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Performance Trade-Offs in Manufacturing Plants

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Performance Trade-Offs in Manufacturing Plants

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ABSTRACT

Performance Trade-offs in Manufacturing Plants

If manufacturing organisations are to remain competitive they must continuously improve their levels of operating performance. In order to do this, operations managers must understand which are the key drivers that are most effective at creating performance improvements and how the various measures of operating performance interact. The research addresses both of these issues. First it attempts to identify the key drivers that seem most effective in achieving increases in overall operating performance. Then it explores the relationship between the levels of performance for different operating measures in the same manufacturing plant.

The basis of the research was a database of 953 UK manufacturing plants. These plants had all participated in the UK Best Factory Awards database during the years 1993–1996. The plants were grouped into 6 industrial categories. The plants in each industrial category were then ranked for each performance measure and divided into three equal-sized groups of high, medium and low performers. The groups of high and low performers were then compared in order to identify characteristics that were statistically different for the two groups. The high performers were found to put a greater emphasis on continuous improvement, involving a higher proportion of the workforce in this activity. The workforce was also more flexible in terms of the range of tasks that they were competent to carry out. The high performers exhibited much less variability in their processes with greater adherence to schedule, more consistent processing times, lower scrap rates and more reliable supplier deliveries.

Using the results of this analysis in combination with an analysis of the literature on the characteristics of high performing plants a tentative model was constructed attempting to show how these characteristics would impact on operating performance. The model suggested that improvements in unit manufacturing cost, quality consistency, speed of delivery and delivery reliability would be positively correlated. The model also suggested that the size of the product range would be negatively correlated with unit manufacturing cost, quality consistency, speed of delivery and delivery reliability. The database was used to test for statistical correlations between measures of these aspects of performance and the results provided general support for both of these propositions.

Six of the plants in the database were visited and staff responsible for planning, purchasing and production were interviewed. The objective was to test whether the conclusions reached on the basis of statistical analysis could also be validated at individual plants. There was general support for the differences in the characteristics of high and low performing plants. There was also general support for the propositions that plants achieve similar performance on unit manufacturing cost, quality consistency, speed of delivery and delivery reliability relative to plants in the same industrial sector and that increasing the size of the product range adversely affects unit manufacturing cost, quality consistency, speed of delivery and delivery reliability.

Acknowledgements

To attempt to successfully complete a PhD research project is a major challenge at any age. To attempt to do so in one's Fifties, many would say is foolhardy. For me it has been an extremely satisfying and stimulating exercise. It has combined the intellectual challenge of solving difficult and complex problems with the excitement of discovering new insights into the subject of operations management and, perhaps, making a small contribution to the sum total of our knowledge of this subject. It has also involved the difficult task of balancing my work on the PhD with the conflicting demands of work and family.

The fact that this thesis is now complete is due in no small part to the support that I have received from my colleagues and my family. In particular, I would like to thank my supervisor and good friend, Colin New. It was he who first encouraged me to embark on this project. Throughout he has been totally supportive, helping me to reorganise my work responsibilities in order to free up time for the PhD.

As a supervisor, his academic rigour and ability to spot the logical weaknesses in any argument have improved this thesis immeasurably.

In addition, I would like to thank my academic review panel, John Towriss, Keith Goffin and Mike Sweeney for the sound guidance and constructive criticism that they have provided. Also, my colleagues, Marek Szwejczewski and John Baker have always been willing to provide comments and advice when I have encountered problems with my research.

A large part of the analysis in this thesis makes use of the database derived from the annual UK Best Factory Awards competition. I am very grateful to Management Today who sponsor the event and Colin New and Marek Szwejczewski who collected the raw data for permission to make use of the database.

The thesis also involved visits to a number of manufacturing plants. I am grateful to all of the staff at these plants for giving up their time and providing so much of the information that is incorporated into this thesis.

Finally, I would like to give a special thanks to my wife, Eleanor and my children, Emma, Richard and Sara for their encouragement and understanding during the several years that it has taken for this thesis to reach completion.

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Chapter 1 : Introduction

1.1 Introduction

Manufacturers now operate in a truly global marketplace in which suppliers, competitors and customers can be located anywhere in the world. As a consequence, competition has become more and more intense. As the range of manufacturers from which customers can purchase has increased, customers have become more and more demanding in their requirements. Pine (1993) has described how customers' requirements have changed from low cost to low cost and reliability and then to low cost, reliability and product variety.

Operations managers have primary responsibility for the manufacture and delivery of the product and so have a major role to play in meeting these customer requirements. If operations managers are to equal or exceed the performance of their competitors then it is crucial that they understand which drivers are the most effective in improving operating performance. It is also extremely important that they understand the way in which the various elements of operating performance interact.

In this chapter the nature of the operations management task is explored further. The programme of research being proposed is introduced and its potential value to operations managers is discussed. Later in the chapter the research to be carried out is described and the structure of the thesis is presented.

1.2 Research Rationale

The research described in this thesis examines the key factors that lead to excellent performance in the management of operations in manufacturing plants. The research goes on to consider how these factors are likely to impact on the inter-relationships and trade-offs between different measures of operating performance.

Heizer and Render (2001) define operations management as follows,

Operations management is the set of activities that creates goods and services by transforming inputs into outputs.

Chase, Aquilano and Jacobs (2001) use a similar definition.

Operations Management is the design, operation, and improvement of the systems that create and deliver the firm's primary products and services.

Finch and Luebbe (1995) provide a definition that more explicitly defines the objectives of operations management.

Operations management organises, plans, controls and improves the use of process, inventory, work force, and facilities and equipment in order to appropriately determine the ranking of the competitive priorities - price, quality, dependability, flexibility, and time - thereby providing short-term profit, long-term profit, and improved market share.

Effective operations management is an essential element of the success of any business enterprise. Hall (1992) gives the results of a survey of Chief Executive Officers in which the most important area of employee know-how for business success was considered to be Operations. Constable and New (1976) have stated that, in a typical company, operations management is responsible for approximately 80 per cent of total costs and a similar percentage of capital resources. Consequently, even small variations in the efficiency with which these resources are managed can produce dramatic changes in the financial performance of the company as a whole.

Operations management decisions affect product costs, product quality, speed of delivery and delivery reliability. These, in their turn, affect sales and hence profitability. If managers of manufacturing organisations are to take effective operational decisions in order to ensure that corporate business objectives are met then it is important that they understand which factors are the key drivers of operational success and the nature of the inter-actions between different measures of operating performance. However, we still have only a limited understanding of what are the key drivers of operational excellence and of the precise mechanisms whereby these impact on the various elements of operating performance. Therefore, this is an area where more research is needed. A better understanding of these key drivers and the nature of manufacturing trade-offs should have important implications for practitioners and other management researchers.

In an attempt to provide a better understanding of how the manufacturing function can be used to support corporate objectives Wickham Skinner (1969) developed the framework that is the foundation of modern operating strategy. This was based on the premise that there are many ways to compete apart from cost and that each manufacturing unit should focus on doing those few things well that are critical to the achievement of the corporate mission. Underlying his ideas is the concept of strategic trade-offs: achievement of high levels of performance on one factor can only be achieved at the expense of performance on one or more other factors. An implication of the trade-off concept is that a number of companies can compete in the same market, each meeting the specific needs of a segment of that market.

In recent years the existence of trade-offs has been questioned and is now the subject of some controversy. Schonberger (1986) has been the most notable of these critics, stating that, for the modern manufacturing company, trade-offs no longer exist. He argues that the factors leading to excellent performance on one factor also lead to excellent performance on the other factors. Therefore, world class companies will be able to out-perform their competitors on every aspect of performance. Schonberger concludes that there is a single generic manufacturing strategy, to become world class, which all manufacturers should be pursuing.

The determination of which of these two schools of thought is correct carries considerable implications for operating strategy. Surprisingly, little rigorous empirical research has been carried out to determine which of the two viewpoints is the more valid.

1.3 Research Agenda

If manufacturing performance trade-offs do exist then, in order for a plant to achieve an increase in performance on one operational measure at a given point in time, it would have to accept a reduction in performance on one or more other operational measures. Conversely, if manufacturing performance trade-offs do not exist then any action taken to increase performance on one operational measure should either have no effect on the performance of other operational measures or lead to an associated increase in the performance of one or more operational measures.

For an individual plant, identification of the consequential effects of a single change will be quite difficult. Manufacturing plants are very complex and dynamic organisations. At any given time, large numbers of decisions are being taken and changes made, which all interact with each other. Separating out the effects resulting from any single decision will be extremely difficult.

However, if the performances of a large number of different plants are compared then some general patterns should be identifiable. Three alternative scenarios with regard to the interactions between two performance measures can be identified.

1.3.1 Scenario 1

At a given point in time a plant can only achieve an improvement in performance measure A at the expense of a reduction in performance measure B. If scenario 1 applies then, for any set of similar plants, a negative statistical correlation between performance measures A and B can be expected.

1.3.2 Scenario 2

For a given plant at a given point in time any change in performance for operating factor A can be achieved without any effect on the performance for operating factor B and vice-versa. If scenario 2 applies then, for any set of similar plants, there will be no significant statistical correlation between performance measures A and B.

1.3.3 Scenario 3

For a given plant, any changes that lead to an improvement in the performance of operating factor A will also lead to an improvement in the performance of operating factor B. If scenario 3 applies then, for any set of similar plants, a positive statistical correlation between performance measures A and B can be expected.

An important step, therefore, in understanding the nature of the relationship between different operating performance measures will be to establish the nature of the statistical correlations between these measures.

1.4 Research Strategy

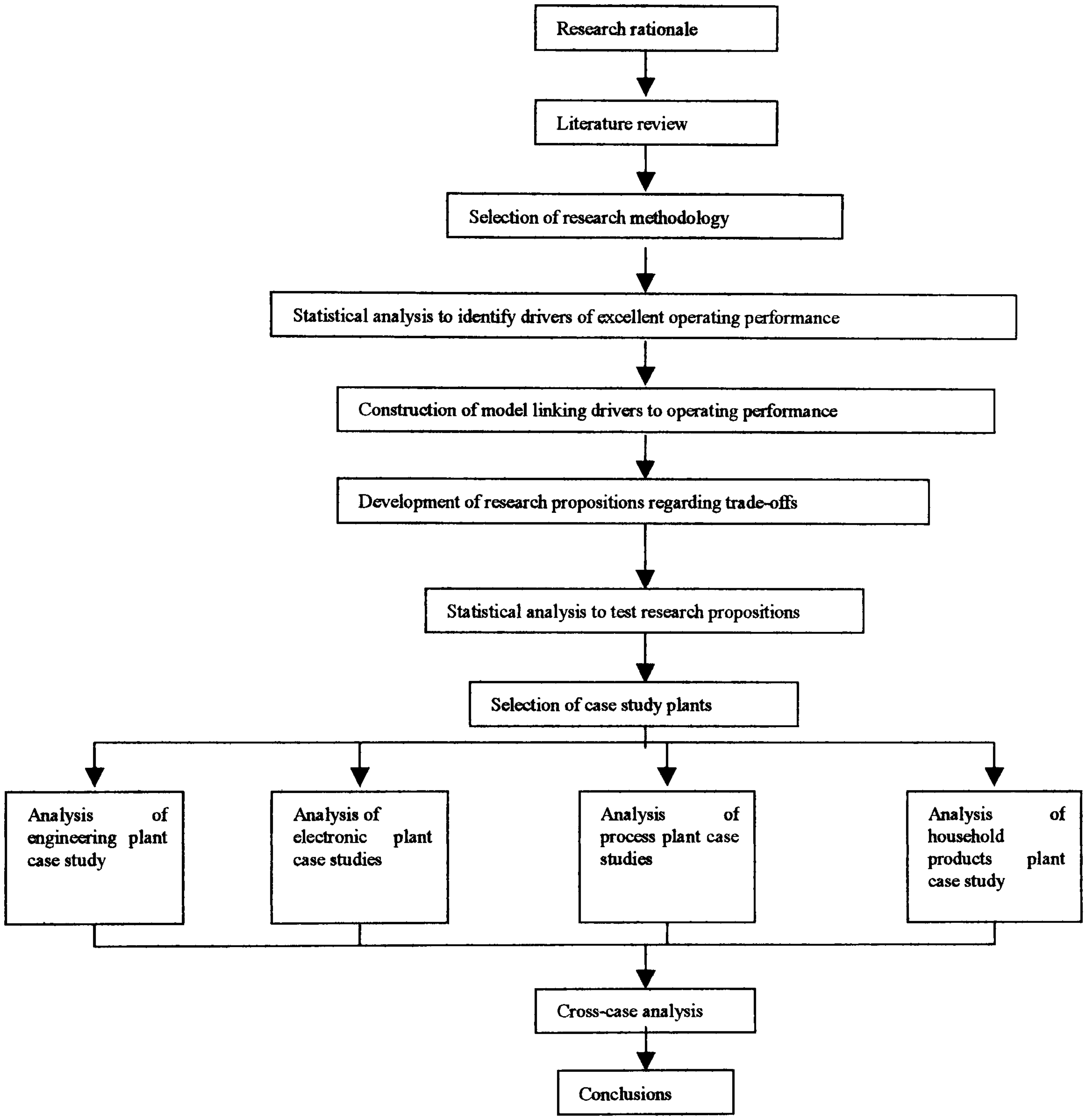
The research questions developed in this thesis will be addressed by a combination of statistical analysis and plant visits. A literature survey will be used to identify a set of key measures of operating performance. Then, using a database of 953 UK manufacturing plants, statistical analysis will be used to identify the key factors that differentiate plants that perform well on these key measures of operating performance and those that perform poorly. By identifying these differentiators it should be possible to construct some tentative propositions about the way in which these drivers will impact on each performance measure and therefore whether each pair of performance measures should be subject to trade-offs or not. Using the database it should be possible to confirm or refute these propositions by testing for the presence or absence of statistical correlations between these performance measures. From this analysis it should be possible to either confirm which of the existing interpretations of the nature of manufacturing trade-offs is correct or, alternatively, to attempt to develop a new model integrating features of these interpretations.

There are numerous inherent problems in comparing differences in operating performance between plants. Even when plants in the same business sector are compared there are still large differences in plant characteristics. The products being manufactured are never exactly the same. The mix of products being manufactured is different. Plant sizes, output levels, degrees of automation can all differ. Therefore, in order to gain an understanding of the interactions of different operating measures within individual plants, a small number of plants will be visited. At each plant, production managers, production planning managers and purchasing managers will be interviewed in order to gain an insight into the factors that influence the key measures of operating performance at individual plants. It should also be possible to gain an understanding of the type of trade-offs that exist at each plant.

1.5 Structure of the Thesis

A route map of the structure of the thesis is given in Figure 1.1. This shows how the various stages described in the thesis are related.

Figure 1.1: Thesis Route Map



A brief summary of the contents of each chapter is given below.

Chapter 1

This chapter explains why the programme of research being carried out is important. The research methodology to be used is introduced and the structure of the thesis is described

Chapter 2

This chapter reviews the literature on the key drivers that lead to excellent operating performance and on the nature of operations management trade-offs. The literature on the existing trade-off models is critically evaluated and areas where further research is necessary are identified.

Chapter 3

This chapter considers the different research methods that are available. The particular research methodology to be used is described and the choice of this methodology is justified.

Chapter 4

In this chapter statistical analysis of the database is carried out and a number of factors that differentiate high and low performance plants are identified.

Chapter 5

Using the literature on drivers of operating performance and the results of the statistical analysis presented in the previous chapter a tentative new trade-off model is developed. This model is used to derive a set of testable research propositions regarding the interactions between unit manufacturing cost, quality consistency, speed of delivery, delivery reliability and product variety.

Chapter 6

In this chapter the research propositions developed in chapter 5 are tested statistically using the Best Factory Awards database. By calculating correlation coefficients for each pair of performance measures the nature of the interactions between the performance measures is explored.

Chapter 7

This chapter introduces the case study part of the research. The rationale underlying the choice of the 6 plants visited, the objectives of the visits and the methodology to be used are explained. The research propositions to be tested during the visits are discussed.

Chapter 8

This chapter presents the results of the visit to the high performance plant from the Engineering Sector. The characteristics of this plant are compared with the sector averages and with a low performance plant from the Engineering Sector. The extent to which the high performance plant supports the research propositions presented in Chapter 7 is discussed.

Chapter 9

This chapter presents the results of the visits to the plants from the Electronics Sector. The characteristics of these plants are compared with the sector averages and with each other. The extent to which the plants support the research propositions presented in Chapter 7 is discussed.

Chapter 10

This chapter presents the results of the visit to the plants from the Process Sector. The characteristics of these plants are compared with the sector averages and with each other. The extent to which they support the research propositions presented in Chapter 7 is discussed.

Chapter 11

This chapter presents the results of the visit to the high performance plant from the Household Products Sector. The characteristics of this plant are compared with the sector averages and with a low performance plant from the Household Products Sector. The extent to which the high performance plant supports the research propositions presented in Chapter 7 is discussed.

Chapter 12

This chapter provides a cross-case analysis of the plants visited and draws conclusions about the extent to which the case studies support the results of the statistical analyses in Chapters 4 and 6.

Chapter 13

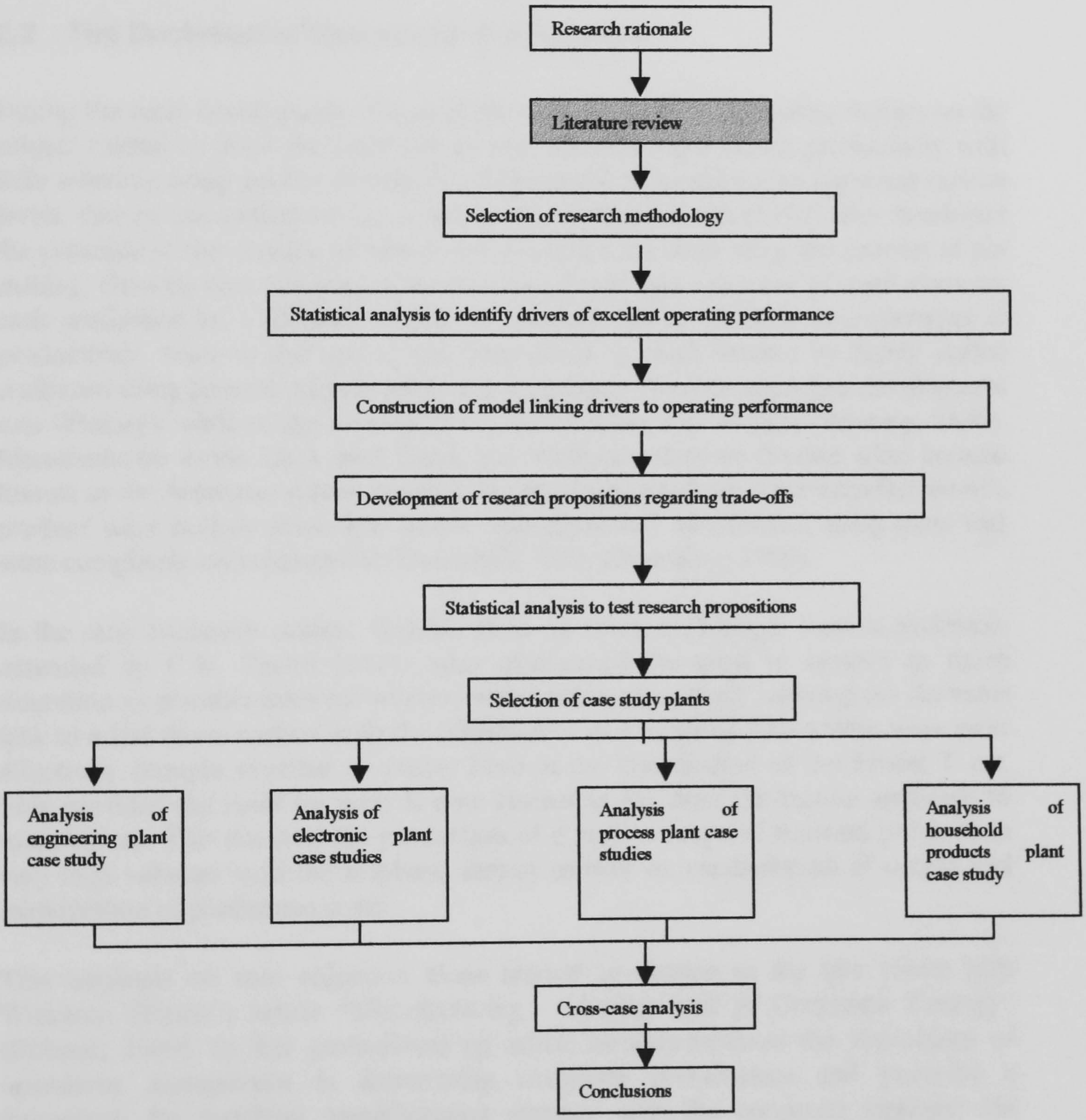
This chapter summarises the main findings of the research and assesses the contribution that the research has made. The limitations of the research are discussed and some suggestions for further research are made.

Chapter 2 : Manufacturing Drivers and Trade-offs - A Literature Review

2.1 Summary

Figure 2.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In the previous chapter the need for more research into the factors leading to improved manufacturing performance and the nature of the interactions between operating performance measures was identified. In this chapter the existing literature on the drivers of operating performance and the nature of manufacturing trade-offs is reviewed and critically evaluated. First a historical review of the development of operations management as a discipline is presented. Then the existing research on the factors that lead to excellent operating performance is discussed. This is followed by a review of trade-off theory. The key articles and papers on trade-off theory are analysed in more detail and an attempt is made to reconcile the apparently conflicting views expressed in the literature. In addition, methodological flaws in some of the papers are identified.

2.2 The Evolution of Operations Management

During the early development of operations management as a discipline, writers on the subject tended to place the emphasis on cost efficiency and labour productivity with little attention being paid to the impact of operations management on customer service levels. One of the earliest writers in this area was Adam Smith (1776) who developed the principle of the division of labour. He illustrated his ideas using the process of pin making, showing how breaking down the overall task into a number of small elements each performed by a different worker or machine led to dramatic improvements in productivity. Prior to this goods had been made in small batches by highly skilled craftsmen using general-purpose tools and equipment. Another important development was Whitney's work on the benefits of the interchangeability of parts (Whitney, 1800). Manufacturers in the USA used Smith and Whitney's ideas to develop what became known as the American system in which the processes involved in the manufacture of a product were broken down into simple operations and mechanised, using parts that were completely interchangeable (Hounshell, 1984; Rosenberg, 1969).

In the early twentieth century, Smith's ideas on division of labour were considerably extended by F.W. Taylor (1911) who emphasised the need to remove as much discretion as possible from the worker, each worker repetitively carrying out the same task to a laid down method with the minimum of interruptions. These ideas were most effectively brought together by Henry Ford in the manufacture of the Model T car. This provided the basis for what is now known as the mass production approach to manufacture. This involved the production of a narrow range of standard products in very high volumes with the emphasis almost entirely on maximisation of output and minimisation of production costs

This emphasis on cost reduction alone started to change in the late 1960s with Wickham Skinner's article "Manufacturing - Missing Link in Corporate Strategy" (Skinner, 1969). In this groundbreaking article he demonstrated the importance of operations management in determining corporate performance and provided a framework for matching manufacturing strategy with the corporate strategy. He developed these ideas further in his article "The Focused Factory" (Skinner, 1974). In this article he argued that a plant cannot perform well on every yardstick and that each manufacturing unit should focus on those performance measures that are most important to their customers, trading these off against performance measures which are less important.

The need to perform well on a wider range of performance measures rather than just cost alone led to two parallel lines of development. In North America and Europe, computer-based solutions were developed. Material requirements planning (MRP) (Orlicky, 1975) provided a computerised approach to production scheduling that enabled reductions in inventory and faster, more reliable delivery. The initial focus of MRP was on the planning and control of materials. It has subsequently been developed into manufacturing resource planning (MRPII) (Wight, 1984). This is a total business system that integrates all aspects of the planning of the resources used within the business.

Another computer-based development initiated in North America and Europe was computer integrated manufacturing (CIM). This involved the integrated application of computer-based automation and support systems to manage the total operation of the manufacturing system from product design through the manufacturing system itself, and finally on to distribution (Harhen and Browne, 1984).

These developments, while delivering significant performance improvements when successful, involved substantial capital investment and high set-up costs. They are also quite complex and difficult to manage so that there has been a high failure rate (Rayner, 1988; Boer et al, 1990).

In Japan a quite different approach was taken, the emphasis being on simplification and continuous improvement. One development was total quality management (TQM). Early supporters of this approach were Juran (1974), Crosby (1979) and Deming (1982). They showed that an emphasis on the elimination of the causes of production defects could lead not only to improvements in quality consistency but also to reduced cost and faster, more reliable delivery. A key feature of their approach was the involvement of everyone in the organisation in continuous improvement through the formation of quality circles and other types of problem-solving groups.

A complementary development, originating in the Japanese automobile industry was just-in-time manufacture (JIT). Leading this development was the Toyota Motor Company (Ohno, 1988; Shingo, 1988). The Toyota Production System provided a revolutionary alternative to mass production. It was a philosophy that sought to eliminate waste in all aspects of the company's production activities. As waste was eliminated it became possible to progressively reduce inventories of raw materials, work-in-process and finished goods. The goal was to manufacture or deliver every item just in time for it to be used by the next stage in the production process.

The various elements of the Japanese approach to production have been embraced by companies throughout the world. The Japanese approach forms the basis of both world class manufacturing (Schonberger, 1986) and lean production (Womack et al, 1990).

As competition has become more intense, companies have looked for ways of competing other than cost, quality and delivery. Mass customisation (Pine, 1993) attempts to provide much greater product variety without sacrificing cost, quality or delivery.

2.3 Previous Surveys of Manufacturing Performance

Something that is of great importance to operations managers is the identification of the drivers that lead to good operating performance. With finite resources it is important that efforts are concentrated on those areas of improvement that will lead to the greatest improvement in those aspects of performance that are of most importance to customers.

One of the first surveys that attempted to statistically analyse the relationships between different characteristics of business units and the levels of business performance achieved was the PIMS (Profit Impact of Marketing Strategy) Survey (Buzzell and Gale, 1987). This considered individual strategic business units, the smallest sub-unit of a company with profit responsibility, and developed regression equations linking measures of financial performance to internal characteristics of the strategic business unit. This is not directly relevant to the research described in this thesis as it was concerned with business performance rather than operating performance. However, it is one of the earliest examples of the use of statistical analysis in order to identify the drivers of performance.

A survey more specifically focused on manufacturing performance is the Global Manufacturing Futures survey (De Meyer and Ferdows, 1988, 1991). This operates at company level and is primarily concerned with monitoring changes in manufacturing priorities in Europe, Japan and the United States.

A more recent survey conducted by Voss (1994, 1995) used interviews at manufacturing plants throughout Europe to construct indices of practice and performance for each plant. Although this survey demonstrated a positive correlation between a plant's index of best practice and its index of operating performance, the survey is of limited relevance to this research. No attempt was made to correlate different aspects of operating performance and the survey results have not been published in sufficient detail to enable other researchers to do this. Also, the research has been criticised by New and Szwejczewski (1995) for the subjective way in which indices were derived for each plant and for its failure to take into account differences in performance norms in different industries.

The Lean Enterprise Benchmarking Report produced by Andersen Consulting (1983) compared 18 automotive components plants, 9 of which were located in Japan and 9 in the UK. Although no statistical evidence was provided, their results appeared to support the no trade-offs view. The best performing plants achieved high quality and productivity in spite of high product variety and a rapidly changing product range. In

1995 a further survey was published (Andersen Consulting, 1995), covering 71 automotive components plants in 9 countries. Again no statistical evidence was provided but in their conclusions they stated that product complexity showed no correlation with productivity in the case of seats and brakes but that there was a negative correlation in the case of exhausts. They also stated that there was a negative correlation between quality specification and productivity.

2.4 Drivers of Performance Improvement

In recent years there has been considerable interest in the specific factors that are the drivers of performance improvement. Schonberger (1982) has developed a model that attempts to show how application of the techniques of Just-in-Time (JIT) and Total Quality Control (TQC) can lead to simultaneous improvements in productivity and quality consistency. In his book *World Class Manufacturing: the lessons of simplicity applied*, (Schonberger, 1986) he suggests the following pre-requisites for world class manufacturing performance on all measures.

1. Get to know the customer
2. Cut work-in-process
3. Cut flow times
4. Cut set up and changeover times
5. Cut flow distance and space
6. Increase make/deliver frequency for each required item
7. Cut number of suppliers down to a few good ones
8. Cut number of part numbers
9. Make it easy to manufacture the product without error
10. Arrange the workplace to eliminate search time
11. Cross-train for mastery of more than one job
12. Record and retain production, quality, and problem data at the work place
13. Assure that line people get first crack at problem-solving – before staff experts
14. Maintain and improve existing equipment and human work before thinking about new equipment
15. Look for simple, cheap, moveable equipment
16. Seek to have plural instead of singular work stations, machines, cells, and lines for each product
17. Automate incrementally, when process variability cannot otherwise be reduced

A view expressed by many researchers is that low throughput time is the most important driver, being closely associated with high levels of quality consistency and productivity and with fast, reliable delivery. Schmenner (1988) reported the results of a survey that demonstrated that the single most important determinant of improved factory productivity was reduced throughput time. He says

While throughput time does not improve productivity by itself, it stimulates a host of complementary actions and tactics within the factory that, in turn, improve productivity.

Stalk (1988) and Stalk and Hout (1990) introduced the concept of time-based competition, demonstrating how low throughput times provide organisations with a major source of competitive advantage. Drucker (1990) in *The Emerging Theory of Manufacturing* argues

The key measure for the new manufacturing accounting is time. Benefit is whatever reduces that time.

Plossl (1991) states

In manufacturing operations all benefits will be directly proportional to the speed of flow of materials and information.

Schonberger (1996) identifies another related factor, stock turns, as the main determinant of business performance. This view has been supported by Shingo (1988), Hall (1983, 1987) and Ohno (1988).

However, short throughput times and high stock turns are intermediate measures. They lead to improvements in external performance but they are themselves the consequence of earlier actions by the organisation. Schonberger (1982) and Hall (1983) both identify three factors that they say are prerequisites for reducing throughput times and inventory levels. These are

Stabilising the master schedule
Cutting variation in process times
Getting suppliers to deliver in smaller lot sizes

Schonberger (1986) went on to say that World Class Manufacturing has two overriding goals. One is reduction of deviation (deviation from zero defects, deviation from zero manufacturing lead time) and the other is reduction of variability. Newman, Hanna and Maffei (1993) claim that reducing uncertainty and increasing flexibility enable capacity, inventory and throughput time to be cut. A number of authors have confirmed this through simulation studies. (Crawford and Cox, 1991; Zangwill, 1992; Huang, Rees and Taylor, 1983; Swenseth, Muralidhar and Wilson, 1993; Lee and Seah, 1988). Wacker (1987) showed that the levels of customer service, productivity and quality achieved by a plant are related and that the degree of the relationship depends on specific estimates of system parameters and how they are related to throughput time.

Hafner (1991) showed that reducing the coefficient of variability of the processing and inter-arrival times had the same effect on throughput times as an increase in capacity.

Oliver, Delbridge, Jones and Lowe (1994) found that the percentage variation from schedule during the month prior to delivery was only 5.5 per cent for world class manufacturing plants in comparison with 11.9 per cent for other plants. They conclude that demand stability and environmental uncertainty more generally seem to be important differentiators of lean and non-lean plants. However, this might be because one of the most significant indicators of leanness - inventory level - is heavily driven by uncertainty in one form or another.

Bennett and Forrester (1994) showed that schedule uncertainty in high variety - high volume plants causes higher inventories, longer lead times and less reliable delivery. Harrison (1997) observed a similar effect at an auto parts supplier.

Zachery and Richman (1993) argue that JIT emphasises variability reduction whereas Computer Integrated Manufacturing (CIM) emphasises variability handling. They conclude that CIM should only be introduced once variability has been reduced as far as possible by other means.

2.5 Summary of the Literature on Drivers of Excellent Performance

There seems to be general agreement that the fundamental drivers that lead to simultaneous improvements in most measures of operating performance fall into two main categories. These are

1. Elimination of waste
2. Reduction in variability

Elimination of waste

The main types of waste are

- Overproduction
- Waiting time
- Transportation
- Unnecessary or inefficient processing
- Inventory
- Unnecessary motion
- Defective output

Reduction in variability

The main ways in which variability can be reduced are

- Stabilisation of the master schedule
- Reducing process time variability
- Increasing the reliability of supplier deliveries

- Reducing scrap rates

Both elimination of waste and reduction in variability enable shorter throughput times and lower levels of inventory. These, in turn, seem to be associated with low manufacturing costs, fast, reliable delivery and high levels of quality consistency.

In summary, the characteristics most commonly associated with world class performance are

1. Involvement of everyone in the organisation with the identification and elimination of the causes of waste and variability
2. High levels of adherence to schedule
3. Low variability in process times
4. Low scrap rates
5. Low throughput times
6. Short changeover times
7. Frequent, reliable delivery from suppliers
8. Low levels of inventory

2.6 Trade-offs

Another crucial area for operations managers wishing to improve performance is an understanding of the interactions that exist between different measures of performance. After Skinner's original article on the importance of recognising and managing trade-offs (Skinner, 1969) it was assumed by most manufacturers that improved performance on one factor could only be achieved by trading this off against reduced performance on one or more other factors. Further support for the existence of trade-offs between different performance areas has been provided by Hayes and Wheelwright (1984), Richardson, Taylor and Gordon (1985), Rosenfield, Shapiro and Bohn (1985), Fine and Hax (1985), Wacker (1987). These authors have refined Skinner's original ideas and have identified the following main performance areas between which trade-offs might be expected to exist.

Quality consistency
Quality specification
Lead time
Delivery reliability
Cost
Flexibility
Innovativeness

While most writers agree that these represent the key performance areas some writers (Skinner, 1992; Corbett and Wassenhove, 1993) have criticised the lack of generally accepted definitions of these key concepts.

Further support for the concept of trade-offs has been provided from outside the Operations Management discipline by Porter (1980). In his book, "Competitive Strategy", he argues that the strategies of cost leadership and differentiation are mutually exclusive. However, several authors have criticised this view. Hall (1987), Hambrick (1983) and Hill (1988) all argue that it is possible for organisations to excel at differentiation and low cost at the same time.

Schonberger (1986, 1990) has raised fundamental questions about the trade-off model proposed by Skinner (1969), arguing that some companies are able to simultaneously improve on all aspects of performance. For these companies there are no trade-offs. Schroeder, Sakakibara, Flynn and Flynn (1991) have shown that many companies, particularly Japanese companies are capable of producing extremely high quality products at extremely low costs. Numerous authors (Deming (1982), Juran, Gryna and Bingham (1974), Crosby (1979), Garvin (1988), Skinner (1986)) have demonstrated that investment in quality improvement programmes can lead to improvements in both quality consistency and cost efficiency.

New (1992) and Skinner (1992) have responded to this argument by saying that although the nature of trade-offs is constantly changing, some trade-offs still remain. New is extremely critical of the position adopted by Schonberger and presents an analysis which shows that although modern manufacturing techniques have eliminated the traditional trade-offs between quality consistency and cost, customer lead time and delivery reliability, the trade-offs between quality specification and cost, product variety and cost still remain. Skinner amplifies on the trade-off aspects of his original ideas, arguing that the nature of the correlation between performance factors changes over time. He therefore suggests that these relationships should be referred to not as trade-offs but as performance relationships.

Slack et al (2001) have also suggested that the nature of the relationships between performance measures is dynamic. They state

Trade-offs [can be] depicted as relationships between performance objectives, which hold true for a given set of technological, organisational, and attitudinal factors. By changing the nature of operations resources, so the nature of the trade-off relationship may also be changed.

New (1992) also recognises the dynamic nature of trade-offs, suggesting that trade-offs are context-specific. Depending on the nature of the change leading to an improvement in one performance measure, the associated effect on other performance measures may sometimes be positive and sometimes be negative.

Harrison (1997) has suggested that there are a number of drivers affecting performance, each of which is either an enabler or an inhibitor.

Enablers can be divided into three groups.

Trade-off enablers - factors creating advantage in one area only to cause offsetting disadvantage in another area.

Best practice enablers - factors that create advantage in all operations situations.

Specific enablers - factors that create advantage only in given operations situations

Although an understanding of the nature of the trade-offs between the various measures of operating performance is extremely important, very little empirical work has been done to establish the nature of these trade-offs. In the papers described above little is presented to support each author's views, other than selective anecdotal evidence.

In an attempt to provide an explanation of the dynamic nature of trade-offs, Ferdows and De Meyer (1990) developed what they refer to as the sand cone model. This is based on the proposition that competences are cumulative rather than mutually exclusive. They suggest

Lasting improvements in performance always involve the same sequence in the performance improvement process. First quality is improved. Then, while improvements in quality continue, reliability is improved. Next, while improvements in these two performance areas improve further, flexibility is improved. Finally, while improvements in these three performance areas continue, cost efficiency is improved.

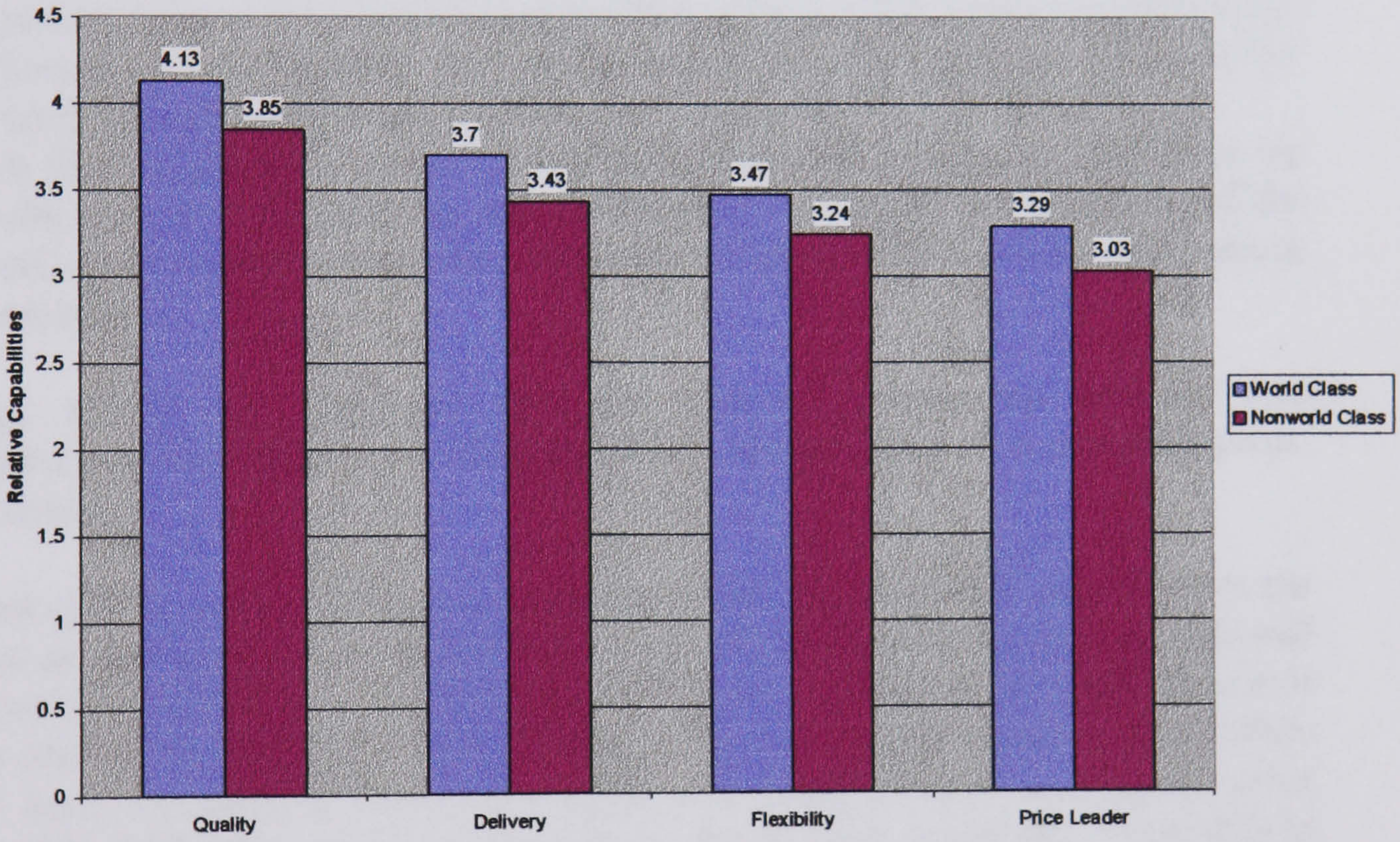
The authors claim that their model is based on empirical data derived from the Manufacturing Futures Survey. However, the empirical data that they present is inconsistent with their model. They try to explain this by arguing that their model is prescriptive, describing what organisations ought to do rather than what they actually do. However, they provide no arguments in support of their particular model other than their unfounded claim that it fits the empirical data. As part of this research their data will be re-analysed to show that it is more consistent with a different trade-off model.

The ideas of Ferdows and De Meyer have been developed further by Roth (1996) in her work on competitive progression theory. This theory proposes:

Sustainable combinative competitive capabilities accumulate in a sequential progression forward - from quality to delivery to flexibility to price leadership - over an innovative cycle leading to strategic agility; combinative competitive capabilities on quality, delivery, flexibility, and price leadership.

In order to test this theory, 1221 respondents were asked to rate the performance of their organisation on a number of factors using a scale from 1 to 5. The respondents were divided into two groups, world class and non-world class. Their responses were then converted into 4 indices, quality, delivery, flexibility and price leadership. If competitive capabilities do, indeed, accumulate sequentially from quality to delivery to flexibility to price leadership then it would be expected that the group average scores would follow the same sequence, being highest for quality and lowest for price leadership. The results obtained confirm this (see Figure 2.2). However, a flaw in the methodology is that quality, delivery and flexibility are all absolute measures while price leadership was assessed relative to competing organisations. Consequently, while it would be theoretically possible for group averages of 5 to be obtained for the first three of these measures, it would be impossible for all organisations to offer lower prices than all other organisations. It is, therefore, not very surprising that price leadership had the lowest group average.

Figure 2.2: Competitive Regression by World Class Manufacturing Status



Source: Roth (1996)

An implication of the sand cone and competitive progression theories is that manufacturing strategy can be represented as a continuum with the only difference between plants being how far they have progressed along this continuum. Other writers suggest that companies must choose between alternative strategies, implying that these strategies are, to some extent, mutually exclusive.

Filippini, Forza and Vinelli (1995) have tried to provide some empirical data regarding the trade-off issue by analysing the compatibility/trade-off between different types of performance for a sample of 42 plants drawn from the metal mechanical industries. However, their method of analysis involves a number of flaws, invalidating their conclusions. A re-analysis of their data will be presented as part of this research showing that their data provides some support for the proposition that high levels of quality consistency are associated with short, reliable lead times.

2.6.1 Ways of representing the dynamic nature of trade-offs

In attempting to portray the dynamic nature of trade-offs most writers (Skinner, 1992; Hayes and Pisano, 1996; Schroeder et al, 1996) represent trade-offs as a function of the kind represented as model I in Figure 2.3. They envisage a number of possibilities.

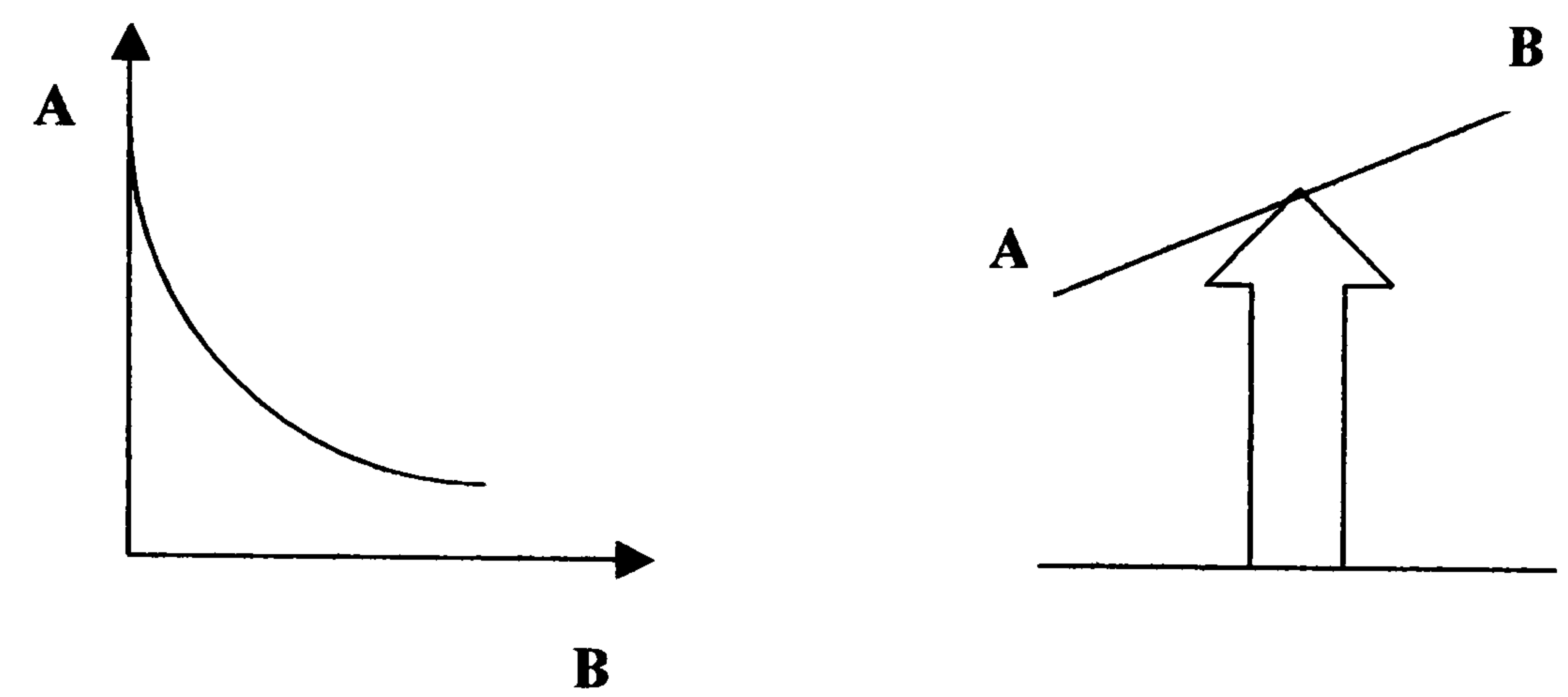
1. A plant might be operating at below the efficiency frontier represented by the trade-off function. Then improvements in efficiency will enable them to achieve simultaneous improvements in both performance measures until the efficiency frontier is reached.
2. A plant might be operating at the efficiency frontier, in which case changes in performance on these two measures will involve movement along the efficiency frontier. Consequently, any improvement in one measure will involve deterioration in performance on the other measure.
3. A plant might devote its efforts to performance improvements that move the efficiency frontier upwards and to the right. Each such repositioning of the efficiency frontier will enable a simultaneous improvement in both performance measures.

Slack (1991) has suggested that the trade-off relationship between two performance measures can be thought of as a seesaw but with a moveable pivot. He states

Think of each trade-off not as a conventional seesaw, but rather as one where the pivot as well as the beam can be moved. As with all seesaws, raising one side will indeed lower the other. And true enough one way of making an improvement in one area is by diverting resources away from, or relaxing standards in another. But here, by applying managerial effort and imagination to moving the pivot upwards, both sides of the seesaw can be raised while preserving the ability to trade-off between them. Alternatively moving the pivot could allow one side of the seesaw to be raised without lowering the other.

The two alternative models of trade-offs are illustrated in Figure 2.3.

Figure 2.3: Alternative Models of Trade-offs



Model I: Function
(Skinner, 1992;
Hayes and Pisano, 1995)

Model II: Pivot and Function
(Slack, 1991)

Source: Slack (2001)

2.6.2 Managers' perceptions of trade-offs

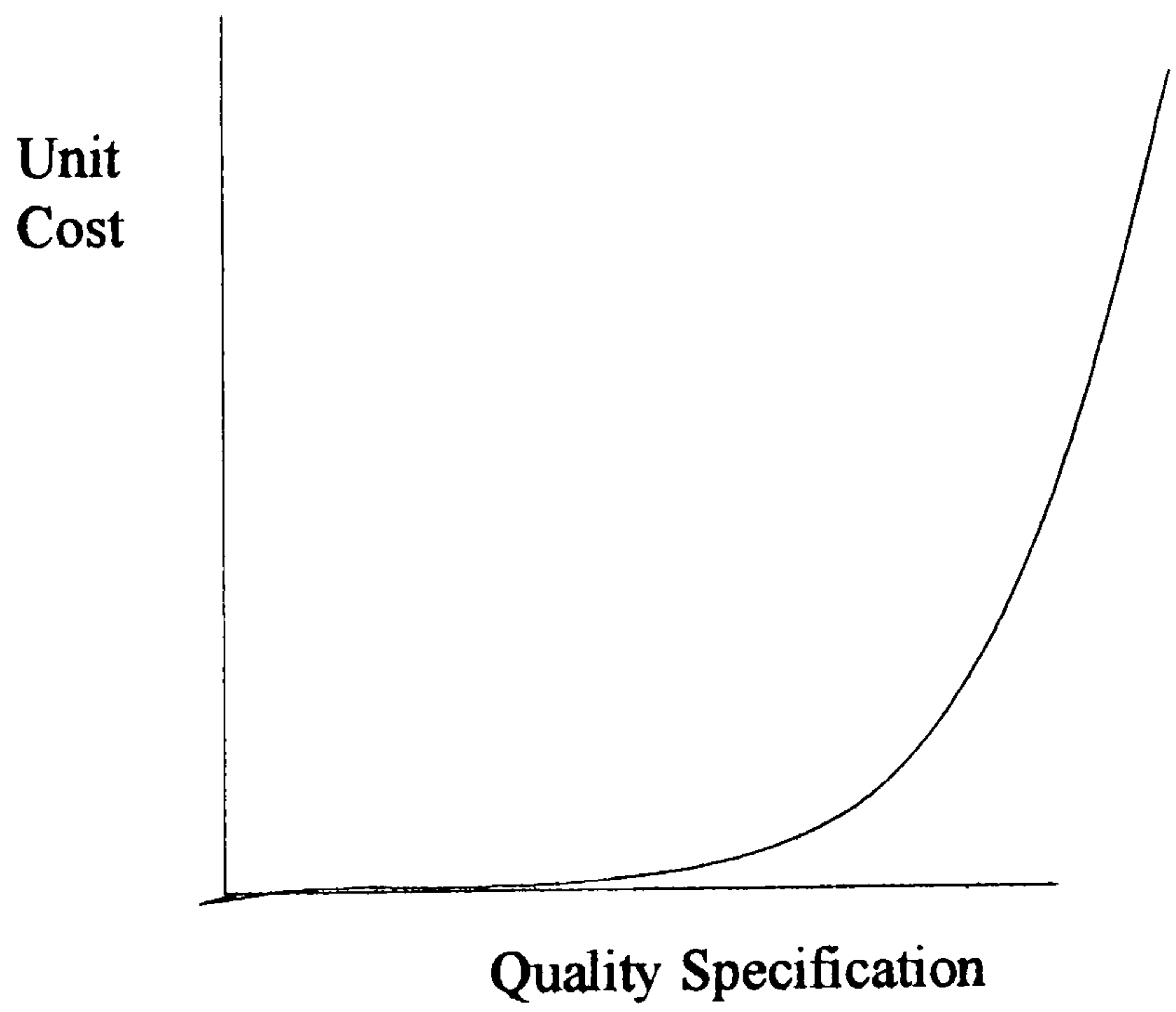
Da Silveira and Slack (2001) interviewed managers at 5 companies in order to explore the managers' perceptions of the existence and importance of trade-offs. They concluded that the idea of trade-offs is not the problematic issue for practising managers that it is for academics. For these managers it is an easily understood concept that describes the operational compromises that they make on a routine basis. Da Silveira and Slack conclude that the significance of specific trade-offs within any operation is likely to be governed by two factors. The first is the "importance" of the trade-off in terms of the impact that it will have on overall operations effectiveness. The second is the "sensitivity" of the trade-off. Sensitivity is the degree of change that will be caused by one element of the trade-off when changes are made to the other.

2.7 Critical Evaluation of Existing Trade-off Models

2.7.1 The Skinner model

This model as described in Skinner's seminal articles of 1969 and 1974 is essentially a static model with its roots in classical economic theory. Assuming a fixed technology, finite resources and a set of performance objectives whose achievement requires these resources then allocation of resources in order to improve one aspect of performance must be at the expense of one or more other measures of performance. For example, in a given plant at a given point in time, a trade-off curve similar to Figure 2.4 must exist between the quality specification of a product and its unit cost.

