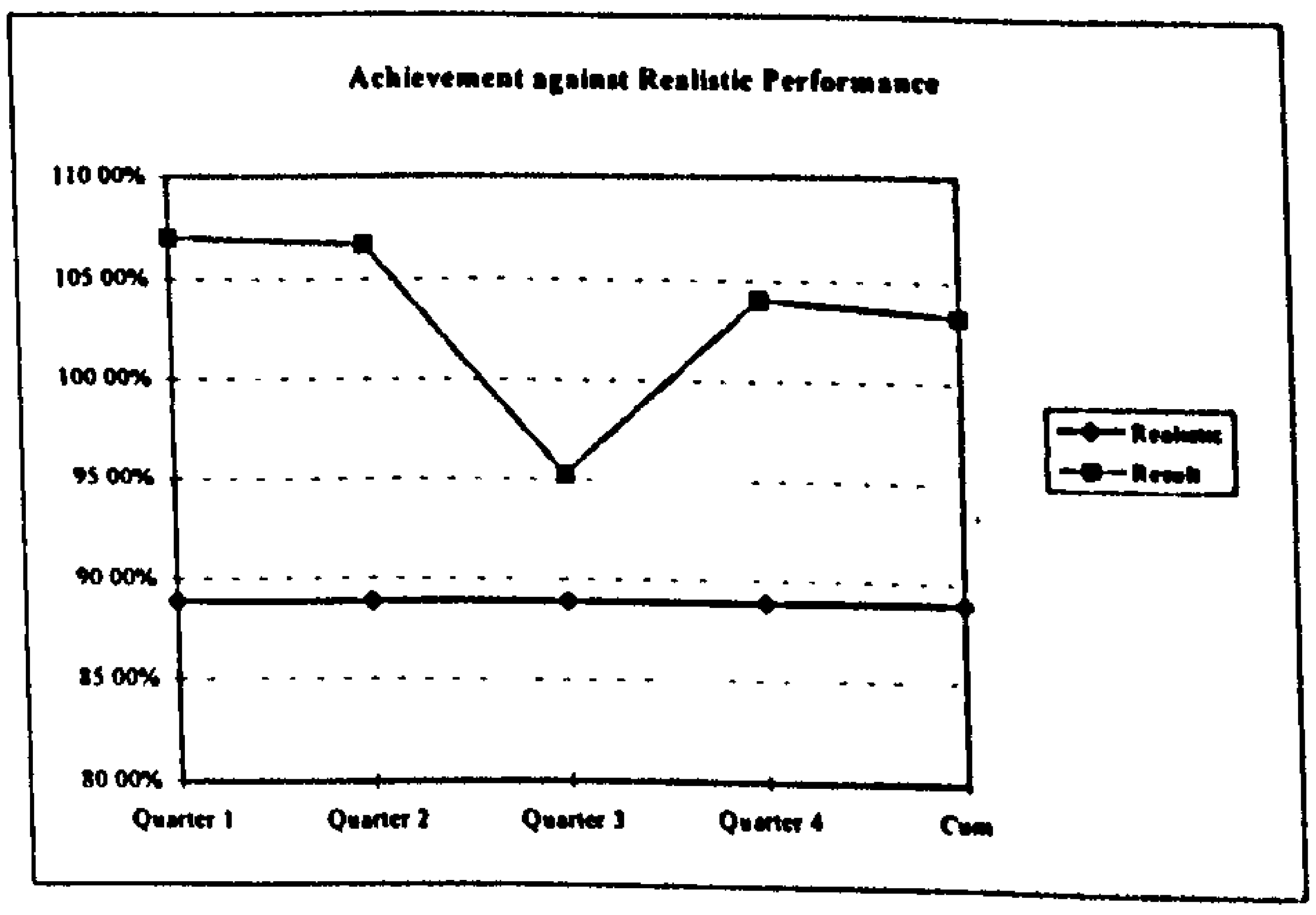
Achievement against Absolute Target -

Achievement against Realistic Target -

		Achievement				
	Target	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Cumulative
Absolute	100.0%	94.2%	93.7%	83.9%	91.4%	90.7%
Realistic	88.9%	107.0%	106.7%	95.3%	104.1%	103.3%

Banking Process - Graphs





Banking Process - Notes

1. The Banking Process is considered to be seven times more important than than the other two Critical Processes.
2. It has three sub-processes which for the purpose of this model are considered to be of equal importance.
3. Both the Customer Service & Cost Efficency elements have two sub-processes which have been 'weighted' as follows, Customer Service - equal importance, Cost Efficency - Fixed Costs are considered to be seven times more important than Variable Costs.

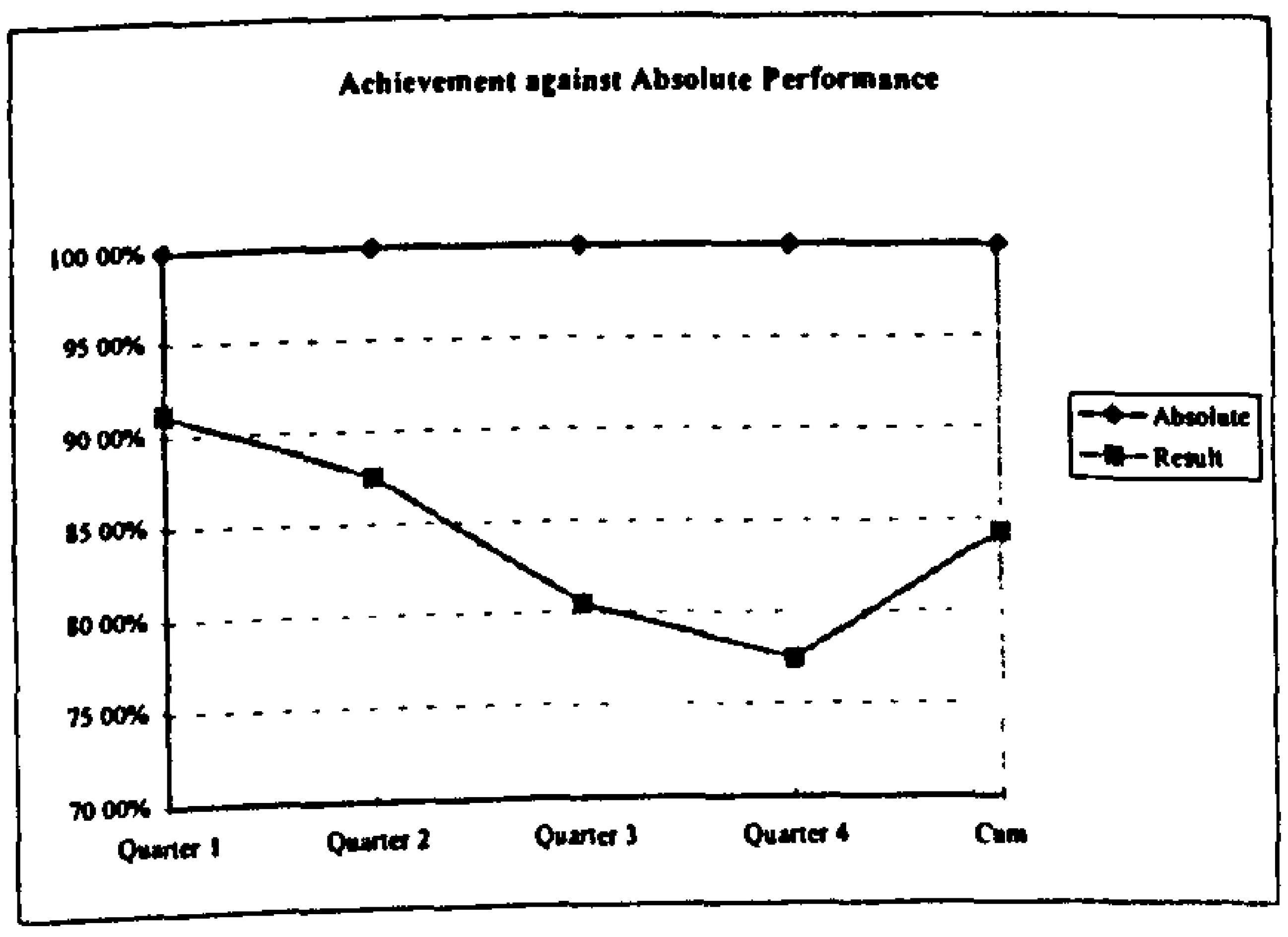
A.O CUMBERNAULD PERFORMANCE MEASUREMENT SYSTEM 1998/99
PROCESS - RECORDS

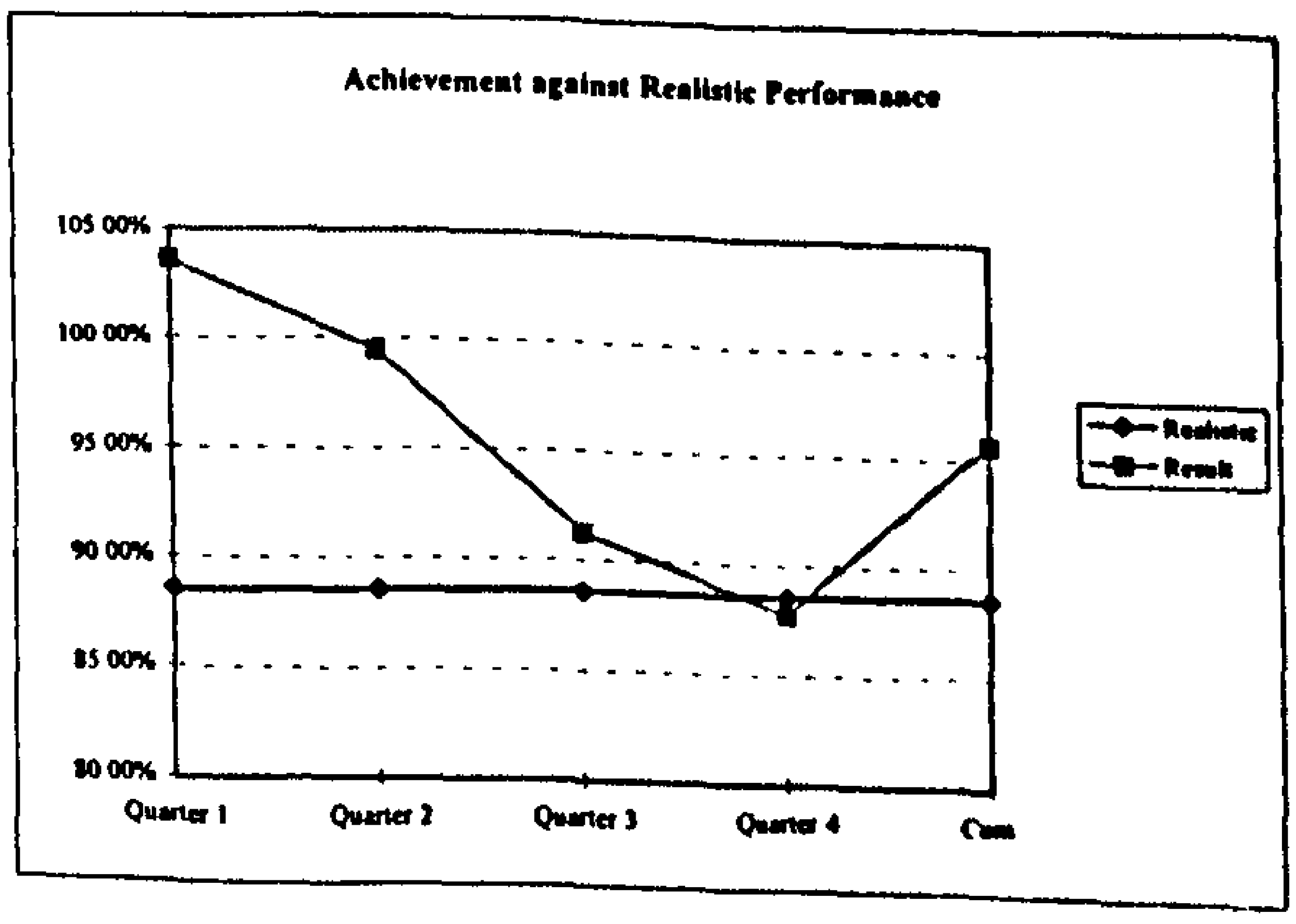
Records Process - Key Results	Absolute Target	Realistic Target	Quarter 1 Result	Quarter 2 Result	Quarter 3 Result	Quarter 4 Result	Cumulative Result
Customer Service -							
1. % of Correspondence dealt with within 28 Days.	100.0%	94.0%	94.5%	95.0%	96.7%	97.4%	96.0%
2. % of PRP Applications processed within 5 Days.	100.0%	97.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3. % of PRP Applications processed over 5 Days.	100.0%	99.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Quality Improvement -							
1. % of all Q.I.M questions answered positively.	100.0%	97.0%	97.3%	96.1%	96.6%	96.7%	96.6%
Compliance -							
1. % of Annual Returns received within 60 Days.	100.0%	80.0%	81.4%	80.6%	81.1%	77.7%	80.3%
2. % of Annual Returns examined within 28 Days.	100.0%	90.0%	97.5%	96.6%	91.6%	94.2%	94.8%
3. Profit & Loss Accounts examined.	100.0%	92.6%	118.5%	125.9%	74.1%	81.5%	100.0%
4. Cases selected for Employer Compliance Unit.	100.0%	100.0%	158.4%	102.4%	91.2%	48.0%	100.0%
Cost Efficiency -							
1. Fixed Unit Costs.	100.0%	70.0%	59.1%	58.3%	51.3%	51.2%	54.9%
2. Variable Unit Costs	100.0%	70.0%	125.8%	87.4%	49.2%	39.8%	62.9%