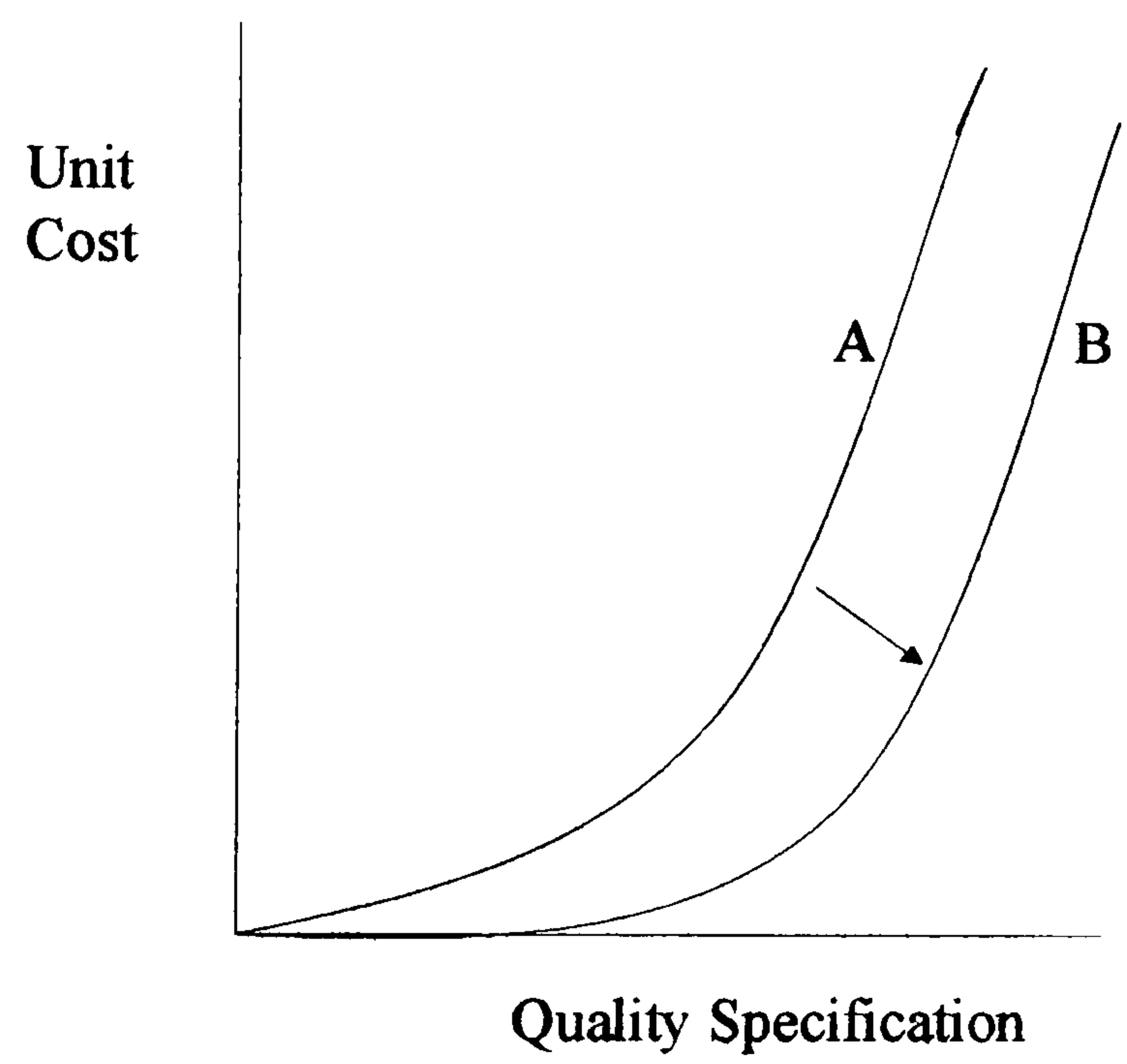
Figure 2.4: Trade-off Between Quality Specification and Unit Cost



The effect of this type of curve can be seen in the car company, VAG, which offers various ranges of cars including Audi, VW and Skoda, each range providing a different level of quality specification at a different price. In doing this, VAG and their customers recognise that an Audi will be more expensive to produce than a VW, which will be more expensive to produce than a Skoda and that this will be reflected in their prices.

However, once a dynamic perspective is introduced and changes over time are considered then technology is no longer fixed and over a period of time the trade-off curve between unit manufacturing cost and quality specification is likely to move downwards and to the right, replacing curve A with curve B as shown in Figure 2.5.

Figure 2.5: Change in Trade-off Curve over Time

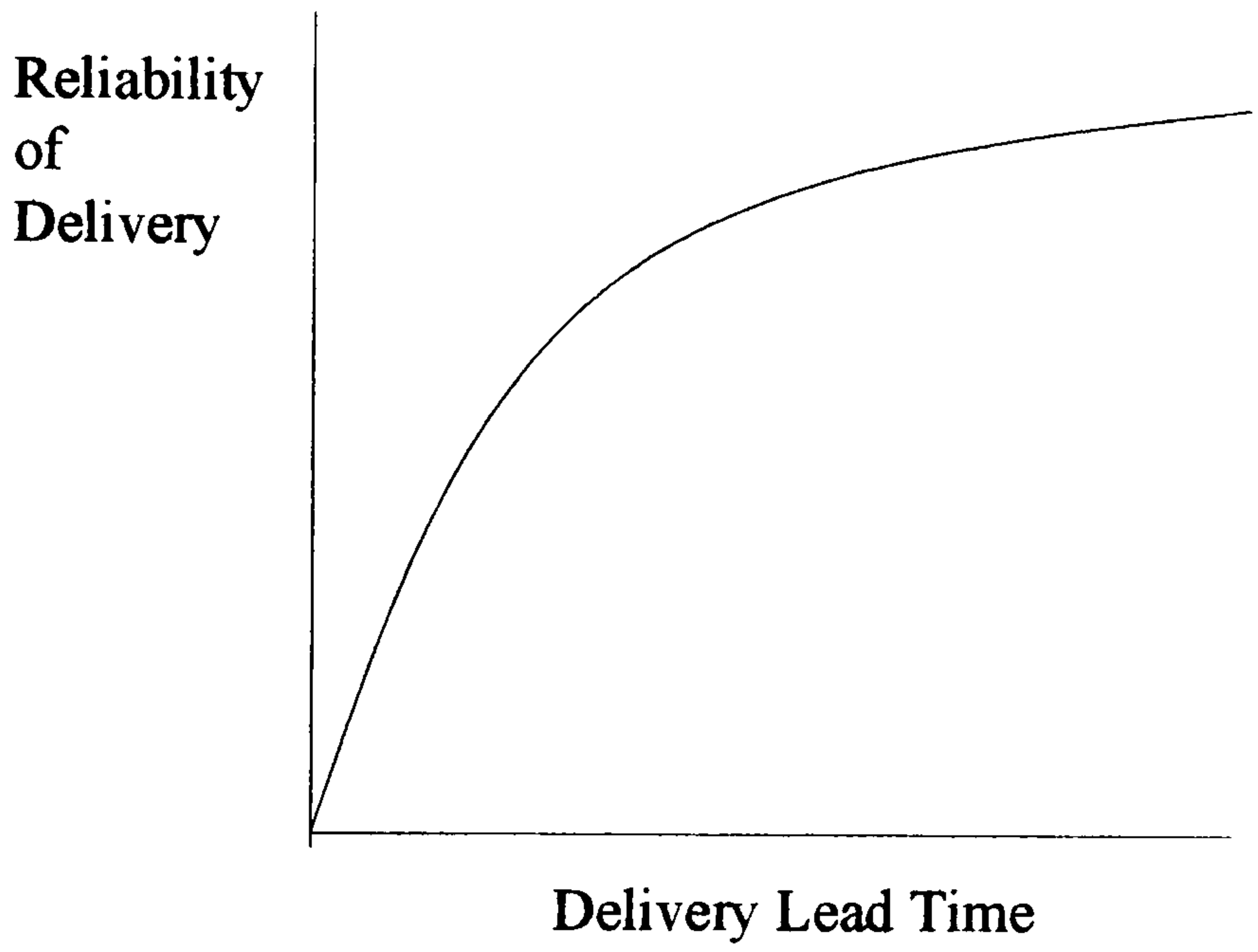


This will have two kinds of consequences. Firstly, it is to be expected that, over time, either the price of a car with a given specification will reduce in real terms or that the quality specification of cars in each price range will improve. This latter effect can be seen at VAG where over time, features that were originally only available on cars in the Audi range have been made available, first on the VW range and then on the Skoda range. Examples include electric windows, central locking and air-conditioning.

Secondly, it could be possible for a plant, by investing in new technology and improved systems and procedures, to move to trade-off curve B while other plants in the same industry still remain on curve A. It would then be possible for that plant to simultaneously achieve a higher quality specification and a lower unit cost than competing plants. Nevertheless, the new operating system will still be subject to trade-off effects within the plant. It will still be more expensive to manufacture a high specification product than a product with a lower quality specification but the relationship will follow curve B rather than curve A.

Consider one of the other trade-offs that Skinner identified, the relationship between speed of delivery and reliability of delivery. Skinner implied that a trade-off curve similar to that in Figure 2.6 exists.

Figure 2.6: Trade-off between Delivery Lead Time and Delivery Reliability



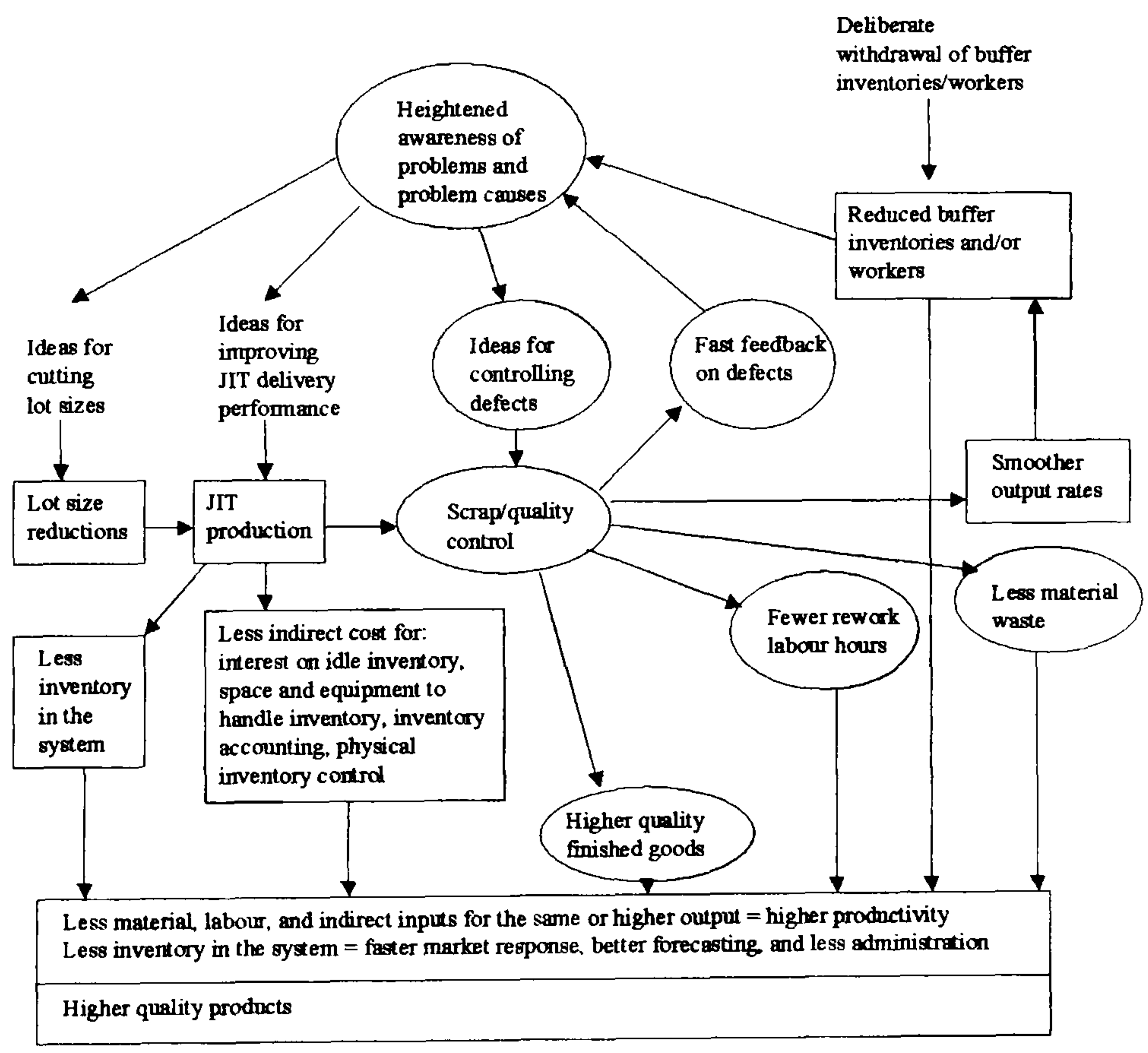
Assuming constant technology, systems and procedures implies that average lead time will also be constant so that quoting shorter lead times to customers inevitably leads to a fall in delivery reliability. But suppose that a method change is introduced which halves the lead time and the plant starts quoting half the previous lead time to customers. What effect will this have on delivery reliability? It will depend on the effect that the method change has had on lead time variability. A reduction in average lead time is nearly always accompanied by a reduction in lead time variability. If this reduction in variability is proportional to the reduction in lead time then delivery reliability will be unchanged. Skinner's point is that when a reduction in lead time has been achieved then the benefits can be passed on to the customer either in the form of a reduction in the quoted lead time, an improvement in delivery reliability, or some combination of the two. However, the larger the reduction in quoted lead time, the smaller the improvement in delivery reliability that will be possible.

To summarise, Skinner's model is concerned with performance trade-offs within a single plant for a specified operating system. Its limitation is that it does not address the question of how the operating system can be improved over time and what effect these improvements would have on operating performance.

2.7.2 The Schonberger model

Schonberger's model is concerned solely with how the operating system can be improved over time and with the effects of these improvements on operating performance. He believes that there are a number of performance drivers, improvements in which lead to simultaneous improvements in most measures of operating performance. The mechanisms whereby this is thought to occur are illustrated in Figure 2.7. His main drivers are the techniques of Total Quality Control blended with the techniques of Just-in-Time production.

Figure 2.7: Total Quality Control Blended with Just-in-Time Production



Source: Schonberger "Japanese Manufacturing Techniques", Page 36 (1982)

The benefits, which he claims, are listed below.

- Lower costs
- Higher productivity
- Lower inventory
- Faster delivery
- More reliable delivery
- Faster response to changes in product mix or quality requirements
- Better quality consistency

Factors not mentioned are

- Quality specification
- Product variety
- Rate of introduction of new products

This is because, unlike the other factors mentioned, improvements in these are not a direct consequence of the TQC and JIT techniques described by Schonberger.

In his book *Building a Chain of Customers* (Schonberger, 1990) he discusses what he calls "The Myth of Trade-offs". He identifies four areas in which he claims simultaneous improvements are possible.

- Cost
- Quality
- Response time
- Flexibility

While his arguments are plausible he provides no formal supporting evidence for his conclusions. Also, his definitions of the four factors of cost, quality, response time and flexibility are extremely vague.

2.7.3 The Ferdows and De Meyer model

In their article 'Lasting Improvements in Manufacturing Performance: In Search of a New Theory' Ferdows and De Meyer (1990) attempt to explain how some manufacturers can achieve better quality, greater dependability, greater responsiveness to changing markets and lower costs than their competitors, all at the same time. The authors contend that, depending on the approach taken in developing each capability, the nature of the trade-offs changes. In certain circumstances, not only can trade-offs be avoided but also one capability actually enhances another. They become cumulative.

The paper quotes numerous authors (Deming, 1982; Juran, Gryna and Bingham, 1974; Crosby, 1979; Garvin, 1988; Skinner, 1986) who have shown that improvements in quality consistency and reliability will also reduce manufacturing costs. They can find less evidence for mutual enhancement of other pairs of capabilities. Ferdows and De Meyer give three examples of plants that appear to be able to offer a wide variety of products without incurring penalties on other aspects of performance. However, these are examples of the absence of trade-offs rather than examples of mutually enhancing capabilities. The authors provide no explanation of how an increase in product variety might be expected to lead to an improvement in quality or a reduction in manufacturing costs. The authors refer to Jaikumar's paper (1986), which showed that Japanese companies are both more dependable and more flexible than comparable companies in the USA. They conclude from this that companies whose production systems are more reliable can, as a consequence, run their systems more flexibly. They provide no explanation of why this might be so, nor do they consider the possibility that this is not a cause and effect relationship but the result of a third common factor.

The authors refer to their own Manufacturing Futures database which seems to show that excellent manufacturers in Europe, North America and Japan follow a distinct sequence of improvement programmes which aim at building one capability upon, and not instead of, another. They suggest that this sequence

Is one which puts the quality at the base; then - while the efforts on quality improvement continue and expand - focuses also on improving the dependability of the production process; next, again while the previous efforts are expanded, also pays attention to improving the reaction speed and flexibility of the production system. It is then, while all previous efforts continue to expand, that direct attention to cost efficiency is justified.

They refer to this as the sand cone model of manufacturing capabilities.

In order to provide empirical evidence for this model they started by testing the trade-off model first proposed by Skinner (1969). They considered the four generic capabilities of cost efficiency, quality, dependability and flexibility. Using data from the 1988 European Manufacturing Futures Survey they measured the percentage change in 8 performance measures between 1985 and 1987 for the 167 respondents in their sample. They selected 4 of these measures that they believed to be representative of the 4 generic capabilities. The measures used were unit manufacturing cost, quality conformance, delivery capability and speed of new product introduction. They then interpreted trade-off theory as saying that a company cannot be expected to improve two or more capabilities simultaneously (although this is not what Skinner said). As 62 per cent of respondents improved more than one capability they concluded that this casts doubt on trade-off theory.

Table 2.1: Changes in Performance Indicators 1985-87

Indices for 1987 (1985 = 100)

	Mean	Standard Deviation	% of Companies Improving
Quality conformance	109	17	70.2
Unit production cost	100	14	50.0
Development speed	106	19	62.4
On-time delivery	108	17	68.1

Source: 1988 European Manufacturing Futures Survey (De Meyer and Ferdows)

In fact they have mis-interpreted trade-off theory. The theory does not say that simultaneous improvement in two or more factors is impossible. It says that above average performance on one measure is likely to be associated with below average performance on one or more other measures. Table 2.1 shows the average improvement index for each performance measure, taken from the original paper. Although they do not give the percentage of companies improving on each measure, they do provide the standard deviation of each index. Provided that performance is assumed to be approximately normally distributed, the percentage of respondents improving their performance on each measure can be estimated. These results have been used to calculate the probability distribution of the number of simultaneous performance improvements assuming that the four performance indicators are independent. The results are shown in Table 2.2. If trade-offs exist then the proportion of respondents achieving 1 or 2 simultaneous improvements should be higher than expected and the proportion of respondents achieving 3 or 4 simultaneous improvements should be lower than expected. If capabilities are mutually enhancing then the reverse should be true. The results in Table 2.2 support the former. In other words, there is evidence of trade-offs between performance measures whereas the authors claim the reverse.

Table 2.2: Simultaneous Improvements in Performance

No. of improvements	Observed	Expected if independent
None	9%	1.8%
1 of 4	25%	12.8%
2 of 4	40%	33.3%
3 of 4	18%	37.2%
All 4	4%	14.9%

However, there is other evidence in the paper that conflicts with these results. Although the authors do not comment on the results, there is a table of correlation coefficients for each pair of performance indices. This is reproduced in Table 2.3. A negative correlation coefficient provides evidence for trade-offs, a positive correlation coefficient provides support for the theory that the performance measures are mutually enhancing and a correlation coefficient close to 0 indicates independence. Of the 10 correlation coefficients in Table 2.3, 5 are positive and statistically significant, a further 3 are positive but not statistically significant and only 2 are negative, neither being statistically significant. In other words, all of the pairs of performance indices whose correlation is statistically significant are mutually enhancing rather than exhibiting trade-offs.

Table 2.3: Correlation between the Performance Indices

	Unit production cost	Development speed	On-time delivery	Delivery speed
Quality conformance	.04	.19**	.17*	.09
Unit production Cost		.08	-.14	-.10
Development speed			.29**	.27**
On-time delivery				.51**

** $p<0.01$
* $p<0.05$
Source: 1988 European Manufacturing Futures Survey (De Meyer & Ferdows, 1988)

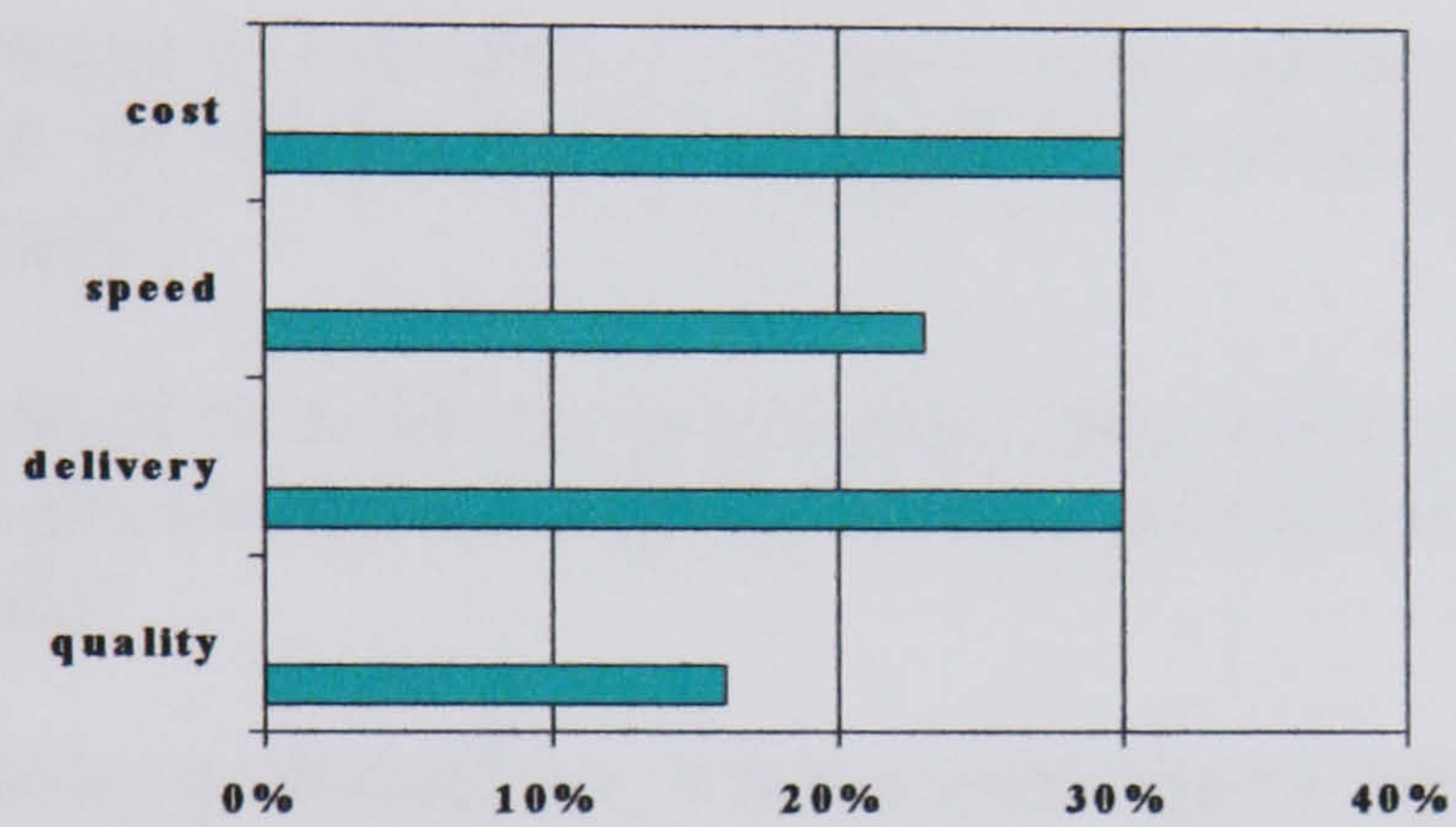
The authors then go on to discuss the cumulative model originally proposed by Nakane (1986). On the basis of a survey of Japanese companies he suggested a cumulative model in which quality improvement is the prerequisite for all other improvements. Improvements in dependability should only be attempted once a minimum quality level has been achieved. Quality and dependability improvements are then prerequisites for cost efficiency improvements. Finally, quality, dependability and cost efficiency are prerequisites for flexibility improvements. This differs slightly from the Ferdows and De Meyer model as can be seen in Table 2.4.

Table 2.4: Comparison of Nakane and Sand Cone Models

Development Sequence	Nakane Model	Sand Cone Model
4	Flexibility	Cost Efficiency
3	Cost Efficiency	Speed
2	Dependability	Dependability
1	Quality	Quality

Finally, the authors examined the group of respondents who had reported improvements in at least two of the four performance measures and measured the frequency with which each of the four occurred. According to the sand cone model, quality conformance should be the most frequent, followed by delivery capability, then speed of new product introduction, then cost efficiency. The results are shown in Figure 2.5 and provide little support for the sand cone theory. The authors deal with this by saying that their model describes what companies should do, not what they actually do.

Figure 2.5: Frequency of Simultaneous Improvements



Note: This chart shows the frequency of improvement of each indicator simultaneously with at least one of the other three indicators.

Source: 1988 European Manufacturing Futures Survey (De Meyer and Ferdows (1988)

While the model presented is intuitively attractive there are weaknesses in the logic of the authors' arguments. They say that the model is based on empirical evidence but the empirical evidence presented does not support their model. They then say that the model describes what should be done rather than what is done but provide no theoretical evidence to explain why the sand cone approach to performance improvement will give more lasting results than alternative approaches.

2.7.4 Filippini, Forza and Vinelli

In their paper 'Compatibility and Trade-off Between Performance: A Theory Formulation and Empirical Evidence', Filippini, Forza and Vinelli (1995) attempted to provide some empirical evidence to resolve the arguments about trade-offs. Their paper examined the relationships between different types of performance for a sample of plants in the metal/mechanical industry. The authors concluded that trade-offs between several performance types still exist. However, a different analysis of the data presented suggests that the evidence for trade-offs is not significant. Indeed, there is evidence that some types of performance are mutually supportive. The results obtained also provide some empirical support for the sand cone model.

Filippini, Forza and Vinelli analysed the compatibility/trade-off between different types of performance for a sample of 42 plants drawn from the metal/mechanical industries. They defined trade-off as the impossibility of reaching high-level performance over several types of performance and compatibility as the possibility of obtaining high-level performance over several types of performance. The following 3 research questions were addressed.

1. On consideration of n different performance areas (where n is ≥ 2), is it possible to find companies in which there is compatibility between a number (k) of these performance types?

2. On consideration of n different performance areas (when n is ≥ 2), are there sets of performance types where a compatibility situation prevails and others where a trade-off situation prevails?

3. Do high levels of compatibility between performance areas go hand in hand with high overall levels of distinctive competences?

The sample was selected to include equal numbers of traditional and world class manufacturing (WCM) plants. Classification was based on the opinions of experts in the field. WCM plants were defined as plants with a reputation for excellence in several areas. Traditional plants were defined as plants focusing on one or a few performance areas. There was no discussion of whether the sample was representative of the population from which they were drawn. There was also no discussion of the problems associated with using a sample carefully selected to meet their definition of compatibility in combination with another sample of equal size carefully selected so that it was less likely to meet their definition of compatibility.

It is not stated whether the data was collected by self-administered questionnaire or by interview. A series of objective and subjective questions were asked and these were used to construct a set of measures of performance and distinctive competence. The measures obtained were tested for reliability and validity using Cronbach's alpha coefficient (Cronbach, 1951), factorial analysis and analysis of variance. Although the results of this analysis are not presented it is stated that only measures with high validity and reliability were used. The criteria used are not stated. The performance measures selected were as follows,

Delivery time - The time that elapses between receipt of the order and delivery to the customer.

Delivery punctuality - The percentage of orders delivered on time.
Quality consistency - The average percentage of rejects and re-processing and of finished products that are defective.
Quality capability - Quality of the product in terms of its characteristics and performance capabilities compared with those of the competitors.
Invested capital turnover - average invested capital turnover and relative trend.
Production cost over turnover - average production cost of sales over turnover and relative trend.

The companies were then divided into 4 quartiles for each performance measure with equal numbers of companies in each quartile. Then the following measures of compatibility and trade-off were determined.

$CT_1(j, i_1, i_2)$

This measure compares performance types i_1 and i_2 for plant j. For compatibility (C) the plant must be in the top 2 quartiles for both types of performance. For a trade-off (T) plant performance on the 2 measures must be in non-adjacent quartiles. Otherwise the measure is classified as neither a compatibility or a trade-off situation (NTC).

$SCT_1(j, i_1, I_2)$

This is a more stringent measure comparing performance types i_1 and i_2 for plant j. For compatibility (C) the plant must be in the top quartile on both performance types. For a trade-off (T) the plant must be in the extreme opposite quartiles for the 2 types of performance.

C(j, G)

This measures the performance of plant j across a sub-set G of k different performance measures taken from the n performance types being studied. For compatibility (C) the plant must be in the upper 2 quartiles for all k performance types.

SC(j,G)

This is a more stringent measure of the performance of plant j across a sub-set G of k different performance measures taken from the n performance types being studied. For compatibility (C) the plant must be in the top quartile for all k performance types.

The first step in the authors' analysis of the data collected was to carry out a correlation analysis between the various performance types. Although they do not present the results of this analysis they state that the performance types examined are tendentially independent. Although they do not develop this further it could be an extremely important conclusion. If it is correct it suggests that, for the industry being studied, trade-offs do not exist. High performance on any of the measures being studied can be achieved without any effect, positive or negative, on any of the other performance measures.

The next stage in their analysis was to count the number of companies in which compatibility between at least k performance types was confirmed. This was done using both the function C(j,G) and the more restrictive function SC(j,G). As none of the companies in the sample achieved compatibility between all 6 performance types they conclude that some trade-offs must still exist. In fact their results provide striking support for the hypothesis that all of the performance types being studied are independent. Under this hypothesis the measure based on C(j,G) would be binomial with n=6 and p=0.5 and the measure based on SC(j,G) would be binomial with n=6 and p=0.25. The observed and theoretical results are compared in Table 2.5. For both the compatibility figures and the stringent compatibility figures the chi squared values support the conclusion that there is no significant difference between the observed figures and the figures that would be expected if all of the performance measures were independent.

Table 2.5: Number of Companies Showing Compatibility between k or More Performance Areas

	Measure based on C(j,G)		Measure based on SC(j,G)	
K	Observed	Expected	Observed	Expected
0 or 1	42	42	42	42
2	31	37.3	16	19.6
3	27	27.5	8	7.1
4	15	14.4	3	1.6
5	6	4.6	1	0.2
6	0	0.7	0	0.0
Chi-squared		0.709		0.739
P		0.95		0.86

The next stage in their analysis was to count the number of companies showing compatibility using the $CT_1(j, i_1, I_2)$ measure for each pair of performance areas. Even if the 2 performance areas show perfect correlation only half of the companies could be in the upper 2 quartiles and meet the compatibility criterion. For this reason the number of companies showing compatibility on each pair of measures was expressed as a percentage of the maximum number possible, 21. Even if a pair of performance measures is completely independent, Table 2.6 shows that 16 combinations could arise, all equally likely, of which 4 meet the compatibility criterion. The expected value of the calculated percentage will therefore be 0.25/0.5 = 50 % if the performance measures are independent of each other. The 95 per cent confidence limits for the actual sample percentage can easily be calculated to be 28 % - 72 %. Table 2.7 shows the observed results taken from the original paper. All lie within the 95 per cent confidence limits further supporting the hypothesis that all of the performance areas studied are independent of each other. The average value across all the cells is 52.2 % compared with an expected value of 50 % for independence. This difference is not statistically significant.

Table 2.6: Performance Combinations Meeting the Compatibility/Trade-off Criteria

		Quartiles for performance area i_1			
		1	2	3	4
Quartiles	1	SC	C	T	ST
For	2	C	C	NCT	T
Performance	3	T	NCT	NCT	NCT
Area i_2	4	ST	T	NCT	NCT

Stringent compatibility = SC
Basic compatibility = SC or C
No compatibility or trade-off = NCT

Stringent trade-off = ST
Basic trade-off = ST or T

Table 2.7: Basic Compatibility between Performance Areas

(The number of companies showing compatibility as a percentage of the maximum number possible)

	Punctuality	Quality Consistency	Quality Capability.	Inventory Capital Turnover	Production Cost over Turnover
Delivery Time	55 %	45 %	50 %	53 %	50 %
Punctuality		55 %	40 %	37 %	55 %
Quality Consistency			55 %	63 %	65 %
Quality. Capability				47 %	50 %
Inventory Capital Turnover					63 %

The authors next considered the percentage of companies meeting the trade-off criteria for each pair of performance areas. If the performance areas are independent then the expected percentage of companies meeting the trade-off criteria will be 37.5 %. The 95 per cent confidence limits for the actual percentage will be 23 % - 52 %. Table 2.8 shows the results from the original paper. Again all of the results lie within the 95 per cent confidence limits. However, the average percentage across all performance area combinations is 31.2 % compared with an expected average of 37.5 %. This difference is significant at the 0.01 level and provides limited evidence that some pairs of performance areas are not independent but rather exhibit some positive correlation. In other words there is limited support for compatibility between the performance measures.

Table 2.8: Basic Trade-offs between Performance Areas

(The number of companies showing trade-off as a percentage of the maximum number possible)

	Punctuality	Quality Consistency	Quality Capability	Inventory Capital Turnover	Production Cost over Turnover
Delivery Time	37 %	31 %	28 %	24 %	29 %
Punctuality		31 %	38 %	42 %	37 %
Quality Consistency			25 %	26 %	31 %
Quality Capability				29 %	36 %
Inventory Capital Turnover					24 %

The next stage of the authors' analysis was to look at compatibilities and trade-offs using their more restrictive definition SCT_1 . Table 2.9 shows the results using their stringent definition of compatibility. If the 2 performance areas are independent then, on average, 1 in 16 plants will meet the stringent compatibility criteria. The maximum percentage of plants that can meet the stringent compatibility criterion is 25 per cent. Therefore, under the independence assumption, each cell in Table 2.9 has an expected value of 6.25 %/25 % = 25 %. The 95 per cent confidence limits for the actual values are 0 % - 52 %.

Table 2.9: Stringent Compatibility between Performance Areas

(The number of companies showing stringent compatibility as a percentage of the maximum number possible)

	Punctuality	Quality Consistency	Quality Capability	Inventory Capital Turnover	Production Cost over Turnover
Delivery Time	37 %	37 %	50 %	25 %	37 %
Punctuality		30 %	30 %	33 %	20 %
Quality Consistency			40 %	44 %	40 %
Quality. Capability				33 %	20 %
Inventory Capital Turnover					22 %

Again all of the results lie within the 95 per cent confidence limits. The average of the results is 33.2 % compared with an expected value of 25 %. This difference is significant at the 0.01 level and provides further support for compatibility between the performance areas being studied.

Table 2.10 shows the corresponding results using the stringent trade-off criterion. Under the independence assumption an average of 1 in 8 plants would meet the stringent trade-off criterion. The maximum percentage of plants that can meet the stringent trade-off criterion is 50 % and so the expected value for each cell in Table 2.10 is 12.5 %/50 % = 25 %. The 95 % confidence limits for the actual values are 6 % - 44 %.

Table 2.10: Stringent Trade-offs between Performance Areas

(The number of companies showing stringent trade-off as a percentage of the maximum number possible)

	Punctuality	Quality Consistency	Quality Capability	Inventory Capital Turnover	Production Cost over Turnover
Delivery Time	12 %	23 %	23 %	23 %	17 %
Punctuality		16 %	32 %	44 %	38 %
Quality Consistency			5 %	22 %	21 %
Quality. Capability				22 %	21 %
Inventory Capital Turnover					16 %

The average of these results is 22.3 % compared with an expected value of 25 %. This difference is not statistically significant. One pair of performance areas gives results outside the 95 per cent confidence limits. Quality consistency and quality capability showed a significantly lower trade-off than expected for independence indicating that very good performance in one was rarely associated with very bad performance in the other.

The last part of the paper addresses the third research proposition that high levels of compatibility between performance types are accompanied by high overall levels of distinctive competence. The authors measured the correlation between the number of performance types that are simultaneously compatible for a given plant and the average of the following 4 measures of distinctive competence.

Process and product technology - manager's perceptions of level of product and process technology compared to that of competitors

Management systems - managers' perceptions of quality management systems and production flow: whether they are superior to those of competitors

Human resources - managers' perceptions of the presence of internal relations with employees: whether they are better than those of competitors

External relations - managers' perceptions about relations with suppliers and customers: whether they are better than those of competitors

Using the basic compatibility function C(j, G) a correlation coefficient of .35, significant at the 0.05 level was obtained. Using the more stringent compatibility function SC(j, G) a correlation coefficient of 0.42, significant at the 0.01 level, was obtained. Although these results appear to support the research proposition, the measures of distinctive competence used were all subjective and could have been influenced by the performance levels being achieved by the plant. The results obtained are equally consistent with the hypothesis that plant performance influences managers' perceptions of competence levels within the plant.

Statistical analysis of these results provides little evidence of trade-offs between the performance areas studied. However, there is evidence for compatibility between at least some of the performance areas studied. Excellent performance on one measure is more frequently associated with excellent performance on other measures than might be expected by chance. Does this mean that Schonberger is right and Skinner and New are wrong? Before that conclusion can be reached there are a number of difficulties to be overcome.

Firstly there is the problem of the sample size. The total number of plants considered was only 42 and some of the measures used are based on only a proportion of these. The stringent compatibility measure SC(j, G), for example, is based on only a quarter of the plants. Secondly there is the fact that the sample of plants included half who were judged by experts to be world class manufacturers. This is almost certainly higher than the proportion of world class manufacturers in industry as a whole, biasing the results and making it difficult to reach generalisable conclusions. Even if this was not a problem, how consistent are the results with the various trade-off theories?

Schonberger (1986) argues that the distinctive competences that lead to continuous improvement in one performance area are the same competences that lead to improvements in other areas. Schonberger would therefore predict that plants that are leaders in one performance area would also be leaders in the other performance areas. Using the measures considered in this paper, the stringent compatibility measures on all pairs of performance types should be higher than the level expected for independence. 12 out of the 15 pairs of performance types meet this criterion. The 3 exceptions all involve production cost over turnover, suggesting that although the various elements of customer service are mutually supportive, high levels of customer service still involve a cost penalty.

New (1992) and Skinner (1992) have both restated their views on trade-offs in order to provide clarification of their original ideas and to take into account the effect of lean manufacturing. They both argue that trade-offs are dynamic and that relationships between different types of performance can be positive or negative depending on how improvements in performance are achieved. New believes that current improvements in manufacturing plants can simultaneously improve quality consistency, delivery reliability, lead times and manufacturing costs. However, increases in product features, greater product variety and higher rates of new product introduction cannot be achieved without some increase in manufacturing costs. If this is correct we would expect to see high levels of compatibility between all the factors studied with the exception of quality capability, which should exhibit high trade-off levels with the other factors. For both the basic and stringent compatibility/trade-off criteria only 9 of the 15 pairs of factors behave as predicted by this model.

The sand cone model assumes that quality is the prerequisite for all other types of performance, followed by dependability, flexibility and then cost. The measures that match most closely with the measures used in Ferdows and De Meyer's original study are as follows,

Quality	Quality consistency
Dependability	Punctuality
Flexibility	No suitable measure available
Cost	Production cost over turnover

The sand cone model would predict that in this study the average level of stringent compatibility with all other factors will be highest for quality consistency, followed by punctuality and then production cost over turnover. The actual figures are as follows,

Measure	Average of Stringent compatibility measures
Quality consistency	38.2 %
Punctuality	30.0 %
Production cost over turnover	27.8 %

This does seem to provide limited evidence in support of the sand cone model.

2.7.5 RG Schroeder, EJ Flynn, BB Flynn and D Hollingsworth

In their paper, "Manufacturing Performance Tradeoffs: An Empirical Investigation", RG Schroeder, EJ Flynn, BB Flynn and D Hollingsworth present a different trade-off model. They attempt to resolve the apparent conflict between classical economists who argue that, for example, higher quality increases costs and writers like Schonberger who argue that higher quality and lower costs are compatible and do not involve a trade-off. The paper considers four aspects of manufacturing performance: cost, quality, delivery and flexibility. Classical economic theory hypothesises that an improvement in one of these aspects of performance can only be achieved at the expense of one or more of the others. The classic economists' view is based on the assumptions that the firm has limited resources, it is operating at the efficient frontier where no slack resources exist, and the technology is fixed.

Schonberger and others take into account the effects of process improvement. (In other words they do not assume that technology is fixed.) They argue that process improvements can simultaneously lead to higher quality, lower costs and higher levels of on-time delivery.

The authors also consider Ferdow and De Meyer's sand cone model that was discussed earlier in this chapter and is based on the idea that the different aspects of manufacturing performance are sequential and cumulative. They also quote New who argues that whether trade-offs occur or do not occur depends on the context of the situation and the nature of the process improvement.

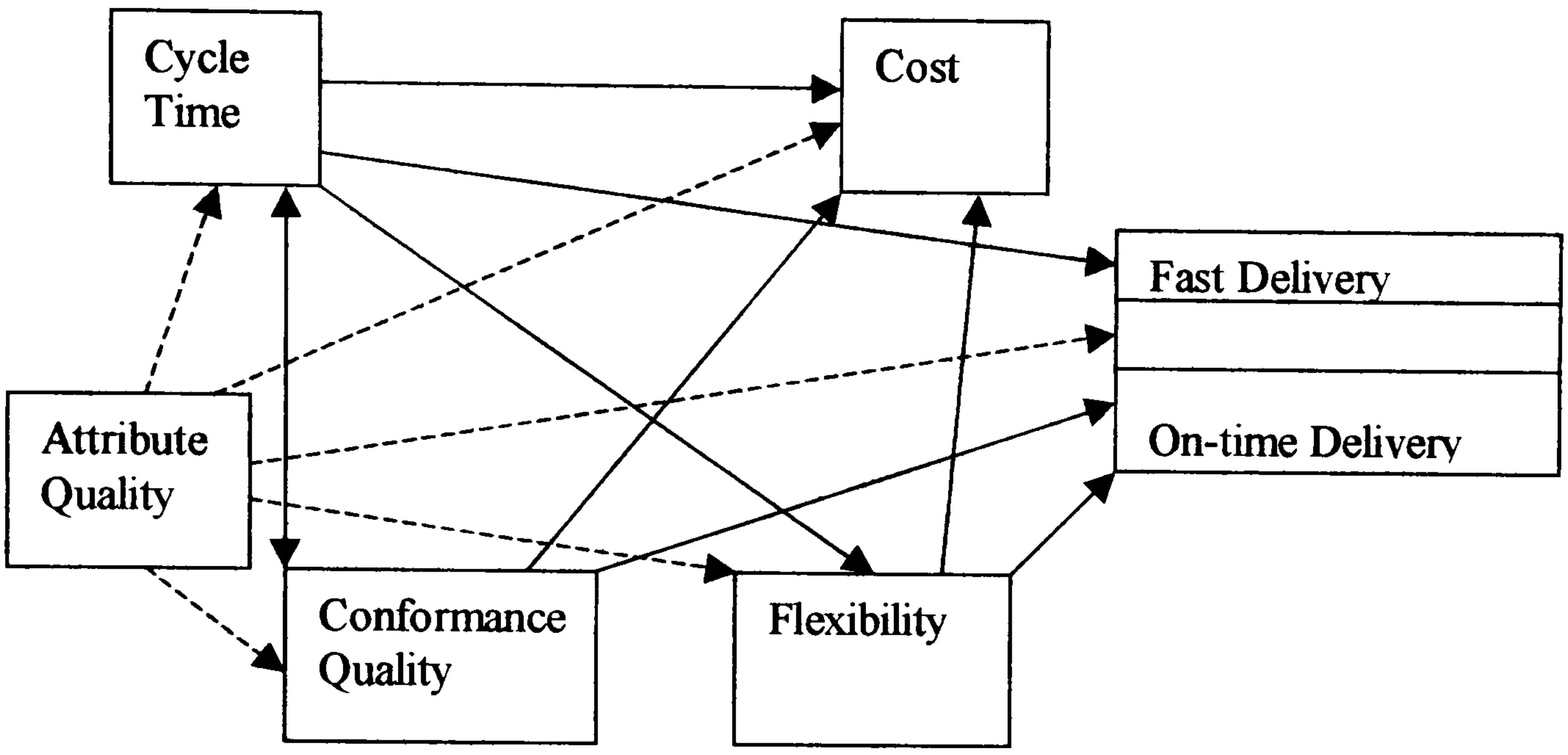
The authors make two points that they believe may, in part, explain the apparent discrepancies between the various theories.

1. Classical economists define quality as a bundle of product attributes (attribute quality) while Schonberger and Ferdows and De Meyer define quality as conformance to specification (conformance quality).

2. The existing theories do not take sufficient account of the role of cycle time (the time from raw materials, through production, to the customer) as a critical variable affecting plant performance.

The authors have therefore developed a new theory of plant performance that they call the "network" theory (see Figure 2.6). Each pair of relationships in the network is classified as either compatible (improvements in both can be accomplished simultaneously) or as trade-offs (improvement in one measure leads to lower performance in the other measure). In fact, the only trade-offs in this model are between attribute quality and everything else. All other relationships are considered to be compatible.

Figure 2.6: Schroeder's Network Model



⟶ Compatible

---▶ Trade-off

Source: Schroeder et al (1996)

This model is rather simplistic and still does not reconcile all of the existing theories. The authors seem to be saying that most pairs of performance measures are compatible under all circumstances whereas New says that it depends on context. Some relationships are shown in the network model as unidirectional, in other words, improvement in the first measure produces improvement in the second measure but not vice versa. This raises the question about whether an improvement in the second measure still involves a trade-off. This raises another question. Does compatibility mean that an improvement in one measure can be achieved without adversely affecting the other measure or does it mean that improvement in one measure is necessarily associated with improvement in the other measure?

The theory was tested using data from 120 plants drawn from the U.S., Japan and Italy. The following measures of plant performance were used.

Cost: Plant Productivity (value added/input costs)
On-time Delivery: Percentage of orders delivered on time
Fast Delivery: Lead time required to fill a customer order

Cycle Time: Time from raw materials through the plant to the final customer
Flexibility: The time fence inside of which no changes are made to the master schedule in either product mix or in volume
Quality Conformance: Percentage of products that arrive at shipping without rework

Attribute quality was not measured.

The network model suggests that the following pairs of variables should exhibit compatibility.

Table 2.11: Pairs of Variables Exhibiting Compatibility

		Dependent	Variable		
Driver	Conformance Quality	Flexibility	Cost	On-time Delivery	Fast Delivery
Cycle Time	Compatible	Compatible	Compatible	Compatible	Compatible
Conformance Quality			Compatible	Compatible	Compatible
Flexibility			Compatible	Compatible	Compatible
Fast Delivery				Compatible	

First the results were standardised by country and industry. (Precisely how this was done is not explained). Then multiple regression analysis was carried out using each variable in the model in turn as the dependent variable and the rest as independent variables. The relationship between each pair of variables was evaluated using a significance level of 0.1 and the following results were obtained.

Table 2.12: Pairs of Variables with Significant Correlations

		Dependent	Variable		
Driver	Conformance Quality	Flexibility	Cost	On-time Delivery	Fast Delivery
Cycle Time	Sig.	Sig.	Sig.	Sig.	Sig.
Conformance Quality			Not Sig.	Sig.	Sig.
Flexibility			Not Sig.	Not Sig.	Sig.
Fast Delivery				Sig.	

In trying to explain why three of the hypothesised relationships are not significant the authors argue as follows.

1. Cost is a difficult variable to measure in cross-industry studies. In fact, they are measuring productivity and they point out that this is likely to be affected by

exogenous factors such as plant size and level of capital investment. They suggest that it might be possible to identify a statistically significant link between cost and conformance quality by comparing plants that make similar products.

2. Flexibility is also a difficult variable to quantify and measure. The measure that they use is based on how far ahead the production schedule is frozen. This has several drawbacks as a measure of flexibility. It takes a very restricted view of the full meaning of flexibility. It could also be misleading. It would not be very surprising, for example, that this measure of flexibility was statistically correlated with cycle time, almost by definition. Also, we know from other research (Mapes, New and Szwejczewski, 1997) that there is a positive correlation between adherence to schedule and these other measures of performance. Do plants with high levels of adherence to schedule lack flexibility or is it that they possess flexibility but through good management only need to make use of it rarely? The authors imply that their measure of flexibility is unsatisfactory by suggesting an alternative, average machine set-up time. Again, this takes into account just one aspect of total flexibility.

In common with many writers on the subject of trade-offs, the authors fail to define their variables very precisely and make no attempt to explain the mechanisms whereby a change in one variable should lead to the change predicted for another variable.

2.8 Summary of the Literature on Trade-offs

There is still considerable conflict in the literature about whether trade-offs between operating performance measures do or do not exist. Much of this apparent conflict seems to be a consequence of some writers taking a short-term perspective and others taking a longer-term perspective.

In the very short-term the only way to reduce the number of defective items reaching the customer might be to add an extra inspection stage at the end of the manufacturing process. This should have the desired effect but it would also increase costs and extend lead times. This corresponds to the seesaw effect in Slack's model. In the longer-term the source of the defects could be identified and the manufacturing process modified to prevent the defect occurring in the first place. This should also have the desired effect but would also result in less scrap and rework. This, in turn, would reduce costs and shorten lead times. This corresponds to an upward movement in the pivot in Slack's model.

Amongst those authors who accept the possible existence of trade-offs there is no general agreement on which performance measures involve trade-offs and which do not. This is not entirely due to the methodological flaws that have been identified in some papers. It is also dependent on the context-dependence of the various trade-offs. As can be seen from the example in the previous paragraph, the nature of the action taken in order to achieve an improvement in one performance measure will affect whether the impact on other performance measures is positive, negative or zero.

Clearly, this context-dependence is very important to practitioners. Given a choice of actions that would all improve one performance measure they are likely to prefer the one that will also improve other performance measures or, at least, not have an adverse effect on other performance measures. In order to be able to do this, practitioners need to have a better understanding of the mechanisms whereby a given action leads to an improvement in performance. Practitioners also need a better understanding of the mechanisms whereby the various performance measures interact. Unfortunately there is little in the literature on the possible nature of these mechanisms.

2.9 Conclusions

The question of how best to achieve improved levels of operating performance is clearly very important to practising operations managers. Not only do they need to understand which are the most effective ways of achieving permanent improvements in performance, but also they need to understand the compromises that might be involved in terms of some measures of performance. In order to assist such managers the answers to five broad research questions are needed.

1. What are the differentiating characteristics that enable manufacturing plants to achieve higher operating performance than comparable plants?
2. What are the mechanisms whereby these characteristics lead to higher levels of operating performance?
3. In a given context, which pairs of operating performance measures are likely to be negatively correlated, exhibiting a classic trade-off relationship?
4. In a given context, which pairs of operating performance measures are likely to be positively correlated, so that improvements in one measure are accompanied by improvements in the other measure?
5. In a given context, which pairs of operating performance measures are likely to be uncorrelated so that improvements in one measure can be achieved without there being any effect on the other performance measure?

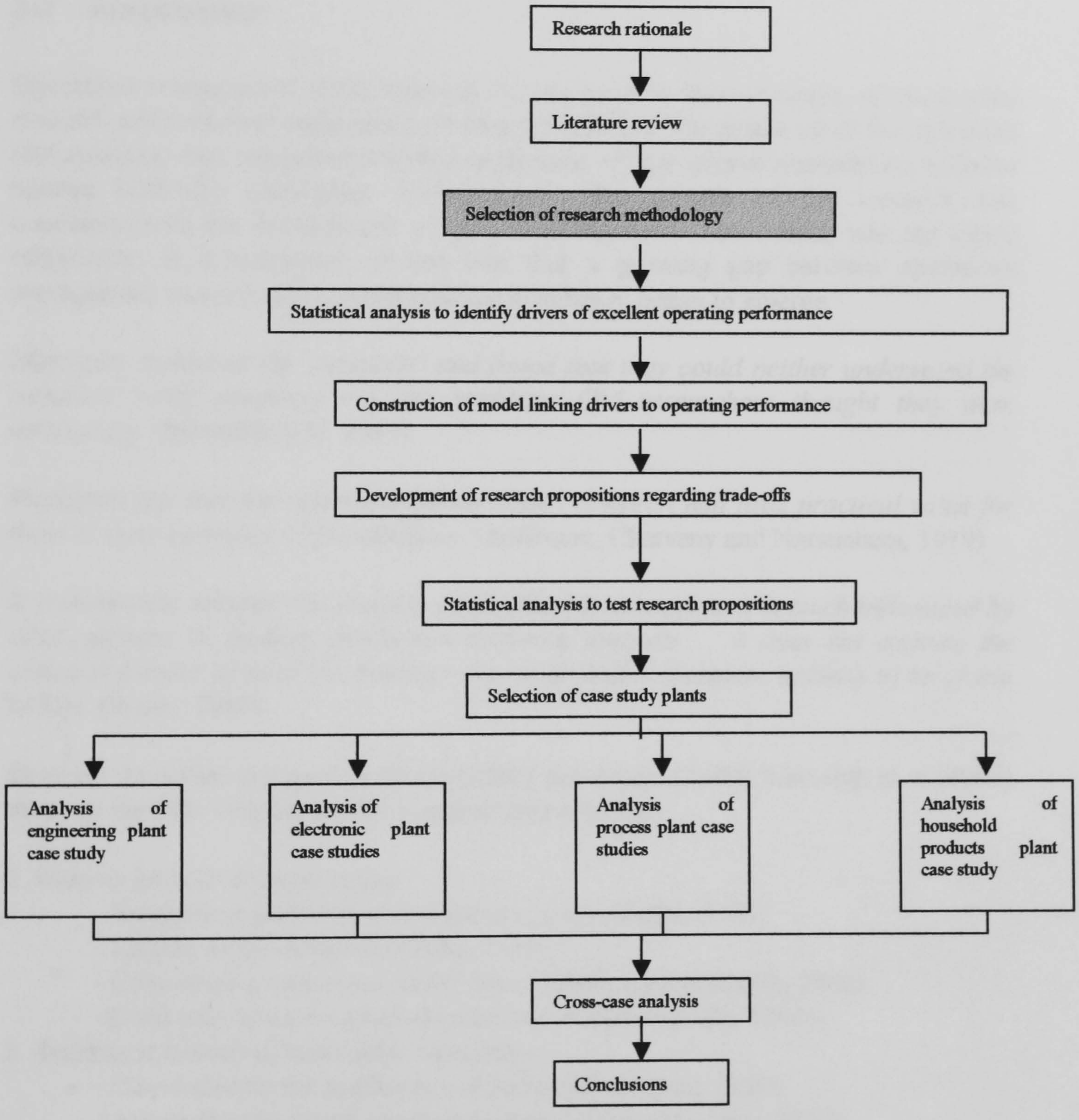
While some research has been carried out with regard to each of these questions, the results are often conflicting. Also several of the research investigations in this area have included methodological errors. Others have relied on anecdotal evidence in which selected examples have been used to provide support for the views of the writer. The research described in this thesis will attempt to address these questions using a more objective and rigorous approach based on statistical analysis.