Records Process - Overall Performance

			Achievement				
		Target	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Cumulative
Achievement against Absolute Target -	Absolute	100.0%	91.2%	87.5%	80.5%	77.4%	84.3%
Achievement against Realistic Target -	Realistic	88.6%	103.6%	99.5%	91.2%	87.8%	95.7%

Records Process - Graphs





Records Process - Notes

1. The Records Process is considered to be seven times less important than the Banking Processes but equally as important as the Support Process.
2. It has four sub-processes which for the purpose of this model are considered to be of equal importance.
3. All the elements have sub-processes with the exception of Quality. These sub-process are considered to be of equal importance within their area except for Cost Efficency where Fixed Costs are considered to be seven times more important than Variable Costs.

A.O CUMBERNAULD PERFORMANCE MEASUREMENT SYSTEM 1998/99
PROCESS - SUPPORT

Support Process - Key Results	Absolute Target	Realistic Target	Quarter 1 Result	Quarter 2 Result	Quarter 3 Result	Quarter 4 Result	Cumulative Result
Customer Service -							
1. % of Personal Callers attended to within 10 minutes.	100.0%	97.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2. % of all Telephone Calls answered within 15 seconds.	100.0%	90.0%	90.7%	92.2%	94.0%	93.0%	92.3%
Quality Improvement -							
1. % of all Q.I.M questions answered positively.	100.0%	97.0%	99.1%	94.7%	98.4%	99.5%	97.5%
Cost Efficiency -							
1. Fixed Unit Costs.	100.0%	70.0%	61.4%	91.2%	62.0%	88.4%	74.2%
2. Variable Unit Costs	100.0%	70.0%	167.2%	96.8%	39.3%	30.6%	63.5%

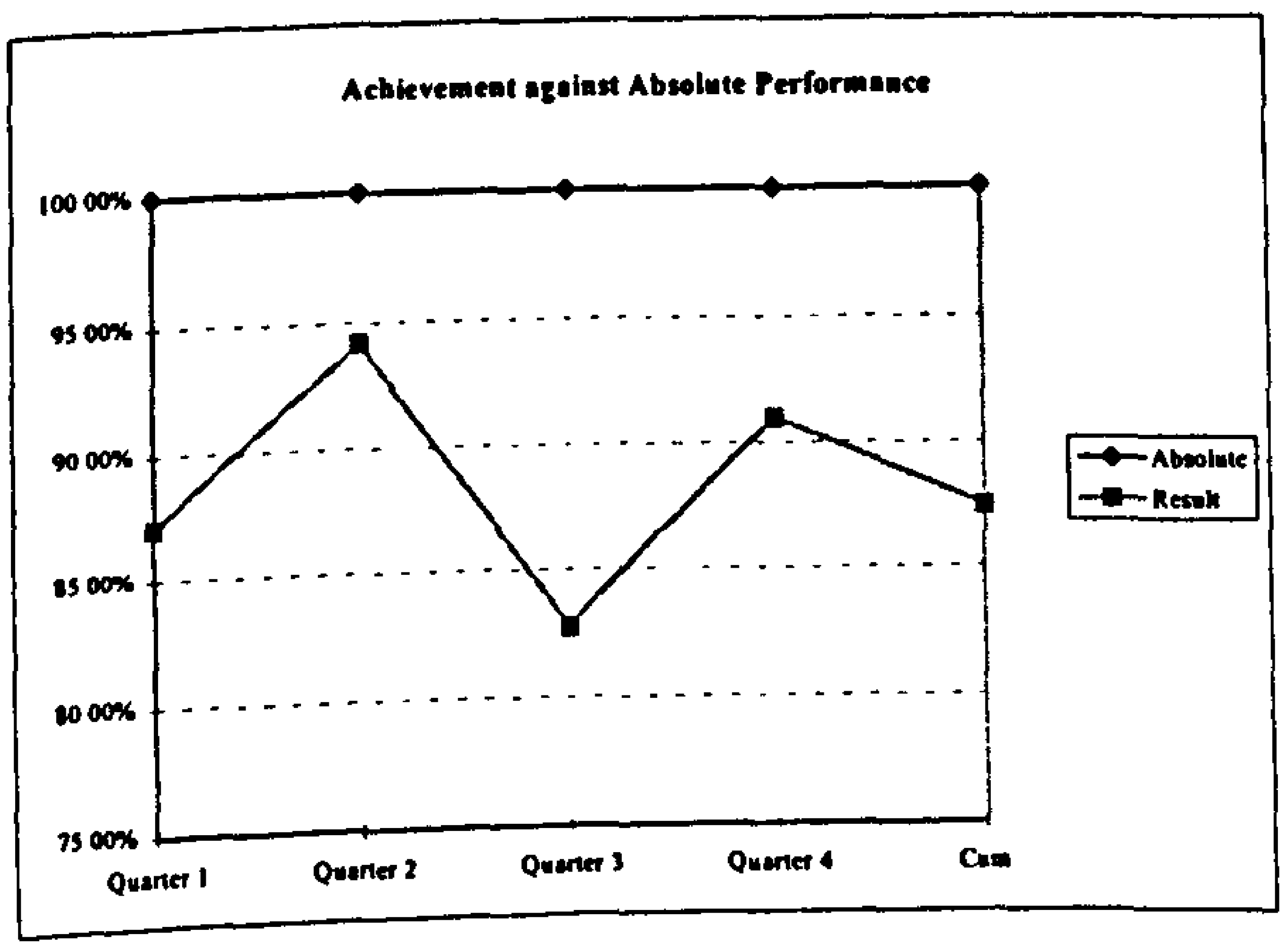
Support Process - Overall Performance

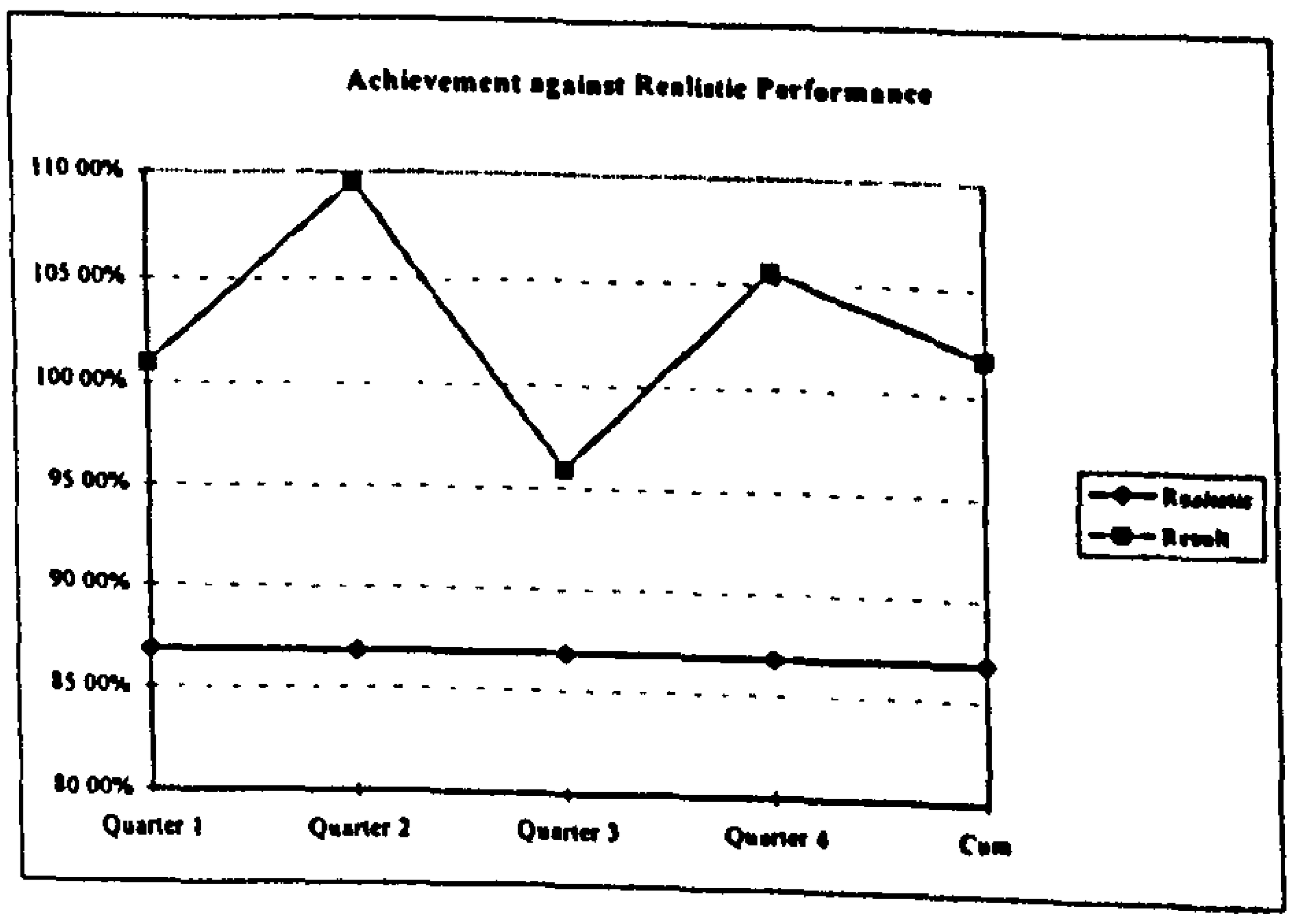
Achievement against Absolute Target -

Achievement against Realistic Target -

	Target	Achievement Quarter 1	Quarter 2	Quarter 3	Quarter 4	Cumulative
Absolute	100.0%	87.1%	94.2%	82.8%	91.0%	87.5%
Realistic	86.8%	100.9%	109.6%	95.9%	105.5%	101.7%

Support Process - Graphs





Support Process - Notes

1. The Support Process is considered to be seven times less important than the Banking Processes but equally as important as the Record Process.
2. It has three sub processes which for the purpose of this model are considered to be of equal importance.
3. Both the Customer Service & Cost Efficency elements have two sub processes which have been 'weighted' as follows, Customer Service - equal importance, Cost Efficency - Fixed Costs are considered to be seven times more important than Variable Costs.

APPENDIX D

Publication of Research to Date

Suwignjo, P., Bititci, U.S. and Carrie, A.S., "Quantitative Model for Performance Measurement System: An Analytic Hierarchy Process Approach", *Proceeding of the Managing Enterprises – Stakeholders, Engineering, Logistics and Achievement Conference*, Loughborough, 1997, pp.237-243.

Suwignjo, P., Bititci, U.S. and Carrie, A.S., "Time-based prioritisation of performance measurement", *Proceeding of the Advances in Manufacturing Technology XI Conference*, Glasgow, 1997, pp.559-564.

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Bititci, U.S., Carrie, A.S. and Suwignjo, P., "Quantitative models for aggregating and prioritising of performance measures", *Proceeding of the Tenth International Working Seminar on Production Economics*, Innsbruck, 1998, pp.55-72.

Suwignjo, P., Bititci, U.S. Carrie, A.S. and Turner, T.J. "Auditing and Prioritisation of Performance Measurement System", *Proceeding of the Performance Measurement – Theory and Practise Conference*, Cambridge, 1998, pp.109-116.

Bititci, U.S., Carrie, A.S., Turner, T.J. and Suwignjo. P., "Dynamic Performance Measurement Systems", *Proceeding of Managing Operations Networks Conference*, Venice, 1999, pp.712-718.

Suwignjo, P., Bititci, U.S. and Carrie, A.S., "Quantitative Models for Performance Measurement Systems", International Journal of Production Economics, Vol. 64, Issue 1-3 (accepted).