Chapter 3 : Proposed Research Method

3.1 Summary

Figure 3.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In the previous chapter the literature on the drivers of manufacturing performance and the various trade-off theories was reviewed and a number of research questions were identified. In this chapter a methodology for addressing these research questions is presented. First the various critiques of the deficiencies of operations management research in the literature are reviewed. Then various alternative approaches to operations management research are discussed and the choice of a deductive-inductive approach is justified. Using the framework for theory development proposed by Hofer and Schendel (1978) a methodology for this research is presented. The difficulties encountered in survey-based research are discussed and the use of the Best Factory Awards database is justified. Finally, the specific measures of performance to be considered in this research are discussed.

3.2 Introduction

Operations management (OM) research has its roots in the techniques of operational research and industrial engineering. During the 60s and 70s almost all of the published OM research was concerned with the application of operational research/management science (OR/MS) techniques. Unfortunately, the majority of this research was concerned with the development of theoretical models whose validity was not tested empirically. A consequence of this was that a growing gap between operations management research and current practice in industry began to emerge.

Managers looked at the 'research' and found that they could neither understand the solutions being proposed nor the problems OM researchers thought they were addressing. (Meredith et al, 1989)

Managers felt that the existing implementation research had little practical value for them in their everyday responsibilities. (Anderson, Chervany and Narsunham, 1979)

It is debatable whether the practice of production management is much influenced by what appears in leading production research journals ... it does not capture the essential flavour of what the manager has to do and is therefore unlikely to be of use to him. (Busey, 1984)

Drawing on earlier critiques by Buffa (1980) and Chase (1980), Meredith et al (1989) drew up the following list of OM research shortcomings.

1. Narrow instead of broad scope
    - Focused on problems with a narrow scope (Buffa, 1980)
    - Largely micro-oriented (Chase, 1980)
    - Concerned a subsystem rather than a whole system (Buffa, 1980)
    - Used only a single-criterion quantitative model (Buffa, 1980)
2. Technique instead of knowledge orientation
    - Dominated by the application of techniques (Chase, 1980)
    - Assumed to be simply applied operations research (Voss, 1984)
3. Abstract instead of reality perspective
    - Used approaches largely confined to the laboratory and based on model formulation and manipulation (Chase, 1980)

- Emphasised equipment rather than people (Chase, 1980)
- Rarely involved field studies (Chase, 1980)

As a result of the lack of relevance of OM research, the new and innovative ideas in the field of OM have tended to come from the practitioners themselves or from consultants.

Chase and Prentis (1987) observed that

The practitioner literature has frequently led the way in identifying significant topics for OM research and in providing new terminology to label particular aspects of the field ... for example, material requirements planning (MRP) was widely discussed in the practitioner literature before any academic research was done on the subject. Likewise, just-in-time (JIT), flexible manufacturing systems (FMS) and optimised production technology (OPT) were hot topics among practitioners before they became widely studied research issues.

Storey (1994) in "New Wave Manufacturing Strategies" says that operations management research has continually lagged behind actual developments. McCutcheon and Meredith (1993) have found growing disparities between widely held operations management assumptions and real conditions.

In addition, writers are often publishing conclusions based on a few highly selective examples. Brown and Mitchell (1991) stated that research conclusions in operations management were largely based on anecdotal evidence.

In 1981 Miller, Graham et al (1981) drew up an agenda for OM research that incorporated the views of leading scholars in the area. The stimulus to develop this agenda was their view that

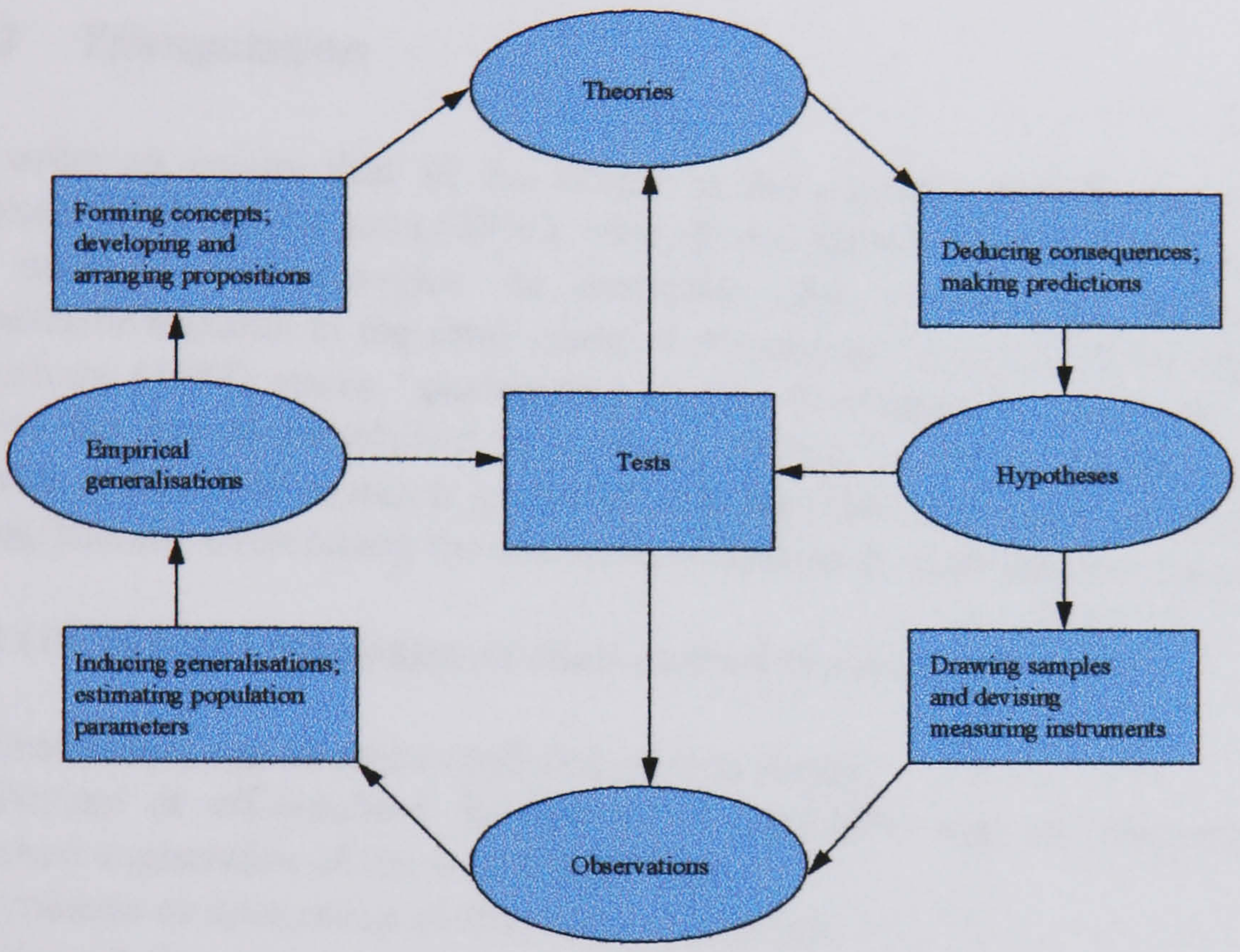
The research directions and techniques in use throughout the field [of OM] appeared to be widening the gap between what was perceived to be the most important to operations managers and what P/OM had to offer.

They advocated a greater focus on the problems of most concern to practising managers with research being firmly based on empirical data. Swamidass (1991) returned to this theme, emphasising the importance of formal, empirical theory building to operations management. He analysed 221 OM articles published in 1987 and found that 85% of them involved the use of operational research/management science, using deductive methods. Only 11% of the articles involved field-based research.

He pointed out that although deductive research has made a significant contribution to OM research in the areas of scheduling, planning and inventory control, the danger with deductive methods is that incorrect conclusions can be logically derived from incorrect starting premises. He advocated the inductive-deductive method generally attributed to Charles Darwin (1859) who used this approach in developing his theory of evolution.

Induction involves the development of general hypotheses from observation of particulars. Deduction involves drawing conclusions about particular instances from general statements. Wallace (1971) has shown diagrammatically how these two approaches can be combined. This is illustrated in Figure 4.1.

Figure 3.2: The Inter-relationship between Inductive and Deductive Strategies



Source: Wallace (1971)

Other writers have developed from this the concept of analytic induction. Ragin (1987) defines this as "any systematic examination of commonalities that seeks to develop concepts or ideas across a limited number of cases." Katz (1982) has suggested that researchers need to work back and forth between theory and evidence, trying to achieve a "double-fitting" of explanations and observations. Observed relationships between phenomena lead to postulation of the existence of structures or mechanisms that, if they existed, would explain the relationships. These are then tested by further research activities designed to isolate or observe these relationships, or to eliminate alternative explanations of the observed phenomena. Meredith, Raturi, Amoaka-Gyampah and Kaplan (1989) found that failure to follow this cyclical, iterative process leads to the following problems in OM research.

1. Failure to provide possible explanations of the causes of the observed data, leading to black boxes with no understanding of the phenomena being observed.

2. Failure to test the validity of the theories being presented, leading to "war stories", where each new explanation takes the field in a new direction.
3. Ignoring the descriptive phase, leading to ivory tower prescriptions disconnected from reality.

They conclude

OM research has failed to be integrative, is less sophisticated in its research methodologies than the other functional fields of business, and is, by and large, not very useful to operations managers and practitioners.

3.3 Triangulation

In order to ensure that all the stages in the research process are covered, several authors (Gill and Johnson (1991), Mitroff and Mason (1982)) have suggested the use of multiple methodologies. In particular, the combination of quantitative and qualitative research in the same research programme is seen to have many advantages. Firestone (1987) states "quantitative studies de-emphasise individual judgement and stress the use of established procedures, leading to more precise and generalisable results. Qualitative research produces rich depiction and strategic comparison across cases, thereby overcoming the abstraction inherent in quantitative studies."

Jick (1979) lists 4 advantages of multi-method research.

1. Researchers can be more confident of their results.
2. Deviant or off-quadrant dimensions of a problem may be uncovered, leading to enriched explanation of the research problem.
3. Synthesis or integration of theories is facilitated.
4. Triangulation may serve as the critical test, by reason of its comprehensiveness, for competing theories.

3.4 The Nature of the Research Process

Meredith, Raturi, Amoaka-Gyampah and Kaplan (1989) state that research has two purposes, to propose knowledge (explanation) and to validate knowledge (testing). In order to achieve these two objectives, research involves a continuous, repetitive cycle of description, explanation and testing (through prediction).

3.4.1 Description

Descriptive research assembles and organises the elements of specified situations and events in order to produce a well-documented and structured presentation of the subject of interest. Monden's (1981a) description of the Toyota Production System is a good example of this. Good descriptive research can then be used to generate theories about the situation described which can then be tested.

3.4.2 Explanation

From the results of descriptive research some initial concepts about the situation may be postulated.

Meredith, Raturi, Amoaka-Gyampah and Kaplan (1989) suggest that these postulates could take any of the following forms

- Hypotheses on action-reaction or cause-effect relationships
- Construction of a more complex set of reactions or relationships to explain the observed behaviour
- Construction of a framework to explain the dynamics of the situation
- Development of a theory describing the principles operating in a situation

3.4.3 Testing

This involves testing the concepts developed at the explanation stage to determine which are correct. This usually involves making a prediction based on the explanation and then making observations to determine whether the prediction is correct. Inconsistencies between predictions and observations are then used to modify and extend the theories developed at the explanation stage and the process is repeated.

Meredith (1993) has criticised failure to complete this iterative cycle of description, explanation and testing with many researchers proposing theories based on inadequate data and then failing to test their theories.

3.5 A Framework for Research Paradigms

Meredith, Raturi, Amoaka-Gyampah and Kaplan (1989) have developed a framework of alternative paradigms for operations. This is shown in Figure 4.2.

Figure 3.3: A Framework for Research Methods

Natural ◄——————————————► Artificial

		Direct Observation of Object Reality	**People's Perceptions of Object Reality**	**Artificial Reconstruction of Object Reality**
Rational	Axiomatic			- reason/logic/ theorems - normative modelling - descriptive modelling
	Logical positivist/ Empiricist	- field studies - field experiments	- structured interviewing - survey research	- prototyping - physical modelling - laboratory experimentation - simulation
	Interpretative	- action research - case studies	- historical analysis - Delphi - intensive interviewing - expert panels - futures/scenarios	- conceptual modelling - hermeneutics
Existential	Critical Theory		- introspective reflection	

Source: Meredith, Raturi, Amoaka-Gryampah and Kaplan (1989)

3.5.1 The rational/existential dimension

This dimension is concerned with the epistemological structure of the research process. At one extreme there is the rationalist approach in which advances in knowledge are achieved through pure logic. At the other extreme there is existentialism in which advances in knowledge are achieved through consideration of the individual and his/her interaction with the environment.

3.5.2 The natural/artificial dimension

This dimension is concerned with the nature of the information used in the research. At the natural end of this spectrum of possibilities there is direct observation of objective reality. At the artificial end there is the artificial reconstruction of reality, usually involving techniques like modelling and simulation. Between these two there is an intermediate category involving people's perceptions of reality.

3.6 Summary of the Literature on Operations Management Research

The following criticisms have been made about the bulk of published operations management research.

1. It did not address the real problems of OM practitioners.
2. It focused on the application of techniques rather than the solution of problems.
3. It was largely based on theoretical modelling and simulation rather than field studies.
4. Research conclusions were frequently based on anecdotal evidence.

Two common approaches used in research are deduction and induction. Deductive research involves the logical derivation of conclusions about the results to be expected in specific instances from a set of initial premises. Inductive research involves the development of general hypotheses from observation of particulars. Wallace (1971) has suggested that these two approaches can be combined into a single, iterative approach that he called deductive-inductive research. Observation is used to identify general premises, which in turn, are used to develop postulated structures or mechanisms. These are then used to make predictions about behaviour, which are tested by further observation. This leads to modification of the general premises and the process is repeated.

Several authors (Mitroff and Mason, 1982; Gill and Johnson, 1991) have suggested the use of multiple methodologies in research. This enables triangulation, the confirmation of results based on one methodology through the use of a different methodology.

3.7 The Proposed Research Methodology

The research being proposed will try to adopt the deductive-inductive approach. Observation of the characteristics of a large number of plants will be used to identify a set of general premises about their behaviour. These premises will then be used to develop an explanatory model of the underlying mechanisms. This model will be used to predict the behaviour of individual plants and these predictions will be tested by further observations of individual plants.

Hofer and Schendel (1978) suggest that theory development evolves through 5 stages.

1. Exploration
2. Construct development
3. Hypothesis generation
4. Hypothesis testing for internal validity
5. Testing for external validity

The current research will try to follow the same series of stages using a database of information on 953 UK manufacturing plants.

1. Exploration

In the exploratory stage the database will be used to identify those characteristics that differentiate high performance plants from low performance plants. Plants will be divided into three equal-sized groups based on their overall operating performance. The plants in the highest performance group will then be compared with the plants in the lowest performance group on a large number of factors. Those factors for which the difference between the means for the two groups is significant at the 0.001 level will be identified.

2. Construct development

The results of this analysis will then be combined with the exploratory work of other researchers on the key factors that lead to high levels of plant performance and a tentative model will be proposed attempting to explain the precise mechanisms by which these key factors lead to high performance levels.

3. Hypothesis generation

A set of testable research propositions will then be developed about the nature of trade-offs between the various performance measures that would be predicted by the model.

4. Hypothesis testing for internal validity

Statistical analysis will then be used to test these propositions for the plants in the database. This will be done using correlation analysis. For the complete set of plants, the correlation coefficients for each pair of performance measures will be calculated and compared with the correlation predicted by the model developed in Step 3.

5. Testing for external validity

Finally, in order to test for external validity, a number of plants will be visited in order to establish whether the general conclusions derived from analysis of the database are consistent with what is observed in individual plants. At each plant visited, managers responsible for purchasing, planning and production will be interviewed. The interviews will be used to explore the factors at each plant that have the most influence on operating performance and the nature of the trade-offs between the elements of operating performance at that plant. In addition, the operating data for each plant will be analysed in order to determine the extent to which each plant possesses the characteristics differentiating high and low performance plants that were identified in Step 1.

The information to be used in the data analysis part of the research is the UK Best Factory Award database for the period 1993-96. This database contains information on 953 different manufacturing plants participating in the competition to select the Best Factory in the UK during each of the years 1993-96. This competition is organised by *Management Today* and is administered by the Cranfield School of Management. Each plant wishing to take part completes a 14 page questionnaire providing a comprehensive profile of each plant's characteristics and performance. This is the source of the information contained in the database. The contents of the questionnaire are included as Appendix 9.

As New and Szwejczewski (1995) have pointed out, there are a number of difficulties encountered in survey-based research.

1. Questions can be ambiguous or biased.

The careful initial design of the Best Factories Award data and its refinement over several years of use should ensure that any ambiguous or biased questions have been eliminated. However, some of the technical terms used in the questionnaire may be defined or interpreted in different ways in different organisations. As far as possible, data is collected at a disaggregated level. For example respondents are not required to report their stock-turns. Instead they are asked for the actual stock quantities that they hold expressed in value terms and in weeks' usage. This reduces the chances of the results being distorted by different methods of calculation in different organisations. In those instances when the use of aggregated data is unavoidable, the method of calculation of the aggregated value is clearly specified in the questionnaire.

2. The size of the sample is often too small.

Survey sample sizes are often so small that few statistically significant conclusions can be reached. This is a particular problem when the sample is broken down into sub-samples. The data being used from the Best Factory Award database includes 953 different plants. For some aspects of the analysis these will be divided into 6 industrial categories. This will still give an average of 159 plants in each category.

3. Survey participants may not be representative of the parent population.

Inevitably the plants participating in a competition of this kind are likely to be above average performers. Consequently, the absolute performance levels of these plants will probably be untypical of the total population of manufacturing plants in the UK. However, this research is concerned with testing the proposition that the achievement of excellence on one performance measure affects the likelihood of achieving high levels of performance on other measures. The Best Factory Award plants should contain a higher proportion of plants achieving excellence on at least one performance measure than would be the case for a completely random sample. The data being used should therefore be suitable for the hypotheses being tested although the results relating to average levels of performance should be interpreted with care in drawing conclusions about the total population of manufacturing plants in the UK.

4. The units being reported on by different respondents may not be comparable.

In some surveys, for example the Global Manufacturing Futures Survey (De Meyer and Ferdows, 1988, 1991) the units being reported on by different respondents may vary considerably. Units might range from a single manufacturing plant to a multi-national company with a number of manufacturing sites located in different parts of the world. This makes comparative analysis very difficult. Each respondent in the Best Factory Awards database is reporting on a single manufacturing plant, regardless of the size of the parent company.

There is a further problem with surveys covering a variety of industries. Differences in the characteristics of the various industries included may obscure and distort the effects being studied. This can never be eliminated completely as all units studied are to some extent unique. In order to ensure that, as far as possible, like was being compared with like, the data was sub-divided into 6 industrial categories and comparisons were made only between plants in the same industrial category.

5. The data often includes inaccuracies and errors.

It is possible that, in order to be short-listed for an award, respondents might not be totally honest, reporting levels of performance higher than those actually being achieved. This is unlikely for two reasons. Firstly, short-listed plants are visited by the judges who verify whether their questionnaire entries are correct. The participants are told that any plants with serious discrepancies between reported and actual performance will be severely penalised. Secondly, the participants receive a benchmarking report comparing their performance with other plants in their industry. This will only be of value if their own responses are accurate. The evidence for the plants visited so far is that the accuracy of the questionnaire data is extremely high.

Another problem with a database that has been prepared by transcribing information from questionnaires is that there will be many errors due to mis-typing or mis-reading the hand-written information in the questionnaires. Before any statistical analysis was carried out the database was carefully checked. All entries that were invalid because they lay outside the range of entries permitted were checked and corrected. Entries that appeared unusually high or low were queried with the compilers. If it was found that there had been a genuine transcription error then the entry was corrected. If the entry on the original questionnaire was found to match the original questionnaire then it was allowed to stand. It was not considered feasible for the author to contact the person who filled in the questionnaire as the participants had been promised anonymity. Their identities were known only to the Best Factory Award Co-ordinator.

6. Use of secondary data.

There are always difficulties in taking data collected for one purpose and trying to use it for a quite different purpose. In this case, although the award and benchmarking aspects are there to encourage participation, the primary purpose of the venture is to provide a reliable database for research purposes. Having said this, the questions asked in a generic questionnaire never quite match the questions that would have been asked in a purpose-designed questionnaire and some compromises had to be made in the selection of data to test the research hypotheses. This was more than compensated for by the size and richness of the database.

It was therefore felt to be justifiable to use the database for the purposes of this research. Because of the shortcomings of survey-based research discussed above it was also considered necessary to carry out a separate study based on visits to 6 plants in order to check that the characteristics of these plants matched the predictions derived from the survey results.

3.7.1 The performance measures to be used

The following aspects of performance were considered in the analysis of the database results.

Area of performance	Measure used
Manufacturing cost	Manufacturing added value per £ of employee cost
Quality consistency	Customer returns as a percentage of output
Lead time	Average lead time quoted to customer
Delivery reliability	% of items delivered on time
Product variety	Number of different products made in the past year

3.7.2 Reasons for the selection of these measures

3.7.2.1 Manufacturing cost

All of the models of the interactions between performance measures include manufacturing cost as one of those measures. They hypothesise that plants making similar products will have different manufacturing costs depending on their performance on quality consistency, speed and reliability of delivery, etc. The problem with the approach to research being adopted in this thesis is that it is difficult to identify plants with similar products due to the need to protect the anonymity of the plants in the database. While a brief description of the products manufactured by each plant is provided, this is insufficiently detailed to enable plants with genuinely similar products to be identified.

Low manufacturing costs do not necessarily result from operating efficiency. They may be a result of the simplicity of the product being manufactured, the volume being produced or the cheapness of the raw materials. Using total annual manufacturing cost as a measure of operating efficiency would therefore be unrealistic, as would manufacturing cost per unit of output. There are two ways in which a measure of operating efficiency can be obtained from the BFA database.

a) Respondents were asked to indicate how the unit manufacturing cost for the product with the largest output had changed over the previous two years. Respondents were required to select one of 9 categories ranging from a decrease of more than 20% (category 1) to an increase of more than 20% (category 9).

This might seem to provide a good measure of the effect of changes in other performance measures on manufacturing costs. However, the changes that have occurred could just as easily be due to inflation, changes in raw material costs or changes in the proportion of bought out materials and components. If this measure were to be used it would need to be related to changes in the other performance measures rather than their absolute values.

b) Manufacturing added value per employee £ could be used. This is calculated by dividing all manufacturing costs other than the costs of bought out materials and services by labour costs. It is, in fact, a measure of labour productivity. An increase in output with no increase in labour or achievement of the same output with less labour will both lead to an increase in manufacturing added value per employee £ but if material wastage is reduced then the measure will be unchanged. If energy costs are reduced then added value per employee £ actually falls.

Due to the difficulties of calculating a measure of manufacturing cost that enables comparisons between different plants, manufacturing added value per employee £ has been used in this analysis but it must be remembered that, strictly speaking, this is only a measure of labour productivity.

3.7.2.2 Quality consistency

The questionnaire provides the following measures of quality consistency.

Table 3.1: Measures of Quality Consistency

Variable	Description
G52	% Scrap or % below ideal yield rate last year
G53	% Scrap or % below ideal yield rate in current year
G62	% of capacity used for reprocessing
G82	% Customer returns or complaints last year
G83	% Customer returns or complaints in current year
G92	% First time pass rate at final test

As this research is concerned with trade-offs between external measures of plant performance then the most appropriate measure would seem to be G83, % customer returns or complaints in the current year. It seems sensible to always use the most recent measure of performance where there is a choice.

3.7.2.3 Delivery reliability

Plants measure delivery reliability in two ways depending on whether they meet customer requirements directly from finished goods stock or manufacture to order. Questions on both measures are included in the questionnaire.

Table 3.2: Measures of Delivery Reliability

Variable	Description
G3A2	% Service level ex-finished stock last year
G3A3	% Service level ex-finished stock in current year
G3B2	% Delivery on time last year
G3B3	% Delivery on time in current year

Most plants measure both ex-stock service level and delivery on time as some products are made to order and others are supplied from stock. Others use just one of the two measures. As both measures are aspects of delivery reliability, both might have been used in the analysis. However, the two measures have different characteristics. Plants that make for stock are, to some extent, de-coupling the relationship between delivery performance and most of the other aspects of performance. Ex-stock performance will be almost entirely a function of the plant's ability to predict customer requirements and the amount of finished stock that they hold. Percentage delivery on time is much more directly affected by the other aspects of plant performance and so this was the measure that was used. Again it was felt to be most appropriate to use % delivery on time for the current rather than the previous year.

3.7.2.4 Speed of delivery

In the model that has been developed in this thesis, speed of delivery is the length of time between receiving a customer order and delivering the goods to the customer. The questionnaire provides three measures of this.

Table 3.3: Measures of Speed of Delivery

Variable,	Description
B51	What is the shortest lead time quoted to customers in days?
B52	What is the average lead time quoted to customers in days?
B53	What is the longest lead time quoted to customers in days?

It could be argued that a more appropriate measure would have been based on actual customer lead times being achieved. It was felt that this could confuse speed of delivery and reliability of delivery. Customers choose suppliers on the lead time quoted (speed of delivery) and the likelihood of that lead time being achieved (reliability of delivery). For this research, therefore, B52, average customer lead time quoted was used. The average was used as it represented the most typical customer lead time for that plant.

3.7.2.5 Product variety

There are 4 variables in the questionnaire that relate to product variety.

Table 3.4: Measures of Product Variety

Variable	Description
B3A1	Total items currently live (in use) within the plant at product level (as sold to customers)
B3C1	Over the last year, how many products were in continuous production in the plant? (Runners)
B3C2	Over the last year, how many different product types (of known design) were produced intermittently in the plant? (Repeaters)
B3C3	Over the last year, how many different product types (of initially unknown design) were produced intermittently in the plant? (Strangers)

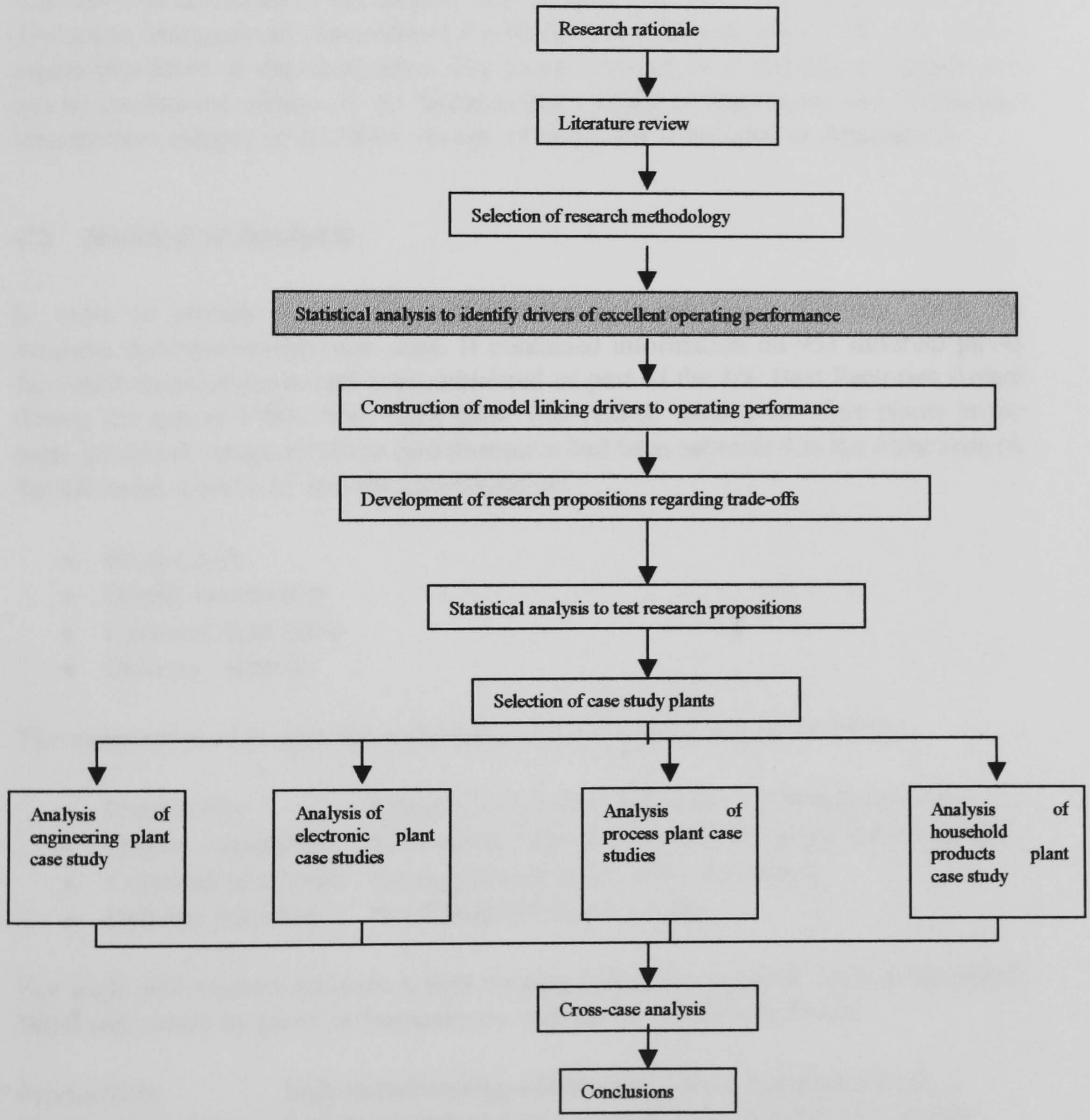
It might seem most appropriate to use B3A1; total different products currently "live" in the plant as the measure of product variety. However, analysis of the responses in the database suggested that this question had been interpreted in different ways by some of the respondents. Some interpreted it as the number of different products physically being manufactured at the moment that the questionnaire was being completed. Others interpreted it as the total catalogue of products that the customer could ask for even though some might be requested very infrequently. It was felt that there could be no ambiguity about the total number of different products manufactured in the last 12 months and this probably better represents the level of complexity that the planners and workforce have to cope with. Consequently, the sum of variables B3C1, B3C2 and B3C3 was used as a measure of product variety within the plant.

Chapter 4 : Identification of the Factors Differentiating High and Low Performing Plants

4.1 Summary

Figure 4.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In the previous chapter the available approaches to operations management research were reviewed and the proposed methodology for this research was presented. In this chapter the first stage of that methodology is presented. It involves the use of statistical analysis to identify differences in the characteristics of high and low performance plants. On the basis of their overall operating performance the plants are divided into 3 equal sized groups of high, medium and low performers. For the complete set of questionnaire variables in the database the means of the high and low performance groups are compared and those variables for which the difference is significant at the 0.001 level are identified. These significant variables are then analysed and 9 propositions regarding the differences between high and low performance plants are identified.

The material contained in this chapter was presented at the 5th International EurOMA (European Management Association) Conference in Dublin in June 1998. Out of 105 papers presented at the conference, this paper was one of 7 selected to appear in a special conference edition of the International Journal of Operations and Production Management (Mapes et al, 2000). A copy of this paper is included as Appendix 8.

4.2 Method of Analysis

In order to identify factors that differentiate high and low-performing plants the database described earlier was used. It contained information on 953 different plants for which questionnaires had been submitted as part of the UK Best Factories Award during the period 1993-1996. Each plant was ranked relative to other plants in the same industrial category whose questionnaires had been submitted in the same year on the following aspects of operating performance.

- Productivity
- Quality consistency
- Customer lead times
- Delivery reliability

The measures used to quantify each aspect of performance are shown below.

- Productivity — manufacturing added value per £ of employee cost
- Quality consistency — % customer returns or complaints in the last 12 months
- Customer lead times — average lead-time quoted to customers
- Delivery reliability — % of items delivered on time

For each performance measure a high ranking (close to 1) meant good performance. What was meant by good performance on each factor is indicated below.

Productivity	high manufacturing added value per £ of employee cost
Quality consistency	low % customer returns or complaints in the last 12 months
Customer lead times	low average lead-time quoted to customers

Delivery reliability high % of items delivered on time

The four rankings were then added to give a composite performance score (COMP) with all measures being given the same weighting. The value of this composite performance score was then used to divide the complete set of plants into three equal-sized groups of high performers, medium performers and low performers. The values of the COMP scores necessary to ensure that the three groups were of equal size were as follows.

Group 1 (high performers): COMP<173.6
Group 2 (medium performers): COMP between 173.6 and 238.0
Group 3 (low performers): COMP>238.0

4.3 Validation of the Database

Inevitably, with such a large database, some errors could be expected when transcribing the entries from the questionnaires to the database. Therefore, before any analysis was carried out, a sanity check was carried out on the data. First, entries that were outside the permitted range or did not match the allowed responses were identified. Three examples are given below.

1. Question A3 asks, "Does your total number of company employees exceed 500? Only two responses were permitted: 1 for Yes and 2 for No. Entries of 9 and 11 were found.
2. Question B2 asks "What proportion of the plant's output (at manufacturing cost) falls into the following categories: capital goods; intermediate goods; and consumer goods. The sum of these three did not always add up to 100%.
3. Question B4(b) (iii) asks "How many hours per week does the component or bulk manufacture part of the plant normally work?" This entry sometimes exceeded 168.

Errors of this type were nearly always due to incorrect transcription or mis-interpretation and were corrected by reference back to the original questionnaires.

Next, each entry was compared with the mean value for that variable and all those that differed by more than 4 standard deviations from the mean were identified. Again, many of these were found to be transcription errors and could be corrected by referring back to the original questionnaires. A common mistake was to enter a zero instead of leaving the entry blank. However, quite a number of these unusual entries were not transcription errors. This left two possibilities. Either the entry, although exceptionally large or small, was correct or an error had been made by the person filling in the questionnaire. Two examples are given below.

1. Question B10(c) asks, "What is the current overall delivery performance (% on time) of your suppliers?" One entry was 2% and might have been the percentage of suppliers delivering late.

2. Question G5 asks, "What is the % scrap or % below the ideal yield rate?" One entry was 98.6% and could have been the percentage of output that was not scrap.

While it would have been theoretically possible to query each of these entries with the plants concerned it was not possible to do this in practice. All plants participating in this exercise are guaranteed anonymity. Once the entries have been transferred from the questionnaires to the database it is not possible to identify the individual plants. The questionnaires themselves are only identified by a reference number. Only two people have access to the file, which identifies the plant associated with each reference number, and it would have been unrealistic to expect either of them to undertake the time-consuming task of checking every dubious entry with the plant concerned.

It was decided that to arbitrarily exclude entries because they were unusual would be dangerous and highly subjective. It was assumed therefore that all entries recorded on the questionnaires were correct unless they were clearly infeasible. An example of this would be an entry of 999 when the maximum possible value was 100%. Infeasible entries were treated as blank entries, the rest were included. There was still the worry that these unusual entries, if incorrect, could distort the statistical analysis and lead to incorrect conclusions being reached. Therefore, as a safety check, the statistical analysis carried out in this research was repeated using data from which all entries more than 4 standard deviations from the mean had been excluded. The results of this analysis are included in Appendix 3. Although the actual numerical values obtained are slightly different the conclusions that can be reached with regard to the propositions being tested are the same.

4.4 Analysis of Results

For the complete set of questionnaire variables in the database the means and standard deviations of each questionnaire variable were calculated for each of the three groups. Differences between each of the three pairs of means were then tested for significance. The complete set of results is in Appendix 4. (An index of the meaning of the variables is included as Appendix 2). Those variables for which the high and low performance groups showed highly significant differences in the means were then identified.

As the basis for classifying the plants into three categories was COMP which is a composite measure of each plant's ranking on quoted lead times, customer returns, delivery reliability and manufacturing added value per employee £ it is no surprise that there are significant differences between the high and low performance plants for the individual rankings on which COMP is based. These are shown below.

Table 4.1: Performance Rankings that Show Significant Differences

Description	Z value	Significance
Ranking on lead time	14.67	0.0000
Ranking on due date performance	12.51	0.0000
Ranking on added value per employee £	10.88	0.0000
Ranking on customer returns	5.77	0.0000

Again, not surprisingly, the absolute measures that underlie the performance rankings in COMP are also significant.

Table 4.2: Absolute Values of Ranked Performance Measures

Description	Z value	Significance
Added value	4.98	0.0000
Customer returns	-2.42	0.0176
Average customer lead time	-5.73	0.0000
Due date reliability	9.17	0.0000

While not a direct basis for the rankings, the following performance measures would also be expected to be different for the high and low performance groups of plants purely as a consequence of the way the groups were constructed.

Table 4.3: Variables Indirectly Linked with Ranked Performance Measures

Description	Z value	Significance
Shortest customer lead time	-3.81	0.0001
Longest customer lead time	-5.96	0.0000
Av. assembly lead time	-4.66	0.0000
Longest assembly lead time	-4.73	0.0000
% On time delivery last year	7.29	0.0000

What is of more concern to this analysis is the identification of other significant differences between the groups that are not a consequence of the classification method.

After excluding the above variables the remaining variables were analysed. The means for the high and low performance groups were compared and all of those differences that were significant at the 0.001 level were identified. The reason for using this level of significance is because a total of 187 variables are being evaluated. Use of a less stringent level of significance might result in some variables being incorrectly included in the list, the apparent difference in the population means being due to sampling error. The significant variables are summarised in descending order of significance in table 4.4.

Table 4.4: Variables that are Significantly Different for High and Low Performance Plants

Description	High Performance Group Mean	Low Performance Group Mean	Z Value of Difference	Significance of Difference in Means
Plant's subjective ranking on process dependability	8.13	6.95	6.72	0.0000
% Scrap rate in current year	1.66	9.23	-6.56	0.0000
Plant's subjective ranking on throughput efficiency	7.92	6.77	6.45	0.0000
Plant's subjective ranking on change as a way of life	7.82	6.62	6.10	0.0000
% Scrap rate in previous year	2.44	11.42	-6.18	0.0000
Plant's subjective ranking on labour flexibility	7.99	6.83	5.94	0.0000
Direct labour costs as a percentage of total manufacturing costs	10.73	15.83	-5.91	0.0000
Indirect labour costs as a percentage of total manufacturing costs	3.24	6.05	-5.84	0.0000
Plant's subjective ranking on importance of process engineering and continuous improvement	7.98	6.87	5.79	0.0000
Plant's subjective ranking on commitment of employees to continuous improvement	7.23	6.17	5.15	0.0000
Plant's subjective ranking on cleanliness	7.77	6.92	5.07	0.0000
Plant's subjective ranking on accuracy of process documentation	8.42	7.51	4.69	0.0000
Plant's subjective ranking on use of labour as a	7.28	6.34	4.65	0.0000

source of brainpower				
Plant's subjective ranking on emphasis on training and competence	7.29	6.34	4.47	0.0000
Other labour costs as a percentage of total manufacturing costs	5.73	9.22	-4.30	0.0000
Stock record accuracy is measured	92.6	75.0	4.23	0.0000
Weeks usage of raw materials stock	4.08	9.02	-4.18	0.0000
Quoted lead times are for a specific time of day	21.88	6.27	4.09	0.0000
% Schedule adherence in current year	93.31	84.75	3.99	0.0001
Current % on time delivery performance of suppliers	90.91	80.99	3.84	0.0001
First time pass rate is measured	79.1	55.0	3.80	0.0001
% of employees involved in problem-solving groups	53.05	35.82	3.69	0.0002
% Schedule adherence last year	88.2	78.1	3.70	0.0002
% of suppliers delivering less frequently than monthly	10.08	23.44	-3.66	0.0003
Sales value of production output	73022	20971	3.54	0.0004
% of capacity used for changeovers	6.16	11.08	-3.37	0.0008

4.4.1 Significant differences between high and low performance plants

While this list includes quite a diverse set of characteristics certain patterns can be identified.

4.4.1.1 Differences in ratings on world class performance

The variables that exhibit the most significant differences between high performance plants and low performance plants are the plants' own subjective ratings on various aspects of world class performance. As part of the questionnaire, plants are asked to rate themselves on a scale from 1 (poor) to 10 (perfect) on a number of indicators usually associated with world class performance. Mean ratings for the complete set of factors are shown in Table 4.5.

Table 4.5: Differences in World Class Rating Assessments between High and Low Performance Plants

World Class Factor	High Performance Plants	Low Performance Plants	Difference	Z-value of difference	Significance of difference
Process dependability	8.13	6.95	1.18	6.72	0.0000
Throughput efficiency	7.92	6.77	1.15	6.45	0.0000
Change as a way of life	7.82	6.62	1.20	6.10	0.0000
Labour flexibility	7.99	6.83	1.16	5.94	0.0000
Emphasis on process eng.	7.98	6.87	1.11	5.79	0.0000
Employee involvement in continuous improvement	7.23	6.17	1.06	5.15	0.0000
Plant cleanliness	7.77	6.92	0.85	5.07	0.0000
Documentation accuracy	8.42	7.51	0.91	4.69	0.0000
Use of labour brainpower	7.28	6.34	0.94	4.65	0.0000
Training	7.29	6.34	0.95	4.47	0.0000

All of these differences are very highly significant. Either the plants in the high performance group are consistently more generous in their ratings than the low performance group or the high performance group is genuinely better at all of these factors.

4.4.1.2 Process reliability

The order of importance of these ratings of world class performance is interesting. The factors that seem to be the most important are the ones that low performing plants are likely to find most difficult to emulate – process dependability, throughput efficiency, change as a way of life and labour flexibility. The most significant factor is process dependability.

This suggests that it might be low variability in lead times, scrap rates, etc. that enables plants to achieve fast, reliable, low cost delivery. Schonberger (1982) and Hall (1983) have both said that cutting variability in process times is one of the most important prerequisites for world class performance. Hafner (1991) showed that reducing the coefficient of variability of processing times led to substantial improvements in the speed and reliability of delivery.

A number of other measures that reflect various aspects of process reliability are also significantly different for the two groups. These measures are

- Percentage scrap rate in current year
- Percentage scrap rate in previous year
- Percentage schedule adherence in current year
- Percentage schedule adherence in previous year
- Customer lead times quoted for a specific time of day

4.4.1.3 Percentage scrap rate

It is not very surprising that low percentage scrap rates both in the current and previous year should be strongly associated with overall performance on the 4 performance measures being used. Low scrap rates should make it less likely that unacceptable product reaches the customer, leading to customer returns. Also less rework and reprocessing will be required, reducing manufacturing costs and shortening lead times. Reduction in scrap rates is also likely to be associated with a reduction in the variability in scrap rates, leading to more predictable lead times and hence greater delivery reliability. It would be interesting to investigate whether poor operating performance was more often associated with high absolute scrap rate levels or high variability in scrap rates.

4.4.1.4 Percentage schedule adherence

It is also possible to hypothesise how high levels of percentage schedule adherence would lead to high levels of performance on the measures being considered. Schedule changes are usually a consequence of non-availability of raw materials, quality problems, delays in earlier production stages and plant breakdowns. High levels of schedule changes are therefore likely to be associated with lower quality consistency and longer, less reliable lead times. Unplanned schedule changes are also likely to lead to lower productivity, reflected in a lower added value per employee £.

4.4.1.5 Quoted lead times are for a specific time of day

The ability to quote lead times for a specific time of day implies that the plant has high levels of process dependability. A high percentage of delivery promises for a specific time of day is therefore likely to be associated with high levels of delivery reliability. It is less obvious how the ability to deliver at a specific time of day would affect the other measures of performance. Another interpretation of this result is that quoting lead times for a specific time of day implies very demanding customers. New and Szwejczewski (1996) found that levels of operating performance for plants with very demanding customers were consistently higher than performance levels in plants with less demanding customers. However, when plants were asked in the Best Factory Awards Survey, how important delivery reliability was to their customers there was no significant difference between the responses of high and low performance plants.

4.4.1.6 Throughput efficiency

The next most significant factor is the plant's rating of its throughput efficiency. This is in agreement with the findings of several other researchers that short throughput times are a major source of competitive advantage (Stalk, 1988; Stalk and Hout, 1990; Plossl, 1991). Another factor relating to throughput efficiency that is also significant is the percentage of capacity used for changeovers. This contributes to throughput efficiency by minimising the amount of production time lost through changeovers. This could be achieved through short changeovers, although the difference in changeover times between high and low performance plants is not statistically significant. It could also be a result of producing relatively few products in large quantities with few changeovers.

4.4.1.7 Continuous improvement

The ratings that plants give themselves on various elements of continuous improvement comes next in importance although there is some variation in the significance of the different elements of continuous improvement. In order of significance we have change as a way of life, then the importance of process engineering and continuous improvement then commitment of employees to continuous improvement and finally use of labour as a source of brainpower.

Another significant result suggesting that emphasis on continuous improvement and the involvement of the workforce in this is the fact that the percentage of production employees involved in problem-solving groups is significantly greater for high performance plants than for low performance plants.

4.4.1.8 Labour costs as a percentage of manufacturing costs

Another significant difference between high performance plants and low performance plants is with regard to the breakdown of manufacturing costs. High performance plants might be expected to devote a smaller percentage of manufacturing costs to labour than low performance plants. Table 4.6 confirms that this is the case.

Table 4.6: Labour Costs as a Percentage of Total Manufacturing Costs

Description	Mean for high performance plants	Mean for low performance plants	Difference	Z value of difference	Significance of difference
Direct labour	10.73	15.83	-5.1	-5.91	0.0000
Indirect labour	3.24	6.05	-2.81	-5.84	0.0000
Other labour	5.73	9.22	-3.49	-4.30	0.0000

These results provide strong evidence that high performance plants spend a lower percentage of their manufacturing costs on labour than low performance plants. There could, of course, be many other reasons for the difference. The levels of capital intensity could be different, for example. However, this particular reason is unlikely as there is no significant difference in the percentage of manufacturing costs devoted to depreciation for the high and low performance groups.

4.4.1.9 Cleanliness

The subjective rating given by each plant for the level of cleanliness and tidiness within the plant was significantly greater for high performance plants than for low performance plants. While it is difficult to see how the level of cleanliness and tidiness would have such a strong direct influence on performance, it is likely that the plant characteristics that lead to consistent and reliable performance will also lead to a clean and tidy workplace.

4.4.1.10 Accuracy of documentation

The subjective rating given by each plant to the accuracy and detail of process documentation was also significantly greater for high performance plants than for low performance plants. It seems reasonable to suppose that good process documentation will ensure that fewer errors are made. Consequently there will be fewer quality problems and fewer delays. This, in turn, will result in fewer customer returns, faster, more reliable delivery and lower costs.

4.4.1.11 Stock levels

The work of other researchers (Hall, 1983, 1987; Ohno, 1988; Shingo, 1988; Schonberger, 1996) would lead us to expect that stock levels would be lower for high performance plants than for low performance plants. Surprisingly, only raw materials stocks show a difference between high and low performance plants that is significant at the 0.001 level. Table 4.7 compares weeks of usage for each category of stock for the high and low performance plants.

Table 4.7: Stock Levels in Weeks of Usage for High and Low Performance Plants

Description	High Performance Plants	Low Performance Plants	Difference	Z value of Difference	Significance of difference
Raw materials	4.08	9.02	-4.94	-4.18	0.0000
Bought out components	5.74	7.95	-2.21	-1.91	0.056
Work in process	3.75	6.12	-2.37	-2.28	0.023
Finished goods	5.18	4.67	+0.51	0.49	0.624

While the difference in raw materials stock is highly significant, there is no significant difference whatsoever in finished goods stocks. In fact, the low performance plants have slightly less weeks of finished goods stock than the high performance plants.

The low level of raw materials stocks for high performance plants could reflect the greater reliability and frequency of delivery of their suppliers. An indication that this is the case is the fact that the percentage on-time delivery of suppliers and the percentage of suppliers who deliver more frequently than monthly are both significantly higher for the high performance group than the low performance group.

The fact that the percentage of suppliers who deliver less frequently than monthly is significantly lower for the high performance group than for the low performance group probably reflects a greater overall frequency of deliveries by suppliers at high performance plants. A better measure of this would be the mean interval between deliveries per supplier at each plant but this was not measured as part of the Best Factory Awards Survey.

4.4.1.12 Measurement of a wide range of metrics

Another significant difference between high performance plants and low performance plants is in the extent to which plants measure various aspects of operating performance. Measurement of stock record accuracy, ex-stock availability and first time pass rate are all significant at the 0.001 level. Table 4.8 shows the percentages of high and low performance plants that measure each aspect of performance.

Table 4.8: Percentage of Plants Measuring Each Aspect of Performance

Performance Measure	% of Group 1 using measure	% of Group 3 using measure	Z value	Significance
Stock record accuracy	92.6	75.0	4.23	0.0000
First time pass rate	79.1	55.0	3.82	0.0002
Ex-stock availability	88.0	67.6	3.18	0.001
Schedule adherence	84.6	67.7	2.87	0.004
Customer returns	98.6	91.2	2.92	0.004
Scrap rate	100.0	98.0	1.74	0.082
% Supplier delivery on time	72.9	63.3	1.17	0.242
Time spent on changeovers	59.4	53.4	1.03	0.303
Time on rework	61.0	56.4	0.80	0.424
Output volume	99.1	99.2	-0.08	0.936
Due date reliability	100.0	100.0	0	Not applicable

It is interesting that the five measures that show the most significant differences are all concerned with some aspect of the reliability and predictability of processes and procedures. The Best Factory Awards questionnaire asks for information about the measurement of 11 different metrics. It seems reasonable to suppose, from consideration of the above table, that high performance plants will measure a higher percentage of these metrics than low performance plants.

4.4.1.13 Differences in sales value

In 1996, plants were asked for their net profit before interest and tax and the sales value of their production output. The average values for both were significantly higher for the high performance group than for the low performance group (Z values of 3.11 with a significance level of 0.0018 and 3.54 with a significance level of 0.0004 respectively) although only sales value is significant at better than the 0.001 level. Average value of output at manufacturing cost was almost identical for the two groups (Z value of -0.13 with a significance level of 0.8966). This suggests that plants that provide high levels of customer service may be able to charge higher premiums, leading to higher levels of sales value.

4.5 Differences in Characteristics of High and Low Performance Plants

One concern with this analysis is that the differences being observed between the plants are merely a consequence of the types of plants in the two groups being different. In other words we are not comparing like with like. For example, high performance plants might all be making a few, simple products in high volume, whereas low performance plants might be making very complex products where every product is to a different specification. A number of potential differences were identified and the results are displayed in Tables 4.9 and 4.10. Table 4.9 considers nominal variables. Table 4.10 considers ordered variables. Differences in these variables were compared by testing the significance of differences in the means of the two groups.

Table 4.9: Differences between Nominal Variables for High and Low Performance Plants

Variable	Description	Z value	Significance
a1	Who owns the plant?	2.55	0.001
a2	No. of plants owned by parent company	-.68	0.496
a3	Is no. of employees above or below 500?	0.16	0.868
Sector	Industrial category	0.92	0.358

Table 4.10: Differences between Ordered Variables for High and Low Performance Plants

Description	High Performance Plants	Low Performance Plants	Z Value of Difference	Significance of Difference
Area of plant	271574	181535	1.75	0.080
No. of employees (1993-4)	1.80	1.77	0.17	0.865
% of output as capital goods	19.54	13.93	1.39	0.165
% of output as intermediate goods	47.83	58.70	-2.03	0.042
% of output as	32.62	27.64	1.00	0.317

consumer goods				
Total items at product level	47236.5	1880	1.03	0.303
Total items at manufactured intermediate level	1576.67	2788.29	-1.66	0.097
Total items at bought out intermediate level	1868.62	6013.41	-1.89	0.059
No. of components in main product	203.78	2647.2	-1.19	0.234
No. of products in continuous production	130.44	217.03	-1.36	0.174
No. of products in intermittent production	631.12	764.36	-0.48	0.631
No. of products of unknown design produced.	200.59	560.86	-1.12	0.263
No. of customers who are third parties	862.61	373.35	1.38	0.168
No. of customers who are own company distribution points	9.33	7.24	0.67	0.503
No. of customers who are other plants within company	2.79	3.01	-0.39	0.697
% of turnover by value of third party customers	69.48	63.48	1.19	0.234
% of turnover by value of own company distribution points	20.76	23.81	-0.67	0.503

% of turnover by value of other plants within company	9.23	12.22	-1.01	0.312

Only one of these variables is significant even at the 0.05 level. The one exception is the highly significant difference in the distribution of plant ownership between the high performance and low performance groups. The main differences can be seen in Table 4.11, which shows the distribution of ownership for all three groups.

Table 4.11: % Distribution of Plant Ownership for High, Medium and Low Performance Plants

Owner	High Performance Plants	Medium Performance Plants	Low Performance Plants
UK	50.7	62.9	72.2
Continental Europe	18.7	11.3	6.0
Japanese	4.0	2.0	1.3
US	14.7	16.7	9.9
Other foreign	2.7	4.0	6.0
Joint UK/foreign	9.3	3.3	4.6

This table indicates that high performing plants are far less likely to be entirely UK owned than lower performing plants. This could mean that UK plants perform less well than their foreign counterparts or it could be that companies with high performance are more likely to be operating internationally rather than locally.

4.6 Research Propositions

Using the foregoing analysis it is possible to identify a number of propositions regarding the differences between high and low performance plants.

Proposition 1: High performance plants will show greater process reliability than low performance plants.

Measures of process reliability that are characteristics of high performance plants are

A higher subjective rating on process dependability
Greater schedule adherence in the current year
Greater schedule adherence in the previous year
A lower percentage scrap rate in the current year

A higher percentage of quoted deliveries that are for a specific time of day

Proposition 2: High performance plants will show greater throughput efficiency than low performance plants.

Measures of throughput efficiency that are characteristics of high performance plants are

A higher subjective rating on throughput efficiency
A lower percentage of capacity used for changeovers

Proposition 3: High performance plants will have greater emphasis on continuous improvement than low performance plants.

Measures of the emphasis on continuous improvement that are characteristics of high performance plants are

A higher subjective rating on change as a way of life
A higher subjective rating on the importance of continuous improvement
A higher subjective rating on the commitment of the workforce to continuous improvement
A higher subjective rating on use of labour as a source of brainpower
A higher percentage of production employees involved in problem-solving groups

Proposition 4: High performance plants will have higher levels of labour flexibility than low performance plants.

Measures of levels of labour flexibility that are characteristics of high performance plants are

A higher subjective rating on labour flexibility
A higher subjective rating on training and competence

Proposition 5: High performance plants will have lower labour costs as a percentage of total manufacturing costs than low performance plants.

Measures of labour costs that are characteristics of high performance plants are

Lower direct labour costs as a percentage of total manufacturing costs
Lower indirect labour costs as a percentage of total manufacturing costs
Lower other labour costs as a percentage of total manufacturing costs

Proposition 6: High performance plants will have higher levels of cleanliness than low performance plants.

The measure of levels of cleanliness that is a characteristic of high performance plants is

A higher subjective rating on cleanliness

Proposition 7: High performance plants will have more accurate and up-to-date process documentation than low performance plants.

Measures of the accuracy of process documentation that are characteristics of high performance plants are

A higher subjective rating on documentation accuracy

Proposition 8: High performance plants will have more frequent and reliable supplier deliveries than low performance plants.

Measures of the emphasis on the frequency and reliability of supplier deliveries that are characteristics of high performance plants are

Less weeks usage of raw materials stocks
A higher percentage on-time delivery performance for suppliers
A lower percentage of suppliers delivering less frequently than monthly

Proposition 9: High performance plants will measure a wider range of metrics than low performance plants

Indications of this will be

High performance plants will be more likely to measure stock record accuracy, first time pass rate and ex-stock availability
High performance plants will measure a higher percentage of the 11 metrics covered in the Best Factory Award questionnaire

4.7 Conclusions

A number of differences between high and low performance plants have been identified by comparing the mean values of responses to each question in the Best Factory Award questionnaire for high and low performance plants.

This analysis suggests the following areas in which high performance plants differ from low performance plants.

1. Higher levels of process reliability
2. Lower scrap rates
3. Higher percentage adherence to schedule

4. Lead times quoted for a specific time of day
5. Higher levels of throughput efficiency.
6. A lower percentage of capacity used for changeovers
7. Greater emphasis on continuous improvement
8. Higher levels of labour flexibility
9. A smaller percentage of manufacturing costs devoted to labour
10. Higher levels of plant cleanliness
11. Greater accuracy of plant documentation
12. More frequent and reliable deliveries from suppliers
13. Lower levels of raw material stocks
14. Measurement of a wider range of performance metrics

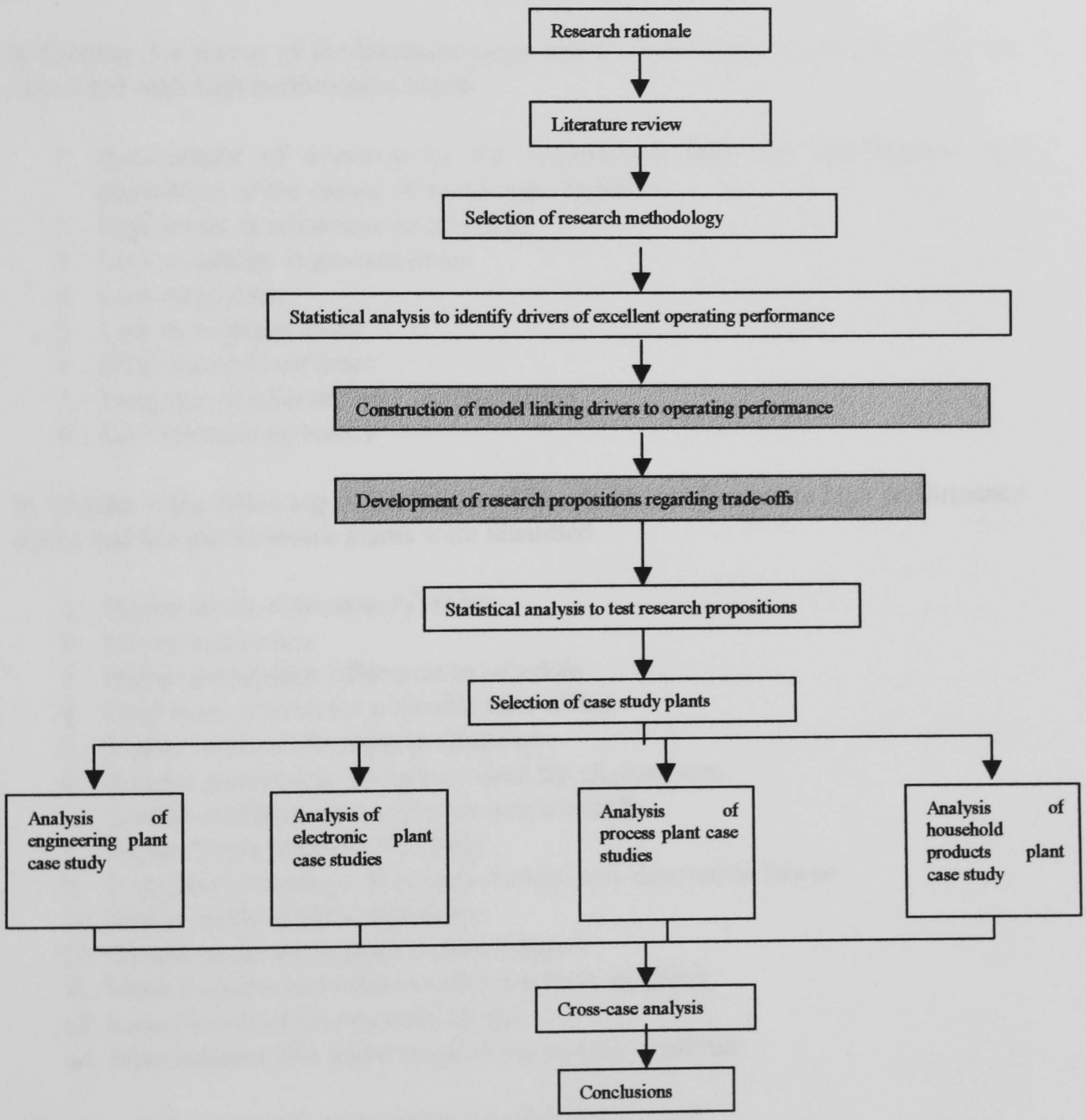
High and low performance plants were not significantly different in size, in the complexity and volume of products made or in type of industry. However, high performance plants were more likely to be owned by a foreign parent company.

Chapter 5 : Development of a New Trade-off Model

5.1 Summary

Figure 5.1: Thesis Route Map

(The sections covered in this chapter are shaded.)



In Chapter 4 a number of characteristics that appear to differentiate high and low performance plants were identified. In Chapter 2 the characteristics associated with good operating performance that have been identified by other writers were discussed. In this chapter the two sets of characteristics are used to construct a tentative model of how these characteristics might interact to produce changes in operating performance. This model is then used to suggest two propositions about the nature of the trade-offs that might exist between the various measures of operating performance being considered in this thesis.

5.2 *Characteristics of Good Operating Performance*

In Chapter 2 a survey of the literature suggested the following characteristics that are associated with high performance plants

1. Involvement of everyone in the organisation with the identification and elimination of the causes of waste and variability
2. High levels of adherence to schedule
3. Low variability in process times
4. Low scrap rates
5. Low throughput times
6. Short changeover times
7. Frequent, reliable delivery from suppliers
8. Low levels of inventory

In Chapter 4 the following characteristics that appear to differentiate high performance plants and low performance plants were identified.

1. Higher levels of process reliability
2. Lower scrap rates
3. Higher percentage adherence to schedule
4. Lead times quoted for a specific time of day
5. Higher levels of throughput efficiency
6. A lower percentage of capacity used for changeovers
7. Greater emphasis on continuous improvement
8. Higher levels of labour flexibility
9. A smaller percentage of manufacturing costs devoted to labour
10. Higher levels of plant cleanliness
11. Greater accuracy of plant documentation
12. More frequent and reliable deliveries from suppliers
13. Lower levels of raw material stocks
14. Measurement of a wider range of performance metrics

There is a fair degree of commonality between the two lists.

Table 5.1: Key Drivers Identified in the Research and in the Literature

Characteristics identified by statistical analysis	Characteristics identified by other researchers
Higher levels of process reliability	High levels of adherence to schedule Low variation in process times
Lower scrap rates	Low scrap rates
Higher percentage adherence to schedule	High levels of adherence to schedule
Lead times quoted for a specific time of day	
Higher levels of throughput efficiency	Low throughput times
A lower percentage of capacity used for changeovers	Short changeover times
Greater emphasis on continuous improvement	Involvement of everyone in the organisation with the identification and elimination of the causes of waste and variability
Higher levels of labour flexibility	
A smaller percentage of manufacturing costs devoted to labour	
Higher levels of plant cleanliness	
Greater accuracy of plant documentation	
More frequent and reliable deliveries from suppliers	Frequent, reliable delivery from suppliers
Lower levels of raw material stocks	Low levels of inventory
Measurement of a wider range of performance metrics	

While there is not total agreement between the two lists, the following characteristics that are common to both lists can be identified.

1. High levels of adherence to schedule
2. Low variation in process time
3. Low scrap rates
4. Low throughput times
5. Short changeover times
6. Emphasis on continuous improvement
7. Frequent, reliable deliveries from suppliers
8. Low levels of raw material stocks

Later in this chapter a tentative model will be proposed attempting to link these factors to the various elements of operating performance. First the various aspects of operating performance that might be expected to exhibit trade-offs will be reviewed.

5.3 Trade-offs

As stated earlier, various writers have identified the following areas between which trade-offs might be expected to occur.

Quality conformance
Quality specification
Lead time
Delivery reliability
Cost
Flexibility

Because of criticisms by some writers that there is a lack of generally accepted definitions for these concepts the following working definitions will be used in order to ensure consistency within this thesis.

5.3.1 Quality conformance

This is the percentage of items delivered to the customer that meet the quality specification agreed between the customer and supplier. This quality specification will include quantitative elements such as whether certain key dimensions lie within the tolerance limits permitted and qualitative elements such as appearance.

5.3.2 Quality specification

This is the detailed description of the characteristics of the product that must be met if the product is to be acceptable to the customer. This description will cover the performance of the product in use, the range of features incorporated into the product and the tolerance limits for key dimensions. The better the performance, the greater the number of features and the tighter the tolerance limits relative to similar products, the higher the specification.

5.3.3 Lead time

This is the total elapsed time between the customer placing the order and the customer being in receipt of the goods ordered.

5.3.4 Delivery reliability

This is the percentage of orders that are delivered in full on or before the delivery time agreed with the customer.

5.3.5 Cost

This is the cost of manufacturing one unit of a given product inclusive of material, labour and overhead costs. Because of differences in specification, comparison of unit costs for different products is difficult. Even for products with similar specifications manufactured by different companies, comparisons of unit costs are difficult because of differences in methods of allocating costs between different products. However, this research is concerned with trade-offs within a particular manufacturing plant. The research question being addressed is whether a specific operational change will cause unit cost for a given product to rise or fall. In most cases the answer to this question will be unaffected by the precise method of calculating unit cost.

5.3.6 Flexibility

Flexibility is a different kind of measure to the other operational measures being described here. It is a measure of how quickly and cheaply changes in the other operational measures can be made. Consequently it has a number of dimensions. One dimension is the ability to rapidly switch operations from one product to another. Another dimension is the ability to change output levels at short notice when demand varies. A further dimension is the ability to respond rapidly to requests from customers to change the delivery date after an order has been placed. There are others. Defining and measuring plant flexibility is a complex subject in its own right and is beyond the scope of this research. Instead just one aspect of flexibility; the number of different products that a plant is currently capable of making, will be used in this thesis. This is a very restricted, uni-dimensional definition of flexibility but it should enable the investigation of how one aspect of flexibility interacts with other performance measures.

One of the purposes of this research is to investigate how a change in one of the above measures causes changes in the other measures. Consideration of the various ways in which a change in a given performance measure might be brought about introduces a further complication. A few measures can be changed directly as a result of management policy. For example, a plant might decide to increase the quality specification of the products being manufactured. The majority can only be changed indirectly by making changes to the operating system, which it is hoped will have the consequential effect of producing the desired change in the performance measure. For example, a plant might achieve an improvement in delivery reliability by reducing process time variability.

Table 5.2: Potential Drivers of Operating Performance

		Outcome		
Driver	Unit Manufacturing Cost	Quality Conformance	Lead Time	Delivery Reliability
Reduced Labour	Better	Worse	Worse	Worse
Less Stock	Better	Unchanged	Worse	Worse
More inspection	Worse	Better	Worse	Worse
Increased Adherence to Schedule	Better	Unchanged	Better	Better
Reduced Process Time Variability	Better	Unchanged	Better	Better
Reduced Product Variability	Better	Better	Better	Better
Shorter changeover times	Better	Unchanged	Better	Unchanged
More Reliable Suppliers	Better	Better	Better	Better
Greater Product Variety	Worse	Worse	Worse	Worse

Table 5.2 lists a number of potential drivers of operating performance and summarises the likely effect of each on the performance measures being considered in this research. In this table, the drivers are all those aspects of operating performance that management can influence directly. Outcomes are those aspects of operating performance that management can only influence indirectly. An explanation of the ways in which each driver might affect each performance measure is given below.

5.3.7 Reduced labour

When a plant needs to make a rapid reduction in costs a common approach is to reduce the size of the workforce. This should have the effect of reducing labour costs but has a number of adverse effects. All manufacturing plants have to cope with fluctuations in demand over time although the size and predictability of these fluctuations may vary from plant to plant. During periods when demand is above average, plants with a reduced labour force will be stretched. Lead times will extend, delivery dates will be missed and quality conformance will suffer. The costs of rework, overtime and sub-contracting could also potentially reduce the apparent cost benefits of reducing the size of the labour force.

5.3.8 Less stock

Another popular target for short-term cost cutting is to reduce the amount of stock held. This will certainly reduce unit costs to some extent. If it is done in isolation, without making other changes that reduce the need for such high levels of stock, then it is likely to have the following outcomes. Less raw materials stock, work in process stocks and finished goods stocks will increase the risk of stock-outs causing unplanned delays. These will increase lead times and reduce delivery reliability. However, there is no reason to suppose that reducing stocks will have any effect on quality conformance.

5.3.9 More inspection

When a plant has a quality conformance problem that must be dealt with as a matter of urgency, the traditional approach is to increase expenditure on methods of detecting non-conforming items. This might involve more inspection, introduction of additional statistical process control checks, expenditure on automated process control, and so on. The effect should be to increase quality conformance as perceived by the customer but at the expense of an increase in unit costs. Not only that, but also the delays resulting from quarantining and rework of batches will increase lead times and reduce delivery reliability.

5.3.10 Increased adherence to schedule

Unplanned changes to the production schedule have a number of adverse effects. The jobs that have been displaced are delayed, increasing average throughput times and work in process stocks. The changes are usually non-optimal and frequently increase the amount of time spent on set-ups and changeovers. The consequence is reduced productivity and further increases in throughput times. The end results are higher costs, longer lead times and late deliveries.

The less uncertainty there is with regard to future customer requirements, the availability of raw materials and bought-in components and the processing times for each stage in manufacture, the easier it is for plants to adhere to the planned schedule. In a survey of UK plants by Armistead and Mapes (1993), two of the most important determinants of high levels of operational efficiency and customer service were sharing of production schedules with customers and suppliers. Sharing information in this way reduces uncertainty and enables increases in the degree of adherence to schedule at every stage along the supply chain.

5.3.11 Reduced process time variability

A major cause of delivery reliability problems is unpredictable variation in processing times at each stage in the manufacturing process. In order to protect other stages in the process from such variations, work in process stocks must be held between stages. This increases costs, extends lead times and increases the risk of late delivery.

5.3.12 Reduced product variability

Product variability can relate to any aspect of the product specification that is of importance to the customer. This may relate to the dimensions of the product, its appearance, its performance, etc. The most obvious consequence of a high level of product variability is the effect on quality conformance. The higher the product variability, the greater the proportion of output that is outside specification. This, in turn, leads to higher levels of scrap, increasing costs. More rework will also be necessary. This not only increases costs but also increases lead time and reduces delivery reliability.

5.3.13 Shorter changeover times

Reductions in changeover times can be used to gain a variety of benefits. If batch sizes remain unchanged then a lower percentage of capacity is devoted to changeovers. Output levels increase with no change in fixed costs and so unit manufacturing costs reduce. Alternatively, batch sizes can be reduced, enabling lower levels of finished goods inventory to be held. With smaller batch sizes each product will be manufactured more frequently. Because forecasts of demand have to be made less far ahead the forecasts are likely to be more accurate. There will therefore be fewer unplanned stock outs and delivery reliability will improve. Smaller batch sizes will also result in a shorter total customer lead time as batches will move through the plant more quickly.

Shorter changeover times will also make it less costly to produce a wider variety of products as the cost of switching from one product to another is reduced. However, here the effect is slightly different. The effect of increasing the size of the product range will still be to increase unit manufacturing costs and so there will still be a trade-off between product variety and manufacturing cost. Using Slack's terminology (Slack et al, 2001), the effect of shortening changeover times is to reduce the sensitivity of manufacturing cost to increases in the size of the product range.

5.3.14 More reliable suppliers

A frequent cause of poor operating performance in manufacturing plants is the unreliability of suppliers of raw material and components. Unreliability of delivery necessitates holding more raw materials and component stocks, increasing costs. Late delivery can cause unplanned delays and schedule changes, increasing lead times and reducing delivery reliability. Poor quality conformance by suppliers often translates into poor quality conformance for the finished product. Even if it does not it causes unplanned delays, increasing lead times and reducing delivery reliability. Conversely, improving supplier reliability can be one of the single most effective ways of simultaneously improving all operating performance outcomes.

5.3.15 Greater product variety

While customers are increasingly demanding greater product variety, this creates numerous problems for operations management. Each product change incurs changeover costs and requires operators to embark on a new learning curve. This adversely affects both cost and quality conformance. The complexity involved in managing the production of a wide range of products requires more sophisticated planning and scheduling systems, further increasing cost. Even with such systems, the complexity involved leads to unplanned delays, extended lead times and reduced delivery reliability.

While the above analysis of drivers is in no way comprehensive it does enable some general patterns to be identified. Using Harrison's terminology (Harrison, 1997) there are a number of drivers, each of which is either an enabler or an inhibitor.

Enablers can be divided into three groups.

Trade-off enablers - factors creating advantage in one area only to cause offsetting disadvantage in another area.

Best practice enablers - factors that create advantage in all operations situations.

Specific enablers - factors that create advantage only in given operations situations.

Some of these drivers have an influence that is generic, that is, their effect on all performance measures is in the same direction. An example of this would be supplier reliability. As supplier reliability improves so do all of the performance outcomes under consideration. Other drivers may well have an influence that is specific, that is, their effect is specific to one performance measure, leaving other performance measures unaffected. However, the analysis just presented suggests that the complexity of the interactions between different performance measures makes it difficult to envisage drivers that do not have some influence on at least two of the performance measures under discussion. Finally, there are drivers whose influence is contextual. Depending on the associated changes taking place, their effect may be to either increase or reduce a given measure of operating performance. An example of this is stock level. If stocks are reduced in isolation then lead times and delivery reliability are likely to suffer. On the other hand, if supplier reliability has improved or process time variability has been reduced then it will be possible to simultaneously reduce stocks, improve quality conformance, reduce lead times and improve delivery reliability. Stock levels have changed from being a driver to being the outcome of more fundamental generic drivers of operating performance.

What conclusions can be drawn then about those elements of performance that involve trade-offs and those that are mutually enhancing? This would seem to depend to some extent on the nature of the changes leading to the change in performance. The analysis in the previous chapter combined with the survey of the literature in Chapter 2 suggests that there are certain characteristics commonly found in plants that achieve excellent operating performance. Firstly, they place considerable importance on continuous improvement, involving a high proportion of the workforce in this activity. Secondly, continuous improvement focuses on two broad objectives, reduction in waste and reduction in variability.

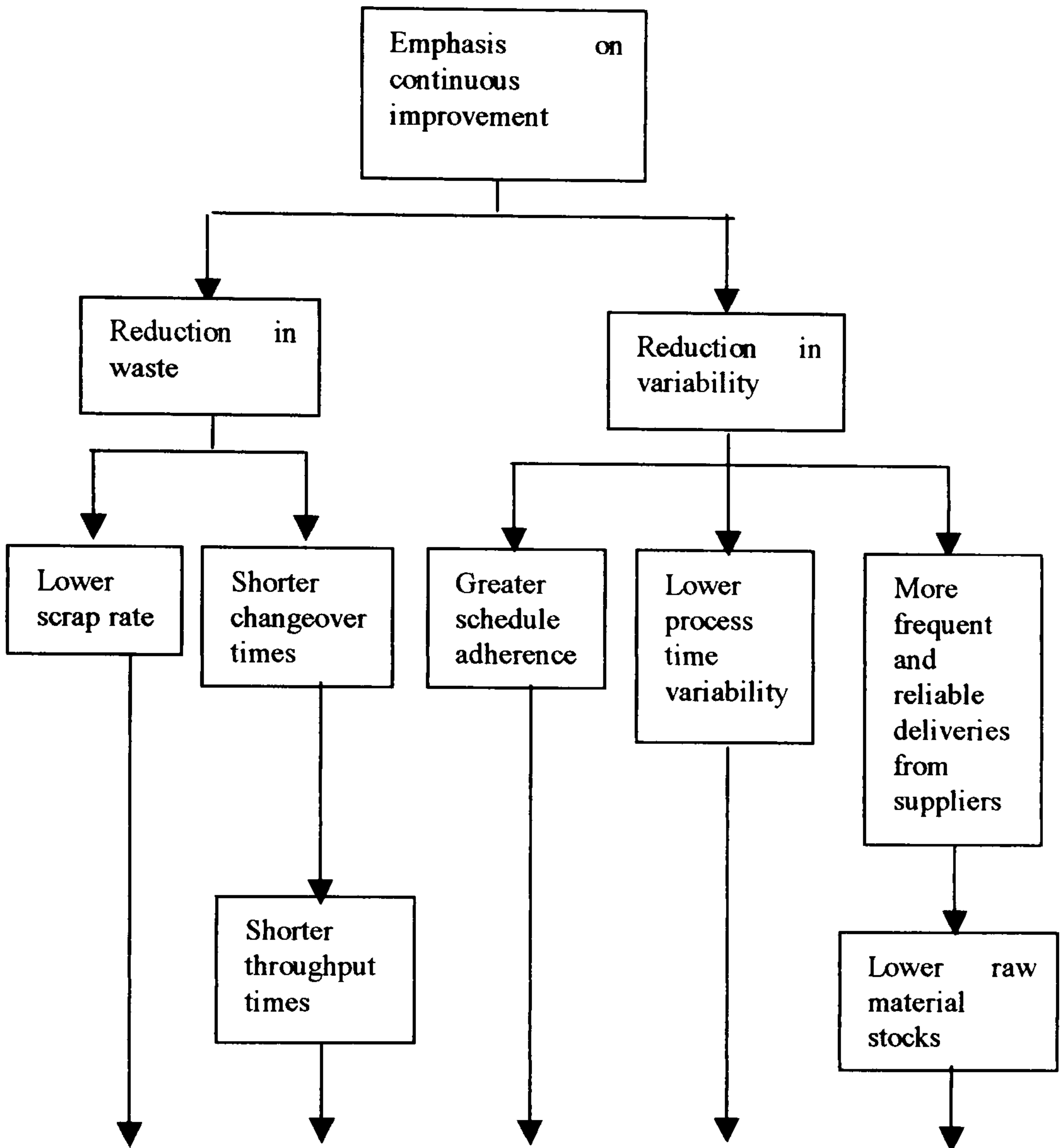
While there are many categories of waste in any plant, the two areas of waste reduction that seem to be most successful in achieving overall improvements in performance are reductions in scrap rates and reductions in changeover times. These improvements in combination enable lower overall throughput times.

In the case of reductions in variability, there are three areas of improvement that seem to be most commonly associated with high performing plants. These are improvements in schedule adherence, reductions in process time variability and increases in the frequency and reliability of supplier deliveries.

The likely effects of reductions in waste and variability are portrayed diagrammatically in figure 5.2. For each of the 5 drivers of performance improvement identified an indication has been given of its likely impact on the four elements of operating performance considered in this research: cost, quality consistency, customer lead time and delivery reliability,

This very tentative model suggests that plants using these drivers to achieve improvements could expect to see simultaneous improvements in unit manufacturing cost, quality consistency, customer lead times and delivery reliability. Rather than these aspects of performance exhibiting trade-off characteristics they should be mutually reinforcing.

Figure 5.2: Drivers of Operating Performance



Unit Manufacturing Cost	Improved	Improved	Improved	Improved	Improved
Quality Consistency	Improved	Unchanged	Unchanged	Unchanged	Unchanged
Speed of Delivery	Improved	Improved	Improved	Improved	Improved
Delivery Reliability	Improved	Unchanged	Improved	Improved	Improved

On the other hand, even for plants using these drivers there are still some strategic choices to be made that will involve trade-offs. There is the question of what level of quality specification to offer. There are two issues here. Offering a greater number of product features, using more expensive materials, providing higher levels of precision, all increase costs. It is not possible to manufacture a Bentley Continental for the same cost as a Skoda Felicia. Additionally, producing a wide variety of different quality specifications in the same plant increases process complexity, increasing the likelihood of producing to the wrong quality specification, of unplanned delays and of scheduling errors with the consequence of poorer quality consistency, longer lead times and poorer delivery reliability.

It is important at this point to differentiate between plant performance and corporate performance. A company can avoid the adverse effects of a wide variety of quality specification levels by having a number of different plants, each focused on a narrow quality range.

Companies are under considerable pressure to produce a wider variety of product variants, more colours, more flavours, and more optional features. Greater variety within the same plant means greater complexity. While a well-managed plant designed to handle product variety may be able to minimise the impact of product variety on cost, quality consistency, lead time and delivery reliability, this impact is unlikely to be zero or negative.

What strategic options do these performance relationships offer at plant level? A plant could concentrate solely on improving reliability and reducing uncertainty. This is likely to lead to production of a narrow range of standard products that are changed infrequently. This strategy should provide fast, reliable delivery, consistent quality and low manufacturing costs. It will be most effective in stable, mature industries where order-winning criteria are price and availability.

Alternative strategies might be to provide products with more features or a higher specification than the competition or to offer a wider variety of products. Each of these strategies offers the customer something extra but, from the earlier discussion, it seems likely that this will be at the expense of cost, quality consistency, delivery reliability or lead time.

In summary, then, a modified trade-off theory is proposed in which some trade-offs have disappeared but those that remain still require us to make strategic choices. Skinner (1992) and New (1992) have recognised this in their most recent papers and their views on which trade-offs have disappeared is consistent with the analysis being presented here. Schonberger's position remains unchanged (Schonberger, 1986, 1996). He still says that there are no trade-offs; it is actually possible to offer a wide product range while still out-performing the competition on cost, quality and delivery. If this is correct then he states that there will be only be one strategy for any organisation, to continuously improve on every performance measure, out-performing the competition on everything.

World class business strategies may be reduced to a single set, applicable to all businesses.
Schonberger (1986)

It is beyond the scope of this research to investigate the trade-off relationships between quality specification and the other aspects of operating performance. In this research attention will be restricted to the relationships between product variety, unit manufacturing cost, quality consistency, customer lead time and delivery reliability.

5.4 The Research Propositions

If the trade-off model developed earlier is correct then the following propositions should be true.

Proposition 10

Rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial category. In particular, plants which achieve a better than average performance level for their category on one of these factors will also achieve a better than average performance on the other factors.

Proposition 11

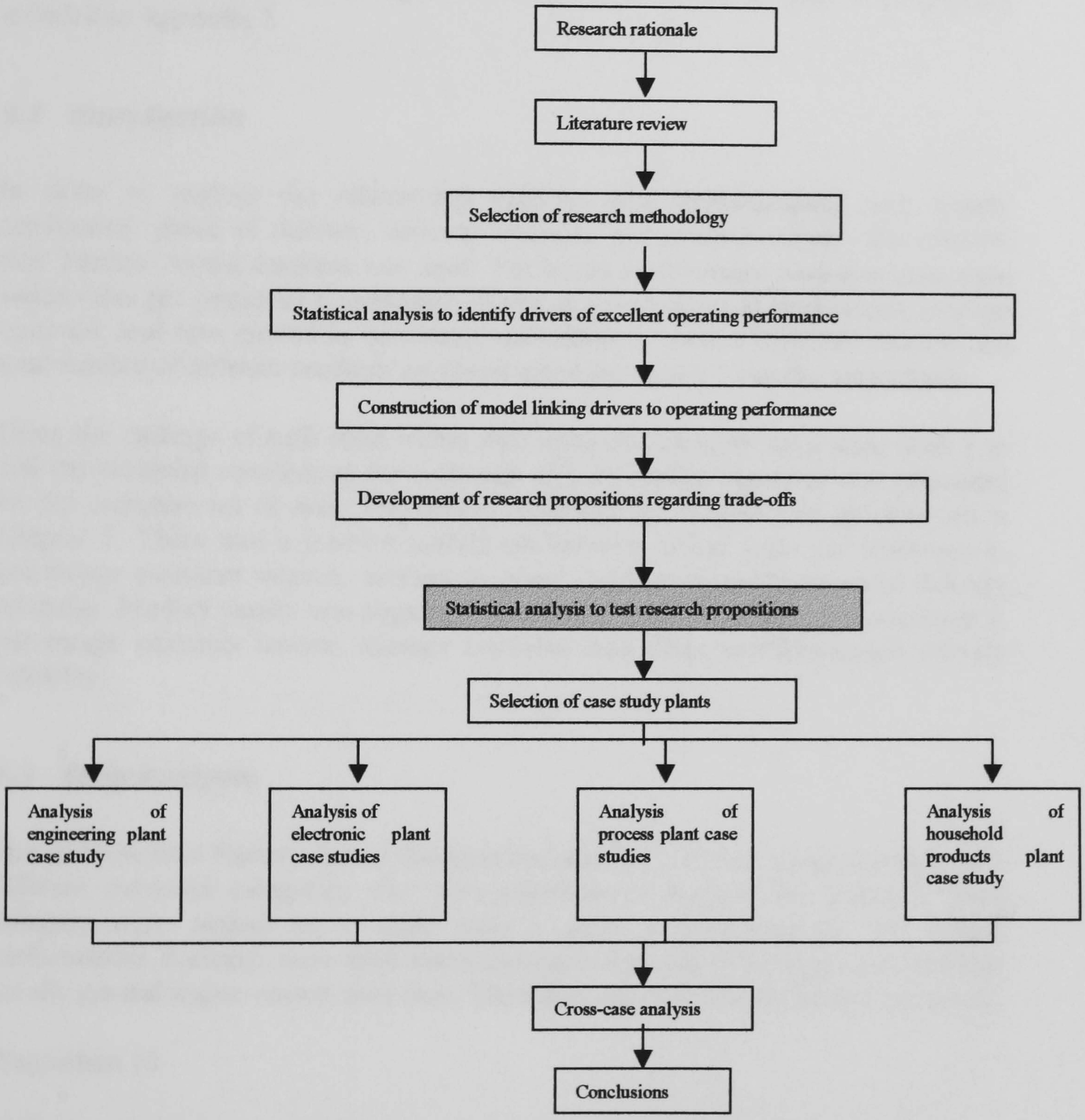
The extent of product variety within a plant will be negatively correlated with rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to other plants in the same industrial category. In other words, plants that manufacture a wide variety of products cannot expect to be competitive on the factors mentioned in comparison with plants manufacturing a narrower product range.

Chapter 6 : Statistical Support for the New Model

6.1 Summary

Figure 6.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In the previous chapter a trade-off model was developed based on the statistical analysis presented in Chapter 4 and the literature review presented in Chapter 2. Using this model it was possible to derive two propositions regarding the relationships between the performance measures being considered in this research. In this chapter correlation analysis is used to test these propositions. The results provide strong support for both propositions.

The material covered in this chapter was presented at the 3rd International EurOMA (European Operations Management Association) Conference on 3-4 June, 1996 at London Business School. Out of the 100 papers presented, this was one of 8 selected for publication in a special conference edition of the International Journal of Operations and Production Management (Mapes et al, 1997). A copy of the paper is included as Appendix 7.

6.2 Introduction

In order to explore the relationship between unit manufacturing cost, quality consistency, speed of delivery, delivery reliability and product variety, the 1993-96 Best Factory Award database was used. The actual performance measures used were added value per employee £, customer returns as a percentage of total output, average customer lead time quoted to customers, percentage of orders delivered on-time and total number of different products produced in the previous 12 months, respectively.

Using the rankings of each plant within their industrial category on a scale from 1 to 100 the statistical correlations for each pair of performance measures was calculated for the complete set of data. The results supported the propositions put forward in Chapter 5. There was a positive correlation between added value per employee £, percentage customer returns, average customer lead times and percentage delivery reliability. Product variety was negatively correlated with added value per employee £, percentage customer returns, average customer lead times and percentage delivery reliability.

6.3 Data Analysis

The 1993-96 Best Factory Award database includes 953 different plants drawn from 6 different industrial categories. For each performance measure the plants in each category were ranked on a scale from 1 (best performance) to 100 (worst performance). Rankings were determined separately for each of the four years to allow for any general improvements over time. The following propositions were to be tested.

Proposition 10

Rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial category. In particular, plants which achieve a better than average performance level for their category on one of these factors will also achieve a better than average performance on the other factors.

Proposition 11

The extent of product variety within a plant will be negatively correlated with rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to other plants in the same industrial category. In other words, plants that manufacture a wide variety of products cannot expect to be competitive on the factors mentioned in comparison with plants manufacturing a narrower product range.

In order to test these propositions Spearman's rank correlation coefficient was determined for each pair of performance measures.

A statistically significant negative correlation coefficient between two measures would indicate that a trade-off existed between them and that good performance on one measure tended to be associated with poor performance on the other measure.

A correlation coefficient that was close to zero for the two measures would indicate an absence of trade-offs between the two measures so that performance on the two performance measures would be independent of each other.

A statistically significant positive correlation coefficient between two measures would indicate that, rather than a trade-off existing between them, the measures were actually mutually reinforcing so that good performance on one measure would tend to be associated with good performance on the other measure.

6.4 The Correlation Results

The results of the correlation analysis are summarised in Table 6.1.

Table 6.1: Correlation Coefficients for Pairs of Performance Measures

	Quality Consistency.	Lead time	Delivery Reliability	Product variety
Added Value per Employee £	0.08*	0.18***	0.14***	-0.16***
Significance	0.035	0.000	0.001	0.000
Quality Consistency		0.20***	0.23***	-0.07*
Significance		0.000	0.000	0.05
Lead time			0.35***	-0.09**
Significance			0.000	0.007
Delivery Reliability				-0.13***
Significance				0.001

*** = Significance level of 0.001
** = Significance level of 0.01
* = Significance level of 0.05

This shows that all of the pairs of performance measure rankings have correlation coefficients that are significant at the 0.05 level or better. The extent to which these results support the propositions put forward earlier is discussed below.

6.4.1 Proposition 10

If proposition 10 is correct then performance rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to other plants in the same category will be positively correlated. The results provide strong support for this. Rankings for added value per employee £, quality consistency, speed of delivery and delivery reliability are all positively correlated. Table 6.2 summarises the statistical significance of the correlation coefficients for each pair of variables.

Table 6.2: Statistical Significance of Correlation Coefficients

	Quality Consistency	Lead Time	Delivery Reliability
Added Value per Employee £	0.035.	.000	.001
Quality Consistency		.000	.000
Lead Time			.000

Each of the six pairs of variables shows a statistically significant correlation. As the model predicts, those competences which lead to high levels of quality consistency also lead to speed of delivery, reliability of delivery and high added value per employee £ so that plants which are above average on quality consistency are also above average on speed of delivery, delivery reliability and added value per employee

While the correlation between rankings on added value per employee £ and quality consistency is statistically significant, the level of significance is lower than for the other pairs of variables. This is rather surprising and requires further investigation. When Schroeder et al (1996) analysed the performance of a sample of 120 plants they were unable to establish a statistically significant correlation between cost and quality conformance and suggested that it might be due to the strong influence on cost of differences in levels of capital investment and plant size.

6.4.2 Proposition 11

If proposition 11 is correct then a plant's ranking on product variety will be negatively correlated with performance rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to other plants in the same category. The results in Table 6.3 provide support for this proposition.

Table 6.3: Correlations with Product Variety

	Correlation Coefficient	Significance level
Added Value per Employee £	-0.16	0.000
Quality consistency	-0.07	0.05
Lead time	-0.09	0.007
Delivery reliability	-0.13	0.001

Ranking on degree of product variety shows statistically significant negative correlations with rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability. This is consistent with the model developed in Chapter 5. It also agrees with conventional wisdom on manufacturing focus, namely that plants manufacturing a wide range of products are likely to perform less well on added value per employee £, quality consistency, speed of delivery and delivery reliability.

One result that is surprising is that the lowest level of statistical significance is for the correlation between rankings on degree of product variety and quality consistency. This is difficult to understand, as greater product variety would be expected to lead to greater operating complexity and greater problems of control. These in turn could be expected to lead to lower levels of quality consistency. This is an area requiring further investigation.

6.5 Conclusions

A model has been developed which attempts to explain the mechanisms which link the different measures of operating performance at plant level. Analysis of the UK Best Factory Awards database provides a fair degree of support for this model. With the exception of product variety and the level of product specification (not dealt with in this thesis), rankings on most measures of operating performance show significant positive correlations with each other. Not only is there an absence of trade-offs, good performance on one measure seems to lead to good performance on other measures. As predicted by the model the number of different products manufactured in the same plant is negatively correlated with added value per employee £, quality consistency, speed of delivery and delivery reliability.

6.6 Limitations

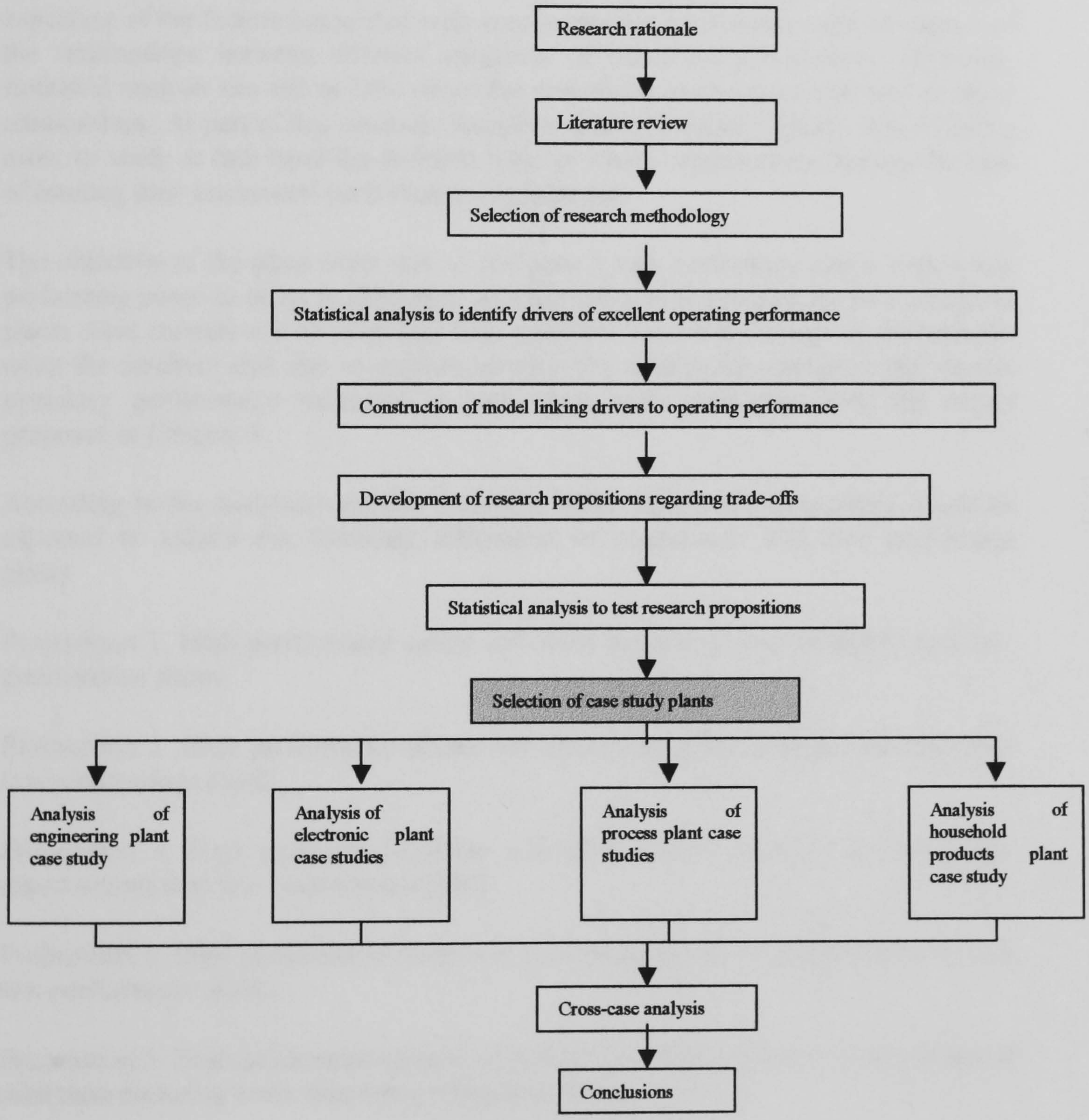
It should be emphasised that the dynamic model that has been presented in this research is being tested using what is, to a very large extent, static data. The statistical analysis considers relationships between different performance measures at a particular point in time. However, what is important to operations managers is the nature of dynamic changes. In order to achieve a higher rate of improvement in one performance measure, what changes in the rates of improvement in other performance measures will be necessary? This is complicated by the fact that, in the average plant, most measures of performance will improve to some extent over time. The question is whether an above average rate of improvement in one performance measure is generally associated with a below average rate of improvement in certain other performance measures. In order to test this, it would be necessary to monitor changes in operating performance measures over time for a sample of manufacturing plants and determine the correlations between the relative rates of improvement.

Chapter 7 : Case Studies

7.1 Summary

Figure 7.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In chapter 4 a number of propositions were presented regarding the main characteristics differentiating high and low performance plants. In chapter 6, further propositions were derived, regarding the relationships between the various measures of operating performance at plant level. In order to test the extent to which the complete set of propositions was supported within individual plants a number of plant visits were made. In this chapter the objectives of the plant visits are discussed. The basis for the selection of the plants visited is explained and the methodology used is presented.

7.1 Introduction

The statistical analyses described in the previous chapters have provided some indication of the factors associated with good operating performance and the nature of the relationships between different measures of operating performance. However, statistical analysis can tell us little about the underlying mechanisms that lead to these relationships. As part of this research, therefore, a small number of plants was visited in order to study at first hand the different ways in which organisations manage the task of meeting their customers' performance requirements.

The objective of the plant visits was to compare 4 high performing plants with 4 low performing plants in order to determine whether differences between the two groups of plants were consistent with what had been predicted from the findings of the research using the database and also to explore whether the relationships between the various operating performance measures at each plant were consistent with the model proposed in Chapter 5.

According to the statistical analysis described earlier high performing plants would be expected to exhibit the following differences in comparison with low performing plants.

Proposition 1: High performance plants will show greater process reliability than low performance plants.

Proposition 2: High performance plants will show greater throughput efficiency than low performance plants.

Proposition 3: High performance plants will have greater emphasis on continuous improvement than low performance plants.

Proposition 4: High performance plants will have higher levels of labour flexibility than low performance plants.

Proposition 5: High performance plants will have lower labour costs as a percentage of total manufacturing costs than low performance plants.

Proposition 6: High performance plants will have higher levels of cleanliness than low performance plants.

Proposition 7: High performance plants will have more accurate and up-to-date process documentation than low performance plants.

Proposition 8: High performance plants will have more frequent and reliable supplier deliveries than low performance plants.

Proposition 9: High performance plants will measure a wider range of metrics than low performance plants

Proposition 10

The performance of each plant on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial category. In particular, plants which achieve a better than average performance level for their category on one of these factors will also achieve a better than average performance on the other factors.

Proposition 11

The extent of product variety within each plant will be negatively correlated with rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to other plants in the same industrial category. In other words, plants that manufacture a wide variety of products will perform less well on the factors mentioned in comparison with plants manufacturing a narrower product range.

The purpose of the plant visits was therefore three-fold.

1. To check whether those expected differences between high performing and low performing plants suggested by the statistical analysis did exist in the plants visited.
2. To check whether there was a correlation between manufacturing cost, quality consistency, speed of delivery and reliability of delivery at each plant.
3. To check whether plants manufacturing a large product range had higher manufacturing costs, lower quality consistency, slower speed of delivery and lower reliability of delivery than comparable plants manufacturing a small product range.

Using the composite performance index (COMP) developed earlier as a basis for selection, plants were selected from the first and fourth quartiles of each of the following manufacturing sectors.

1. Engineering
2. Electrical
3. Household
4. Process

This is the classification used by the Best Factory Award judges. In addition to the overall best plant of the year award there are awards for the best plants in each of these sectors. Consideration was given to selecting two plants from each of the six industrial categories in the database (Capital Equipment, Engineering, Electrical and Electronics, Chemicals and pharmaceuticals, Food, Drink and Tobacco and Miscellaneous) but time constraints prevented this.

When selecting the plants to be visited, only the plants that submitted questionnaires in the most recent year (1996) were considered in order to ensure that the changes occurring between the time that the questionnaire was completed and the time of the plant visit were kept to a minimum. Plants that had been visited by Cranfield personnel during the previous 12 months as part of other research projects were also excluded, as were plants that were scheduled to be visited as part of the 1997 Best Factory Awards judging process. In order to ensure that, as far as possible, like was being compared with like, small organisations were excluded. Therefore, only plants with 50 employees or more from organisations with at least two plants were considered.

The 8 plants selected were each sent the letter shown in Appendix 5 and were contacted by telephone a few days later. The 4 high performing plants all agreed to take part but resistance was encountered from the 4 low performing plants. Two declined to take part. Two replacement plants were selected and they also declined to take part. The two plants that agreed to participate both emphasised that they had introduced, or were introducing major changes as a result of the Best Factory Awards benchmarking process. One had recruited several new members of staff with experience of lean manufacturing, including a production engineer from the plant that was the BFA Plant of the Year for 1995. The other plant was introducing a computerised planning and scheduling system.

To have selected further replacement plants would have meant selecting plants from the third rather than the fourth quartile. It was therefore decided that a different approach should be adopted. The 4 high performing plants were visited and their characteristics were compared with average performance for plants in the same industrial sector. The two fourth quartile plants that had agreed to participate were visited in order to establish whether the changes that had been introduced or were being planned were consistent with what would be expected from the research. Again, the performance of these plants as indicated on the Best Factory Awards questionnaire was compared with average performance for plants in the same industrial sector. The two sectors for which only a high performing plant was visited were the Engineering and Household Products sectors. In the subsequent analysis of these plants comparisons were still made with the Best Factory Award survey data for a typical low performance plant from the same sector. At each plant visited, staff responsible for planning, purchasing and production were interviewed. The interviews were kept fairly open-ended but a consistent framework for the interviews was employed using the questions listed in Appendix 6.

7.2 Comparisons between the High Performers and the Low Performers

The plants were selected using a performance index (COMP) based on the sum of their rankings on the following performance measures.

- Manufacturing added value per employee £
- % Scrap
- Speed of delivery
- % of orders delivered on time

Actual rankings for the 6 plants visited are summarised below. As mentioned earlier, statistics for the two low performance plants not visited is included for completeness and to provide a basis for comparison in the subsequent analysis.

Table 7.1: Actual Rankings for the Six Plants Visited

	Engineering		Electronics		Process		Household Products	
	High	Low	High	Low	High	Low	High	Low
Added Value	65	85	58	26	12	88	25	50
% Returns	20	23	29	63	25	96	5	68
Delivery Speed	2	65	20	27	24	64	36	94
Delivery Reliability	7	66	9	73	8	96	39	57
Product Variety	52	2	89	18	79	29	18	88

The corresponding actual absolute measures were as follows.

Table 7.2: Absolute Performance Measures for the Six Plants Visited

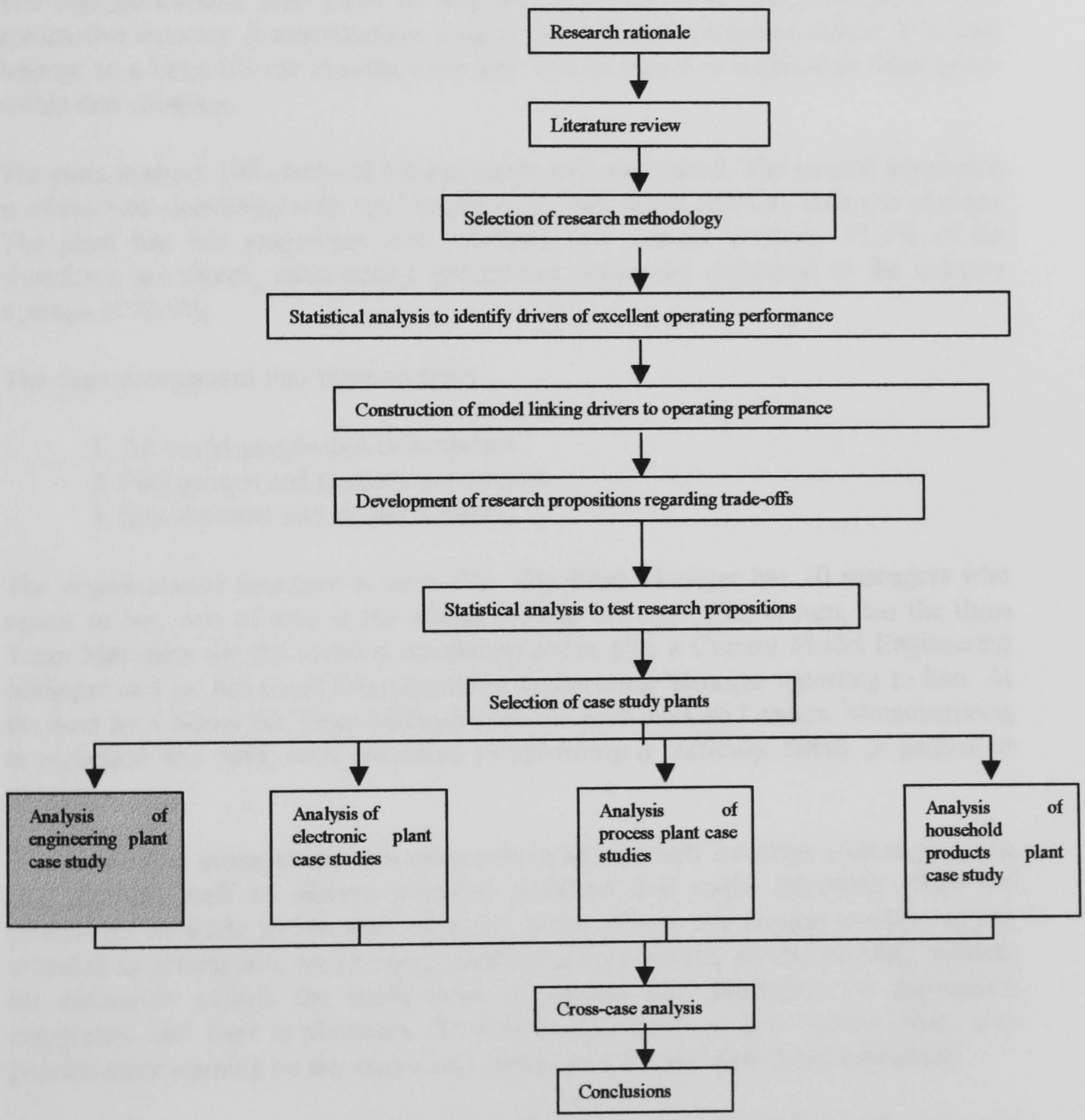
	Engineering		Electronics		Process		Household Products	
	High	Low	High	Low	High	Low	High	Low
Added Value	1.36	1.24	1.39	1.53	2.01	1.23	1.90	1.63
% Returns	0.02	0.057	0.31	0.6	0.05	2.5	0.000006	1.0
Delivery Speed	1	30	15	20	5	28	10	80
Delivery Reliability	100	85	99.8	85	99.2	50	99.1	95
Product Variety	547	5535	260	1307	225	640	336	38

Chapter 8 : The High Performing Plant from the Engineering Sector

8.1 Summary

Figure 8.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In the previous chapter the objectives of the plant visits and the rationale behind the selection of the plants to be visited was explained. In this chapter the results of the visit to the high performance plant from the engineering sector are described. The plant's approaches to planning, purchasing and performance improvement are analysed. Finally, the extent to which the plant supports the research propositions identified in chapters 4 and 6 is tested.

8.2 The High Performance Engineering Plant

8.2.1 Plant overview

The high performing plant from the engineering sector is a supplier of parts to the automotive industry. It manufactures a variety of types of instrument cluster. The plant belongs to a large US car manufacturer and 92% of output is supplied to other plants within that company.

The plant is about 100 years old but extremely well maintained. The general impression is of extreme cleanliness with marked places for everything and very little out of place. The plant has 966 employees with relatively few indirect workers. 71.7% of the workforce are direct, value-adding production employees compared to the industry average of 52.9%.

The plant is organised into three sections

1. Air cored gauges and tachometers
2. Fuel gauges and temperature sensors
3. Speedometer and cluster assembly

The organisational structure is fairly flat. The Plant Manager has 10 managers who report to her, one of who is the Manufacturing Manager. He, in turn, has the three Team Managers for the sections mentioned above plus a Current Model Engineering Manager and an Advanced Manufacturing Engineering Manager reporting to him. At the next level below the Team Managers are the working Cell Leaders. Manufacturing is organised into cells; each dedicated to producing a particular family of gauges or clusters.

The production managers in each section have regular daily meetings with engineering and planning staff to discuss potential problems that might adversely affect the production schedule and to take necessary action. There is a regular weekly meeting attended by production, engineering, planning and sales staff. At this meeting, subjects for discussion include the implications of planned new products, any production constraints and their implications for delivery promises on new orders. Sales also provide early warning on any major new orders that are currently being negotiated.

Four managers were interviewed at this plant. They were the Materials Planning and Logistics Manager, the Advanced Manufacturing Engineering Manager (who covered relations with suppliers), the Manufacturing Manager and the Plant Manager. The information that they provided on the systems and procedures within the plant is summarised below.

8.2.2 Planning

The planning process starts with the preparation of a master production schedule by the plant's parent company (their main customer). This is done at a central location for all plants within the company. Each plant then receives its schedule through an Electronic Data Interchange (EDI) system. The schedule covers the next 6 months with the first 4 week's requirements being firm. Requirements for this 4-week period are extremely accurate. The 6-month plan is re-issued fortnightly, receiving a major update every 4 weeks.

The master production schedule is then exploded using a Material Requirements Planning (MRP) package to give the raw demand. This is converted into a level production schedule taking into account capacity constraints. The resulting parts schedule for each supplier is generated with detailed daily shipping requirements for the next 4 weeks and monthly requirements beyond that.

8.2.3 Purchasing

Suppliers can be classified into three groups.

8.2.3.1 UK suppliers

Key UK suppliers receive their schedule by EDI. For each item, the schedule shows the number to be shipped each day and the delivery frequency (up to 3 times a day). The daily shipment quantity can be varied from plan within agreed limits and such changes are transmitted by fax.

8.2.3.2 USA/Far East suppliers

Items supplied from USA and the Far East are all small, low complexity, low cost items. Co-ordination of these suppliers and shipment of the parts is managed for the whole company by an external agent. Suppliers ship their parts to a central location in the USA. There, the items required by the UK are loaded into containers, which are shipped to a central depot in the UK and de-consolidated. Those items required by the plant are then shipped by lorry. The agent receives the shipping schedule for all suppliers and each supplier receives their individual shipping schedule. These schedules are updated and re-issued once a month.

8.2.3.3 European suppliers.

Most items from European suppliers are high quality, high cost items. These suppliers ship weekly, based on information from the master schedule, sent electronically. Shipment typically takes 5 days. The items are sent to a warehouse in the UK which is managed by an agent who checks the accuracy of each schedule sent and is responsible for shipping items from the warehouse to the plant daily.

All suppliers are self-certified. The plant has its own quality standards, similar to ISO9000, that all of its suppliers must meet. On those rare occasions when problems are encountered, quality inspectors check the next three batches from that supplier on arrival.

The Materials Planning and Logistics Manager said that over the last few years this plant has made considerable efforts to reduce its supplier base and to strengthen relationships with its suppliers. The plant currently has 80 suppliers compared with an industry sector average of 287. Over a 3-year period, this plant has reduced its supplier base by 18%. In terms of frequency of delivery, 70% of the plant's suppliers deliver daily or twice weekly. The corresponding industry average is 21%. The plant's suppliers achieved a delivery reliability of 93%, compared with an 82% average for the industry as a whole.

Although the plant has achieved a considerable degree of rationalisation in their supplier base, part of the explanation for the reduction in suppliers was that a number of components that had previously been sub-contracted were now in-sourced. The Materials Planning and Logistics Manager claimed that this gave them an advantage in areas where component designs were constantly changing. Agreements with suppliers required the plant to give 1 month's notice of engineering changes and 3 months notice of changes affecting the raw materials or components used by the supplier. Such changes could be implemented much more rapidly for items manufactured in-house.

The Materials Planning and Logistics Manager described relations with suppliers as very close and long-term.

"Many of our suppliers have been with us for over ten years and we frequently set up joint projects to develop new components or to improve existing ones."

8.2.4 Performance improvement

Currently four major changes are taking place.

1. Construction of an extension that will approximately double the available floor area at a cost of £45,000,000.

2. Phasing out of a section manufacturing products that are of low added value and do not fit with this plant's core business of cluster manufacture. These products will be transferred overseas, enabling this plant to become more focused.
3. Increasing the proportion of output that is sold to customers outside the parent company. The Plant Manager said that their long-term aim is for 20% of total output to be sold to external customers.
4. Increasing further the transfer of responsibility to the individual operators. This will be achieved through a new Company Production System, which the Manufacturing Manager claims is an improved version of the Toyota Production System.

With regard to this last initiative, the Manufacturing Manager commented,

"Giving the operators more responsibility represents an area of major current concern within the plant. Historically this plant has adopted a very traditional approach to the division of responsibility between management and the workforce. The workforce were given relatively little discretion, hence the emphasis on detailed process information. Suggestions for improvement tended to come from management or from technical support departments. The plant is trying to change this but there are still major cultural barriers. Problem-solving groups exist but only about half of employees are involved. Considerable progress has been made on worker empowerment but there is still some way to go."

An important feature of the plant's current strategy is multi-skilling. This is being achieved through a programme of off-the-job training involving the whole workforce. The Plant Manager said that this should enable further reductions in the number of indirect workers required.

8.2.5 Management views on trade-offs

The Manufacturing Manager considered the most important trade-off for his plant to be between product and component variety and all of the other performance measures. One of his main current objectives is to reduce the number of different products being produced at this plant and to reduce the total number of components being used by simplification and standardisation. He believed that this would lead to lower costs, fewer quality problems, shorter manufacturing lead times and more reliable delivery.

When pressed on the trade-offs between these four performance measures he said that their programme of transferring more responsibility to operators and increasing the involvement of the workforce in performance improvement would lead to simultaneous improvements in quality conformance, manufacturing cost and speed and reliability of delivery.

8.3 Comparative Analysis of Plant Characteristics

8.3.1 Process reliability

The high performance plant's process reliability is summarised in Table 8.1. Average performance for the engineering sector as a whole and the figures for a low performance plant are provided as a comparison. These results provide some support for the proposition that high performance plants show greater process reliability than low performance plants. All of the 5 measures of process reliability for the high performance plant show better than average performance. However, only 2 of the 5 measures for the low performance plant show below average performance. The plant's rating on process dependability is below the sector average but only slightly and percentage adherence to schedule in the current year is below the sector average. The other three measures are contrary to what would be predicted by the proposition.

Table 8.1: Process Reliability Data for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Plant's subjective rating on process dependability	9	7.2	7
% Adherence to schedule this year	100	88.2	85
% Adherence to schedule last year	98.7	83.0	85
% Scrap rate this year	0.9	3.1	0.6
% Scrap rate last year	1.4	4.3	1.0

As can be seen, the high performance plant rated itself very highly on process dependability, significantly higher than the average rating for the engineering sector or the rating for the low performance engineering plant. This high level of process dependability is also reflected in the level of adherence to schedule, which again is significantly higher for this plant than either the engineering sector average, or the percentage adherence to schedule for the low performance engineering plant. While scrap rates for this plant are much lower than the average scrap rates for the engineering sector as a whole, they are slightly higher than those for the low performance engineering plant.

The Manufacturing Engineering Manager attributed the high level of adherence to schedule to their very sophisticated computer-based finite capacity production planning system and to the sharing of planning information with suppliers and customers.

8.3.2 Precision of quoted lead times

The results for these plants support the proposition that high performance plants have a higher percentage of quoted deliveries that are for a specific time of day than low performance plants. The high performance plant is dealing with extremely demanding customers, most of who are part of the same organisation. All deliveries must be for a particular time of day. None of the deliveries quoted by the low performance plant were for a particular time of day and only 10 per cent of all deliveries in this sector were for a particular time of day.

Table 8.2: Precision of Quoted Lead Times for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Specific Week	0	41%	0
Specific Day	0	46%	100
Specific Time of Day	100	10%	0
Other time		3%	

8.3.3 Throughput efficiency

The results for these plants provide some support for the proposition that high performance plants show greater throughput efficiency than low performance plants. The high performance plant had devoted considerable effort to reducing changeover times and this is reflected both in the high rating for throughput efficiency and in the very low percentage of capacity devoted to changeovers. However, the results are less clear-cut for the low performance plant. This plant gave itself a rating of 9 out of 10 for throughput efficiency; significantly better than the engineering sector average although the percentage of capacity used for changeovers was well above the sector average. The differences in throughput efficiency measures are summarised below.

Table 8.3: Throughput Efficiency Measures for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Plant's subjective rating on throughput efficiency	9	7.3	9
% of capacity used for changeovers	3%	9.8%	20%

8.3.4 Involvement of workforce in continuous improvement

The high performance plant provided strong support for the proposition that high performance plants place greater emphasis on continuous improvement than low performance plants. This plant out-performed the sector averages on all 5 measures of continuous improvement. While this plant rated itself very highly on the use of continuous improvement, three of the four managers interviewed expressed some degree of dissatisfaction with the extent to which the workforce were involved in this process. They considered that, to a very large extent, the improvements that had been made in reducing lead times and scrap rates had been achieved through the efforts of teams of staff specialists rather than through the involvement of the workforce. The plant management as a whole are very much aware of this and the involvement of the whole workforce in performance improvement is one of their top priorities. In fact, with 60 per cent of their workforce involved in performance improvement, they are doing better than almost any other plant in the engineering sector. However, their own comparisons are with Japanese manufacturing plants and there is still some way to go to match these plants in terms of worker involvement.

Results for the low performance plant were more mixed. Only two measures, the rating on the importance of performance improvement and the percentage of the workforce involved in problem-solving groups were worse than the sector average. On the other three measures the low performance plant out-performed the sector averages, contrary to what would be expected from the proposition.

Table 8.4: Use of Problem-solving Groups at Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Plant's subjective rating on change as a way of life	9	7.2	9
Plant's subjective rating on the importance of continuous improvement	9	7.0	6
Plant's subjective rating on the commitment of employees to continuous improvement	7	6.5	8
Plant's subjective rating on use of labour as a source of brainpower	7	6.5	7
% of production employees involved in problem-solving groups	60	45	13

8.3.5 Labour flexibility

The support from these plants for the proposition that high performance plants have higher levels of labour flexibility than low performance plants is rather mixed. The high performance plant gave itself a rating for labour flexibility that is about average for the engineering sector but gave itself a rating on training and competence that is well above the sector average. The manufacturing manager at this plant recognises that this is another area where improvements need to be made. Multi-skilling of the workforce is an important feature of the plant's current strategy. This is being achieved through a programme of off-the-job training. As a consequence all production employees are competent to carry out more than half the jobs in their area. This compares with an industry sector average of 69 per cent of workers being competent to carry out more than half the jobs in their area.

In the case of the low performance plant, the rating on labour flexibility was about average for the engineering sector but the rating for training and competence was above the sector average. This is contrary to what would be predicted by the proposition.

Table 8.5: Labour Flexibility for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Plant's subjective rating on labour flexibility	7	7.2	7
Plant's subjective rating on emphasis on training and competence	9	6.5	7

8.3.6 Labour costs

These plants provide some degree of support for the proposition that high performance plants have lower labour costs as a percentage of total manufacturing costs than low performance plants. In the case of the high performance plant, direct labour costs are higher than the sector average but this is offset by the lower than average levels of indirect and other labour costs. Consequently, total labour costs are 27.4 per cent of total manufacturing costs compared with a sector average of 30.1 per cent. This has been achieved by a combination of slimming down management and supervisory staff and de-layering. However, the level of support staff is still quite high and the next priority is to reduce support staff by transferring more of these responsibilities to direct workers.

The low performance plant has a higher level of direct labour costs as might be expected from the proposition. However, indirect and other labour costs are lower than the sector average. Overall, total labour costs are 32.0 per cent of total manufacturing costs, higher than the sector average and in line with what would be expected from the proposition.

Table 8.6: Labour Costs as a Percentage of Total Manufacturing Costs at the Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Direct labour	18.6%	15.9%	19.3%
Indirect factory labour	3.1%	5.3%	3.9%
Other labour (including staff and managerial)	5.7%	8.9%	8.8%

8.3.7 Cleanliness

There is mixed support from these plants for the proposition that high performance plants have higher levels of cleanliness than low performance plants. The high performance plant obviously placed great emphasis on cleanliness and neatness. The plant gave itself an above average rating on cleanliness. However, the low performance plant also gave itself an above average rating for cleanliness.

Table 8.7: Measure of Cleanliness for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Plant's subjective rating on cleanliness	8	7.2	8

8.3.8 Accurate documentation

There was mixed support for the proposition that high performance plants have more accurate and up-to-date process documentation than low performance plants. The high performance plant placed considerable emphasis on the quality and detail of the documentation at every level in the organisation. Considerable effort was devoted to ensuring that process manuals were kept up to date and that they were available to all staff who might need them. The plant gave itself a rating of 10 out of 10 for the accuracy and up-to-dateness of its documentation. Computer screens at each workstation provided detailed information on the task to be completed at that workstation for the current item being worked on. This minimised the possibility of incorrect assembly.

However, the low performance plant also gave itself an above average rating, 8 out of 10, on accuracy and up-to-dateness of documentation. The average rating for the engineering sector was 7.7.

The high and low performance plants both measured stock record accuracy, as did the majority (77.8%) of all engineering sector plants.

Table 8.8: Measures of Documentation Accuracy for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Plant's subjective rating on accuracy of documentation	10	7.7	8
Is stock record accuracy measured?	Yes	74.8%	Yes

8.3.9 Suppliers

The results for the high performance plant supported the proposition that high performance plants have more frequent and reliable supplier deliveries than low performance plants. The high performance engineering plant obtained much greater delivery reliability from their suppliers than the engineering sector average or the low performance plant. The high performance plant also had much lower raw materials stocks in weeks' usage. Its suppliers also delivered more frequently than the sector average.

All four of the managers interviewed at the high performance plant mentioned the importance of working closely with suppliers in order to improve the quality consistency and delivery reliability of delivered raw materials. However, the Advanced Manufacturing Engineering Manager made it clear that if a supplier fails to meet the performance targets set and, after a reasonable period of time, there is no improvement then that supplier is replaced.

The results for the low performance plant were less consistent with what would be predicted by the proposition. Percentage on time delivery by suppliers was below the sector average in line with the proposition. However, stocks of raw materials are below the sector average and frequency of delivery is better than the sector average. These results are contrary to the proposition.

Table 8.9: Measures of Supplier Delivery Performance for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Weeks' usage of raw material stock	3.2	7.1	4
% On time delivery performance of suppliers	93	81.6	70

8.3.10 Supplier delivery frequency

One of the stated long-term aims of the high performance plant is to receive just-in-time delivery of bought-in materials and components with deliveries several times each day. The plant still has some way to go in achieving this aim but they are ahead of the rest of the engineering sector with regard to this objective. Seventy per cent of their suppliers deliver at least twice weekly compared with 21 per cent of suppliers for the engineering sector as a whole. None of the suppliers to the low performance plant delivered more frequently than weekly.

Table 8.10: Supplier Delivery Frequency at Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Daily delivery	30%	8%	0%
Twice weekly delivery	40%	13%	0%
Weekly delivery	25%	34%	100%
Monthly delivery	5%	29%	0%
Delivery less frequently than monthly	0%	16%	0%

8.3.11 Measurement of a wide range of metrics

These plants provide mixed support for the proposition that high performance plants measure a wider range of metrics than low performance plants. Both the high performance plant and the low performance plant measured 90 per cent of the metrics specified in the Best Factory Award questionnaire. This is significantly better than the industry sector average of 63 per cent of metrics measured.

Table 8.11: Metrics Measured at Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Is output volume measured on a regular basis?	Yes	95	Yes
Is production schedule adherence measured on a regular basis?	Yes	59	Yes
Is ex-stock availability measured on a regular basis?	Not applicable	27	Not applicable
Is due date reliability for items on quoted lead times measured on a regular basis	Yes	66	Yes
Is inventory record accuracy measured on a regular basis?	Yes	72	Yes
Is scrap or yield loss rate measured on a regular basis?	Yes	70	Yes
Is time spent on rework/reprocessing measured on a regular basis?	No	54	Yes
Is time spent on setting/changeover measured on a regular basis?	Yes	41	Yes
Are customer's returns/complaints measured on a regular basis?	Yes	63	Yes
Is first time pass rate measured on a regular basis?	Yes	49	No
Is supplier delivery performance measured on a regular basis?	Yes	59	Yes
% of metrics measured	90	63	90

8.3.12 Trade-offs

8.3.12.1 Proposition 10

Proposition 10 states that rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial sector. If this is the case then it would be expected that the high performance engineering plant would perform better than the industry sector average on these factors and the low performance engineering plant would perform worse than the industry sector average. Actual performance on these measures for the high and low performance plants is summarised in Table 8.12.

Table 8.12: Absolute Performance Measures for Engineering Plants

	High performance plant	Engineering sector average	Low performance plant
Added value per employee £	1.36	1.44	1.24
% Customer returns in current year	0.02	0.39	0.06
Average quoted customer lead time	1	23	30
% On time delivery	100	89	85

In the case of the high performance plant performance is much better than the sector average for 3 out of the 4 measures. The exception is added value per employee £ which is just a little below the sector average. In the case of the low performance plant performance is worse than the sector average for 3 out of the 4 measures. The exception this time is percentage customer returns.

8.3.12.2 Proposition 11

Proposition 11 states that the extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability. If this is the case then it would be expected that plants with a smaller product range than the industry sector average would perform better than the industry sector average on these factors and plants with a larger product range than the industry sector average would perform worse than the industry sector average on these factors.

Three of the four managers interviewed mentioned the importance of reducing the product range in order to reduce production costs. One of the objectives of the parent company of the high performance plant has been to increase the degree of focus in each manufacturing plant in terms of the total number of different products being produced and also to reduce the total number of different components being used by simplification and standardisation. As a consequence, the number of different products, components and raw materials in the plant are considerably lower than the corresponding industry averages. In contrast with this the low performance plant has a much wider product range than the engineering sector average although the number of components, sub-assemblies and raw materials seems to be fairly similar to the engineering sector average. The main differences between the two plants and the industry as a whole are summarised below.

Table 8.13: Product Focus for Engineering Plants

	High Performance Plant	Engineering Sector Average	Low Performance Plant
Total products currently live	539	5,126	9,464
Total manufactured components, bulk intermediates and sub-assemblies currently live	1,150	6,872	13,216
Total bought out components and sub-assemblies currently live	1,500	6,277	-
Total purchased raw materials currently live	20	3,623	-
Products in continuous production last year	89	121	25
Products in intermittent production last year	450	433	5,500
Products of initially unknown design produced last year	8	193	10
Total different products made last year	547	747	5535

If proposition 11 is correct then it would be expected that the high performance plant would have a small product range and the low performance plant would have a large product range and this is in accordance with the results above. With the exception of added value per employee £ for the high performance plant and percentage customer returns for the low performance plant as discussed earlier, all of the performance measures match what would be predicted by proposition 11.

8.4 Conclusions

This is a plant in transition between traditional mass production and lean manufacturing. While the plant management has made considerable progress in achieving this transition, the managers readily admit that there is still some way to go.

The emphasis is very much on the minimisation of variability and uncertainty. This is achieved through the use of a sophisticated finite capacity planning system, the sharing of planning information with suppliers and customers and close adherence to the production plan. The workforce is thoroughly trained and receives detailed assembly instructions at each stage of the construction process, ensuring few errors and high levels of quality consistency. The disadvantages of their current operating procedures are a lack of flexibility when faced with short-term changes in customer demand and a lack of operator autonomy that is preventing them from exploiting the full potential of their workforce.

In order to provide a greater degree of flexibility a number of components that were previously sub-contracted are now made in plant. Although this appears to go against their policy of increased plant focus and simplification the Planning Manager justified it on the grounds that it would eliminate the long notice required by suppliers for specification changes.

Planned changes at the plant include a doubling of the available floor space and an increase in the proportion of output sold to customers outside the parent company. Both of these initiatives will involve significant challenges if the plant is to maintain or improve current levels of operating performance. To assist the managers with this the product range is being reduced by phasing out a section that produces low added value products. They are also introducing their own version of lean manufacturing, which will transfer much more responsibility to the individual operators.

In terms of operating performance this plant is very good at producing a relatively narrow product range to high levels of quality consistency and achieving fast, reliable delivery. The model developed in this research would suggest that this plant would also achieve high added value per employee £ but this is not the case. Added value per employee £ is a little less than the sector average. This might be a result of the low added value products that are currently being phased out.

The level of support at this plant for the propositions being tested in this research is summarised in Table 8.14.

Table 8.14: Support for Research Propositions at the High Performance Engineering Plant

Proposition	Description	Level of support
1	Process reliability	Excellent
2	Throughput efficiency	Excellent
3	Emphasis on continuous improvement	Excellent
4	Labour flexibility	Good
5	Low labour costs	Good
6	Cleanliness	Excellent
7	Accurate documentation	Excellent
8	Frequent, reliable supplier delivery	Excellent
9	Measurement of wide range of metrics	Excellent
10	Positive correlation between added value per employee £, quality consistency, customer lead time and delivery reliability	Good
11	Negative correlation between product variety and added value per employee £, quality consistency, customer lead time and delivery reliability	Good

The plant provides support for all of the propositions being tested. However, added value per employee £ is lower than would be expected from propositions 10 and 11.

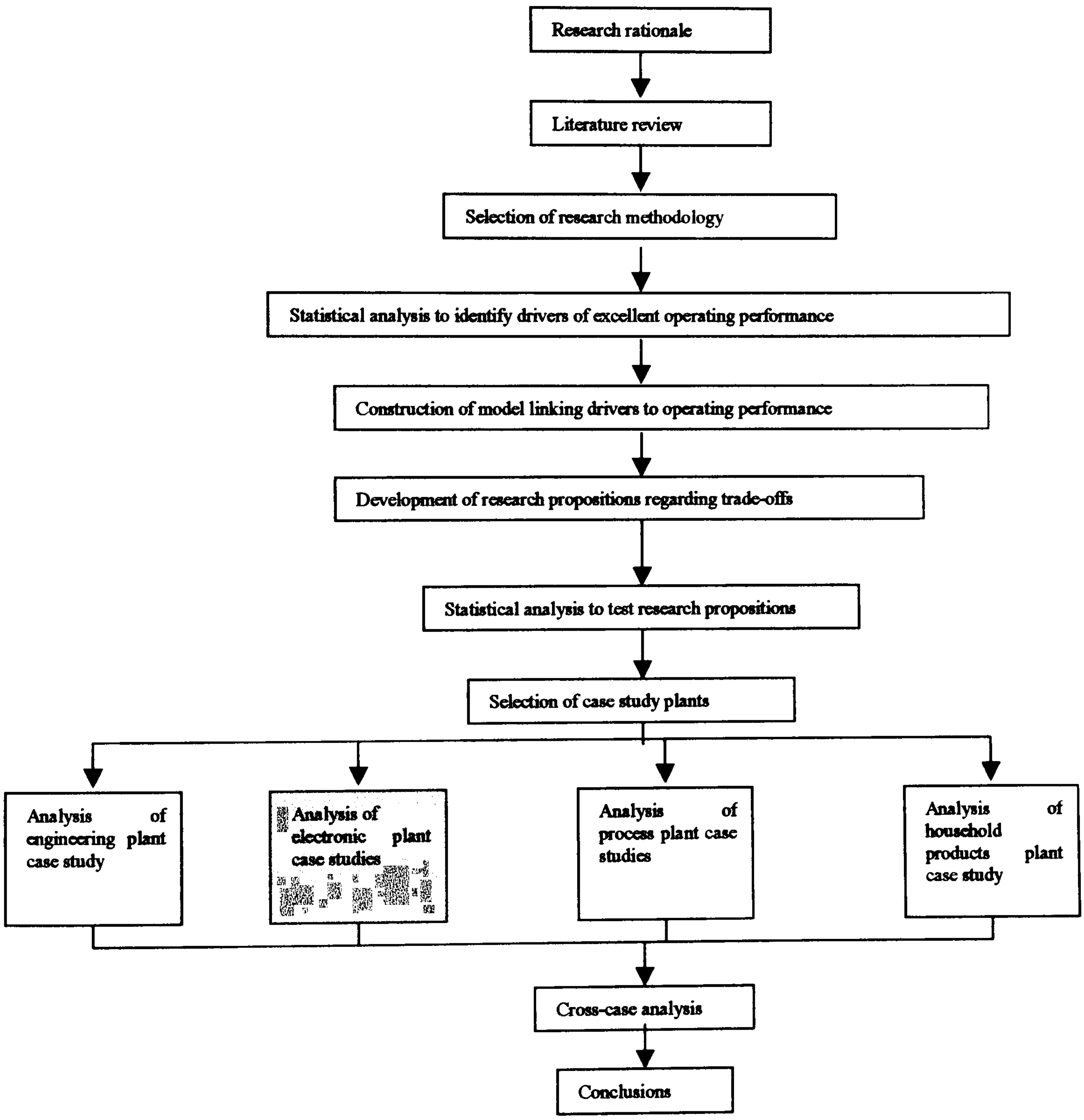
The plant's strategy for improvement – greater multi-skilling of the workforce, greater involvement of the workforce in continuous improvement, more frequent deliveries by suppliers are all areas for improvement that are consistent with the propositions developed in this research.

Chapter 9 : The Plants from the Electronics Sector

9.1 Summary

Figure 9.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In this chapter the results of the visits to the high and low performance plants from the electronics sector are described. Each plant's approach to planning, purchasing and performance improvement is analysed. Finally, the extent to which the plants support the research propositions identified in chapters 4 and 6 is tested.

9.2 The High Performing Electronics Plant

9.2.1 Plant overview

Interviews at this plant were conducted with the Purchasing Director, the Production Planning Manager and the Manufacturing Engineering Manager.

This plant's original activity was repairing electro-mechanical telecommunications equipment. As the technology within the telecommunications industry changed it started to repair and service printed circuit boards and eventually began to manufacture them. In 1987, the parent company reorganised the business, moving the repair work elsewhere and leaving this plant to manufacture telecommunications equipment. In 1991 a Japanese company took a majority share in the company. The plant was moved from a city-centre location to a modern site on the outskirts of the city and a major programme of investment and performance improvement took place. The plant had excessive stocks, unnecessary duplication of parts and long lead times. The design process failed to take account of ease of manufacture and consequently, only 20 per cent of each board's components could be placed automatically.

Attention was concentrated on improving the degree of communication between the design and manufacturing functions. Design started to take into account the constraints of the manufacturing process. Designers were persuaded to use existing components as far as possible. As far as possible the design process was automated, including the capability to simulate operation of the product before any physical production had taken place. These changes enabled the design time for a new product to be halved. At the same time dramatic improvements in first time pass rates, lead times and delivery reliability were achieved.

The Purchasing Director said that although it is part of a large Japanese company, the UK Company operates, to a large extent, autonomously. This means that it is a small player relative to its main competitors. However, since 1989, turnover has grown from £30 million to £100 million. The Purchasing Director attributed their success to four factors.

1. Very good internal communications
2. Locating Marketing, Sales, Design and Production all in close proximity, all within the same building
3. Close links with customers
4. Joint development, with customers, of new products, sharing the risk.

The Purchasing Director stated that one of the first changes that were made after the Japanese company took over was to replace the cumbersome, multi-layered hierarchy with a much flatter management structure. In manufacturing the functional structure was replaced by manufacturing cells, each with a working cell leader. The current manufacturing structure is shown below.

Operations Director

Manufacturing Manager

Production Manager

6 working cell leaders

Some parts of the shop floor work 2 shifts, 0600 - 1400 and 1400 - 2200. Other parts work 0745 - 1630. Each morning there is a production meeting attended by the manufacturing manager, the production manager, the cell leaders and production control staff. There is a further production meeting at 1430, which the production control staff do not attend. Total throughput time for a typical order is 4-9 days.

9.2.2 Planning

The Production Planning Manager stated that the nature of their products means that close liaison between Design and Production is essential. This is partly achieved by having the two departments in close proximity. It is also aided by a fully integrated computer planning system that incorporates Computer Aided Design, Computer Aided Engineering and Finite Capacity Planning. The Design Department work very closely with the customer and there is electronic sharing of information. This ensures that the customer approves all aspects of specification and quality before production starts. The CAD software then automatically generates the bill of materials. The Computer Aided Engineering software enables simulation of the production process before physical production commences. This enables potential production problems to be identified and dealt with at the planning stage. It also ensures that production costs are fully taken into account at the design stage.

A database of standard components is maintained and wherever possible design engineers are expected to use these components. For the small proportion of non-database components, design and out-sourcing occurs in parallel. The CAD software can download specifications and requirement schedules electronically to suppliers.

The computer system provides a 3 month detailed production plan and suppliers receive an 8 week requirements plan rolled forward weekly. The last 4 weeks of the production plan is frozen. Changes to the production plan must be approved by a senior manager.

9.2.3 Purchasing

The Purchasing Director stated that the plant works closely with suppliers.

"Many of the new products that we develop for customers are joint ventures between us and one or more of our suppliers."

The company organises regular forums, attended by all of their key suppliers. These forums enable sharing of information on how suppliers can reduce lead times, reduce costs and increase flexibility.

Over the last few years the plant has operated a policy of reducing the supplier base and then working closely with the suppliers remaining. The plant has reduced bare board PCB suppliers from 11 to 1 with 1 backup supplier. Boards are provided on a 2 to 3 day lead time. Packaging suppliers have also been reduced to 2 and are also on a 2 day lead time with deliveries varying from daily to weekly depending on usage volume. Other raw materials tend to be delivered less frequently, with delivery quantities varying from 2 weeks to 6 weeks usage.

Suppliers receive an 8 week forward plan of which 4 weeks is firm. The Manufacturing Engineering Manager said that there are still a few problem areas with suppliers. Many Japanese suppliers still insist on orders being placed on long lead times with no changes once the order has been placed. Some suppliers of mechanical parts still find it difficult to achieve the parts per million quality reliability that the company requires. However, with these few exceptions, most suppliers can now meet the company's requirements on quality, price and delivery. Choice of supplier is, therefore, now based on flexibility and ease of business. By ease of business the company means fast response to enquiries and queries, simple and error-free billing procedures and a willingness to work jointly on mutually beneficial improvements. Flexibility is important because the company is very customer-oriented and is essentially selling flexibility. In order to be able to offer flexibility to their own customers, their suppliers must also be able to react flexibly to changing end-customer requirements.

Over the next 5 years the Purchasing Director expects that there will be greater emphasis on global rather than local sourcing. They are already working more closely with the rest of the group in order to take advantage of their joint buying power. They are also establishing worldwide standards for materials and components to make joint purchasing possible and to enable more rapid switching of components from one supplier to another.

9.2.4 Performance improvements

The Manufacturing Engineering Manager said that since the Japanese company had acquired the plant in 1991, dramatic improvements in operating performance have been achieved. These include the following,

- On-time delivery performance had been increased by 145%.
- Printed circuit board first time pass rate had been increased by 40%.
- Average manufacturing lead time had been reduced by 70%.
- Average unit manufacturing cost had been reduced by 40% in real terms (after allowing for inflation).

The Manufacturing Engineering Manager considered that the main reasons for these improvements were as follows,

A major review of all aspects of the business by working parties largely staffed by managers from the parent Japanese company
The move to a modern plant
Heavy investment in computerised systems and automated equipment

The Manufacturing Engineering Manager stated that, currently, improvement initiatives are largely focused on improving flexibility.

"Quality, price and delivery are now taken for granted. Business is now won through increased flexibility, the ability to respond rapidly to changes in market requirements."

The plant is currently implementing a programme to involve the whole workforce in performance improvement through problem-solving groups. Any operator with an idea for improvement can call a member of the Design Department down to the shop floor to discuss it. Progress has not been as rapid as the Manufacturing Engineering Manager would like.

"Most of the ideas come from the 20-odd year olds."

"For the older workers there is still a clash between the UK and Japanese cultures."

"Because the new plant has been so successful it is now difficult to get change."

9.2.5 Management views on trade-offs

The Manufacturing Engineering Manager considered the main trade-off to be between capital investment in technology and operational performance. By investing in automation of the design process with emphasis on ease of manufacture, simultaneous improvements in all aspects of operating performance had been possible. He considered that the impact of increasing the product range would be neutral at current levels of operation, as it would be achieved by adding additional semi-autonomous cells that would have little interaction with the existing cells.

9.3 *The Low Performing Electronics Plant*

9.3.1 Plant overview

At this plant the Purchasing Director, the Production Manager and the Production Planning Manager were interviewed.

This plant manufactures electrical fuses. These are relatively simple, low cost products with few components, produced in high volume. In the period between the completion of the Best Factory Award questionnaire and the plant visit, considerable changes were made. The plant was moved to a new location, which was much more modern and spacious. A new production manager was appointed. A production engineer was recruited from the plant that won the BFA Best Factory of the year award in 1995, and a major performance improvement initiative called Project 2001 was set up. The following description relates to the situation at the plant in July 1997. The numerical data in the tables has been extracted from the questionnaire, which the plant completed 15 months earlier.

There are three grades of operative. The lowest grade is that of operator. The middle grade includes key operators and set-up operators. The top grade includes the team leaders and the fitters. Since moving to the new plant, the shop floor has been re-organised into a number of manufacturing cells, each dedicated to a particular family of products. Although some of the standard, high volume fuses are produced on fully automatic, dedicated machines, production of most of the lower volume fuses is still extremely labour intensive. The majority of the shop floor employees work 0800-1630 with some working on a 2 shift basis, 0600-1400, 1400-2200. The plant works a 5-day week with regular overtime on Saturdays.

The automatic machines achieve a first time pass rate of 98-99% but on the manual lines this falls to 92%.

9.3.2 Planning

There are 4 components in a conventional fuse; solder, glass, cap and wire. There are 700 different types of wire. In addition, some fuses have glass or ceramic bodies. Stocks of glass, caps and bodies are reviewed weekly using a kanban system in which any usage since the last review is replaced. Solder stocks are reviewed fortnightly also using a kanban system. Wire, packaging and other raw materials are reviewed monthly using a fixed re-order point/re-order quantity system. The plant currently holds 5.5 weeks of raw material stock.

Suppliers are sent an 8 week forward plan of forecast requirements. Most raw materials are self-certified; the exception being wire, which must be checked by the quality control department before it can be released.

Most large customers receive deliveries weekly. The largest customers call off their requirements daily or twice weekly. Not all of the items supplied are manufactured at the UK plant. Many are shipped across from the USA and held in stock at the UK plant for supply to UK customers.

The existing production planning process involves a sales and order-processing system based on a 400 series computer and a PC based system for production planning and manufacturing. There is no automatic link between the two systems so that transfer of data has to be done manually. The Production Manager said that in the existing system, Sales have no idea of the existing factory workload and so often make unrealistic delivery promises to customers. She also said that Sales do not provide production planning with forecasts of future requirements and so frequent changes to the production schedule are necessary.

9.3.2.1 The new computer system

The new computer system is the outcome of a project that was started last year to redesign the order fulfilment process. This project covered all aspects of the order handling process from receipt of the order to despatch of the goods, including order entry, production planning, manufacturing and purchasing.

A team was formed consisting of representatives from all departments involved in the order handling process. Their first task was to devise on paper a logical and efficient procedure for order handling, ignoring existing methods. Once this was done it was clear that a new computer system would be needed to implement the new procedure.

After a survey of available software an MRPII system linked to a windows-based report generating system was selected. The system is entirely PC-based and is extremely user-friendly and flexible. The new system has an available to promise feature. The Production Manager said that this should mean that, provided Sales do not accept orders in excess of available capacity, there should be no reason for failure to fulfil orders other than non-delivery by suppliers or a plant breakdown. When an emergency order is received which is in excess of available capacity then the computer can rapidly determine the effect that this order will have on existing orders.

The plan will be updated daily. The Production Manager said that the experience of plants with larger parts bases is that the run time will be less than an hour. If the actual run time is much less than this then consideration will be given to up-dating the plan twice daily.

Forecasts will be generated for a year ahead using Microsoft Access. The computer will use this information, together with data on firm orders and safety stock criteria to generate schedules for manufacturing and materials purchase. Rough cut capacity planning will be used to match load and capacity over an 8 week period with the schedule for the first 3 weeks being frozen.

Suppliers will be provided with forecast requirements 12 weeks ahead. In the case of caps, glass and solder, a kanban system has already been introduced with order requirements being determined by usage. Eventually, EDI links with suppliers will be established.

Shop floor scheduling is not part of the system. The computer will determine the orders to be released each day. The supervisor and team leader for each manufacturing cell will then determine the sequence in which the orders will be carried out. The Production Manager said that in the short-term, manufacture will be largely for stock but as the system becomes more reliable it should be possible to make to order and still meet the 9 day lead time target.

The overall project will involve 4 phases.

Phase 1	Computer installation and implementation of associated software
Phase 2	Introduction of bar coding for core processes
Phase 3	Introduction of EDI
Phase 4	Provision of sales analysis/forecasting information

9.3.3 Purchasing

The Purchasing Director said that the plant operates in a highly competitive market in which cost is a very important order-winning criterion. The plant is part of a multi-national company with plants in the UK, Switzerland, USA, Korea, China and Switzerland and customers in most parts of the world. The Purchasing Director stated

"Increasingly, location of manufacture is being determined by market and economic forces, the need to get products to customers rapidly and differences in labour costs. However, product standards tend to be different for different countries. In order to manufacture for a global market, the company's products must be of a sufficiently high quality to satisfy all of these standards. As a consequence, the first step in selection of a supplier is identification of those suppliers who can meet the quality specification."

Once a short list of potential suppliers worldwide has been identified capable of meeting quality requirements, the final selection is based on cost. This has to take into account the full economic price for each supplier, including freighting costs. However, by purchasing for all plants centrally, combined purchasing power can often lead to better trading terms than if each plant operated independently. The Purchasing Director said that there is, of course, a risk with this approach that the purchasing department will be somewhat remote and divorced from the quality and urgency problems of the individual plants. Consequently, each country has its own purchasing department, responsible for purchasing materials for their own plants but these purchasing departments are encouraged to co-operate with each other in order to organise joint agreements with suppliers.

The Purchasing Director stated

"As an example of this joint approach, the UK plant has a German supplier providing weekly deliveries of small, high value ceramic parts. The supplier had been identified as world class and plants in Mexico and the USA also use the parts. Consequently, their requirements have been tagged onto the UK order as part of the weekly delivery. This resulted in significant cost reductions, as much as 70 per cent in some cases. The UK plant already makes weekly deliveries of finished goods to the USA and so the ceramic parts are sent out with these. Because these are small, high value parts the additional delivery costs are relatively small, about 22 per cent of the cost of the items. Total transit time from Germany to the USA is about 5 days.

A slightly different example is the purchase of parts by the UK purchasing department on behalf of China. Currently, it is difficult to find suppliers in China capable of meeting the quality standards required by the company. The company is also having problems with manufacturing quality in the Chinese plant. By purchasing parts in the UK and shipping them out to China, the company can ensure that incoming parts are of high quality and low variability so that any problems with finished goods will be known to be due to operations at the Chinese plant. Eventually, as supplier quality in China improves it is the intention to purchase parts in the Chinese marketplace, as this will give a substantial cost saving."

Raw materials at the UK plant represent 65 per cent of total costs and at the China plant this percentage is likely to be even greater and so purchasing at low cost is crucial to profitability.
Although price has been the key selection factor used by purchasing in the past, it is now recognised that this has caused serious problems for manufacturing. Delivery reliability and quality conformance have been major problems with many suppliers. This has led to line stoppages and unplanned changes in the production schedule. This has, in turn, resulted in high levels of scrap and late deliveries to their own customers. Consequently, a supplier performance index has recently been introduced, based on the following factors.

Delivery performance (number of days early or late)
Incoming goods rejected on receipt
Goods rejected during the manufacturing process
Volume variance
Paperwork accuracy

Price is not taken into account in this index. The weightings of the factors in the index are changed as the relative importance of the various factors to the company changes.

Although some key suppliers have been with the company for 15 years, there has been little direct contact between the plant and its suppliers. As part of their current performance improvement programme the plant is trying to work more closely with their suppliers. Recent developments to improve relationships with suppliers include the appointment of a supplier liaison officer and the setting up of a supplier development initiative. This involves groups visiting suppliers to look at their production methods, to discuss problems encountered in using the products supplied and to find out how best to store and handle material. Recently, a group which included an operator from the wire winding department, visited the wire manufacturer in Switzerland to discuss quality problems and discovered that most of these problems were due to the way that the wire was being handled during the manufacturing process.

Key suppliers are now provided with an annual forecast of requirements, which is updated monthly. As a consequence, over the last 3 years, supplier delivery has improved significantly.

9.3.4 Performance Improvement

There are have been a number of other initiatives aimed at improving overall performance. These are all part of the major performance improvement programme, Project 2001, mentioned earlier. This programme has 3 main objectives.

Cost reduction
Quality improvement
Improved delivery performance

The following specific quantitative targets have been set.

A yield improvement of 1 per cent per annum
Lead time reduction to 9 days average
99 per cent on-time delivery
Stock levels of 0.5 weeks
A 25% reduction in customer complaints
The plan has been broken down into a series of tasks with named individuals responsible for each. The main tasks are summarised below.

1. Order Fulfilment Project

This involves a complete redesign of the order fulfilment process. It covers all aspects of the order handling process from receipt of the order to despatch of the goods, including order entry, production planning, manufacturing and purchasing. As a result of this project a new computer system is to be introduced. This is described in more detail in the next section.

2. Maintenance Project

This project is concerned with the introduction of preventive maintenance. The objective is to reduce the disruption caused by the current high level of unplanned breakdowns.

3. Statistical Process Control Project

This project is concerned with the introduction of statistical process control (SPC). It has the following objectives,

Reduce process variation
More efficient charting
Convert data into information
Reduce non-value-adding activities
Achieve 15% reduction in unplanned failures
Inspect process not product

4. Supplier Development Project

This was discussed earlier and covers the following,

Supplier approval
Supplier appraisal
Supplier rating
Working together with suppliers in cross-functional teams

5. Capital Investment Project
Two major capital investments are taking place.

a) Replacement of visual inspection by machine inspection
b) Introduction of automatic/semi-automatic fuse bagging

Currently the average number of operator hours per week to bag 220,000 parts is 182 hours. The machine is capable of bagging 84,000 parts per hour.

The improvement programme has already produced a fall in the number of customer orders past due. Over a 3 month period past due items has fallen from 4,100,000 units (20 days) to 956,000 units (5 days). Annual output is 51,243,000 units. Also, a 24% increase in sales value has been achieved with an increase in stock value of only 3.8%.

9.3.5 Management views on trade-offs

The Purchasing Director considered that there was a clear trade-off between quality consistency/delivery reliability and price when purchasing raw materials and components. In the past the emphasis had been on purchasing at low cost and this had led to quality problems and unreliability of supply. The future emphasis will be on identifying suppliers capable of providing more consistent quality and more reliable delivery. He said that this is likely to involve a cost penalty.

The Production Manager believed that the performance improvement initiative that was under way would lead to simultaneous improvements in cost reduction, quality improvement and better delivery performance. However, the initiative involves a substantial investment in a new computer system and so the trade-off is between capital investment and cost, quality and delivery reliability.

9.4 Comparative Analysis of the Characteristics of the Two Plants

9.4.1 Process reliability

Table 9.1 compares various measures of process reliability for the two plants with the averages for the process sector. The results provide strong support for the proposition that high performance plants have greater process reliability than low performance plants. On every single measure of process reliability, the high performance electronics plant exceeded the sector average and the low performance plant was either equal to or worse than the sector average.

Table 9.1: Process Reliability Data for Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Plant's subjective rating on process dependability	9	7.4	5
% Adherence to schedule this year	99.8	87.4	Not measured
% Adherence to schedule last year	99.0	77.1	Not measured
% Scrap rate this year	0.2	3.1	4.2
% Scrap rate last year	0.9	4.4	4.4

9.4.2 Precision of quoted lead times

There is also support for the proposition that high performance plants quote more precise lead times than low performance plants. All quoted lead times at the high performance plant are for a specific day while only 62 per cent are for a specific day or time of day for the sector as a whole and only 40 per cent of the lead times quoted by the low performance plant are for a specific day or time of day.

Table 9.2: Precision of Quoted Lead Times for Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Specific time of day	0	3	5
Specific day	100	59	35
Specific week	0	34	60
Other time	0	4	0

9.4.3 Throughput efficiency

The proposition that high performance plants have greater throughput efficiency than low performance plants is supported by the results for both plants. The high performance electronics plant has a better than average rating on throughput efficiency and uses a below average percentage of capacity for changeovers. The low performance plant has a below average rating on throughput efficiency and does not measure the percentage of capacity used for changeovers.

Table 9.3: Throughput Efficiency Measures at Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Plant's subjective rating on throughput efficiency	8	7.5	7
% of capacity used for changeovers	2.5	6.6	Not measured

9.4.4 Involvement of workforce in continuous improvement

With regard to the proposition that high performance plants will have a greater emphasis on continuous improvement than low performance plants the evidence is less clear-cut. The high performance plant is a little better than average on three of the five measures of continuous improvement. It has a slightly below average rating on change as a way of life and only 25 per cent of the workforce are involved in problem-solving groups compared with a sector average of 44.5%. This probably reflects a plant philosophy that performance is the responsibility of the management rather than the workforce. This philosophy is changing and efforts are being made to involve more of the workforce in problem-solving and performance improvement.

The low performance plant is below average on all 5 measures of continuous improvement and at the time of the survey none of the workforce was involved in problem-solving groups. This is now changing and one of the priorities at this plant is to involve the workforce in performance improvement.

Table 9.4: The Use of Problem-solving Groups at Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Plant's subjective rating on change as a way of life	7	7.1	7
Plant's subjective rating on the importance of continuous improvement	8	7.3	7
Plant's subjective rating on commitment of employees to continuous improvement	7	6.7	6
Plant's subjective rating on use of labour as a source of brainpower	7	6.9	5
% of production employees involved in problem-solving groups	25%	44.5%	0%

9.4.5 Labour flexibility

The proposition that high performance plants have higher levels of labour flexibility than low performance plants receives mixed support from these plants. Ratings on labour flexibility are fully consistent with the proposition. The high performance electronics plant gave itself a rating of 9 out of 10 for labour flexibility while the low performance electronics plant only gave itself a rating of 6 out of 10. The electronics sector average was 7.3 out of 10.

However, the rating for training and competence at the high performance plant only matches the sector average of 7.0. This is surprising as 98% of production employees at the high performance electronics plant could carry out more than 50% of the tasks in their area compared with the average figure for the electronics sector of 65.9%. The rating for training and competence at the low performance plant was below the sector average, which is consistent with the proposition.

Table 9.5: Labour Flexibility at Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Plant's subjective rating on labour flexibility	9	7.3	6
Plant's subjective rating on emphasis on training and competence	7	7.0	6

9.4.6 Labour costs

The proposition that high performance plants will have lower labour costs as a percentage of total manufacturing costs is supported by the high performance plant but not the low performance plant. At the high performance plant, direct labour costs, indirect labour costs and other labour costs are all below the sector average. In the case of the low performance plant total labour costs are lower than the sector average. This is the opposite of what the proposition would suggest.

Table 9.6: Labour Costs as a Percentage of Total Manufacturing Costs for Electronics Plants

	High performance plant	Electronics sector average	Low performance plant
Direct labour	8.4%	11.9%	11.3%
Indirect factory labour	0.2%	4.1%	4.6%
Other labour (including staff and managerial)	5.9%	7.9%	4.2%

9.4.7 Cleanliness

The proposition that high performance plants will have higher levels of cleanliness than low performance plants is consistent with the results for these plants. The high performance electronics plant gave itself a rating of 9 out of 10 for cleanliness. The low performance plant gave itself a rating of 7 out of 10 for cleanliness. The average figure for the electronics sector is 7.3 out of 10.

Table 9.7: Measure of Cleanliness for Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Plant's subjective rating on cleanliness	9	7.3	7

9.4.8 Accurate documentation

The proposition that high performance plants will have more accurate and up-to-date process documentation than low performance plants is consistent with the results for these plants. The high performance electronics plant gave itself a rating of 9 out of 10 for documentation accuracy. The low performance plant gave itself a rating of 7 out of 10 for documentation accuracy. The average figure for the electronics sector is 7.8 out of 10.

Table 9.8: Measures of Documentation Accuracy for Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Plant's subjective rating of documentation accuracy	9	7.8	7
Is stock record accuracy measured?	Yes	84	No

9.4.9 Suppliers

The proposition that high performance plants will receive more frequent and reliable deliveries from suppliers than low performance plants receives good support from these plants. The high performance plant has above average delivery performance and lower than average raw materials stocks. Its suppliers also deliver more frequently than the sector average. The low performance plant has below average delivery reliability but raw material stocks and frequency of supplier delivery are about average for this sector.

Table 9.9: Measures of Supplier Delivery Performance for Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Raw materials	0	6	6
% on time delivery performance	99.8	90	85

Table 9.10: Frequency of Raw Materials Delivery for Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Daily	10	8	0
Twice weekly	30	8	0
Weekly	50	32	63
Monthly	10	31	12
Less frequently than monthly	0	21	26

9.4.10 Measurement of a wide range of metrics

An important feature of the high performance electronics plant is the extent to which all aspects of operating performance are measured. This can be seen from the large number of graphs and charts displayed around the plant. The plant provides strong support for the proposition that high performance plants will measure a wider range of metrics than low performance plants. All of the relevant metrics referred to in the Best Factory Awards questionnaire are measured at this plant. In contrast only 73% of these metrics are measured at the low performance plant.

Table 9.11: Metrics Measured at Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Is output volume measured on a regular basis?	Yes	99	Yes
Is production schedule adherence measured on a regular basis?	Yes	63	No
Is ex-stock availability measured on a regular basis?	N/A	19	Yes
Is due date reliability for items on quoted lead times measured on a regular basis	Yes	83	Yes
Is inventory record accuracy measured on a regular basis?	Yes	84	No
Is scrap or yield loss rate measured on a regular basis?	Yes	84	Yes
Is time spent on rework/reprocessing measured on a regular basis?	Yes	61	Yes
Is time spent on setting/changeover measured on a regular basis?	Yes	34	No
Are customer's returns/complaints measured on a regular basis?	Yes	94	Yes
Is first time pass rate measured on a regular basis?	Yes	84	Yes
Is supplier delivery performance measured on a regular basis?	Yes	70	Yes
% of metrics measured	100%	76%	73%

9.4.11 Trade-offs

9.4.11.1 Proposition 10

Proposition 10 states that rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial sector. If this were the case then it would be expected that the high performance electronics plant would perform better than the industry sector average on these factors and the low performance electronics plant would perform worse than the industry sector average. Actual performance on these measures for the high and low performance plants is summarised in Table 9.12.

Table 9.12: Absolute Performance Measures for Electronics Plants

	High performance plant	Electronics sector average	Low performance plant
Added value per employee £	1.39	1.42	1.53
% Customer returns in current year	0.31	0.49	0.6
Average quoted customer lead time	15	36	20
% On time delivery	99.8	90	85

In the case of the high performance plant, performance is much better than the sector average for 3 out of the 4 measures. In the case of the low performance plant performance is worse than the sector average for 2 out of the 4 measures. Performance is actually better than average for added value per employee £ and for average quoted customer lead time.

9.4.11.2 Proposition 11

Proposition 11 states that the extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability. If this is the case then it would be expected that plants with a smaller product range than the industry sector average would perform better than the industry sector average on these factors and plants with a larger product range than the industry sector average would perform worse than the industry sector average on these factors.

If proposition 11 is correct then it would be expected that the high performance plant would have a small product range and the low performance plant would have a large product range and this is in accordance with the results for these plants.

Table 9.13: Product Focus at Electronics Plants

	High Performance Plant	Electronics Sector Average	Low Performance Plant
Total products currently live	30	787	2
Total manufactured components, bulk intermediates and sub-assemblies currently live	150	1803	2
Total bought out components and sub-assemblies currently live	6,000	5491	Not known
Total purchased raw materials currently live	0	631	2
Products in continuous production last year	0	56	0
Products in intermittent production last year	173	331	1,286
Products of initially unknown design produced last year	87	100	21
Total number of different products made last year	260	487	1307

9.5 Conclusions

9.5.1 The high performance electronics plant

This plant shares many of the performance characteristics of the high performance engineering plant. It is producing a relatively narrow product range to a high level of quality consistency and achieving fast, reliable delivery. However, added value per employee £ is below the sector average and there is no obvious explanation for this.

Although the Purchasing Director states that the plant operates largely independently of the parent company, most of the improvements in performance seem to have resulted from initiatives by the parent company. These have included de-layering the management structure, automation of product assembly, introduction of CAD/CAM computer systems and reducing the size of the supplier base.

This plant operates in an environment with low levels of uncertainty and variability. Process times are highly predictable and scrap rates are low. They operate a highly integrated, finite capacity planning system with 4 weeks frozen. Many components and products are produced as joint ventures with either suppliers or customers and there is a high degree of sharing of planning information with suppliers and customers.

Current improvement initiatives are focused on reducing the time it takes to design and manufacture new products. This mainly affects the Design and Planning Departments. On the shop floor the main initiative is a programme to involve the whole workforce in performance improvement through problem-solving groups.

9.5.2 The low performance electronics plant

This plant produces a very simple product in a wide range of variants. Delivery is relatively rapid in comparison with the rest of the electronics sector and added value per employee £ is high. However, the percentage of customer returns and delivery reliability are both poor. The management are aware of the need for improvement and in the period between the completion of the Best Factory Award questionnaire and the plant visit the plant had moved to a new, modern location. There had also been a complete change in the plant management.

Prior to the move production was largely manual and organised in long assembly lines. The first time pass rate at each stage was quite low making batch lead times highly variable and unpredictable. In the new plant organisation is in manufacturing cells. High volume fuses are now produced on automatic machines with very high first time pass rates. This, combined with the high speed of these machines, results in short, reliable manufacturing lead times. However, production of low volume fuses is still very labour intensive.

The current planning system is very fragmented. The sales and order processing system and the production planning system are quite separate. Transfer of data between the two systems is done manually. Sales do not know the existing workload when making delivery promises. Sales do not provide Planning with forecasts of future requirements. The production planning system is unable to take into account capacity constraints when preparing schedules. The result is unrealistic delivery promises and a schedule that is constantly being changed. One of the major changes being implemented is a fully integrated finite capacity planning system that should eliminate these deficiencies.

In selecting suppliers, cost is still a major factor. This, combined with their need to frequently change their requirements at short notice has resulted in poor delivery reliability and poor quality conformance by their suppliers. This, in turn, has resulted in late deliveries and high levels of customer returns from the plant's own customers. They are trying to address this issue by introducing a supplier performance index and by providing suppliers with a 12-week forward schedule of requirements.

The plant is also implementing a major performance improvement schedule focused on cost reduction, quality improvement and improved delivery performance.

9.5.3 Support for the research propositions

Support for the research propositions at these plants is summarised below. Excellent support at the high performance plant would be performance above the sector average on the full range of relevant measures. Excellent support at the low performance plant would be performance below the sector average on the full range of relevant measures.

Table 9.14: Support for the Research Propositions at the Electronics Plants

Proposition	Description	Level of support at the high performance electronics plant	Level of support at the low performance electronics plant
1	Process reliability	Excellent	Good
2	Throughput efficiency	Excellent	Excellent
3	Emphasis on continuous improvement	Neutral	Excellent
4	Labour flexibility	Good	Excellent
5	Low labour costs	Excellent	Negative
6	Cleanliness	Excellent	Excellent
7	Accurate documentation	Excellent	Excellent
8	Frequent, reliable supplier delivery	Excellent	Neutral
9	Measurement of wide range of metrics	Excellent	Excellent
10	Positive correlation between added value per employee £, quality consistency, customer lead time and delivery reliability	Good	Neutral
11	Negative correlation between	Good	Neutral

	product variety and added value per employee £, quality consistency, customer lead time and delivery reliability		

The high performance plant provides good support for 10 of the 11 research propositions being tested. Support for the proposition that high performance plants place greater emphasis on continuous improvement is neutral. Also, added value per employee £ is lower than would be expected from propositions 10 and 11.

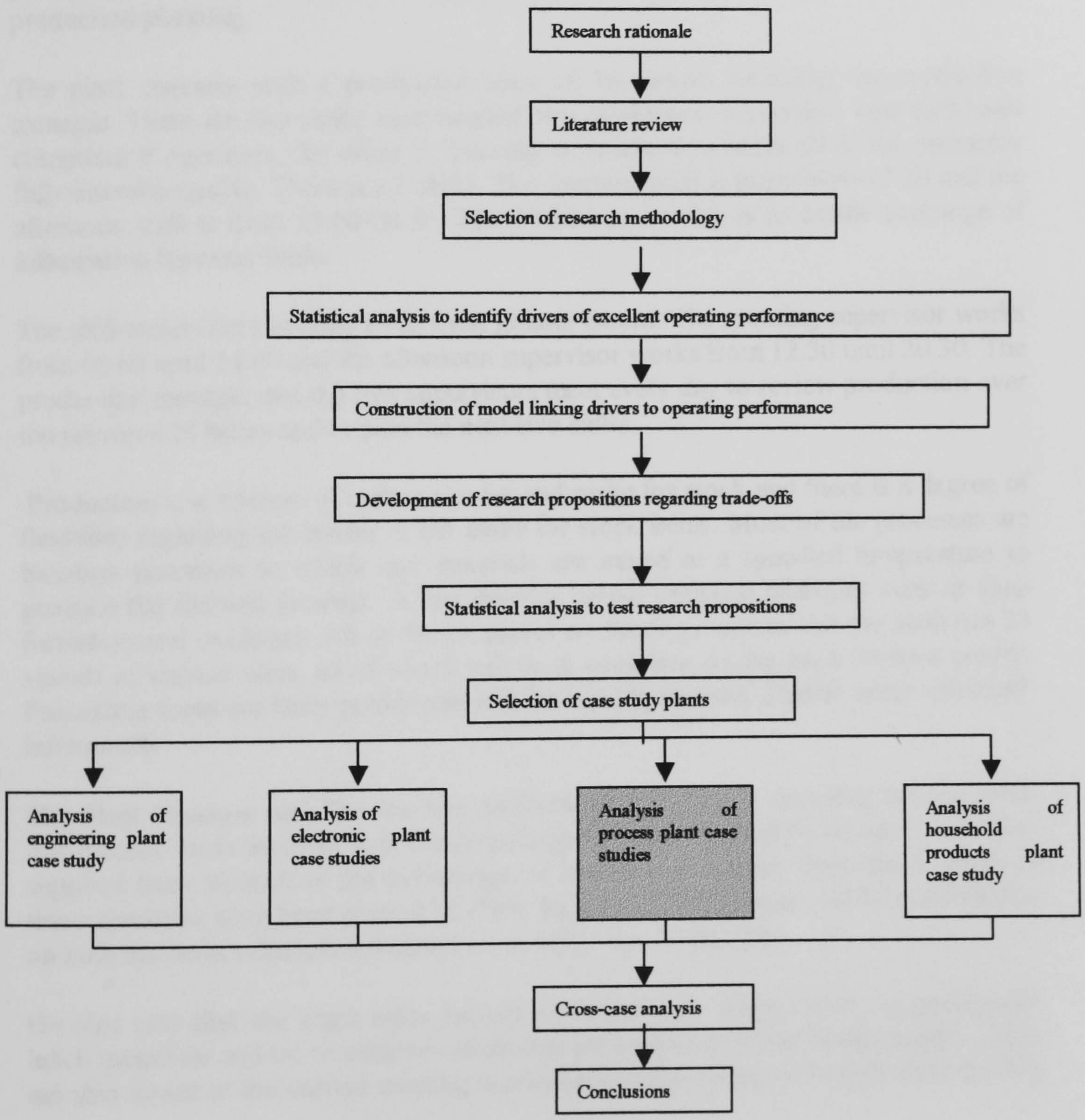
In the case of the low performance plant the evidence is more mixed. There is support for only 7 of the propositions being tested. The plant is manufacturing a simple product with a short manufacturing cycle time. This enables the plant to promise rapid delivery and to achieve high added value per employee £. However, there are specific deficiencies with their current systems which impact most severely on quality consistency and delivery reliability.

Chapter 10 : The Plants from the Process Sector

10.1 Summary

Figure 10.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In this chapter the results of the visits to the high and low performance plants from the process sector are described. Each plant's approach to planning, purchasing and performance improvement is analysed. Finally, the extent to which the plants support the research propositions identified in chapters 4 and 6 is tested.

10.2 High Performance Process Plant

10.2.1 Plant overview

At this plant only two managers were interviewed, the production manager and the purchasing manager. The plant manager was responsible for both manufacturing and production planning.

The plant operates with a production team of 18 people, including the production manager. There are two shifts; each headed by a production supervisor. One shift team comprises 8 operators, the other 7. Training is designed to make all of the operators fully interchangeable. There are 2 shifts. The morning shift is from 0600-13.30 and the afternoon shift is from 13.00-20.30. The 30-minute overlap is to enable exchange of information between shifts.

The shift supervisors overlap to an even greater extent. The morning supervisor works from 06.00 until 14.00 and the afternoon supervisor works from 12.30 until 20.30. The production manager and the two supervisors meet every day to review production over the previous 24 hours and to plan the next two shifts.

Production is a mixture of make to order and make for stock and there is a degree of flexibility regarding the timing of the make for stock items. Most of the processes are blending processes in which raw materials are mixed at a specified temperature to produce the finished product. A few involve simple chemical reactions such as soap formation and oxidation. All of the processes are batch processes and the plant has 28 vessels of various sizes, all of which will be in operation during each 24-hour period. Processing times are fairly predictable and the need to re-work a batch arises extremely infrequently.

The Plant Manager said that the key performance measure is customer service level. For batches made to order it is the percentage of orders delivered on time. For items supplied from stock it is the percentage of orders met directly from stock. Both of these measures have been around 98-99% for the last 30 months. 100% performance on both has been achieved in 4 months out of the last 18 months.

He also said that the plant relies heavily on teamwork. Sales know the production batch quantities and try to achieve orders that are multiples of the batch quantity. Sales are also aware of the current existing workload for each group of vessels and take this into account when making delivery promises to customers. Also, they make more effort to sell products for those groups of vessels that are running out of work.

The Plant Manager said that on those rare occasions when a batch is returned by a customer, or a batch is rejected by Quality Control and has to be reworked, a special meeting is convened. This will include technical, sales and production staff, including operators. The group discusses what went wrong and discusses what action should be taken to ensure that the same problem could not occur again.

Quality control is the responsibility of a separate department, which works closely with production. At specified stages in each process, the operator takes a sample from the batch and passes it to the quality control department. The operator cannot proceed to the next stage in the process until approval is received from the quality control department with instructions on what quantities of further additives need to be blended with the batch.

The Plant Manager said that because the number of people on each shift is quite small the production staff are able to work as a team with little concern about hierarchy. Problem solving, process improvements and new product developments are handled by setting up informal teams, which might include a research & development specialist, a quality controller, a production supervisor and an operator.

A distinctive feature of this plant is the extent to which they adhere to written procedures. For every product there is a Product Specification Document. This covers every aspect of that product's manufacture including raw material specification, method of manufacture, details of quality tests to be carried out and detailed specification of the performance characteristics of the final product. From this specification a batch card is prepared for each batch to be processed in the plant. This contains full details on how the batch is to be manufactured and tested. No process can be started, including new product trials unless a batch card has been issued. This ensures consistency of production methods and easier traceability when problems do occur.

Operators do not carry out routine maintenance. The Engineering Department does this. Nor, as mentioned earlier, do the operators carry out their own quality checks. However, they are responsible for cleaning and the movement and storage of raw materials.

10.2.2 Planning

Production planning is relatively straightforward as there are only a small number of reaction vessels and each process is essentially single stage. Some vessels are dedicated to particular products. Other vessels can be used for a variety of different products and products are sequenced in order to minimise cleaning time between batches. This increases the effective utilisation of the vessels and reduces material waste. A computer package monitors stock levels in the warehouse and places orders on manufacturing whenever stocks fall below their re-order points. Although an outside contractor runs the warehouse on behalf of the company, production can access this package at any time in order to decide on the urgency of each order for stock.

External orders are of three types. There are long-term contracts from regular customers. These are usually for regular deliveries of specified quantities on set dates. While quantities might be varied between agreed limits, any changes will be notified 4 weeks ahead. Then there are one-off contracts, which the plant has been asked to bid for. While the plant cannot be certain of winning these contracts, the staff do have advance warning of the size and likely timing of the contract. Finally there are individual orders, which are phoned or faxed in, sometimes at short notice, and the planning system must have the flexibility to cope with these orders.

The production schedule is a rolling plan revised weekly. Orders are classified into hard orders, those which are firm and for a specified date, and soft orders, those that are known about but which still have to be confirmed by the customer. Both types are included in the rolling plan. Detailed planning for the next 2 weeks is done on a whiteboard in the production area. Direct orders are allocated first. The process start time is determined by working backwards from the shipment date and time agreed with the customer. It is then allocated to the most suitable available vessel. Once a direct order has been scheduled it cannot be moved except in exceptional circumstances. Remaining capacity is then used to produce batches for stock. Each Friday lunchtime there is a production-planning meeting to review the plan for the week ahead. It is attended by representatives from production, sales, quality control and the technical department. Unusual requirements for the coming week, such as special quality tests are highlighted and people have the opportunity to suggest schedule changes that might improve product sequencing. Each Thursday afternoon, senior management holds a strategic production-planning meeting to discuss the longer-term order situation and its marketing and capacity implications.

10.2.3 Purchasing

The plant does not operate an MRP system. Orders for additional raw materials are triggered when stock reaches a re-order point set jointly by purchasing and production. For commodity items there are three or four approved suppliers and selection is based on availability and price. For other items there is a single source of supply plus a back-up supplier. For bulk items, delivery is within 3 days. For most other items, delivery is within 7 working days. Many items are supplied on consignment and the proportion of consignment items is likely to increase. There is currently a company-wide group purchasing initiative. Purchasing managers from different sites meet regularly to identify common suppliers in order to use joint purchasing power to obtain better prices and service.

Although the finished goods warehouse is on site a contract warehousing and distribution company manages it. Previously the plant was responsible for its own warehousing and distribution. The new arrangement has enabled a reduction from 5 day delivery to next day delivery with no increase in total costs.

10.2.4 Performance improvement

Over the last few years, manning has reduced from 30 to 18 and output per head has increased significantly. The Plant Manager said that the main reason for this was the loss of a major contract in 1991. This contract was extremely labour intensive as most of the output was in 25 litre cans, which had to be filled manually. The work that has replaced this contract has largely been for bulk deliveries, usually in tankers, which requires much less labour.

10.2.5 Management views on trade-offs

The Plant Manager believed that for his plant the various performance measures were inter-related so that no trade-offs were involved. Instead the various performance measures were mutually reinforcing. He identified the key drivers as quality consistency and lead time. Improvements in either of these would lead to reduced costs, fewer customer returns and greater delivery reliability. The only trade-off that he could identify for his plant related to product variety. He believed that the high levels of operating performance being achieved by the plant were, at least in part, a consequence of the very narrow range of products being produced. He considered that any significant increase in the size of the product range would result in a deterioration in operating performance – higher costs, quality problems, longer lead times and late deliveries.

10.3 Low Performance Process Plant

10.3.1 Plant overview

At this plant two managers were interviewed, the Production Manager and the Stock Control Manager. The Stock Control Manager was also responsible for Planning.

This plant had been losing money for a number of years when, three years ago, it was taken over by a larger company that had a similar carbide plant. The other plant was closed down and all production transferred to this site. More recently the company has bought up another carbide company and so they now have a second carbide plant elsewhere.

Quality control of incoming materials is the responsibility of the laboratory. All incoming material is fully certified so all that is necessary is to check that the certificate details match the order placed. When an order goes into the furnace for either sintering or de-waxing, it is accompanied by some small blanks made from material from the same batch. These samples go to the lab for analysis and the batch cannot start the next stage of the process until the lab has passed the samples. The plant has been ISO9000 accredited since 1993.

The plant was functionally organised into the following three sections.

1. Pressing Department
2. Semi-sintered Department (rough machining of the part after pressing to a fair degree of tolerance)
3. Finish Grinding Department

The Pressing Department was run by a junior supervisor, a secondary foreman ran the Semi-sintered Department and the Finish Grinding Department was managed by a senior foreman. All reported to the production manager.

The majority of staff works 0730 - 1600, Monday to Thursday and 0730 - 1230 on Fridays. The rest work a 2-shift system, 0600 - 1400, 1400 - 2200, Monday to Thursday, 0600 - 1100, 1100 - 1600 on Fridays. Staff on shifts receive a 17.5 % shift premium, which takes their pay up from £6 per hour to £7.20 per hour. In addition, the plant has a full order book and so they are currently working a substantial amount of overtime, every Saturday and 2 Sundays out of 4.

Piecework and measured day work schemes are not in use but there is a monthly output-related plant-wide bonus. The bonus is calculated using a complicated formula based on the ratio of the value of orders shipped to hours worked. Everyone gets the same bonus, including managers.

Three years ago, when only 23 people were employed, time on each job could be recorded using a log-on log-off system. As the volume of work increased this system could not cope, particularly with short jobs. A computer system was purchased but this still could not cope with short jobs

A new computer-based planning and control system is about to start in the next two weeks, involving the use of swipe cards. This will enable the efficiency of individual sections to be measured by comparing estimated and actual times. This will also provide feedback on the accuracy of the estimates used in quotations. Although they have a standard costing system, they have no actual costs to compare with the standard costs. The new system will provide this. The new system will also keep track of which stage each job has reached. The Production Manager said that, at the moment, when a customer enquires about the progress of a job, a physical check has to be made to find which stage the job has reached. Typically, there will be 1000 jobs in progress at any one time.

The Plant Manager stated that one of their problems is that many orders are so small that they are uneconomic. The plant has specified a minimum order value of £50 but when customers place orders for less it is difficult to turn them down. A particular problem is that a new customer may place a small trial order and then, if this is satisfactory, follow it with a larger order with a value of £5,000 - £10,000. The Plant Manager believes that for most customers, quality is a given and orders are won on cost and delivery reliability with speed of delivery becoming more and more important.

The biggest production delay occurs when there is insufficient blended powder for an order and the powder has to be specially blended. Because of this, the plant is investing £100,000 in a new kind of blender capable of blending 200 kilograms of powder in less than a shift. At the moment there are 42 different grades of powder with a total annual usage of 50 tonnes per year. The aim is to hold stocks of all of these although it is expensive at £10,000 per tonne. Most types of powder are sourced in the UK but some are imported. Four suppliers of powder are used. The Stock Control Manager said

"Quality is a given, price is not an issue and all offer 2 - 3 days delivery if the item is in stock. The main factor in selecting a supplier is, therefore, availability in stock of the item required."

The other main incoming materials are sub-contracted items. The Stock Control Manager said that these are a major problem as delivery is so unreliable. This is because sub-contractors take on more work than they can handle. There are no formal measures of supplier performance.

10.3.1.1 The manufacturing process

The first stage is the blending of the carbide powders. This currently takes 5 days. Although stocks of blended powders are held, a large order might exceed the available stock of blended powders, extending the manufacturing lead time by a week.

The next step is to compress the powder to the required shape. To do this there are 7 steel mould presses and 3 isostatic presses. The isostatic presses can handle larger items but some items are too large even for these presses and have to be sub-contracted. Also, the pressure capability of the presses is less than many of their competitors and this has quality implications for some items.

The next stage is to heat the compressed part in a de-waxing furnace at 400°C. This evaporates off the wax in the powder. There are 3 de-waxing furnaces. The de-waxing process takes 8 hours but in production planning they allow a day due to the variability in processing time. The next stage is rough machining. This is done before sintering because the material is softer and easier to machine.

The next stage is sintering in one of 3 sintering furnaces. Again the process takes 8 hours but production planning allows a day because of the variability in the time required at this stage. (New furnaces are now available that de-wax and sinter at the same time and are capable of more consistent processing times.)

At the moment, machine breakdowns are fairly frequent. This is, to a large extent, because of the age of the machines. The most recently installed grinder was manufactured in 1971. Another factor is the lack of any kind of planned maintenance.

10.3.2 Planning

Orders are received, either by fax, through the post or by telephone. These may either be new orders for an existing product or acceptance of a quotation. Customers are always asked to follow up telephone requests with a written order. The order processing staff then retrieve the quotation, where appropriate, in order to ensure that the order and quotation match on price, quantity and specification. If the order is not accompanied by a drawing they check to ensure that the item is one for which drawings already exist.

For complex parts a manufacturing drawing is then prepared to provide clearer instructions to the shop floor. For all components a route card is prepared.

Most items are made to order. The only items supplied from stock are nozzles, which are small low cost items. As the plant does not have a capacity-based scheduling system, lead times for make to order items are based on general guidelines derived from the number of stages in the production process for that item. For example, for a solid carbide component that requires machine finishing after it has gone through the furnace cycle the quoted lead time would be 4-5 weeks. Although most orders are one-offs, there are about 6 contract jobs in the factory. These are large orders where the plant is required to ship, say, 20 items each month for 4 months.

Scheduling of work within individual sections is left to the section supervisors. Overall plant performance is measured monthly and is based on the percentage of orders for that month that were despatched by the date agreed with the customer. During the last 3 years, output has almost doubled while late deliveries have remained fairly constant.

At the moment, quotations are prepared by experienced staff who estimate times for each stage in the process. The Production Manager said that the current system cannot provide information on the actual times taken at each stage and so the estimators receive little feedback on the accuracy of their estimates.

Quality control involves 100% inspection of all items once they are completed. About 70% of jobs can then be despatched. The other 30% require further certification, either materials certification or dimensional certification. These certificates are all produced by the inspection department.

Once a job has been despatched then the route cards and all other relevant information, including material and dimensional certificates are stored in the records department for 10 years so that they can be retrieved in the event of a complaint. There are sufficient complaints to justify a weekly complaints meeting consisting of the production manager, the metrologist and a member of the accounts department. All complaints are investigated within 7 days of receipt. If the complaint is justified then a credit is raised against the order.

The plant has several hundred customers. There are 3 large ones, representing £1,200,000 in sales out of an annual turnover of £3,500,000. The majority of the other customers are quite small.

10.3.3 Purchasing

The Stock Control Manager said that raw material stock replenishment is based on minimum re-order levels. The total number of suppliers is about 30. Some orders have to be sub-contracted because they are outside this plant's manufacturing capability. Deliveries from these sub-contractors are somewhat unreliable. Typical lead times are 3-4 weeks.

10.3.4 Performance improvement

In the next few weeks the plant is introducing a computer-based planning and scheduling system. This system will plan all production and issue each supervisor with a detailed production schedule. Data capture using bar codes will enable the progress of each order to be monitored and will provide detailed information on the processing times at each stage.

10.3.5 Management views on trade-offs

The Production Manager considered that the main trade-off was between investment in machinery and operating performance. New machines would be capable of producing output to a higher quality specification and with greater quality consistency. There would be fewer breakdowns and less rework so that faster, more reliable delivery would be possible. Against this had to be balanced the increase in unit manufacturing cost that would result.

Without investment in new machines there existed a trade-off between quality specification and the other performance measures. Because of the difficulty in meeting customers' requirements for more stringent quality specifications costs tended to be higher and lead times were longer and more variable leading to a worsening in delivery reliability. A higher level of customer returns could also be expected for orders with more stringent quality specifications. While new machines would not eliminate this set of trade-offs completely, the impact of tighter customer specifications on customer returns, manufacturing lead time and delivery reliability would be reduced.

He did not consider that there was a trade-off relationship between quality consistency, manufacturing lead time and delivery reliability. Removal of the constraints that led to poor performance on any one of these performance measures would lead to improvements in all three. On the other hand, he considered that there was a clear trade-off between product variety and the other performance measures. As the size of the product range being produced in the plant increased then this would be accompanied by increases in unit manufacturing costs, worsening quality consistency, longer manufacturing lead times and poorer delivery reliability.

10.4 Comparative Analysis of the Characteristics of the Two Plants

10.4.1 Process reliability

The process plants provided strong support for the proposition that high performance plants will show greater process reliability than low performance plants. On all of the performance measures related to process reliability the high performance plant out-performed the sector average and the low performance plant under-performed against the sector average.

Table 10.1: Process Reliability Data for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Plant's subjective rating on process dependability	9	7.4	6
% Adherence to schedule this year	99.1	88.8	55
% Adherence to schedule last year	95.1	83.1	45
% Scrap rate this year	0.8	5.0	5.5
% Scrap rate last year	1.25	5.7	6.7

10.4.2 Precision of quoted delivery promises

There was mixed support for the proposition that high performance plants quote more precise lead times than low performance plants. All quoted lead times of the high performance plant are for a specific time of day while only 53 per cent are for a specific day or time of day for the sector as a whole On the other hand 70 per cent of the lead times quoted by the low performance plant are for a specific day. This is rather higher than would be suggested by the proposition.

Table 10.2: Precision of Quoted Lead Times for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Specific time of day	100	6	0
Specific day	0	47	70
Specific week	0	42	30
Other time	0	5	0

10.4.3 Throughput efficiency

The high performance plant supports the proposition that high performance plants show greater throughput efficiency than low performance plants. Both measures of throughput efficiency for this plant are significantly better than the process sector averages. It is difficult to draw firm conclusions about the low performance plant. The plant's rating on throughput efficiency is almost identical with the process sector average and the percentage of capacity used for changeovers is not measured.

Table 10.3: Throughput Efficiency Measures for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Plant's subjective rating on throughput efficiency	8	6.9	7
% of capacity used for changeovers	2	9	Not measured

10.4.4 Involvement of workforce in continuous improvement

There is strong support for the proposition that high performance plants have greater emphasis on continuous improvement than low performance plants. The high performance plant out-performs the sector average on all of the measures of emphasis on continuous improvement. The low performance plant under-performs against the sector average on all of these measures.

Table 10.4: Use of Problem-solving Groups at Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Plant's subjective rating on change as a way of life	9	6.7	6
Plant's subjective rating on the importance of continuous improvement	8	7.2	4
Plant's subjective rating on the commitment of employees to continuous improvement	9	6.2	6
Plant's subjective rating on use of labour as a source of brainpower	8	6.2	5
% of production employees are involved in problem-solving groups	100	43.0	15

10.4.5 Labour flexibility

The process plants also support the proposition that high performance plants have higher levels of labour flexibility than low performance plants. The high performance plant has above average ratings on both measures of labour flexibility. The low performance plant has ratings that are equal to or less than the sector average.

Table 10.5: Labour Flexibility for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Plant's subjective rating on labour flexibility	9	7.0	7
Plant's subjective rating on emphasis on training and competence	8	6.2	5

10.4.6 Labour costs

The costs for these plants support the proposition that high performance plants will have lower labour costs as a percentage of total manufacturing costs than low performance plants. In the case of the high performance plant, direct, indirect and other labour costs are all a smaller percentage of manufacturing costs than the sector averages. In the case of the low performance plant direct and other labour costs are significantly higher than the sector average although indirect labour costs are slightly lower.

Table 10.6: Labour Costs as a Percentage of Total Manufacturing Costs for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Direct labour	3.5%	12.5%	32.6%
Indirect factory labour	1.0%	4.3%	3.5%
Other labour (including staff and managerial)	3.8%	7.0%	13.6%

10.4.7 Cleanliness

The results for both plants support the proposition that high performance plants have higher levels of cleanliness than low performance plants.

Table 10.7: Measure of Cleanliness for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Plant's subjective rating on cleanliness	7	6.9	5

10.4.8 Accurate documentation

The plants provided strong support for the proposition that high performance plants have more accurate and up-to-date process documentation than low performance plants. The high performance plant placed considerable emphasis on the quality and detail of the documentation at every level in the organisation. The plant gave itself a rating of 10 out of 10 for the accuracy and up-to-dateness of its documentation. The low performance plant gave itself a rating of 6 out of 10 on accuracy and up-to-dateness of documentation. The average rating for the process sector was 8.1.

The high performance plant measured stock record accuracy, as did 80 per cent of process plants. The low performance plant did not.

Table 10.8: Measures of Documentation Accuracy for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Plant's subjective rating on documentation accuracy	10	8.1	6
Is stock record accuracy measured?	Yes	80%	No

10.4.9 Suppliers

The results for these plants provide mixed support for the proposition that high performance plants have more frequent and reliable supplier deliveries than low performance plants. As might be expected from this proposition, weeks of raw materials stocks are less than the sector average for the high performance plant and greater than the sector average for the low performance plant. Surprisingly, the high performance plant does not even measure percentage on time delivery by suppliers. Delivery reliability of suppliers at the low performance plant is less than the sector average in accordance with the proposition.

Frequency of supplier deliveries for the high performance plant is not what would be expected from the proposition. Only 10 per cent of the high performance plant's suppliers deliver more frequently than monthly compared with a sector average of 46 per cent. In the case of the low performance plant 30 per cent of suppliers deliver more frequently than monthly. This is lower than the sector average in accordance with what the proposition would predict.

Table 10.9: Measures of Supplier Delivery Performance for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Raw materials	4.2	7	8
% On time delivery of suppliers	Not measured	90	75

10.4.10 Frequency of supplier delivery

Table 10.10: Supplier Delivery Frequency for Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Daily	0	11	0
Twice weekly	0	11	0
Weekly	10	24	30
Monthly	70	34	60
Less frequently than monthly	20	20	10

10.4.11 Measurement of a wide range of metrics

In accordance with the proposition that high performance plants measure a wider range of metrics than low performance plants, the high performance plant measures 91 per cent of the metrics considered while the low performance plant only measured 64 per cent of the metrics.

Table 10.11: Metrics Measured at Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Is output volume measured on a regular basis?	Yes	99	Yes
Is production schedule adherence measured on a regular basis?	Yes	46	Yes
Is ex-stock availability measured on a regular basis?	Yes	43	No
Is due date reliability for items on quoted lead times measured on a regular basis	Yes	75	Yes
Is inventory record accuracy measured on a regular basis?	Yes	77	No
Is scrap or yield loss rate measured on a regular basis?	Yes	88	Yes
Is time spent on rework/reprocessing measured on a regular basis?	Yes	42	No
Is time spent on setting/changeover measured on a regular basis?	Yes	49	No
Are customers' returns/complaints measured on a regular basis?	Yes	87	Yes
Is first time pass rate measured on a regular basis?	Yes	61	Yes
Is supplier delivery performance measured on a regular basis?	No	49	Yes
% of metrics measured	91%	65%	64%

10.4.12 Trade-offs

10.4.12.1 Proposition 10

Proposition 10 states that rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial sector. If this were the case then it would be expected that the high performance process plant would perform better than the industry sector average on these factors and the low performance process plant would perform worse than the industry sector average. Actual performance on these measures for the high and low performance plants is summarised in Table 10.12.

Table 10.12: Absolute Performance Measures for Process Plants

	High performance plant	Process sector average	Low performance plant
Added value per employee £	2.01	1.62	1.23
% Customer returns in current year	0.05	0.91	2.5
Average quoted customer lead time	5	20	28
% On time delivery	99.2	76	50

In the case of the high performance plant performance is better than the sector average for all of the 4 measures. In the case of the low performance plant performance is worse than the sector average for all of the 4 measures. This provides strong support for Proposition 10.

Proposition 11

Proposition 11 states that the extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability. If this is the case then it would be expected that plants with a smaller product range than the industry sector average would perform better than the industry sector average on these factors and plants with a larger product range than the industry sector average would perform worse than the industry sector average on these factors.

If proposition 11 is correct then it would be expected that the high performance plant would have a small product range and the low performance plant would have a large product range and this is in accordance with the results for these plants.

Table 10.13: Product Focus at Process Plants

	High Performance Plant	Process Sector Average	Low Performance Plant
Total products currently live	225	1,380	200
Total manufactured components, bulk intermediates and sub-assemblies currently live	35	393	500
Total bought out components and sub-assemblies currently live	4	419	20
Total purchased raw materials currently live	288	299	80
Products in continuous production last year	78	30	40
Products in intermittent production last year	117	289	400
Products of initially unknown design produced last year	30	147	200
Total number of different products made last year	225	466	640

10.5 Conclusions

10.5.1 The high performance process plant

This is a small plant with a small, highly integrated and flexible workforce. A relatively narrow range of products is manufactured. The manufacturing process is very simple, involving few stages and processing times are predictable. Consequently, this plant is able to achieve fast, reliable delivery with few customer returns and high added value per £.

Key features of the operation of this plant are the flexibility of the operators with most operators able to carry out all tasks, a simple but effective visual capacity planning system and very accurate and detailed process documentation.

10.5.2 The low performance process plant

This plant is also quite small but in this case manufacturing lead times are extremely unpredictable. This is partly due to the high variability in processing time at some stages in the manufacturing process and partly due to the frequent machine breakdowns that occur. Further delays result from the frequent stock outs of their basic raw materials.

Production planning is very unsystematic. The staff who estimate processing times receive no feedback on actual processing times and so the accuracy of their estimates is unlikely to improve. The planners are unable to take into account available capacity and so jobs are issued to the shop floor as soon as the materials are available. At any one time around 1000 jobs will be in progress and there is no system for tracking the progress of each order.

The plant has an arms-length relationship with its suppliers. The plant provides no schedules of future requirements to its suppliers. There are several suppliers for each item. When replenishment of an item is required supplier selection is based on which one has stocks of the material currently available.

With a few exceptions, customers provide no forward schedules of their requirements. Customers might ask for a quotation but the first indication that this is a firm order is when the written or telephoned order is received for immediate delivery. Some orders have to be sub-contracted as they are outside the plant's manufacturing capability. The delivery reliability of these sub-contractors is very poor.

This plant is producing a wider range of products than the sector average under conditions of considerable variability and uncertainty. Not surprisingly, quality consistency, delivery speed, delivery reliability and added value per employee £ are very poor.

The plant is about to introduce a computer-based planning and scheduling system. This should enable them to address some but not all of their current problems.

10.5.3 Support for the research propositions at the process plants

The level of support at these plants for the propositions being tested in this research is summarised below.

Table 10.14: Support for the Research Propositions at the Process Plants

Proposition	Description	Level of support for high performance process plant	Level of support for low performance process plant
1	Process reliability	Excellent	Good
2	Throughput efficiency	Excellent	Neutral
3	Emphasis on continuous improvement	Excellent	Excellent
4	Labour flexibility	Excellent	Good
5	Low labour costs	Excellent	Good
6	Cleanliness	Excellent	Excellent
7	Accurate documentation	Excellent	Excellent
8	Frequent, reliable supplier delivery	Neutral	Excellent
9	Measurement of wide range of metrics	Excellent	Excellent
10	Positive correlation between added value per employee £, quality consistency, customer lead time and delivery reliability	Excellent	Excellent
11	Negative correlation between product variety and added value per employee £, quality consistency, customer lead time and delivery reliability	Excellent	Excellent

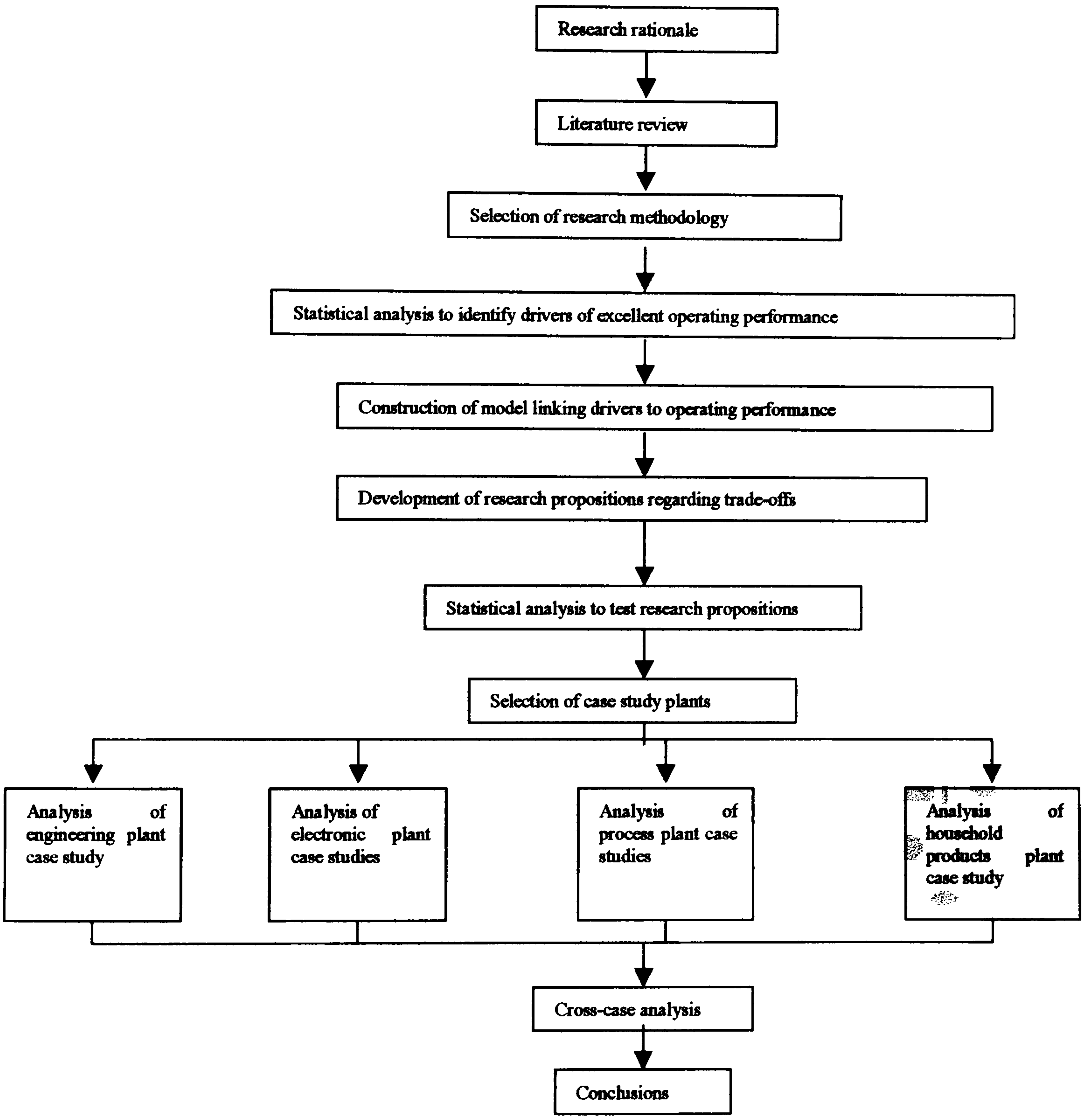
Both plants provide good support for the propositions being tested. The high performance plant supports 10 out of the 11 propositions. The exception is the frequency and reliability of supplier deliveries. The low performance plant also supports 10 out of the 11 propositions. In this case the exception is throughput efficiency. This result is rather surprising as observations during the plant suggested that throughput efficiency was very poor, as the research proposition would suggest. However, as the plant did not measure the percentage of capacity used for changeovers, the only measure of throughput efficiency was the plant's own subjective rating. Conversations with the managers at the plant suggested that through lack of benchmarking against other plants they were unaware of just how poor their own performance was. They rationalised the Best Factory Award results by saying that the other plants in the survey were too dissimilar to their own for comparisons to be made.

Chapter 11 : The Plant from the Household Sector

11.1 Summary

Figure 11.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In this chapter the results of the visit to the high performance plant from the household products sector are described. The plant's approaches to planning, purchasing and performance improvement are analysed. Finally, the extent to which the plant supports the research propositions identified in chapters 4 and 6 is tested.

11.2 The High Performing Household Products Plant

11.2.1 Plant overview

The high performing plant in this section manufactured cider. It belonged to a UK company with 5 plants in total. At this plant the Purchasing Manager, the Logistics Manager and the Production Manager were interviewed.

11.2.2 The cider production process

The apples used in the cider process are harvested between mid-September and early January with the peak occurring during October and November. Half of the apples come from the company's own orchards and half are from orchards under contract. The apples arrive at the plant either in sacks or in bulk. They are then fed into deep silos. They are transferred to the mill along water channels. The apples are then washed to remove debris, dirt and pebbles. The apples are cut into cubes and pressed to produce the juice. Some of the juice is concentrated and stored in order to enable cider production to take place throughout the year. The rest of the juice is pumped to stainless steel fermentation vessels where it is sterilised with sulphur dioxide. Yeast is then added to start the fermentation process. The fermentation process lasts for 9 - 11 days. The carbon dioxide produced during this process is collected, liquefied and sold. When fermentation is complete, the juice is separated from the sediment and secondary fermentation takes place. The duration of this process is highly variable but averages about 4 weeks. The cider is then filtered to produce bright cider. The different ciders are then blended to produce the various finished products and then packed in glass or plastic bottles, cans or kegs.

The Production Manager stated that the company was, in the past, very paternalistic, leading to over-staffing. This was corrected about 4 years ago when there were major job losses. For example, mechanisation of hand packing reduced packing staff from 500 to 100. They now have an exceptionally flexible and reactive workforce. Due to the seasonality of product demand the workforce have to be able to deal with variations in monthly demand from 4% of annual demand in January and February to 13% of annual demand in December. The peaks in demand are handled using casual staff, some of who come back year after year.

11.2.3 Planning

Logistics plan production, materials and associated activities in order to achieve a predetermined level of service, currently set at an ex-stock availability of 99.5%. This target is set at 1% above the service level demanded by the supermarkets, currently 98.5%. For major customers, service level performance is measured daily. A weekly internal report is generated which covers the following aspects of performance for the whole plant with separate reports for the 4 major customers.

1. Delivery performance
2. Order complete
3. Volume complete
4. Stock availability

The Logistics Manager stated that achieving the target performance is difficult because of trade-offs with line utilisation and line efficiency. High efficiency implies long runs with few changeovers but the flexibility that customers demand often necessitates short runs. Providing flexibility through holding larger stocks of finished goods is difficult as internal warehousing space is limited and external warehousing is expensive. Also, as all products carry duty, external storage can involve pre-payment of duty whereas the internal warehouse is a bonded warehouse.

Because almost everything is manufactured for stock, Logistics build to forecast rather than actual demand. The Logistics Manager considered that the accuracy of forecasting within the company is not particularly good. A number of groups are working on ways of improving forecasting accuracy. A new computer-based forecasting system is to be introduced shortly. Finished goods stock varies between 2.5 weeks and a 4 week maximum. Deliveries to the major supermarkets are made daily. Demand is heavily influenced by sales promotions. The company has a computer-based promotion initiation system that predicts the effect of the promotion on the demand profile. The major supermarkets provide information on forthcoming promotions. Sometimes this will include their own forecasts of the effect of the promotion on demand.

The Production Manager stated that the company is very fortunate in having a very flexible workforce. Provided that Production is told of an increase in requirements by Wednesday it can organise overtime and weekend shifts to ensure that the additional output is available by the end of the following week under an annualised hours agreement. He stated that the workforce is hardworking and highly trained. Most have NVQ1, NVQ2 and NVQ3 qualifications.

The Logistics Manager stated that the plant is under constant pressure from customers to increase the variety of pack sizes and types. This makes production scheduling even more complex.

Four years ago the company had a major re-organisation. The size of the workforce was reduced from 1,400 to 900. Manufacture of soft drinks was abandoned. New practices and automation were introduced with the aim of complexity reduction at a cost of £20 million. Management of distribution was sub-contracted to Excel Logistics.

At this time the Logistics Department introduced a planning system called Oracle. The Logistics Manager considered that the system was rather slow. It is not capable of scheduling individual lines and so the company is now in the final stages of implementing a Manugistics finite capacity scheduling package. This will provide a week by week production plan 13 weeks ahead. It will also generate a 13-week plan for each supplier. The system will also generate a report measuring deviations from plan with the reasons for each deviation.

11.2.4 Purchasing

The Purchasing Manager reports to the Operations Director. The Purchasing Manager has a staff of 7.5 people controlling a total expenditure of £65 million.

The main ingredient of cider is apples and the company owns 2,500 acres of cider orchards that are managed by a separate division of the company. This represents about half of total requirements. Growers under contract supply a further 30 per cent. Contracts are negotiated biennially and a price is agreed for a 2-year period. For the remaining 20 per cent of apples required the company declares a price per tonne of apples delivered at the beginning of the season and invites tenders. Once tenders have been accepted the fruit office agrees a schedule with all of the apple suppliers in order to ensure a steady supply of 1,200-1,400 tonnes of apples per day throughout the season. The season starts in September and can continue until early January.

The delivered apples are either fermented immediately, turned into concentrate or the juice is extracted and put into long-term storage tanks. In addition, apple juice concentrate is purchased from sources throughout Europe as needed. The Purchasing Manager stated that judgement is needed in making such purchases, as apple juice is a commodity whose price can be volatile. Its price can be affected by fluctuations in the price of orange juice and grape juice as these can substitute for each other in highly flavoured fruit juices.

Glucose is another commodity. The Purchasing Manager stated that its price is affected by the price of maize and wheat and also by the degree of over-capacity or under-capacity in the marketplace. Due to the large quantities of glucose required, annual contracts have to be negotiated with a number of suppliers. Sugar prices are controlled within the EU but the Purchasing Manager said that there is usually still scope for negotiating rebates.

The main packaging items are cans, glass bottles, plastic bottles and corrugated cardboard. For all of these except glass bottles, 3 year contracts are negotiated, as total industry capacity is restricted. The Purchasing Manager said that capacity is less of a problem with glass bottles and so annual contracts are negotiated.

The Purchasing Manager said that the company is experiencing demand from their supermarket customers for ever shorter lead times and the flexibility to react to sudden changes in demand. Consequently, the company is looking for ways to reduce the lead times for their own suppliers.

The company is currently developing a vendor rating system that will monitor the quality and service of all suppliers under contract but this is still in its infancy.

In order to call off against contract the Logistics Department converts forecast demand into a production schedule. This is, in turn, converted into material requirements for each supplier.

Cans and plastic bottles are delivered on a JIT basis, being delivered 2-3 hours before they are needed. 3-4 days stock of packaging is carried. The Logistics Manager said that this is necessary because the production schedule often has to be altered at short notice according to which juice is available or as a result of a machine breakdown and this amount of stock gives the required flexibility. Glass bottles are delivered daily and in theory the supplier could deliver today what will be required tomorrow. In practice about 3 days of stock are held for the same reasons as for packaging and also because of the unreliability of the supplier. In addition, contracts for cans and bottles specify a minimum buffer stock that suppliers must hold at their premises. If there is a sudden increase in demand then the plant can call off from this buffer stock. Auditors check these buffer stocks at intervals to ensure that they are being kept at the correct levels. A consequence of this buffer stock policy is that major write-offs occur whenever the Marketing Department makes design changes. All suppliers receive a 4-month forward forecast, which is revised monthly. Only the schedule for the current month is firm.

The Purchasing Manager said that requirements for wet materials like glucose and sugar are much more variable, being affected by the freshness of the juice, the characteristics of the yeast being used and the external temperature. The process operators order their requirements directly from the supplier. The lead time for cider making is also extremely variable. The time from the start of the fermenting process to the cider being ready to blend can be anything from 14 days to 48 days.

Demand is extremely seasonal with natural peaks at Christmas and in the summer and self-inflicted peaks at the half-year and full year-end. The trend is for supermarket demand at Christmas to move nearer and nearer to Christmas. At one time the peak was at the beginning of November. Now it is the second week in December. Demand in January and February is always extremely low. The Logistics Manager said that the company attempts to counteract this by scheduling price increases around the end of this period to encourage pre-increase buying. During this period shelf life can be a problem. Product in cans and plastic bottles has a shelf life of 8-9 months. Customers require 75 per cent of this leaving 2 months available to the company. In fact they operate a policy of 4 weeks' maximum shelf life. Product in glass bottles is less of a problem as shelf life is 2 years. This means that some low demand specialist products can be made once every 6 months. Although production methods are now extremely up-to-date the Logistics Manager said that the company tends to be rather traditional in its approach to the product range. Some rationalisation has been carried out under the guidance of McKinsey Consultants and a further re-examination is likely to take place after the activity based costing exercise currently in progress has been completed. The Logistics Manager stated

"The main problem is likely to be own label for which the true costs are likely to be much higher than the current figures suggest. Unfortunately, supermarkets like to have all of their own label requirements from one supplier and can apply pressure by threatening to de-list the company's branded products. The problem is that an annual demand of 30,000 cans only represents a 30 minute run on the packing line and because of the shelf life problem this would require 12 separate runs with the associated waste during changeover."

11.2.5 Performance improvement

The Production Manager said that over the last few years there had been major changes in the role of operators.

"At one time they had virtually no discretion other than switching the machine on and off. If there was a production problem they called in their supervisor. Engineering problems were dealt with by the fitters. If the area was dirty then a service cleaner was called in. Supply of materials was decided by the Materials Control Room and quality control was maintained by a large team of inspectors. As the workforce had so little discretion they had to be very heavily supervised."

Three and a half years ago the company decided that the workforce should be multi-skilled. This involved them taking on the following additional tasks.

1. Completing line changeovers
2. Carrying out all quality control checks
3. Doing all hygiene, cleaning and sterilisation of the equipment
4. House-keeping around the machines
5. Basic maintenance
6. Ensuring correct setting of the machines

The Production Manager said that the ultimate aim is to incorporate engineering staff into the packing teams. Eventually, all engineers whose activities relate to production will report to a production supervisor rather than an engineering supervisor. Although good progress has been made on team building the Production Manager believes that they are still 3-4 years away from full integration of engineering and production. There are currently 45 engineers in the plant. Half are responsible for the packing lines and the other half are responsible for processing and general engineering services.

The Production Manager said that his long-term plan is that the workforce will eventually be responsible for

- Monitoring their own work
- Agreeing their own objectives
- Scheduling their own production
- Hiring and firing staff

Training has been carried out through the National Vocational Qualifications (NVQ) scheme with 80 per cent of staff obtaining NVQ1 and NVQ2. Multi-skilling of trades people had started 6 years earlier and now about half of the trades people are fully trained in both electrical and mechanical skills and the rest are partially trained.

11.2.6 Management views on trade-offs

The Production Manager believed that in the process industry the main trade-off was between capital investment and operating performance. He mentioned the £20 million investment in automation 4 years earlier that had enabled a 35% reduction in the workforce while at the same time increasing quality.

He also considered that for their type of industry with long changeover times between runs there is a trade-off between the size of the product range and cost, delivery reliability and manufacturing lead time but not with quality. On the other hand, the current programme of multi-skilling and the introduction of problem-solving groups should lead to simultaneous improvements in cost reduction, quality consistency, shorter lead times and more reliable delivery.

11.3 Comparative Analysis of Plant Characteristics

11.3.1 Process reliability

According to the research propositions being tested, high performance plants will show greater process reliability than low performance plants. This proposition is not supported by the results for the high performance household products plant. Percentage schedule adherence was only average at this plant. The plant manager argued that this was an inevitable consequence of the unpredictability of the fermentation process. Fermentation times are extremely variable and this often necessitates short-term changes in the production schedule to accommodate these variations. However, the high performance plant did have a much lower than average scrap rate both in the current year and the previous year.

The low performance plant also did not support this proposition. Again its rating on process reliability was close to the sector average. This plant had only recently introduced measurement of many performance metrics and so no figures were available for percentage schedule adherence and percentage scrap rate in the previous year. Percentage schedule adherence for the current year was much higher than the sector average, contrary to what would have been predicted by the proposition. However, percentage scrap rate was below the sector average. This is consistent with what would have been predicted by the proposition.

Table 11.1: Process Reliability Data for Household Product Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Plant's subjective rating on process dependability	7	7.3	7
% Adherence to schedule this year	87	87.8	96
% Adherence to schedule last year	80	86.1	Not measured
% Scrap rate this year	1.5	5.3	7.0
% Scrap rate last year	2.0	7.1	Not measured

11.3.2 Precision of quoted lead times

The proposition that high performance plants quote a higher percentage of deliveries that is for a specific time of day than low performance plants is supported by the results for these plants. The high performance plant quoted all lead times for a specific time of day and the low performance plant quoted none of its lead times for a specific time of day. For the sector as a whole 22 per cent of lead times were quoted for a specific time of day.

Table 11.2: Precision of Quoted Lead Times for Household Product Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Specific time of day	50	22	0
Specific day	50	47	80
Specific week	0	28	20
Other time	0	3	0

11.3.3 Throughput efficiency

Support for the proposition that high performance plants show greater throughput efficiency than low performance plants is mixed. The plants' ratings on throughput efficiency support the proposition. The high performance plant has a rating well above the sector average and the low performance plant has a rating well below the sector average. However, the percentage of capacity used for changeovers is the reverse of what would be predicted by the hypothesis. The percentage of capacity used for changeovers at the high capacity plant is above the sector average while the percentage of capacity used for changeovers at the low capacity plant is well below the sector average.

Table 11.3: Throughput Efficiency Measures at Household Product Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Plant's subjective rating on throughput efficiency	9	7.3	5
% Of capacity used for changeovers	12	11	5

11.3.4 Involvement of workforce in continuous improvement

The results for both plants fully support the proposition that high performance plants put greater emphasis on continuous improvement than low performance plants. All of the 5 measures of emphasis on continuous improvement are above the sector average for the high performance plant and below the sector average for the low performance plant.

Table 11.4: Use of Problem-solving Groups at Household Product Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Plant's subjective rating on change as a way of life	7	6.9	3
Plant's subjective rating on the importance of continuous improvement	8	7.1	5
Plant's subjective rating on the commitment of employees to continuous improvement	7	6.4	4
Plant's subjective rating on use of labour as a source of brainpower	8	6.4	5
% of production employees involved in problem-solving groups?	65%	40.8%	15%

11.3.5 Labour flexibility

The Production Manager at the high performance plant considered that increasing labour flexibility was one of his main priorities. Because he saw this as an important area for improvement this perhaps explains why the high performance plant only gave itself a rating of 7 out of 10 for labour flexibility compared with a sector average of 7.6. Certainly, the high performance plant's rating on emphasis on training and competence was well above the sector average. The low performance plant gave itself below average ratings on both labour flexibility and emphasis on training and competence. Overall then some degree of support for the proposition that high performance plants have higher levels of labour flexibility than low performance plants.

Table 11.5: Labour Flexibility for Household Product Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Plant's subjective rating on labour flexibility	7	7.6	4
Plant's subjective rating on emphasis on training and competence	9	6.6	6

11.3.6 Labour costs

There is mixed support from these plants for the proposition that high performance plants have lower labour costs as a percentage of total manufacturing costs than low performance plants. The high performance plant has lower than average direct and other labour costs but above average indirect labour costs. However, total labour costs as a percentage of total manufacturing costs are below average, 13.1 per cent compared with a sector average of 24.9 per cent. Contrary to what would be predicted by the proposition, the low performance plant has below average direct and indirect labour costs and other labour costs that are about the same as the sector average. Consequently, total labour costs are 20.3 per cent, less than the sector average.

Table 11.6: Labour Costs as a Percentage of Total Manufacturing Costs for Household Products Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Direct labour	1.5	14.2	12.9
Indirect factory labour	6.8	4.7	1.3
Other labour (including staff and managerial)	4.8	6.0	6.1

11.3.7 Cleanliness

Again, there is some degree of support for the proposition that high performance plants have higher levels of cleanliness than low performance plants. The high performance plant had a rating on cleanliness that was about average for the sector. The nature of the cider-making process is, perhaps, such that the maintenance of high levels of cleanliness is difficult in comparison with other types of household products plants. The results for the low performance plant supported the proposition with a rating on cleanliness well below the sector average.

Table 11.7: Measure of Cleanliness for Household Products Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Plant's subjective rating on cleanliness	7	7.1	4

11.3.8 Accurate documentation

The proposition that high performance plants will have more accurate and up-to-date process documentation than low performance plants is not supported by the results for these plants. The high performance plant's rating on documentation accuracy was below average and the low performance plant's rating was above average. Both measured stock record accuracy, as did 70 per cent of plants in the sector.

Table 11.8: Measures of Documentation Accuracy for Household Products Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Plant's subjective rating on documentation accuracy	7	7.8	8
Is stock record accuracy measured?	Yes	70	Yes

11.3.9 Suppliers

The results for these plants provide some support for the proposition that high performance plants have more frequent and reliable supplier deliveries than low performance plants. The high performance plant had lower than average stocks of raw materials and the low performance plant had higher than average stocks of raw materials. Surprisingly, neither plant measured the delivery reliability of their suppliers. The frequency of delivery by suppliers was similar to the sector average for the high performance plant. Frequency of deliveries by suppliers to the low performance plant was well below the sector average with 95 per cent of suppliers delivering monthly or less frequently.

Table 11.9: Measures of Supplier Delivery Performance for Household Product Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Raw materials	4.3	5.3	7.0
% On time delivery of suppliers	Not measured	90%	Not measured

11.3.10 Supplier delivery frequency

Table 11.10: Supplier Delivery Frequency for Household Products Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Daily	5	12	0
Twice weekly	20	14	0
Weekly	40	31	5
Monthly	10	31	60
Less frequently than monthly	25	12	35

11.3.11 Measurement of a wide range of metrics

The results for these plants provide mixed support for the proposition that high performance plants measure a wider range of metrics than low performance plants. Although the high performance plant measures a higher percentage of metrics than the sector average, so does the low performance plant. There are some surprising omissions in the range of metrics that are measured by the high performance plant. Neither supplier delivery reliability nor first time pass rate are measured on a regular basis. At the time of the plant visit, measurement of supplier delivery reliability was about to commence as part of a process for monitoring a variety of different aspects of supplier performance.

Table 11.11: Metrics Measured at Household Products Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Is output volume measured on a regular basis?	Yes	97	Yes
Is production schedule adherence measured on a regular basis?	Yes	51	Yes
Is ex-stock availability measured on a regular basis?	Yes	48	Yes
Is due date reliability for items on quoted lead times measured on a regular basis	Yes	68	Yes
Is inventory record accuracy measured on a regular basis?	Yes	70	Yes
Is scrap or yield loss rate measured on a regular basis?	Yes	88	Yes
Is time spent on rework/reprocessing measured on a regular basis?	Yes	49	No
Is time spent on setting/changeover measured on a regular basis?	Yes	56	No
Are customers' returns/complaints measured on a regular basis?	Yes	86	Yes
Is first time pass rate measured on a regular basis?	No	48	Yes
Is supplier delivery performance measured on a regular basis?	No	50	No
% of metrics measured	82%	65%	73%

11.3.12 Trade-offs

11.3.12.1 Proposition 10

Proposition 10 states that rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial sector. If this is the case then it would be expected that the high performance household products plant would perform better than the industry sector average on these factors and the low performance household products plant would perform worse than the industry sector average. Actual performance on these measures for the high and low performance plants is summarised in Table 11.12.

Table 11.12: Absolute Performance Measures for Household Products Plants

	High performance plant	Household Product sector average	Low performance plant
Added value per employee £	1.90	1.63	1.63
% Customer returns in current year	0.000006	0.71	1.0
Average quoted customer lead time	10	27	80
% On time delivery	99.1	76	95

In the case of the high performance plant performance is much better than the sector average for all of the 4 measures. In the case of the low performance plant performance is worse than the sector average for 2 out of the 4 measures and equal to the sector average on one measure. It is much better than the sector average on percentage on-time delivery, contrary to what would be predicted by proposition 10.

11.3.12.2 Proposition 11

Proposition 11 states that the extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability. If this is the case then it would be expected that plants with a smaller product range than the industry sector average would perform better than the industry sector average on these factors and plants with a larger product range than the industry sector average would perform worse than the industry sector average on these factors.

If proposition 11 is correct then it would be expected that the high performance plant would have a small product range and the low performance plant would have a large product range. The results are completely at variance with this. The high performance plant has a larger product range than the average and the low performance plant has a smaller product range than the average.

Table 11.13: Product Focus at Household Products Plants

	High Performance Plant	Household Products Sector Average	Low Performance Plant
Total products currently live	330	3,075	38
Total manufactured components, bulk intermediates and sub-assemblies currently live	112	607	-
Total bought out components and sub-assemblies currently live	4000	395	55
Total purchased raw materials currently live	27	402	12
Products in continuous production last year	310	17	4
Products in intermittent production last year	16	117	30
Products of initially unknown design produced last year	10	66	4
Total number of different products made last year	336	200	38

11.4 Conclusions

The characteristics of this plant are rather different from the characteristics of the other plants visited. The main raw material, apples, is only available during the autumn and stocks for the whole year must be obtained at this time. The cider fermentation process is highly variable in duration. In addition, demand for the product is highly seasonal with December demand being around 3 times the January demand.

The plant is also under constant pressure from their customers to widen the product range. As a consequence this plant produces a wider product range than the sector average. In spite of this the plant still manages to out-perform the sector average on added value per employee £, quality consistency, delivery speed and delivery reliability.

Unlike the other high performance plants, which have found ways of reducing variability and uncertainty, this plant has found ways of coping with variability and uncertainty. It decouples the rest of the manufacturing process from the highly variable fermentation stage by holding bulk stocks of cider. Variability in demand during the seasonal peak is handled by employing casual labour who return year after year. Short-term demand fluctuations are handled by varying the hours worked by the workforce in line with demand.

However, in other respects the plant uses many approaches that are similar to those used by the other high performance plants. They have a multi-skilled workforce that is taking over more and more tasks previously carried out by indirect and supervisory staff. The plant places great emphasis on involvement of the workforce in continuous improvement. They have an integrated computer-based planning and control system and they share their production schedules with suppliers and customers.

Future improvement plans include further increases in the multi-skilling and autonomy of the workforce, introduction of an improved planning and control system and rationalisation of the product range in order to reduce product variety.

11.4.1 Support for the research propositions at the high performance household products plant.

The level of support at the high performance household products plant for the research propositions being tested is summarised below.

Table 11.14: Support for the Research Propositions at the Household Products Plant

Proposition	Description	Level of support
1	Process reliability	Neutral
2	Throughput efficiency	Good
3	Emphasis on continuous improvement	Excellent
4	Labour flexibility	Good
5	Low labour costs	Good
6	Cleanliness	Neutral
7	Accurate documentation	Negative
8	Frequent, reliable supplier delivery	Neutral
9	Measurement of wide range of metrics	Excellent
10	Positive correlation between added value per employee £, quality consistency, customer lead time and delivery reliability	Excellent
11	Negative correlation	Negative

	between product variety and added value per employee £, quality consistency, customer lead time and delivery reliability	

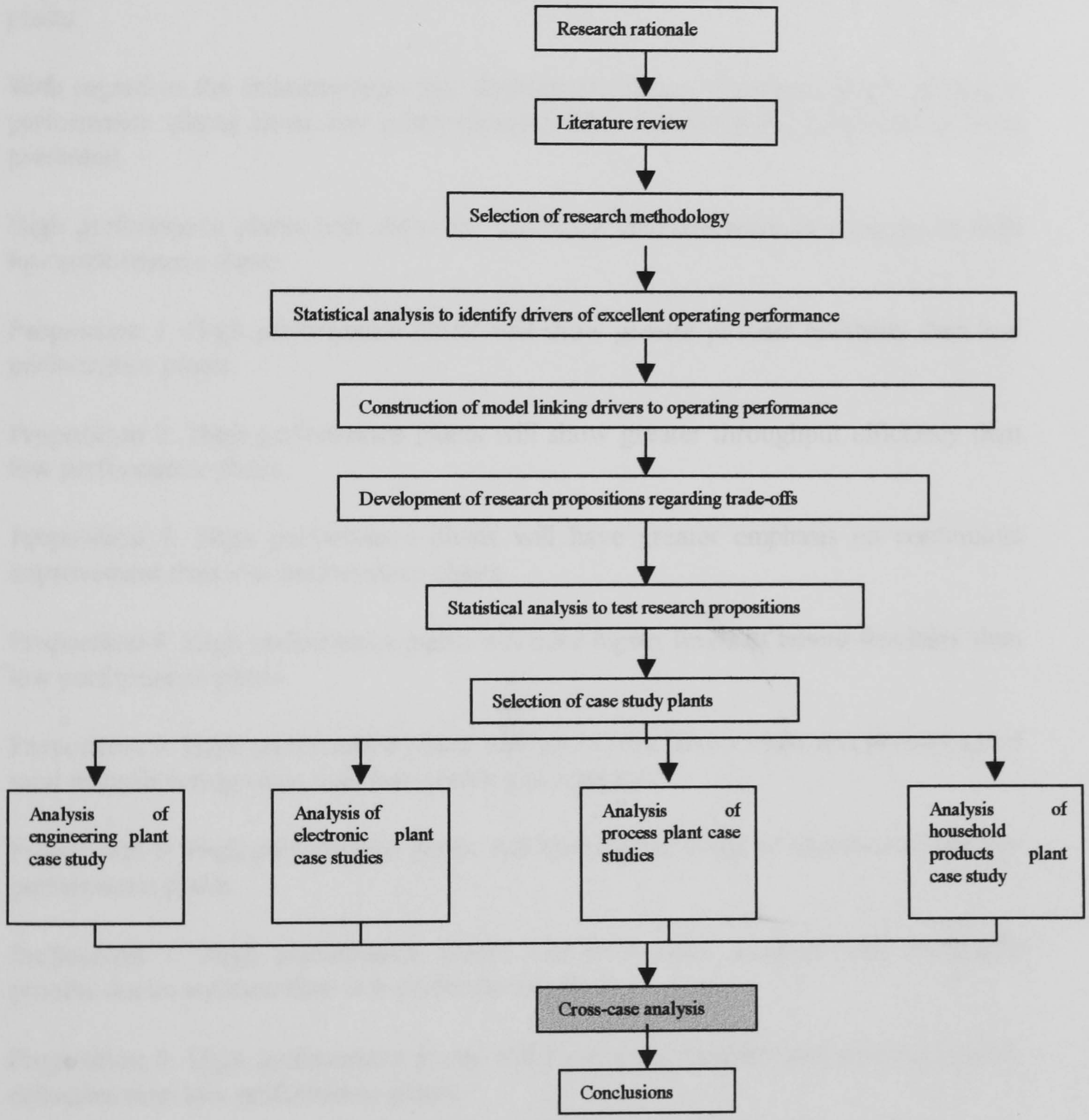
This plant provides the lowest level of support for the research propositions amongst all of the plants visited. Only 6 out of the 11 research propositions are supported. As was discussed earlier, this plant seems to be adopting a different approach to the achievement of high performance. Rather than finding ways of reducing variability and uncertainty it has found ways of coping with the inherent variability and uncertainty that it faces.

Chapter 12 : Cross Case Analysis

12.1 Summary

Figure 12.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In Chapters 8 to 11 the results of visits to 6 manufacturing plants were presented. In this chapter the results of the analyses of these case studies are summarised and used to test the strength of support for the propositions identified in Chapters 4 and 6.

12.2 Introduction

The propositions identified in this research can be divided into two groups. First there are those that relate to the characteristics that differentiate high performance plants from low performance plants. Secondly there are those that relate to the nature of the trade-offs that exist between the various elements of operating performance in these plants.

With regard to the characteristics that differentiate high performance plants from low performance plants from low performance plants, the following propositions were presented.

High performance plants will show the following characteristics in comparison with low performance plants.

Proposition 1: High performance plants will show greater process reliability than low performance plants.

Proposition 2: High performance plants will show greater throughput efficiency than low performance plants.

Proposition 3: High performance plants will have greater emphasis on continuous improvement than low performance plants.

Proposition 4: High performance plants will have higher levels of labour flexibility than low performance plants.

Proposition 5: High performance plants will have lower labour costs as a percentage of total manufacturing costs than low performance plants.

Proposition 6: High performance plants will have higher levels of cleanliness than low performance plants.

Proposition 7: High performance plants will have more accurate and up-to-date process documentation than low performance plants.

Proposition 8: High performance plants will have more frequent and reliable supplier deliveries than low performance plants.

Proposition 9: High performance plants will measure a wider range of metrics than low performance plants

With regard to the nature of the trade-offs between performance measures in manufacturing plants, the following hypotheses were proposed.

Proposition 10: Rankings of plants relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated. In particular, plants which achieve a better than average performance level for their sector on one of these factors will also achieve a better than average performance on the other factors.

Proposition 11: The extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability. In other words, plants that manufacture a wide variety of products cannot expect to match the performance on the factors mentioned achieved by other plants in the same sector manufacturing a narrower product range.

In total, 6 plants were visited. Four were plants whose overall performance placed them in the top quartile for their sector and two were plants whose overall performance placed them in the bottom quartile for their sector. Questionnaire data on a further 2 plants whose overall performance placed them in the bottom quartile of their sector was also available but it was not possible to visit these plants. In the following analysis, all 8 plants have been used to test the level of support for the 11 research propositions.

12.3 Characteristics that Differentiate High and Low Performance Plants

12.3.1 Process reliability

In this case the following proposition is being tested.

Proposition 1: High performance plants will have greater process reliability than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to process reliability were found to be significantly different for high performance and low performance plants.

- The plant's subjective rating on process dependability
- Percentage schedule adherence in the current year
- Percentage schedule adherence in the previous year
- Percentage scrap rate in the current year
- Percentage scrap rate in the previous year
- Lead times quoted for a specific time of day

Table 12.1 summarises the values of these measures for each of the plants considered in Chapters 8 to 11. In those cases where a plant visit was not possible figures are still included for comparison. Table 12.2 shows which pairs of figures provide support for the proposition, that is, the process reliability measure is better for the high performance plant than the low performance plant. These results are shown as in agreement with the proposition. Those cases where the high and low performance plants have identical measures are shown as neutral. Those results where the process reliability measures are worse for the high performance plant than the low performance plant are shown as in disagreement with the proposition. In those cases where one of the plants does not calculate the desired measure, the proposition is tested by comparing the measure for the other plant with the mean value of the measure for all plants in that sector.

Table 12.1: Comparison of Process Reliability Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Rating on process dependability	9	7	9	5	9	6	7	7
% Schedule adherence in current year	100	85	99.8	Not measured	99.1	55	87	96
% Schedule adherence in previous year	98.7	85	99.0	Not measured	95.1	45	80	Not measured
% Scrap rate in current year	0.9	0.6	0.2	4.2	0.8	5.5	1.5	7.0
% Scrap rate in previous year	1.4	1.0	0.9	4.4	1.25	6.7	2.0	Not measured
Lead times quoted for specific time of day	100	0	0	5	100	0	50	0

Table 12.2: Support for Influence of Process Reliability on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Rating on process dependability	Agrees	Agrees	Agrees	Neutral
% Schedule adherence in current year	Agrees	Agrees	Agrees	Disagrees
% Schedule adherence in previous year	Agrees	Agrees	Agrees	Disagrees
% Scrap rate in current year	Disagrees	Agrees	Agrees	Agrees
% Scrap rate in previous year	Disagrees	Agrees	Agrees	Agrees
Lead times quoted for specific time of day	Agrees	Disagrees	Agrees	Agrees

These results provide reasonable support for this proposition. 75% of the results are in agreement with the proposition. 4% of the results are neutral. 21% are in disagreement with the proposition.

12.3.2 Throughput efficiency

In this case the following proposition is being tested.

Proposition 2: High performance plants will show greater throughput efficiency than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to process reliability were found to be significantly different for high performance and low performance plants.

- The plant's subjective rating on throughput efficiency
- Percentage of capacity used for changeovers

Table 12.3 shows the values of these measures for the 8 plants. Table 12.4 shows which pairs of plants provide support for this proposition.

Table 12.3: Comparison of Throughput Efficiency Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Throughput efficiency rating	9	9	8	7	8	7	9	5
% of capacity used for changeovers	3	20	2.5	Not measured	2	Not measured	12	5

Table 12.4: Support for Influence of Throughput Efficiency on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Throughput efficiency rating	Neutral	Agrees	Agrees	Agrees
% of capacity used for changeovers	Agrees	Agrees	Agrees	Disagrees

Again 75% of the results are in agreement with the proposition. 12.5% of the results are neutral and 12.5% of the results disagree with the proposition.

12.3.3 Continuous improvement

In this case the following proposition is being tested.

Proposition 3: High performance plants will have greater emphasis on continuous improvement than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to continuous improvement were found to be significantly different for high performance and low performance plants.

- The plant's subjective rating on change as a way of life
- The plant's subjective rating on importance of process engineering and continuous improvement
- The plant's subjective rating on the commitment of employees to continuous improvement
- The plant's subjective rating on use of labour as a source of brainpower
- Percentage of the workforce involved in problem-solving groups

Table 12.5 shows the values of these measures for the 8 plants. Table 12.6 shows which pairs of plants provide support for this proposition.

Table 12.5: Comparison of Continuous Improvement Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Rating on change as a way of life	9	9	7	7	9	6	7	3
Rating on importance of process engineering and continuous improvement	9	6	8	7	8	4	8	5
Rating on commitment of employees to continuous improvement	7	8	7	6	9	6	7	4
Rating on labour as a source of brainpower	7	7	9	6	9	7	7	4
% of production employees involved in problem-solving groups	60	13	25	0	100	15	65	15

Table 12.6: Support for Influence of Continuous Improvement on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Rating on change as a way of life	Neutral	Neutral	Agrees	Agrees
Rating on importance of process engineering and continuous improvement	Agrees	Agrees	Agrees	Agrees
Rating on commitment of employees to continuous improvement	Disagrees	Agrees	Agrees	Agrees
Rating on labour as a source of brainpower	Neutral	Agrees	Agrees	Agrees
% of production employees involved in problem-solving groups	Agrees	Agrees	Agrees	Agrees

Again 80% of the results are in agreement with the proposition. 15% of the results are neutral and 5% of the results disagree with the proposition.

12.3.4 Labour flexibility

In this case the following proposition is being tested.

Proposition 4: High performance plants will have higher levels of labour flexibility than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to labour flexibility were found to be significantly different for high performance and low performance plants.

- The plant's subjective rating on labour flexibility
- The plant's subjective rating on training and competence

Table 12.7 shows the values of these measures for the 8 plants. Table 12.8 shows which pairs of plants provide support for this proposition.

Table 12.7: Comparison of Labour Flexibility Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Rating on labour flexibility	7	7	9	6	9	7	7	4
Rating on training and competence	9	7	7	6	8	5	9	6

Table 12.8: Support for Influence of Labour Flexibility on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Rating on labour flexibility	Neutral	Agrees	Agrees	Agrees
Rating on training and competence	Agrees	Agrees	Agrees	Agrees

87.5% of the results are in agreement with the proposition. 12.5% of the results are neutral and none of the results disagree with the proposition.

12.3.5 Labour costs as a percentage of manufacturing costs

In this case the following proposition is being tested.

Proposition 5: High performance plants will have lower labour costs as a percentage of total manufacturing costs than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to labour costs were found to be significantly different for high performance and low performance plants.

- Direct labour costs as a percentage of total manufacturing costs
- Indirect labour costs as a percentage of total manufacturing costs
- Other labour costs as a percentage of total manufacturing costs

Table 12.9 shows the values of these measures for the 8 plants. Table 12.10 shows which pairs of plants provide support for this proposition.

Table 12.9: Comparison of Labour Cost Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Direct labour costs as a % of manufacturing costs	18.6	19.3	8.4	11.3	3.5	32.6	1.5	12.9
Indirect labour costs as a % of manufacturing costs	3.1	3.9	0.2	4.6	1.0	3.5	6.8	1.3
Other labour costs as a % of manufacturing costs	5.7	8.8	5.9	4.2	3.8	13.6	4.8	6.1

Table 12.10: Support for the Influence of Labour Cost Measures on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Direct labour costs as a % of manufacturing costs	Agrees	Agrees	Agrees	Agrees
Indirect labour costs as a % of manufacturing costs	Agrees	Agrees	Agrees	Disagrees
Other labour costs as a % of manufacturing costs	Agrees	Disagrees	Agrees	Agrees

83% of the results are in agreement with the proposition. 17% of the results disagree with the proposition.

12.3.6 Cleanliness

In this case the following proposition is being tested.

Proposition 6: High performance plants will have higher levels of cleanliness than low performance plants.

In the statistical analysis presented in Chapter 4 the only characteristic relating to cleanliness that was found to be significantly different for high performance and low performance plants was the plant's subjective rating on cleanliness.

Table 12.11 shows the value of this measure for the 8 plants. Table 12.12 shows which pairs of plants provide support for this proposition.

Table 12.11: Comparison of Cleanliness Measure for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Rating on cleanliness	8	8	9	7	7	5	7	4

Table 12.12: Support for Influence of Cleanliness on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Rating on cleanliness	Neutral	Agrees	Agrees	Agrees

75% of the results are in agreement with the proposition. 25% of the results are neutral.

12.3.7 Accuracy of documentation

In this case the following proposition is being tested.

Proposition 7: High performance plants will have more accurate and up-to-date process documentation than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to accuracy of documentation were found to be significantly different for high performance and low performance plants.

- The plant's subjective rating on documentation accuracy
- Whether stock record accuracy is measured

Table 12.13 shows the values of these measures for the 8 plants. Table 12.14 shows which pairs of plants provide support for this proposition.

Table 12.13: Comparison of Documentation Accuracy Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Rating on documentation accuracy	10	8	9	7	10	6	7	8

Table 12.14: Support for Influence of Documentation Accuracy on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Rating on documentation accuracy	Agrees	Agrees	Agrees	Disagrees

75% of the results are in agreement with the proposition. 25% of the results disagree with the proposition.

12.3.8 Suppliers

In this case the following proposition is being tested.

Proposition 8: High performance plants will have more frequent and reliable supplier deliveries than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to the frequency and reliability of supplier deliveries were found to be significantly different for high performance and low performance plants.

- Weeks' usage of raw materials stock
- % On-time delivery performance of suppliers
- Percentage of supplier deliveries that are less frequent than monthly
- Mean interval in days between supplier deliveries

Table 12.15 shows the values of these measures for the 8 plants. Table 12.16 shows which pairs of plants provide support for this proposition.

Table 12.15: Comparison of Supplier Delivery Measures for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Weeks of raw materials stock	3.2	4	0	6	4.2	8	4.3	7
% On-time supplier delivery	93	70	83	98	Not measured	75	Not measured	Not measured
% of supplier deliveries that are less frequent than monthly	0	0	0	26	20	10	25	35

Table 12.16: Support for Influence of Supplier Deliveries on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Weeks of raw materials stock	Agrees	Agrees	Agrees	Agrees
% On-time supplier delivery	Agrees	Disagrees	Agrees	Neutral
% of supplier deliveries that are less frequent than monthly	Neutral	Agrees	Disagrees	Agrees

67% of the results are in agreement with the proposition. 17% of the results are neutral and 17% of the results disagree with the proposition.

12.3.9 Range of metrics measured

In this case the following proposition is being tested.

Proposition 9: High performance plants will measure a wider range of metrics than low performance plants.

In the statistical analysis presented in Chapter 4 the following characteristics that relate to accuracy of documentation were found to be significantly different for high performance and low performance plants.

- Whether stock record accuracy is measured
- Whether first time pass rate is measured
- Whether ex-stock availability is measured
- The percentage of metrics that are measured

Table 12.17 shows the values of these measures for the 8 plants. Table 12.18 shows which pairs of plants provide support for this proposition.

Table 12.17: Comparison of Range of Metrics Measured for High and Low Performance Plants

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Is stock record accuracy measured?	Yes	Yes	Yes	No	Yes	No	Yes	Yes
Is first time pass rate measured?	Yes	No	Yes	Yes	Yes	Yes	No	Yes
Is ex-stock availability measured?	Not applicable	Not applicable	Not applicable	Yes	Yes	No	Yes	Yes
% of metrics measured	90	90	100	73	91	55	82	73

Table 12.18: Support for Influence of the Range of Metrics Measured on Operating Performance

	Engineering Sector	Electronics Sector	Process Sector	Household Products Sector
Is stock record accuracy measured?	Neutral	Agrees	Agrees	Neutral
Is first time pass rate measured?	Agrees	Neutral	Neutral	Disagrees
Is ex-stock availability measured?	Not applicable	Not applicable	Agrees	Neutral
% of metrics measured	Neutral	Agrees	Agrees	Agrees

50% of the results are in agreement with the proposition. 43% of the results are neutral and 7% of the results disagree with the proposition.

12.3.10 Trade-offs

12.3.10.1 Proposition 10

Proposition 10 states

Rankings of plants relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated. In particular, plants which achieve a better than average performance level for their sector on one of these factors will also achieve a better than average performance on the other factors.

Table 12.19 shows the rankings achieved by each of the 8 plants being considered in this chapter on added value per employee £, quality consistency, speed of delivery and delivery reliability.

Table 12.19: Rankings on Performance Measures

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Added value per employee £	65	85	58	26	12	88	25	50
Quality consistency	20	23	29	63	25	96	5	68
Speed of delivery	2	65	20	27	24	64	36	94
Delivery Reliability	7	66	9	73	8	96	39	57

If this proposition were correct then it would be expected that an above average ranking (1 to 49) on one factor would be associated with an above average ranking on the other three factors. Similarly, a below average ranking (50 to 100) on one factor would be associated with a below average ranking on the other three factors. Table 12.20 summarises the extent to which this is the case for each pair of performance measures. For each pair of performance measures, both rankings for a plant being above average or both pairs being below average counts as agreement with the proposition. One ranking for a plant being above average and one being below average counts as disagreement with the proposition.

Table 12.20: Rankings Classified into Above Average and Below Average Performance

		Quality consistency	Speed of delivery	Delivery reliability
Added value per employee £	Agrees	4	6	5
	Disagrees	4	2	3
Quality consistency	Agrees		6	7
	Disagrees		2	1
Speed of delivery	Agrees			7
	Disagrees			1

While the results, do in general support the proposition; at least one plant is inconsistent with the proposition for every pair of performance measures. Also there is no evidence to support the proposition that added value per employee £ and quality consistency are correlated either positively or negatively.

12.3.10.2 Proposition 11

Proposition 11 states

The extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability. In other words, plants that manufacture a wide variety of products cannot expect to match the performance on the factors mentioned achieved by other plants in the same sector manufacturing a narrower product range.

Table 12.21 repeats the rankings shown earlier but with the inclusion of a ranking for each plant on product variety. A ranking from 1 to 49 means that the plant has a larger than average product range. A ranking from 50 to 100 means that the plant has a smaller than average product range.

Table 12.21: Plant Rankings Including Product Variety

	Engineering Sector		Electronics Sector		Process Sector		Household Products Sector	
	High	Low	High	Low	High	Low	High	Low
Product variety	52	2	89	18	79	29	18	88
Added value per employee £	65	85	58	26	12	88	25	50
Quality consistency	20	23	29	63	25	96	5	68
Speed of delivery	2	65	20	27	24	64	39	57
Delivery Reliability	7	66	9	73	8	96	38	57

If proposition 11 is correct then it would be expected that plants with a product range that is larger than average (a ranking of 1 to 49) would be associated with rankings for added value per employee £, quality consistency, speed of delivery and reliability of delivery that are below average (rankings of 50 to 100). Plants with a product range that is smaller than average (a ranking of 50 to 100) would be associated with rankings for added value per employee £, quality consistency, speed of delivery and reliability of delivery that are above average (rankings of 1 to 49). Table 12.22 shows how many plants are in agreement with this for each of the 4 performance measures.

Table 12.22: Support for Proposition 11

		Product Variety
Added value per employee £	Agrees	3
	Disagrees	5
Quality consistency	Agrees	5
	Disagrees	3
Speed of delivery	Agrees	5
	Disagrees	3
Delivery reliability	Agrees	6
	Disagrees	2

These results provide little support for the proposition. There appears some degree of negative correlation between product variety and delivery reliability but added value per employee £, quality consistency and speed of delivery appear to be unaffected by the size of the product range being produced by the plant. This is a rather surprising result. It is at variance with the results of the statistical analysis in Chapter 6. It is also at variance with the views expressed by the plant managers interviewed who all believed that reducing the size of the product range being produced in the plant would lead to improvements in all of these performance measures.

12.4 Managers' Views on Performance Trade-offs

At each of the plants visited the production managers were asked which trade-offs existed at their plants. Their responses for each pair of performance measures were classified into three groups.

1. Trade-offs – an improvement in one measure tended to be associated with deterioration in the other measure.
2. Mutual reinforcement – an improvement in one measure tended to be associated with an improvement in the other measure.
3. Neutral – a change in one measure had no effect on the other measure.

A summary of the managers' responses is shown in Table 12.23.

Table 12.23: Plant Managers' Responses on Trade-offs

	Unit manufacturing cost	Quality specification	Quality consistency	Delivery speed	Delivery reliability
Capital investment		TTTT	TTT	T	TTT
Product variety	TTTTN		TTTNN	TTTTN	TTTTN
Unit manufacturing cost		T	RRRRR	RRRR	RRRRR
Quality consistency				RRRRR	RRRRRR
Delivery speed					RRRRR

T = trade-off
R = mutually reinforcing
N = neutral

Analysis of the managers' responses suggests a number of general patterns.

1. Four out of the six managers mentioned the trade-off between the level of capital investment and operating performance measures. In other words there was a belief that improvements in various aspects of operating performance can be achieved by increasing the level of capital investment. There was fairly general agreement that increased capital investment enabled higher levels of quality specification, greater quality consistency and greater delivery reliability. Shorter customer lead times were mentioned less frequently. There were differing views on whether increased levels of capital investment would lead to an overall increase or decrease in unit manufacturing cost. Most felt that this would vary from case to case. Although consideration of the effect of capital investment was outside the scope of this research, variations in the level of capital investment between plants might explain some of the apparent anomalies in levels of added value per employee £.
2. Four out of the six managers considered that there would be a trade-off between product variety within the plant and the various measures of operating performance. In other words, an increase in the number of different products manufactured within the plant would lead to deterioration in various measures of operating performance. Another manager mentioned product variety but considered that increasing product variety would have no effect on the various measures of operating performance. One of the four managers who mentioned the trade-off between product variety and operating performance considered that increasing product variety would have no effect on quality consistency.

3. All of the managers mentioned that at least some of the measures – unit manufacturing cost, quality specification, delivery speed and delivery reliability were mutually reinforcing. The mutual reinforcement between quality consistency and delivery reliability was mentioned most frequently.
4. One manager mentioned the trade-off between quality specification and unit manufacturing cost.

Consideration of the managers' views on trade-offs suggests that they would give broad support for the following statements.

- Actions that lead to improvements in one of the factors unit manufacturing cost, quality consistency, delivery speed, delivery reliability, will usually lead to improvements in the other factors as well.
- Plants that increase the variety of different products being manufactured can expect deterioration in unit manufacturing cost, quality consistency, delivery speed and delivery reliability.

These two statements are consistent with Propositions 10 and 11 of the current research.

12.5 Conclusions

The overall level of support from the plant visits for the 11 research propositions being tested is summarised in the table below.

Table 12.24: Support for the Research Propositions at the Plants Visited

Proposition	Agree	Neutral	Disagree
Greater process reliability	75%	4%	21%
Greater throughput efficiency	75%	12.5%	12.5%
Greater emphasis on continuous improvement	80%	15%	5%
Greater labour flexibility	87.5%	12.5%	0%
Lower labour costs as a % of manufacturing costs	83%	0%	17%
Higher levels of cleanliness	75%	25%	0%
More accurate documentation	75%	0%	25%
More frequent and reliable supplier deliveries	69%	12%	19%
Wider range of metrics measured	50%	43%	7%
Correlated performance on added value, quality consistency, speed of delivery and delivery reliability	73%	0%	27%
Negative correlation between product	59%		41%

variety and added value, quality consistency, speed of delivery and delivery reliability			

Obviously, any results based on such a small sample of plants have to be treated with caution. However, there does seem to be some degree of support for propositions 1 to 8. In the case of proposition 9 there seems to be little difference in the range of metrics measured by high and low performance plants. There also appears to be some degree of support for proposition 10. Plants do, in the main achieve similar levels of performance on added value per employee £, quality consistency, customer lead time and delivery reliability. However, surprisingly, the degree of support for proposition 11 is very small indeed. There is little evidence to suggest that plants with a large product range perform less well on added value per employee £, quality consistency, customer lead time and delivery reliability than plants with a narrow product range. This is at variance with the results of the statistical analysis and merits further investigation.

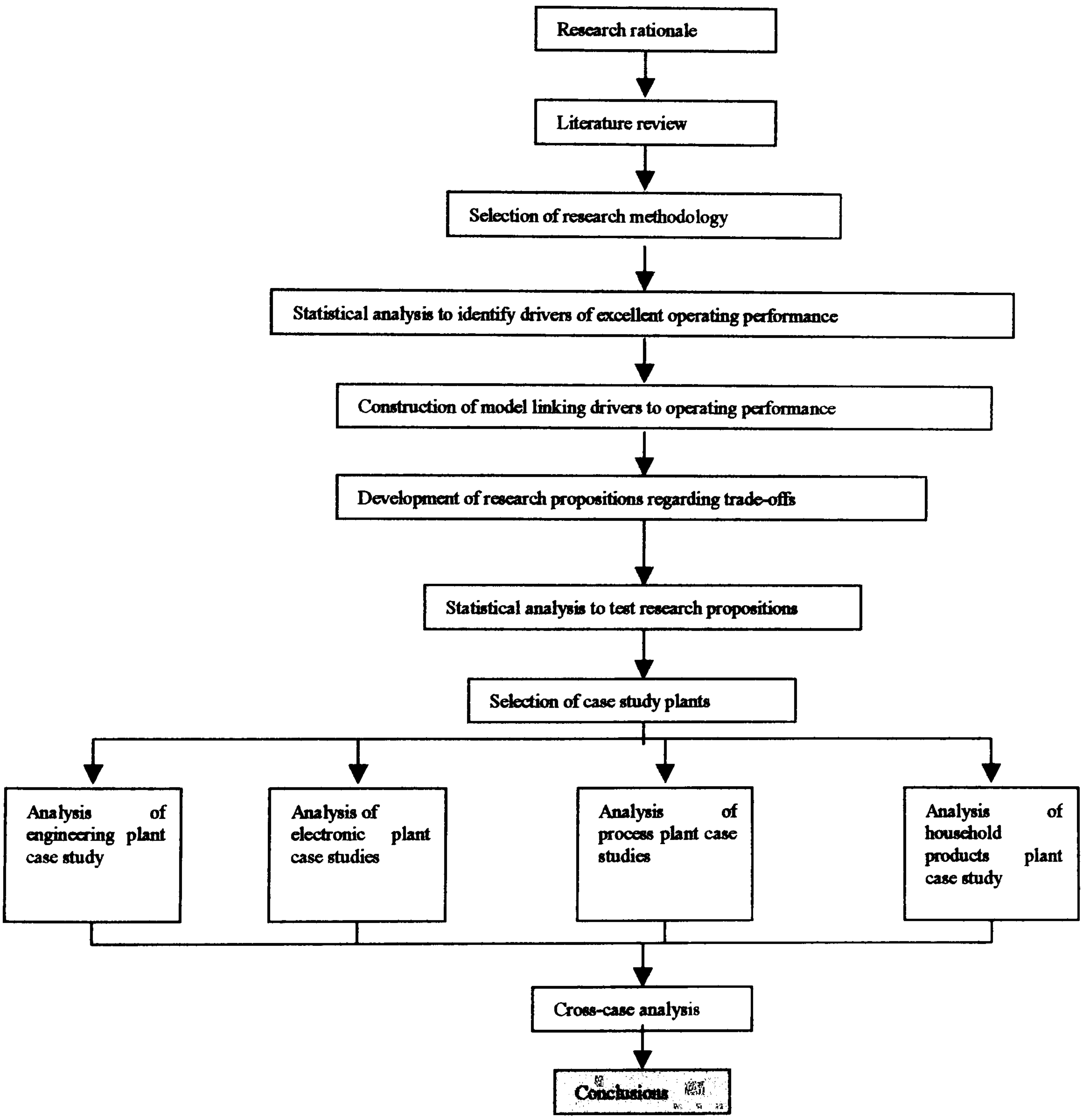
On the other hand, the views on trade-offs expressed by the production managers at the plants visited provided broad support for both Proposition 10 and Proposition 11.

Chapter 13 : Conclusions

13.1 Summary

Figure 13.1: Thesis Route Map

(The section covered in this chapter is shaded.)



In this chapter the research presented in this thesis is summarised. The main findings of the research are presented and the importance of these findings to practitioners is discussed. Finally some ideas for further research are presented.

13.2 Introduction

The purpose of this research has been to address the following broad research questions.

1 What are the differentiating characteristics that enable manufacturing plants to achieve higher operating performance than comparable plants?
2 What are the mechanisms whereby these characteristics lead to higher levels of operating performance?
3 Which pairs of operating performance measures are negatively correlated, exhibiting a classic trade-off relationship?
4 Which pairs of operating performance measures are positively correlated, so that improvements in one measure also lead to improvements in the other measure?
5 Which pairs of operating performance measures are uncorrelated so that improvements in one measure can be achieved without there being any effect on the other performance measure?

In addressing these questions the following 5 stage approach to theory development suggested by Hofer and Schendel (1978) was used.

1. Exploration
2. Construct development
3. Hypothesis generation
4. Hypothesis testing for internal validity
5. Testing for external validity

Step 1: Exploration

The purpose of the first stage was to identify those characteristics that appeared to differentiate manufacturing plants with high levels of operating performance from manufacturing plants with low levels of operating performance. In order to do this a database was used containing information on 953 different plants that had submitted information as part of the UK Best Factories Award during the period 1993-1996. These plants were grouped into the following industrial categories.

Industrial category	Number of plants in sample
1. Capital equipment	56
2. Engineering	278
3. Electrical and electronics	140
4. Chemicals and pharmaceuticals	158
5. Food, drink and tobacco	99
6. Miscellaneous	222
Total	953

The plants for each year of the survey were ranked within their category on the following measures of performance.

- Added value per employee £
- Percentage customer returns or complaints in the last 12 months
- Average lead time quoted to the customer in days
- Percentage delivery on time

These rankings were then added to give a composite performance score (COMP). Based on this score the plants were divided into three groups of equal size, comprising high, medium and low performance plants respectively. Then, for the complete set of questionnaire variables in the database, the differences in the mean value of each variable for the high performance group and the low performance group were tested for significance. A significance level of 0.001 was used. Analysis of the statistically significant variables suggested the following propositions regarding the main characteristics that differentiate high and low performance plants.

13.2.1 Research propositions

Proposition 1: High performance plants will show greater process reliability than low performance plants.

Proposition 2: High performance plants will show greater throughput efficiency than low performance plants.

Proposition 3: High performance plants will have greater emphasis on continuous improvement than low performance plants.

Proposition 4: High performance plants will have higher levels of labour flexibility than low performance plants.

Proposition 5: High performance plants will have lower labour costs as a percentage of total manufacturing costs than low performance plants.

Proposition 6: High performance plants will have higher levels of cleanliness than low performance plants.

Proposition 7: High performance plants will have more accurate and up-to-date process documentation than low performance plants.

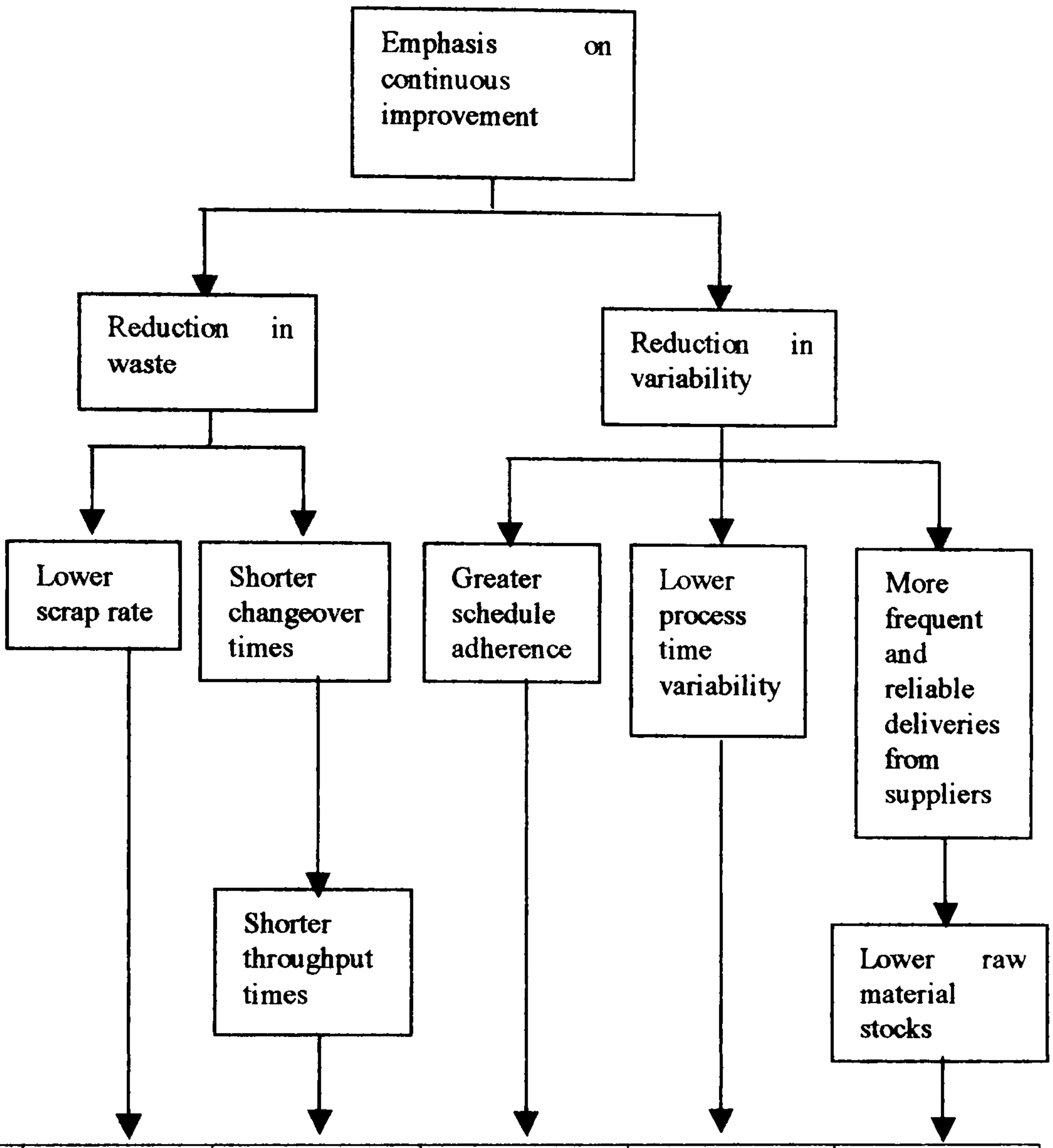
Proposition 8: High performance plants will have more frequent and reliable supplier deliveries than low performance plants.

Proposition 9: High performance plants will measure a wider range of metrics than low performance plants

Steps 2 and 3: Construct Development and Hypothesis Generation

Using the results of the exploratory stage in combination with the literature on drivers of operating performance a tentative model was constructed showing how the drivers of operating performance and the various measures of operating performance might interact. This model is shown in Figure 13.2.

Figure 13.2: Drivers of Operating Performance



Unit Manufacturing Cost	Improved	Improved	Improved	Improved	Improved
Quality Consistency	Improved	Unchanged	Unchanged	Unchanged	Unchanged
Speed of Delivery	Improved	Improved	Improved	Improved	Improved
Delivery Reliability	Improved	Unchanged	Improved	Improved	Improved

The model was used to develop the following propositions with regard to trade-offs.

Proposition 10

Rankings of plants on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated relative to other plants in the same industrial category. In particular, plants which achieve a better than average performance level for their category on one of these factors will also achieve a better than average performance on the other factors.

Proposition 11

The extent of product variety within a plant will be negatively correlated with rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to other plants in the same industrial category. In other words, plants that manufacture a wide variety of products cannot expect to be competitive on the factors mentioned in comparison with plants manufacturing a narrower product range.

Step 4: Hypothesis Testing for Internal Validity

In order to test these propositions the Best Factory Award database of 953 plants was again used. The rankings for each plant on added value per employee £, quality consistency, speed of delivery and delivery reliability were taken and Spearman's rank correlation coefficient was determined for each pair of performance measures.

The analysis provided strong support for proposition 10. Added value per employee £, quality consistency, speed of delivery and delivery reliability were all positively correlated. Most of these variables were very highly correlated. The exception was the correlation between added value per employee £ and quality consistency. While this correlation was still significant, it was only significant at a significance level of 0.035.

There was also strong support for proposition 11. The size of the product range within each plant was negatively correlated with added value per employee £, quality consistency, quality consistency, speed of delivery and delivery reliability. Again, most of the correlations were extremely high. The exception was the correlation between the size of the product range and quality consistency, which had a significance level of 0.05

Step 5: Testing for external validity

The final stage in the research was to visit a small number of individual plants and establish whether the general conclusions reached on the basis of the statistical analyses carried out earlier were valid for these specific plants. The original intention was to select 8 plants, two from each of the following industrial sectors.

Engineering
Electrical
Process
Household Products

The two plants from each sector were to be drawn from plants whose overall operating performance placed them in the top and bottom quartiles of their sector. In the event it proved difficult to persuade low-performing plants in each sector to participate and so it was only possible to visit 6 of the 8 plants selected. Brief descriptions of the plants visited are listed in Table 13.1.

Table 13.1: Details of Plants Visited

Sector	Performance	Description of product
Engineering	High	Car accessories
Electronics	High	Telecommunications accessories
Electronics	Low	Fuses
Process	High	Chemicals
Process	Low	Carbide
Household	High	Cider

The objective of the plant visits was to compare 4 high performing plants with 4 low performing plants in order to determine whether differences between the two groups of plants were consistent with what had been predicted from the findings of the research using the database.

The objectives of the plant visits were therefore as follows

1. To check whether those expected differences between high performing and low performing plants suggested by the statistical analysis did exist in the plants visited.
2. To check whether there was a correlation between manufacturing cost, quality consistency, speed of delivery and reliability of delivery at each plant.
3. To check whether plants manufacturing a large product range had higher manufacturing costs, lower quality consistency, slower speed of delivery and lower reliability of delivery than plants manufacturing a small product range.

At each plant staff responsible for planning, purchasing and production were interviewed. The level of support for the research propositions identified in Steps 1 and 4 at the plants visited is summarised in the table below.

Table 13.2: Level of Support for the Research Propositions at the Plants Visited

Proposition	Agree	Neutral	Disagree
Greater process reliability	75%	4%	21%
Greater throughput efficiency	75%	12.5%	12.5%
Greater emphasis on continuous improvement	80%	15%	5%
Greater labour flexibility	87.5%	12.5%	0%
Lower labour costs as a % of manufacturing costs	83%	0%	17%
Higher levels of cleanliness	75%	25%	0%
More accurate documentation	75%	0%	25%

More frequent and reliable supplier deliveries	69%	12%	19%
Wider range of metrics measured	50%	43%	7%
Correlated performance on added value, quality consistency, speed of delivery and delivery reliability	73%		27%
Negative correlation between product variety and added value, quality consistency, speed of delivery and delivery reliability	59%		41%

Obviously, any results based on such a small sample of plants have to be treated with caution. However, there does seem to be some degree of support for propositions 1 to 8. In the case of proposition 9 there seems to be little difference in the range of metrics measured by high and low performance plants. There also appears to be some degree of support for proposition 10. Plants do, in the main achieve similar levels of performance on added value per employee £, quality consistency, customer lead time and delivery reliability. However, surprisingly, the degree of support for proposition 11 is very small indeed. There is little evidence to suggest that plants with a large product range perform less well on added value per employee £, quality consistency, customer lead time and delivery reliability than plants with a narrow product range. This is at variance with the results of the statistical analysis and merits further investigation.

However, when the production managers at the plants visited were asked for their opinions on trade-offs between operating performance measures their views were broadly in support of both Proposition 10 and Proposition 11.

13.3 Assessment of the Contribution Being Made

All manufacturing plants need to continuously improve their operating performance. At a minimum this enables them to avoid losing ground in comparison with their competitors who are also continuously improving. At best it provides plants with a competitive advantage by increasing their operating performance relative to their competitors.

The question for operations managers concerns the most appropriate strategy for achieving this competitive advantage. Management writers offer conflicting advice on this. The three main schools of thought are as follows.

13.3.1 The trade-off school

This group supports the view first expressed by Skinner (1974). This approach involves identifying the performance factors most important to customers and developing a strategy for providing significantly better performance on these factors than their competitors while accepting that performance on factors less important to their customers are likely to be below that of their competitors.

13.3.2 The world class manufacturing school

This group supports the views of Schonberger (1986). They argue that the set of skills and competences which leads to improvement in performance on one factor is the same set of skills and competences which leads to improvement in performance on all the other factors. Consequently, a plant's strategy should be to develop these underlying skills and competences. The plants that are most successful in achieving this will outperform their competitors on all performance factors.

13.3.3 The sand cone/competitive progression schools

The sand cone model was first presented by Ferdows and De Meyer (1990). The competitive progression model was developed by Roth. Both models imply that trade-offs can be avoided provided that plants improve performance factors in a particular sequence. Once a certain level of performance has been reached on a given factor then performance improvements in the next factor in the sequence can be achieved without adversely affecting the rate of improvement in performance for earlier factors in the sequence.

There are two problems with these three models. Firstly, they involve contradictory elements and so they cannot all be correct. Secondly, they are largely unsupported by empirical evidence. What evidence there is tends to be anecdotal or based on case studies selected to support the writer's views.

The research described in this report has contributed to the debate concerning the validity of these various models by examining the extent to which the models are consistent with empirical data derived from a large sample of manufacturing plants. As a consequence the findings of the research should provide much more positive guidance to managers on how best to tackle performance improvement within their plants

While the development of this model is still not complete, some tentative implications for managers can be drawn. Existing operations improvement programmes tend to focus on the elimination of waste in all its forms. This is still important, but equally important and complementary to the elimination of waste are the elimination of uncertainty and unreliability from the system. Much of the surplus stock, labour and capital equipment in the operating system is there as a consequence of uncertainty and unreliability. Causes of this include unreliable delivery by suppliers, variability in processing times and high defect rates. If attention is directed to the identification and elimination of uncertainty and unreliability from the system then it should be possible to simultaneously reduce manufacturing costs, customer returns and speed of delivery and increase delivery reliability.

The statistical analysis part of the research also confirms existing thinking on manufacturing focus. Plants with a narrow product range tend to perform better on most measures of operating performance than plants with a wide product range. However, this was less apparent at the plants visited as part of the research. New (1995) has suggested that, in future, focus will occur at the level of the manufacturing cell rather than at plant level. The implication of this for the current research is that when plants are organised in self-contained manufacturing cells, the negative correlation observed in this research between degree of product variety and good performance on added value per employee £, speed of delivery and delivery reliability will cease to exist. Provided that there is focus at cell level the degree of focus at plant level will have little effect on overall levels of operating performance. Several of the plants visited had adopted a cellular organisation. This might, in part, explain why product variety seemed to have little impact on the other performance measures at these plants. Further research is needed to establish whether adopting a cellular organisational structure does cause the trade-off between product variety and the other performance measures to disappear.

13.4 Limitations of the Research

There are a number of limitations to the research methodology used. Use of the Best Factory Awards questionnaire limited the database of plants to those volunteering to take part in the survey. Such plants are unlikely to be typical of plants in general. The database is likely to include a higher proportion of high performing plants and plants that are actively trying to improve than in the population of UK plants as a whole. Consequently, general conclusions about all manufacturing plants based on this research would be dangerous without further supporting evidence. The research was also based solely on UK plants and so, again, it would be dangerous to draw general conclusions about plants worldwide without further supporting evidence.

Another limitation results from the use of secondary data. Inevitably, the questions asked in order to help select the UK plant of the year are not necessarily the same questions that would have ideally been selected for this research. Also, the performance measures considered in the research had to be derived from the questions included in the Best Factory Awards questionnaire. One of the performance measures that was of interest in the research was unit manufacturing cost. It was extremely difficult to identify a method of measuring unit manufacturing cost in such a way that meaningful comparisons could be made between different manufacturing plants. Instead added value per employee £ was used as a surrogate measure. This had the merit of being easily derived from the information on the database but it is a measure of labour productivity rather than unit manufacturing cost. There is also still a question mark over whether this measure can be used to make comparisons between plants with very different manufacturing cost profiles.

The first research question addressed related to the characteristics that differentiate high performance plants and low performance plants. What are of primary interest here are the cause and effect relationships. In other words, which are the characteristics that lead to changes in performance? It is possible that, for some of the differentiating characteristics, the cause and effect relationship is in the opposite direction. The differentiating characteristics might be a result of the differences in performance rather than the cause of it.

The second research question considered the nature of trade-offs between different aspects of operating performance in manufacturing plants. A serious obstacle for all researchers into trade-off analysis is the difficulty in differentiating between variations in operating performance that are a result of differences in the quality of management within a plant and variations in operating performance that are a result of strategic choice. When a plant has been poorly managed it is possible for a new management team to take over the plant and, by introducing sound management practices, improve operating performance in almost every area. This is not evidence of the lack of trade-offs. It is a consequence of the various kinds of slack within the system. It is only when this slack has been eliminated that trade-offs come into play.

To take a specific example, a plant might be incurring high costs due to the excessive level of stocks being held. Some of this stock might be obsolete. Stocks of other items might be far in excess of foreseeable customer requirements, and so on. In such circumstances, large reductions in stock will be possible without there being any effect on lead times and delivery reliability. Eventually, a point will be reached at which further reductions in inventory can only be achieved at the expense of delivery reliability and other performance measures. At this point attention would need to be switched to identifying changes in the operating infrastructure that might permit a simultaneous reduction in stocks, delivery reliability and other performance measures.

Few would disagree that at any given point in time there is a multi-dimensional efficiency frontier beyond which it is not possible for a plant to operate. Supporters of the trade-off concept believe that this efficiency frontier is a surface, each point representing different combinations of the various performance measures. Depending on their chosen strategy, plants can choose whereabouts they wish to be on the efficiency frontier and hence what combination of performance measures they will provide to customers.

Those who believe that there are no trade-offs consider that, for a given plant, the efficiency frontier is a point, representing the plant's current performance on the various performance measures. Over time this point will move forward as the plant introduces those changes that permit progressive improvement in all of the performance measures.

A weakness of the research described in this thesis is that no attempt was made to differentiate between effective plants operating at or close to the efficiency frontier and ineffective plants, operating well behind the efficiency frontier.

13.5 Suggestions for Further Research

Several possibilities for further research suggest themselves.

1. Longitudinal studies could be carried out on a few plants, monitoring changes in operating performance over time. Preferably, these should be plants that had won or been short-listed for Best Factory Awards. There are some practical difficulties with longitudinal studies, as they might need to be extended over 10 or 20 years. However, such studies should provide clear evidence regarding which of the competing theories about trade-offs was more correct. If trade-offs do exist then there would be some periods when performance on some measures worsened while others simultaneously improved. If there were no trade-offs then all performance measures would progressively improve over time In particular, if the sand cone model were correct, these improvements would follow a specific chronological sequence.
2. The analysis described in this thesis could be repeated using only plants that are close to the efficiency frontier. Selecting these plants will be difficult. One approach would be to identify the key performance measures and select the top 10 per cent of plants for each performance measure separately. (If there are performance trade-offs then there will be relatively little overlap between the plants selected for each measure. If there are no trade-offs then there will be considerable overlap between the plants selected for each measure.) This should eliminate the ineffective plants that are not outstanding on any aspect of performance. Analysis of the plants remaining should more clearly reveal the presence or absence of trade-offs.

As mentioned earlier, the increasing use of manufacturing cells within plants could change the nature of some of the trade-offs identified in this research. By making each cell an autonomous unit, producing products that are very similar, much of the complexity and variability of conventional manufacturing is eliminated. This enables simultaneous improvements in quality conformance, lead time and delivery reliability as was found in this research. There is a cost associated with this as autonomous cells require duplication of items of plant and inevitably involve lower levels of plant utilisation. We would therefore expect a negative correlation between unit cost and these other performance measures for plants using cellular manufacturing techniques. Also, cellular manufacture permits the production of a wide variety of different products within the same plant without incurring the complexity penalties that would apply in a conventional plant. A consequence of this should be that, as a plant progressively moves from a predominantly traditional organisational structure to a predominantly cellular structure the correlation between product range and the other measures of operating performance should change from negative to close to zero. Comparisons need to be made between plants organised on traditional lines and plants using a cellular structure in order to determine whether there is a difference in the nature of the trade-offs within the two types of plants.

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Appendix 1

Acronyms Used in the Thesis

BFA	Best Factory Award
CI	Continuous Improvement
CIM	Computer Integrated Manufacturing
COMP	Composite Performance Index
EDI	Electronic Data Interchange
FMS	Flexible Manufacturing System
IT	Information Technology
JIT	Just-in-Time
LT	Lead Time
MRP	Material Requirements Planning
MRPII	Manufacturing Resource Planning
MS	Management Science
NCB	National Coal Board
NVQ	National Vocational Qualifications
OM	Operations Management
OPT	Optimised Production Technology
OR	Operational Research
P/OM	Production/Operations Management
PC	Personal Computer
PCB	Printed Circuit Board
PIMS	Profit Impact of Marketing Strategy
SPC	Statistical Process Control
TQC	Total Quality Control
TQC	Total Quality Control
TQM	Total Quality Management
WCM	World Class Manufacturing

Appendix 2

Variables Used in the Statistical Analysis

a1	Who is the plant owned by? (Possible responses, 1-7), 95-96
a1x	Who is the plant owned by? (Possible responses, 1-7), 93-94
a2	How many plants does the parent company control worldwide? (Possible responses, 1-8), 93-95
a2x	How many plants does the parent company control worldwide? (Possible responses, 1-8), 96
a3	Does your total number of company employees exceed 500? (1 = yes, 2 = no)
a4	What is the total area of the plant buildings?
a4a	Number of full time equivalent employees in plant (5 categories) 93-94
av	Manufacturing added value per employee £
b10a1	How many suppliers do you currently have for manufacturing purposes?
b10a2	How many suppliers did you have for manufacturing purposes last year?
b10a3	How many suppliers did you have for manufacturing purposes three years ago?
b10b1	What percentage of your suppliers currently deliver to you daily?
b10b2	What percentage of your suppliers currently deliver to you twice weekly?
b10b3	What percentage of your suppliers currently deliver to you weekly?
b10b4	What percentage of your suppliers currently deliver to you monthly?
b10b5	What percentage of your suppliers currently deliver to you less frequently than monthly?
b10c1	Do you formally measure the delivery performance of your suppliers? (1 = yes, 2 = no)
b10c2	If yes, what is the current overall delivery performance? (% on time)
b21	What percentage of the plant's output (at manufacturing cost) is capital goods?
b22	What percentage of the plant's output (at manufacturing cost) is intermediate goods?
b23	What percentage of the plant's output (at manufacturing cost) is consumer goods?
b3a1	How many different item records are currently live (in use) within the plant at product level? (as sold to customers)
b3a2	How many different item records are currently live (in use) within the plant at manufactured component, bulk intermediate or sub-assembly level?
b3a3	How many different item records are currently live (in use) within the plant at bought out component or sub-assembly level?
b3a4	Total items currently live within the plant at purchased raw material, bought out component or sub-assembly level?
b3b	How many different manufactured components, purchased items or purchased assemblies are there in the product which has the largest

output (at manufacturing cost) in the pant?

b3c1 Over the last year, how many products were in continuous production in the plant? (runners)

b3c2 Over the last year, how many different product types (of known design) were produced intermittently in the plant? (repeaters)

b3c3 Over the last year, how many different product types (of initially unknown design) were produced in the plant?

b4a What is the planned procurement lead time in days for the main bought out item/material?

b4b11 What is the planned component (or intermediate/bulk product) manufacturing lead time for the shortest manufacturing lead time item?

b4b12 What is the planned component (or intermediate/bulk product) manufacturing lead time for the average manufacturing lead time item?

b4b13 What is the planned component (or intermediate/bulk product) manufacturing lead time for the longest significant manufacturing lead time item?

b4b2 What is the processing time in hours for the average lead time item?

b4b3 How many hours per week does the component or bulk manufacture part of the plant usually work?

b4c1 What is the planned assembly (or final packing) lead time in days for the average assembly lead time item?

b4c2 What is the planned assembly (or final packing) lead time in days for the longest significant assembly lead time item?

b51 What is the shortest customer lead time quoted in days?

b52 What is the average customer lead time quoted in days?

b53 What is the longest customer lead time quoted in days?

b7b1 What percentage of quoted lead times are for a specific week ending date?

b7b2 What percentage of quoted lead times are for a specific day date?

b7b3 What percentage of quoted lead times are for a specific time of day (delivery slot)?

b7b4 What percentage of quoted lead times are for some other date?

b7c1 To what extent is good delivery performance in your plant determined by excess capacity? (1 = most important, 7 = least important)

b7c2 To what extent is good delivery performance in your plant determined by a reliable supply chain? (1 = most important, 7 = least important)

b7c3 To what extent is good delivery performance in your plant determined by workforce flexibility? (1 = most important, 7 = least important)

b7c4 To what extent is good delivery performance in your plant determined by reliable processes? (1 = most important, 7 = least important)

b7c5 To what extent is good delivery performance in your plant determined by quick changeovers? (1 = most important, 7 = least important)

b7c6 To what extent is good delivery performance in your plant determined by a responsive planning and control system? (1 = most important, 7 = least important)

b7c7 To what extent is good delivery performance in your plant determined by other factors? (1 = most important, 7 = least important)

b81 What is the shortest changeover in minutes for component/intermediate manufacture?

b82 What is the average changeover in minutes for component/intermediate manufacture?

b83 What is the longest changeover in minutes for component/intermediate manufacture?

b84 What is the shortest changeover in minutes for assembly/packing?

b85 What is the average changeover in minutes for assembly/packing?

b86 What is the longest changeover in minutes for assembly/packing?

b9a1 How many of your customers are third parties?

b9a2 How many of your customers are distribution points in your own company?

b9a3 How many of your customers are other plants within your own company?

B9b1 Percentage of turnover by value of third party customers

B9b2 Percentage of turnover by value of own company distribution points

B9b3 Percentage of turnover by value of other plants within own company

c11 Annual value of plant output (at manufacturing cost) for previous budget year (£000s)

c12 Annual value of plant output (at manufacturing cost) for current budget year (£000s)

c13 Annual value of plant output (at manufacturing cost) for next budget year (£000s)

c21 Percentage of manufacturing cost that is bought out raw materials

c22 Percentage of manufacturing cost that is purchased components, assemblies and packaging

c23 Percentage of manufacturing cost that is energy costs

c24 Percentage of manufacturing cost that is bought out services (rent, rates, equipment hire, etc.)

c25 Percentage of manufacturing cost that is direct labour

c26 Percentage of manufacturing cost that is indirect factory labour

c27 Percentage of manufacturing cost that is all other labour (including staff and managerial)

c28 Percentage of manufacturing cost that is depreciation charges

c29 Percentage of manufacturing cost that is other items

c211 Other costs associated with output

c212 Sales value of production output

c213 Sales value of production output

c3 How has unit cost for the product with the largest output (at manufacturing cost) changed over the last two years? (1 = down more than 20%, 9 = up more than 20%)

c4 Amount owing to suppliers at end of last budget year

d11 Average value in £s of raw material stock over the year

d12 weeks of usage of raw material stock

d13 Average value in £s of bought out components and assemblies over the year

d14	weeks of usage of bought out component and assembly stock
d15	Average value in £s of work in process stock over the year
d16	weeks of usage of work in process stock
d17	Average value in £s of finished goods stock over the year
d18	weeks of usage of finished goods stock
d1b	Percentage deviation + or - in stocks over the year
d2	How has the inventory profile changed over the last two years? (1 = more than 50% decrease, 9 = more tan 50% increase)
e11	Number of plant management and supervisory full time equivalent employees
e110	Total employees
e12	Number of technical support full time equivalent employees
e13	Number of materials management full time equivalent employees
e14	Number of quality management full time equivalent employees
e15	Number of other indirect support full time equivalent employees
e16	Number of direct value adding full time equivalent production employees
e17	Total number of full time equivalent production employees
e18	Number of design full time equivalent employees
e19	Number of other full time equivalent employees
e2	Percentage of direct value adding production employees who are temporary or on contract
e3a1	Percentage of production related employees aged under 30
e3a2	Percentage of production related employees aged 30-40
e3a3	Percentage of production related employees aged 41-50
e3a4	Percentage of production related employees aged over 50
e3b	Average length of service in years
e3c	Percentage rate of absenteeism
e3d	Percentage annual labour turnover rate
e3e	Change in total employee numbers over the last two years (1 = more than 20% decrease, 5 = more than 20% increase)
e41	Average number of days on job training received per annum by each new starter
e42	Average number of days off job training received per annum by each new starter
e43	Average number of days on job training received per annum by each existing employee
e44	Average number of days off job training received per annum by each existing employee
e5	Percentage of production employees who can carry out more than 50% of tasks in their area
e51	Does your plant have TQM? (1 = yes, 2 = no)
e52	Number of years since TQM was introduced
e6a1	Do you run an employee suggestion scheme? (1 = yes, 2 = no)
e6a2	Number of suggestions per employee last year
e6a3	What type of reward was offered as part of the scheme? (Responses, 1-4)

e6b1	Are production employees involved in formal problem solving groups? (1 = yes, 2 = no)
e6b2	What percentage of production employees is involved in the groups?
e6b3	Are groups temporary or permanent? (Responses, 1-3)
e6b4	How frequently do the groups meet? (Responses, 1-4)
e6b5	Who leads the group? (Responses, 1-4)
f1	How many months does it take to bring a typical product innovation to market?
f2a	How many significantly new products have been introduced in the last 5 years?
f2b	How many significantly new products do you expect to introduce in the next 5 years?
g11	Is output volume measured on a regular basis? (1 = yes, 2 = no)
g12	Units of measurement for output volume
g21	Is production schedule adherence measured on a regular basis? (1 = yes, 2 = no)
g22	% schedule adherence last year
g23	% schedule adherence in current year
g3a1	Is ex-stock availability measured on a regular basis? (1 = yes, 2 = n0, 3 = not applicable)
g3a2	% service level ex-finished stock last year
g3a3	% service level ex-finished stock in current year
g3b1	Is due date reliability for items on quoted lead times measured on a regular basis? (1 = yes, 2 = no, 3 = not applicable)
g3b2	% delivery on time last year
g3b3	% delivery on time in current year
g41	Is inventory record accuracy measured on a regular basis? (1 = yes, 2 = no)
g42	% of inventory records correct
g51	Is scrap or yield loss rate measured on a regular basis? (1 = yes, 2 = no)
g52	% scrap or % below ideal yield rate last year
g53	% scrap or % below ideal yield rate in current year
g61	Is time spent on rework/reprocessing measured on a regular basis? (1 = yes, 2 = no)
g62	% of capacity used for reprocessing
g71	Is time spent on setting/changeover measured on a regular basis? (1 = yes, 2 = no)
g72	% of capacity used for changeover
g81	Are customer returns or complaints measured on a regular basis? (1 = yes, 2 = no)
g82	% returns last year
g83	% returns in current year
g91	Is first time pass rate measured on a regular basis? (1 = yes, 2 = no)
g92	% first time pass rate
h11	Relative importance to customer of quoted delivery lead time (1 = most important, 7 = least important), 95-96

h12 Relative importance to customer of delivery reliability or service level (1 = most important, 7 = least important), 95-96
h13 Relative importance to customer of product features or performance (1 = most important, 7 = least important), 95-96
h14 Relative importance to customer of technical support (1 = most important, 7 = least important), 95-96
h15 Relative importance to customer of after sales service (1 = most important, 7 = least important), 95-96
h16 Relative importance to customer of brand image/reputation (1 = most important, 7 = least important), 95-96
h17 Relative importance to customer of price (1 = most important, 7 = least important), 95-96
h11x Relative importance to customer of quoted delivery lead time (1 = most important, 7 = least important), 93-94
h12x Relative importance to customer of delivery reliability or service level (1 = most important, 7 = least important), 93-94
h13x Relative importance to customer of product features or performance (1 = most important, 7 = least important), 93-94
h14x Relative importance to customer of product customisation (1 = most important, 7 = least important), 93-94
h15x Relative importance to customer of price (1 = most important, 7 = least important), 93-94
h21 Relative importance to auditable plans of rapid product design change (1 = most important, 7 = least important)
h22 Relative importance to auditable plans of consistent quality (1 = most important, 7 = least important)
h23 Relative importance to auditable plans of short delivery lead times (1 = most important, 7 = least important)
h24 Relative importance to auditable plans of dependable delivery dates (1 = most important, 7 = least important)
h25 Relative importance to auditable plans of after sales support (1 = most important, 7 = least important)
h26 Relative importance to auditable plans of improved product performance (1 = most important, 7 = least important)
h27 Relative importance to auditable plans of manufacturing cost reduction (1 = most important, 7 = least important)
h31 Over the next 6 months what is the degree of unpredictability of customer demand levels? (1 = highly predictable, 5 = highly unpredictable)
h32 Over the next 6 months what is the degree of unpredictability of competitor activity? (1 = highly predictable, 5 = highly unpredictable)
h33 Over the next 6 months what is the degree of unpredictability of raw material prices? (1 = highly predictable, 5 = highly unpredictable)
h34 Over the next 6 months what is the degree of unpredictability of raw material or component availability? (1 = highly predictable, 5 = highly unpredictable)

h35	Over the next 6 months what is the degree of unpredictability of the legislative environment? (1 = highly predictable, 5 = highly unpredictable)
h41	Rank your plant on cleanliness (10 = perfect, 1 = poor)
h410	Rank your plant on change as a way of life (10 = perfect, 1 = poor)
h42	Rank your plant on process dependability (10 = perfect, 1 = poor)
h43	Rank your plant on accuracy of process documentation (10 = perfect, 1 = poor)
h44	Rank your plant on importance of process engineering and continuous improvement (10 = perfect, 1 = poor)
h45	Rank your plant on throughput efficiency (10 = perfect, 1 = poor)
h46	Rank your plant on labour flexibility (10 = perfect, 1 = poor)
h47	Rank your plant on commitment of employees to continuous improvement (10 = perfect, 1 = poor)
h48	Rank your plant on emphasis on training and competence (10 = perfect, 1 = poor)
h49	Rank your plant on use of labour as a source of brainpower (10 = perfect, 1 = poor)
h7a	Do you differentiate between the rate of return required for operational investment and strategic investment? (1 = yes, 2 = no)
h7b1	Required internal rate of return for operational investment
h7b2	Required internal rate of return for strategic investment
h7b3	Required payback for operational investment
h7b4	Required payback for strategic investment
pav	Percentage ranking on added value per employee £
pvdel	Percentage ranking on delivery reliability
pvlt	Percentage ranking on lead time
pvprod	Percentage ranking on product variety
pvret	Percentage ranking on % of customer returns on quality grounds
pvscr	Percentage ranking on scrap or yield loss rate
pvst	Percentage ranking on ex-stock availability
pmlt	Percentage ranking on manufacturing lead time
palt	Percentage ranking on assembly lead time
pcco	Percentage ranking on changeover time in component/intermediate manufacture
paco	Percentage ranking on changeover time in assembly/packaging
psch	Percentage ranking on production schedule adherence
pacc	Percentage ranking on inventory record accuracy
pfirst	Percentage ranking on first time pass rate
psdel	Percentage ranking on suppler delivery reliability
prms	Percentage ranking on raw material stocks
pcs	Percentage ranking on component stocks
pwip	Percentage ranking on work in process stocks
pfgs	Percentage ranking on finished goods stocks
prep	Percentage ranking on time spent on rework/reprocessing

Appendix 3

Re-analysis of Data Excluding Outliers

The data was re-analysed and the correlation coefficients recalculated excluding all cases that were more than 4 standard deviations from the mean for the relevant variables. The rules for exclusion are summarised in Table 1 below.

Table 1: Rules for Exclusion of Cases

Variable 1	Variable 2	Rules for Exclusion	
Added Value per Employee £	Quality Consistency	AV>4.9	G83>14.0
Added Value per Employee £	Lead Time	AV>4.9	B52>311
Added Value per Employee £	Delivery Reliability	AV>4.9	G3B3<26.6
Added Value per Employee £	Product Variety	AV>4.9	B3A1>124484
Quality Consistency	Lead Time	G83>14.0	B52>311
Quality Consistency	Delivery Reliability	G83>14.0	G3B3<26.6
Quality Consistency	Product Variety	G83>14.0	B3A1>124484
Lead Time	Delivery Reliability	B52>311	G3B3<26.6
Lead Time	Product Variety	B52>311	B3A1>124484
Delivery Reliability	Product Variety	G3B3<26.6	B3A1>124484

Each pair of variables was treated separately. After cases had been excluded according to the above rules the rankings for the two variables being considered were recalculated and the new correlation coefficient calculated. The resulting correlations are shown in Table 2.

Table 2: Correlation coefficients between performance measures

	Quality Consistency	Lead time	Delivery Reliability	Product variety
Added Value per Employee £	0.0826*	0.1773***	0.1305**	-0.1646***
Significance	0.033	.000	0.002	0.000
Quality Consistency		0.1800***	.2195***	-0.0832*
Significance		0.000	.000	.021
Lead time			0.357***	-.1070***
Significance			.000	.001
Delivery Reliability				-0.1238***
Significance				.001

*** = Significance level of 0.001
** = Significance level of 0.01
• = Significance level of 0.05

These results are close to the results for the analysis of the complete set of data. There have been changes in the correlation coefficients, some increasing and some decreasing but the changes are small. There has been little change in the levels of significance and all correlations are still significant. We can therefore feel confident that the suspect entries are having little effect on the analysis.

Appendix 4

Comparison of Variable Means for High, Medium and Low Performing Plants

Table 1: Means and Standard Deviations for High, Medium and Low Performance Plants Based on Value of COMP

	High Performance Plants			Medium Performance Plants			Low Performance Plants		
Variable	Mean	SD	Cases	Mean	SD	Cases	Mean	SD	Cases
a1	3.0704	2.0862	71	2.5342	1.8565	73	2.2063	1.833	63
a1x	2.1714	1.4937	70	2.0147	1.5307	68	1.9367	1.5717	79
a2	3.9073	1.5604	109	4.1321	1.3386	106	4.0431	1.4043	116
a2x	6.9063	2.0218	32	6.4	2.546	35	6.0385	2.8211	26
a3	1.16	0.3678	150	1.1457	0.354	151	1.1533	0.3615	150
a4	271574	575456	149	275135	452904	149	181535	248395	150
a4a	1.8028	1.1541	71	1.7059	0.8297	68	1.7722	1.0616	79
av	1.9681	1.1708	151	1.5808	0.3546	152	1.4608	0.4413	151
avr	0.702	0.4589	151	0.4408	0.4981	152	0.2649	0.4427	151
b10a1	116.40	208.90	112	183.39	219.83	102	239.45	497.89	100
b10a2	134.34	224.67	113	293.56	614.54	101	335.84	786.60	96
b10a3	170.82	264.60	109	540.83	2143.8	99	488.15	1215.7	86
b10b1	7.636	15.609	14	7.1515	16.677	103	4.1222	12.335	99
b10b2	41.174	39.290	103	25.780	31.069	89	27.993	35.119	82
b10b3	32.784	27.648	71	36.769	25.022	72	25.553	24.313	62
b10b4	30.362	28.399	71	29.703	22.069	72	35.694	24.568	62
b10b5	10.075	16.67	68	12.239	15.247	71	23.436	23.695	61
b10c1	1.2714	0.4479	70	1.2639	0.4438	72	1.3667	0.486	60
b10c2	90.912	7.9208	51	87.164	11.400	53	80.987	14.411	38
b21	19.543	37.383	151	14.666	32.833	151	13.933	32.125	149
b22	47.833	46.959	151	56.871	44.027	151	58.7	45.960	150
b23	32.624	43.984	151	28.934	40.131	152	27.644	42.435	149
b3a1	47236	534441	148	10549	73618	149	1880	4646	148
b3a2	1576.7	3785.5	144	2341.8	5243.8	45	2788.3	7915.5	145
b3a3	1868.6	3433.3	110	2728.7	4749.0	97	6013.4	21228	96
b3b	203.78	523.50	113	506.99	2202.4	101	2647.2	20353	99
b3c2	631.12	2491.5	148	1010.5	2764.8	150	764.36	2270.2	148
b3c3	200.59	1098.6	147	474.98	2024.5	147	560.86	3779.8	149
b4a	43.893	49.517	149	45.526	50.697	152	71.347	88.357	150
b4a4	1810.66	14276.1	111	1139.9	4597.1	100	5047.11	33737.5	97
b4b11	2.7551	7.149	134	3.543	5.742	131	7.781	15.877	133
b4b12	6.5662	10.946	134	9.8822	10.876	133	17.854	22.634	134
b4b13	17.109	36.52	134	23.772	31.557	131	37.292	41.078	133
b4b2	19.295	49.674	138	19.379	32.150	137	59.250	202.18	137

b4b3	89.062	49.586	140	100.70	105.47	140	105.02	253.12	137
b4c1	2.816	4.575	125	4.4408	10.094	126	9.2196	13.994	114
b4c2	6.2552	15.279	125	9.5802	19.603	124	19.753	26.856	115
b51	5.7072	27.099	148	8.3566	21.896	152	22.941	48.183	150
b52	15.902	38.690	151	27.763	47.97	152	64.457	96.756	151
b53	46.803	73.087	147	68.344	94.023	151	135.09	166.29	151
b7b1	27.844	38.424	112	36.767	41.331	103	43.05	42.342	100
b7b2	47.25	39.848	112	51.204	41.299	103	45.89	42.288	100
b7b3	21.880	34.422	112	9.2816	23.664	103	6.27	19.969	100
b7b4	3.1161	14.702	112	2.7476	15.397	103	5.3861	20.344	101
b7c1	5.6667	1.397	111	5.0962	1.6694	104	5.0792	1.7475	101
b7c2	2.7838	1.569	111	2.9231	1.7219	104	2.8713	1.6166	101
b7c3	3.2054	1.3764	112	3.4904	1.4548	104	3.3366	1.2983	101
b7c4	2.973	1.2895	111	2.8654	1.5141	104	2.9802	1.6308	101
b7c5	4.5676	1.3116	111	4.9904	1.4714	104	4.6931	1.528	101
b7c6	2.5	1.6219	112	2.7019	1.5509	104	2.9109	1.6858	101
b7c7	5.303	2.2734	66	4.5938	2.635	64	5.5645	2.1851	62
b81	39.204	249.59	133	35.835	131.25	142	96.079	616.71	139
b82	91.076	383.86	134	111.03	232.32	140	340.89	2562.8	139
b83	313.20	746.49	132	452.94	854.40	142	880.02	4403.0	139
b84	9.3938	18.882	117	14.178	33.530	119	22.910	57.425	106
b85	29.231	63.498	119	37.780	74.479	118	68.140	136.30	107
b86	110.58	221.98	118	142.89	402.07	119	293.16	1020.1	106
b9a1	862.61	4230.1	149	1046.2	3166.2	151	373.35	847.15	146
b9a2	9.3289	33.169	149	6.1361	18.087	147	7.2365	19.254	148
b9a3	2.7933	4.8719	150	3.5342	8.4251	146	3.0134	4.9986	149
b9b1	69.480	35.605	115	65.836	39.306	104	63.476	37.732	99
b9b2	20.761	32.258	113	24.25	35.916	100	23.805	33.913	98
b9b3	9.2259	20.643	114	10.460	23.260	103	12.223	22.295	97
c11	55161	181790	117	27319	51625	116	73596	510822	125
c12	58241	17757	140	24490	300174	136	63132	449800	140
c13	65429	207139	123	28017	344295	121	30121	60849	121
c21	34.222	178	151	31.535	23.368	152	31.420	20.849	151
c22	26.206	27.502	151	23.483	23.892	152	20.006	20.470	151
c23	2.5402	2.5881	149	2.8012	2.5615	152	2.7936	2.4704	151
c24	4.0087	4.5614	151	4.1256	4.2234	152	5.4429	5.206	151
c25	10.732	6.7693	151	14.492	7.5115	152	15.826	8.1556	151
c26	3.2447	3.1208	151	4.8714	3.7843	152	6.0469	4.9988	151
c27	5.7333	5.0347	151	6.8958	5.1934	152	9.2227	8.5987	151
c28	5.0706	3.8809	150	5.2157	4.0609	152	4.7977	4.1184	151
c29	7.5967	8.1363	151	6.6868	6.6773	148	5.2841	5.3976	147
c211	8222.3	15041	21	7198.2	15528	27	1952.1	2246.3	18
c212	9318.3	11420	26	3,414	3534.4	27	2154.2	2586.8	22
c213	73022	75656	28	58339	172913	31	20971	17374	26

c3	3.94	1.9772	150	4.2252	2.1077	151	4.1467	2.1249	150
c4	4703.5	17822	136	7809.7	62219	132	8814.5	83080	136
cmb3	83.715	42.735	151	53.678	49.366	152	20.510	38.211	151
cmb4	76.426	45.740	148	48.86	50.271	150	30.767	44.412	150
comb	808240	444430	148	570941	496560	144	211556	386320	143
d11	2579.8	13628	146	804.57	1808.8	143	1934.6	9465.5	144
d12	4.0825	6.104	141	5.9338	7.0663	136	9.0181	12.338	135
d13	1682.5	5767.2	134	1058.5	1862.8	124	1097.4	2565.8	127
d14	5.7435	9.6814	126	6.3039	7.685	122	7.9483	8.2678	116
d15	2274.3	10060	143	1315.0	2940.9	144	3654.9	14475	145
d16	3.746	8.8422	136	3.6414	5.7021	137	6.1159	8.2556	135
d17	3260.0	15600	147	974.66	1458.4	143	1331.9	3636.4	138
d18	5.1823	10.395	141	3.2445	4.0632	137	4.6748	6.22	128
d1b	11.523	18.844	107	9.7091	12.327	99	8.1359	11.112	103
d2	4.0596	1.9157	151	4.3067	2.2102	150	4.245	2.1165	151
delr	0.8146	0.3899	151	0.4474	0.4989	152	0.245	0.4315	151
e11	20.097	29.443	150	21.066	26.149	152	23.718	49.181	150
e110	447.21	998.10	150	373.73	469.59	152	365.23	522.21	150
e12	28.827	51.55	150	28.38	61.896	150	29.810	72.595	146
e13	33.649	57.815	151	24.313	27.994	151	29.436	48.667	150
e14	10.174	16.500	149	11.08	17.444	150	15.352	31.320	149
e15	26.934	69.466	144	22.354	53.319	150	25.687	48.494	146
e16	194.38	330.30	151	199.98	266.39	151	177.74	223.21	148
e17	313.37	490.16	150	307.52	401.41	152	298.60	406.75	150
e18	24.077	59.879	149	24.698	48.993	151	21.432	73.506	147
e19	49.732	116.30	151	41.941	73.942	151	45.679	84.140	150
e2	10.132	23.778	112	6.8108	12.632	102	5.4394	10.022	98
e3a1	31.135	19.098	141	24.702	11.814	137	25.665	14.916	140
e3a2	29.257	9.5892	140	29.502	8.1895	137	29.998	10.299	140
e3a3	23.107	10.509	140	26.876	9.017	137	25.851	8.5576	140
e3a4	15.596	10.222	140	18.318	9.6689	137	18.627	9.9919	140
e3b	9.1206	5.0112	142	0.5229	4.7304	138	10.877	4.9914	137
e3c	3.5794	1.8455	139	3.7862	1.9051	142	3.4037	1.7909	138
e3d	6.2353	7.5664	141	5.9968	7.4652	136	5.8603	7.4532	137
e3e	2.9504	1.2891	141	2.7183	1.2625	142	2.8143	1.3335	140
e41	16.827	21.956	107	28.989	64.507	93	18.334	33.880	97
e42	5.1037	10.773	109	9.6592	30.504	98	4.2184	6.9299	98
e43	5.3514	4.9426	108	7.6936	12.568	97	6.8867	11.631	93
e44	3.4757	3.6088	110	3.4781	3.0505	97	2.697	2.9878	100
e5	80.859	17.443	32	78.083	22.089	36	67.16	26.992	25
e51	1.2243	0.4191	107	1.2857	0.4539	105	1.3739	0.486	115
e52	4.057	3.0674	79	3.4733	2.7125	75	3.0329	3.4168	73
e6a1	1.4732	0.5192	112	1.4571	0.5005	105	1.62	0.4878	100
e6a2	1.8195	1.9261	53	14.324	47.795	46	1.611	2.1591	33

e6a3	2.4375	0.9574	64	2.1833	0.9828	60	2.4146	0.9741	41
e6b1	1.1316	0.3395	114	1.0769	0.2678	104	1.18	0.3861	100
e6b2	53.052	33.592	96	48.433	36.153	93	35.819	28.285	80
e6b3	2.3737	0.8279	99	2.3299	0.8747	97	2.122	0.9348	82
e6b4	3.2828	0.6707	99	3.2887	0.6916	97	3.4458	0.6853	83
e6b5	1.9091	1.0507	99	1.701	0.9483	97	1.8072	1.0413	83
f1	13.662	14.106	151	15.047	15.118	146	17.236	18.369	144
f2a	54.629	119.87	151	74.533	330.60	152	22.550	147.38	151
f2b	71.128	196.43	148	81.227	363.01	150	21.265	88.886	147
g11	1.0072	0.0851	138	1.0496	0.218	141	1.0071	0.0845	140
g12	21.794	26.952	97	20.021	24.211	94	17.441	26.013	111
g21	1.1538	0.3625	104	1.2525	0.4367	99	1.3232	0.4701	99
g22	88.218	15.813	82	80.506	18.977	67	78.057	15.438	53
g23	93.31	12.100	90	86.726	15.624	76	84.754	13.688	63
g3a1	1.8108	0.9573	148	2.0884	0.9358	147	2.1565	0.9043	147
g3a2	86.795	19.535	76	84.091	20.401	56	85.892	18.091	39
g3a3	92.097	18.317	82	89.580	19.519	62	88.169	18.659	50
g3b1	1.0548	0.6621	146	1	0	147	1.0067	0.0819	149
g3b2	89.954	15.091	137	81.311	17.836	129	72.916	21.706	124
g3b3	96.000	6.055	151	89.034	14.081	152	81.864	17.950	151
g41	1.0743	0.2632	148	1.1611	0.3688	149	1.302	0.7685	149
g42	94.941	10.145	135	94.462	8.7711	126	92.438	13.714	114
g51	1	0	148	1.0208	0.1433	144	1.0201	0.1409	149
g52	2.445	3.2163	143	6.11	8.7279	139	11.421	16.634	136
g53	1.6615	2.2561	151	4.4504	7.9791	152	9.2334	14.008	151
g61	1.3904	0.4895	146	1.4765	0.5011	149	1.4667	0.6203	150
g62	2.4665	3.1665	101	2.477	3.2642	86	5.4098	9.5447	94
g71	1.4056	0.4927	143	1.4797	0.5013	148	1.5101	0.7317	149
g72	6.1566	10.214	94	8.5118	7.5636	82	11.081	9.1611	82
g81	1.0132	0.1178	144	1.0621	0.2421	145	1.0884	0.2849	147
g82	2.5492	17.385	133	1.9677	3.1297	124	2.7857	6.8576	110
g83	0.6334	1.1451	143	1.3013	1.9222	136	1.9714	6.0583	124
g91	1.2091	0.4085	110	1.4118	0.4946	102	1.45	0.5	100
g92	94.985	11.499	88	93.426	13.327	63	92.527	7.8086	55
h11	4.3857	1.7709	70	4.3784	1.6444	74	4.1587	1.7617	63
h12	2.4714	1.3907	70	2.6486	1.4376	74	2.7302	1.6383	63
h13	3.0714	1.9658	70	2.7671	1.7521	73	2.8413	1.7432	63
h14	4.7429	1.6033	70	4.7361	1.3737	72	4.8065	1.3286	62
h15	5.4429	1.451	70	5.4583	1.5739	72	5.7258	1.3928	62
h16	4.6714	2.1313	70	4.75	2.2059	72	4.8689	2.0855	61
h17	2.8857	1.6466	70	2.8108	1.7255	74	2.5714	1.4996	63
h11x	3.2394	1.3359	71	3.3088	0.9659	68	3.1646	1.1484	79
h12x	2.1831	1.0995	71	2.0294	0.9769	68	2.2278	1.143	79
h13x	2.7746	1.4061	71	2.8209	1.5756	67	3.0256	1.4592	78

h14x	3.9286	1.4578	70	4.2388	1.2072	67	4.3377	1.1426	77
h15x	2.3239	1.2395	71	2.2794	1.1951	68	2.2785	1.1316	79
h21	4.6479	1.8725	142	4.7246	1.8552	138	4.7643	1.9253	140
h22	2.5704	1.652	142	2.3929	1.4379	140	2.6901	1.5942	142
h23	4.333	1.9186	141	3.9496	1.7417	139	4.5352	1.9228	142
h24	3.7042	1.7495	142	3.3669	1.8104	139	3.4085	1.7183	142
h25	4.5704	2.0745	142	5.0362	1.9832	138	4.8643	1.9718	140
h26	4.3163	1.8197	98	4.7103	1.9858	107	4.6117	1.8054	103
h27	3.1531	1.8576	98	2.8716	1.6728	109	2.6154	1.6797	104
h31	3.1739	1.1567	115	3.2286	0.9432	105	3.7327	4.1711	101
h32	3	0.9551	115	3.0097	0.8911	103	2.9406	0.8924	101
h33	2.4386	1.0646	114	2.8558	1.161	104	2.68	1.1796	100
h34	2.1652	0.9994	115	2.3077	0.9762	104	2.5545	0.9537	101
h35	2.087	0.9231	115	2.0571	0.9388	105	2.1683	0.9281	101
h41	7.7682	1.246	151	7.3882	1.3225	152	6.9205	1.6351	151
h410	7.8212	1.4926	151	7.3618	1.7588	152	6.6159	1.9144	151
h42	8.1325	1.335	151	7.6382	1.4718	152	6.947	1.708	151
h43	8.4172	1.4893	151	7.9474	1.5938	152	7.5099	1.8542	151
h44	7.9801	1.5032	151	7.6053	1.5828	152	6.8675	1.8209	151
h45	7.9205	1.3091	151	7.4474	1.4908	152	6.7682	1.7605	151
h46	7.9868	1.4514	151	7.5132	1.5526	152	6.8344	1.8918	151
h47	7.2252	1.7095	151	6.7829	1.6232	152	6.1656	1.8599	151
h48	7.2914	1.7873	151	6.9737	1.7938	152	6.3377	1.9214	151
h49	7.2848	1.7025	151	6.9145	1.6675	152	6.3377	1.8363	151
h5a	2.649	1.1558	151	2.5921	1.1472	152	2.3974	1.12	151
h7a	1.2946	0.4579	112	1.3619	0.4829	105	1.4257	0.4969	101
h7b1	24.118	12.196	44	19.417	7.9341	42	23.553	15.606	38
h7b2	18.757	6.7269	42	19.892	8.4048	37	19.036	4.8875	28
h7b3	25.443	10.719	79	26.246	17.385	65	27.091	12.534	77
h7b4	43.588	19.957	68	35	12.493	59	41.5	23.127	64
ltr	0.7351	0.4427	151	0.5197	0.5013	152	0.1788	0.3845	151
pav	35.803	25.272	151	53.146	25.368	152	67.158	24.804	151
prodr	0.4797	0.5013	148	0.5933	0.4929	150	0.5667	0.4972	150
pvdel	32.053	24.083	151	54.314	25.124	152	67.682	25.387	151
pvlt	34.087	23.969	151	49.767	25.629	152	73.064	22.181	151
pvprod	50.277	28.096	148	42.021	27.472	149	46.904	29.441	148
pvret	39.951	25.709	143	54.584	28.202	136	59.242	28.505	124
pvscr	33.792	24.728	151	52.287	25.631	152	72.062	22.884	151
pvst	47.313	27.463	82	54.107	27.115	62	61.973	26.266	50
scrr	0.7483	0.4354	151	0.4868	0.5015	152	0.1788	0.3845	151
sector	5.6755	3.5638	151	5.6382	3.6676	152	5.2914	3.6943	151
shcmb	814.19	441.99	151	568.78	496.91	152	207.93	383.78	151

Table 2: Comparison of Z Values for High, Medium and Low Performing Plants

	Z Values		
Variable	High versus Low	High versus Medium	Medium versus Low
a1	2.552194	1.627746	1.034096
a1x	0.934013	0.608435	0.304248
a2	-0.68468	-1.1348	0.483348
a2x	1.317513	0.905055	0.515743
a3	0.159116	0.343632	-0.18427
a4	1.754438	-0.05936	2.213569
a4a	0.168382	0.570164	-0.42454
av	4.982236	3.891488	2.60811
avr	8.423649	4.747607	3.249525
b10a1	-2.29742	-2.27986	-1.03163
b10a2	-2.42728	-2.46109	-0.41895
b10a3	-2.37673	-1.70555	0.208866
b10b1	0.807406	0.10806	1.471654
b10b2	2.405403	3.028708	-0.43493
b10b3	1.604971	-0.90329	2.626987
b10b4	-1.16082	0.154843	-1.47484
b10b5	-3.66439	-0.79752	-3.16967
b10c1	-1.15547	0.10021	-1.25852
b10c2	3.835647	1.953031	2.195432
b21	1.39466	1.204614	0.195367
b22	-2.02907	-1.72542	-0.35254
b23	0.998095	0.762762	0.270848
b3a1	1.032415	0.827358	1.434545
b3a2	-1.66176	-0.90771	-0.43713
b3a3	-1.8916	-1.47582	-1.47987
b3b	-1.19417	-1.34994	-1.04033
b3c2	-0.48091	-1.24481	0.840504
b3c3	-1.11665	-1.44434	-0.24412
b4a	-3.31706	-0.28283	-3.10942
b4a4	-0.87857	0.4688	-1.13049
b4b11	-3.33087	-0.99024	-2.8923
b4b12	-5.19735	-2.48302	-3.67247
b4b13	-4.24163	-1.59021	-3.00146
b4b2	-2.24674	-0.01668	-2.27957
b4b3	-0.72444	-1.18164	-0.18464
b4c1	-4.66391	-1.64459	-3.00662
b4c2	-4.73111	-1.492	-3.32313
b51	-3.8119	-0.92998	-3.37874

b52	-5.72573	-2.36966	-4.17794
b53	-5.95923	-2.21142	-4.2932
b7b1	-2.72623	-1.6355	-1.06947
b7b2	0.240189	-0.71318	0.905462
b7b3	4.089897	3.147923	0.981011
b7b4	-0.9246	0.179136	-1.04302
b7c1	2.686677	2.708109	0.071185
b7c2	-0.39916	-0.61873	0.222123
b7c3	-0.71571	-1.47636	0.799143
b7c4	-0.03542	0.559208	-0.52195
b7c5	-0.63866	-2.21865	1.418384
b7c6	-1.80845	-0.93513	-0.92307
b7c7	-0.66353	1.64091	-2.2538
b81	-1.00469	0.138749	-1.12699
b82	-1.13609	-0.51779	-1.05315
b83	-1.49531	-1.44416	-1.12309
b84	-2.31274	-1.35352	-1.37117
b85	-2.701	-0.95048	-2.04392
b86	-1.80484	-0.76677	-1.4215
b9a1	1.383794	-0.42506	2.519658
b9a2	0.665383	1.029971	-0.50595
b9a3	-0.38553	-0.92295	0.644058
b9b1	1.191328	0.7163	0.436602
b9b2	-0.66514	-0.74201	0.089637
b9b3	-1.00667	-0.41165	-0.54713
c11	-0.37868	1.593029	-1.00731
c12	-0.12856	11.32741	-1.01415
c13	1.81264	1.975557	-0.33098
c21	0.19215	0.183929	0.045365
c22	2.222103	0.919724	1.36054
c23	-0.86726	-0.87923	0.026288
c24	-2.54619	-0.23143	-2.41783
c25	-5.90508	-4.57729	-1.48023
c26	-5.84321	-4.08317	-2.30668
c27	-4.30324	-1.97828	-2.84894
c28	0.591676	-0.31747	0.889525
c29	2.898465	1.057976	1.984809
c211	1.885943	0.230715	1.728605
c212	3.106119	2.522709	1.4384
c213	3.541384	0.429475	1.196062
c3	-0.87219	-1.2108	0.321761
c4	-0.56423	-0.55202	-0.11229
cmb3	13.54828	5.663691	6.542332
cmb4	8.740966	4.952231	3.303493

d11	0.468735	1.559998	-1.40704
d12	-4.18343	-2.32983	-2.52267
d13	1.068225	1.187309	-0.1375
d14	-1.90953	-0.50571	-1.5872
d15	-0.94092	1.094874	-1.90718
d16	-2.28071	0.116064	-2.87232
d17	1.456908	1.76823	-1.07384
d18	0.490948	2.057745	-2.19978
d1b	1.593827	0.823546	0.951516
d2	-0.79806	-1.03617	0.24733
delr	12.03545	7.140839	3.777692
e11	-0.77381	-0.30229	-0.58408
e110	0.891414	0.816839	0.148807
e12	-0.13403	0.067918	-0.18213
e13	0.684103	1.785914	-1.11843
e14	-1.78516	-0.46115	-1.4556
e15	0.17703	0.632415	-0.56302
e16	0.511435	-0.16208	0.783133
e17	0.284124	0.113373	0.191945
e18	0.339184	-0.09817	0.450072
e19	0.346563	0.694613	-0.40923
e2	1.90415	1.291499	0.852276
e3a1	2.67679	3.388185	-0.59661
e3a2	-0.62288	-0.22855	-0.44422
e3a3	-2.39521	-3.20531	0.970117
e3a4	-2.50856	-2.27705	-0.2614
e3b	-2.93246	14.76676	-17.6533
e3c	0.804103	-0.92427	1.731484
e3d	0.41628	0.264056	0.151178
e3e	0.869737	1.530078	-0.62063
e41	-0.37287	-1.73305	1.416537
e42	0.710009	-1.40189	1.721835
e43	-1.18418	-1.7199	0.459543
e44	1.708792	-0.00518	1.815025
e5	2.203572	0.578096	1.671722
e51	-2.46093	-1.02281	-1.39178
e52	1.938744	1.252441	0.866991
e6a1	-2.12189	0.232563	-2.35983
e6a2	0.453624	-1.77316	1.801434
e6a3	0.11831	1.457449	-1.16762
e6b1	-0.96765	1.32642	-2.208
e6b2	3.694826	0.909175	2.571982
e6b3	1.898332	0.359899	1.526682
e6b4	-1.61378	-0.06061	-1.52666

e6b4	-1.61378	-0.06061	-1.52666
e6b5	0.654833	1.456204	-0.71061
f1	-1.86784	-0.81569	-1.10713
f2a	2.075032	-0.69754	1.769631
f2b	2.811859	-0.29919	1.963843
g11	0.00983	-2.14831	2.157468
g12	1.180856	0.478444	0.734661
g21	-2.86511	-1.74756	-1.09634
g22	3.699207	2.657166	0.779591
g23	3.988888	2.992904	0.792983
g3a1	-3.18851	-2.51851	-0.63448
g3a2	0.2464	0.766125	-0.4528
g3a3	1.181498	0.786839	0.389668
g3b1	0.871297	1.000077	-0.99858
g3b2	7.28997	4.253641	3.353572
g3b3	9.169608	5.600228	3.866631
g41	-3.42038	-2.33581	-2.01769
g42	1.611491	0.408707	1.346198
g51	-1.74132	-1.7418	0.042147
g52	-6.18396	-4.65317	-3.30477
g53	-6.55777	-4.14565	-3.64875
g61	-1.17645	-1.49285	0.150318
g62	-2.84748	-0.02223	-2.80518
g71	-1.43667	-1.27164	-0.41792
g72	-3.37166	-1.75178	-1.95857
g81	-2.95293	-2.18558	-0.85043
g82	-0.14394	0.379255	-1.14947
g83	-2.42217	-3.50409	-1.17872
g91	-3.80089	-3.23943	-0.54581
g92	1.521044	12.26715	15.15341
h11	0.740138	0.025596	0.750024
h12	-0.97655	-0.75178	-0.30725
h13	0.715441	0.975751	-0.24694
h14	-0.24909	0.027107	-0.30106
h15	-1.14201	-0.06065	-1.04367
h16	-0.53517	-0.21595	-0.31905
h17	1.152063	0.266538	0.868797
h11x	0.365729	-0.35207	0.826853
h12x	-0.24399	0.872099	-1.1347
h13x	-1.06886	-0.18174	-0.80694
h14x	-1.88075	-1.35887	-0.5027
h15x	0.233364	0.215495	0.004665
h21	-0.51458	-0.34428	-0.17508
h22	-0.62131	0.962809	-1.64438

h23	-0.88549	1.751243	-2.67679
h24	1.436941	1.587684	-0.19749
h25	-1.21953	-1.92081	0.724652
h26	-1.1548	-1.48239	0.376732
h27	2.153562	1.140854	1.114958
h31	-1.30309	-0.38576	-1.18577
h32	0.472303	-0.07756	0.553345
h33	-1.56291	-2.75678	1.072363
h34	-2.92694	-1.06663	-1.83099
h35	-0.64398	0.237846	-0.85482
h41	5.067134	2.574383	2.736433
h410	6.101315	2.451915	3.53106
h42	6.719929	3.062334	3.772438
h43	4.687939	2.651207	2.201847
h44	5.790205	2.113563	3.763107
h45	6.454186	2.935685	3.622868
h46	5.938935	2.743043	3.412807
h47	5.154244	2.309176	3.077173
h48	4.465909	1.544264	2.977753
h49	4.647646	1.912513	2.861756
h5a	1.920995	0.43006	1.494793
h7a	-1.99538	-1.05195	-0.93405
h7b1	0.180766	2.128357	-1.47074
h7b2	-0.20051	-0.65664	0.515154
h7b3	-0.88151	-0.32509	-0.32657
h7b4	0.553875	2.945343	-1.95961
ltr	11.65815	3.965027	6.644359
pav	-10.8811	-5.96134	-4.86149
prodr	-1.50402	-1.97225	0.465328
pvdel	-12.5114	-7.87347	-4.60662
pvlt	-14.6663	-5.5006	-8.46227
pvprod	1.008374	2.560146	-1.47744
pvret	-5.77082	-4.5223	-1.32272
pvscr	-13.9579	-6.39243	-7.08504
pvst	-3.05717	-1.48051	-1.55307
scrr	12.04761	4.847523	6.001613
sector	0.919506	0.08978	0.819974
shcmb	12.72709	4.543006	7.076993

Appendix 5

Letter sent to the plants visited

Dear XXXXXX

UK BEST FACTORY AWARD

As part of the Best Factory Awards research programme, we are currently investigating the factors that are most important in improving plant performance. As part of this research, we have selected a sample of plants for further investigation from those plants that submitted Best Factory Award questionnaires in 1996. Your plant was one of those selected and I am writing to ask if you would be willing to be one of the participants.

It will involve one of our most senior researchers, John Mapes, who is a Senior Lecturer here at Cranfield, visiting your plant for a day and conducting three interviews of approximately 60 minutes with each of the staff responsible for the following departments:

a. Production (Production Manager or Plant Manager)
b. Production planning (Production Control Manager or Master Production Scheduler)
c. Purchasing (Purchasing or Procurement Manager)

(It may be that at your plant the same person is responsible for two or more of these functions in which case only one or two interviews will be necessary.)

The interviews will cover the following topics:

1. Which measures of performance are used in that department?
2. What systems and procedures are used by that department?
3. What methods of performance improvement are used within that department?

It would also be helpful if John could have a short conducted tour of the plant.

Any information provided to us will be treated as totally confidential and any results published in research reports will either be in the form of summary data for the whole sample of plants being investigated or in disguised form to conceal the identity of the individual plants and their parent companies.

One of the outcomes of the research will be a report on the key factors leading to improved plant performance and all participants in the research will receive copies of this report well in advance of any public dissemination.

I do hope that you will be willing to take part in the research and, to proceed further, John Mapes will be contacting you in the next few days in order to make the necessary arrangements. If, however, you feel that it would be impossible, for any reason, for you to participate in this research, we will quite understand.

Yours sincerely

Colin New

Professor of Manufacturing Strategy

Cranfield School of Management

Appendix 6

Interview plan for plant visits

Production

1. First could you take me through the production process explaining the organisational structure?
2. What aspects of operating performance do you measure and how would you rank them in order of importance?
3. How has performance on these measures changed over the last 3 years?
4. What methods do you use to achieve improvements in operating performance?
5. What is the degree of contact with customers?
6. What is the degree of contact with suppliers?
7. Who is responsible for stock and how is it controlled
8. What action has been taken over the last 3 years to reduce stock and what has been the result?
9. How is quality managed?
10. Do you have ISO 9000 accreditation?
11. How closely does production match the customer demand rate?
12. What does multi-skilling mean in this plant?
13. What performance recording and problem-solving is done by the workforce?
14. To what extent is the workforce empowered?
15. What are the main trade-offs between the different measures of operating performance at this plant?

Planning

1. First could you take me through the production planning process explaining the organisational structure?
2. What aspects of planning performance do you measure and how would you rank tem in order of importance?
3. How has planning performance changed over the last 3 years?
4. What methods do you use to achieve improvements in performance?
5. How does the customer communicate orders to you?
6. How often do customer orders get changed?
7. How are orders communicated to your suppliers?
8. How often do these orders get changed?

Purchasing

1. First could you take me through the purchasing process explaining the organisational structure?
2. What aspects of purchasing performance do you measure and how would you rank them in order of importance?
3. How has performance on these measures changed over the last 3 years?

4. What methods do you use to achieve improvements in purchasing performance?
5. What actions have you taken to improve supplier reliability?
6. Has frequency of delivery changed significantly over the last 3 years?
7. Is your aim to reduce the size of your supplier base? If so, how are you going about it?
8. How do you communicate your requirements to suppliers?

Appendix 7

Performance Trade-offs in Manufacturing Plants

This paper was jointly authored by John Mapes, Colin New and Marek Szwejczewski. It appeared in the International Journal of Operations and Production Management, Volume 17, Number 10, 1997, pages 1020-1033.

Performance Trade-offs in Manufacturing Plants

ABSTRACT

A sample of 782 manufacturing plants drawn from the UK Best Factory Awards database was used to investigate the nature of trade-offs between different measures of manufacturing performance. Each plant was ranked within its industry on each performance measure, a high ranking indicating good performance on that measure and a low ranking indicating poor performance. By comparing the ranking of each plant within its industry on each performance measure it was possible to determine the extent to which good performance on one measure was correlated with good performance on other measures. Rankings on added value per employee £, quality consistency, delivery reliability, speed of delivery and the rate of new product introduction were positively correlated, suggesting that good performance on each of these factors is associated with good performance on the rest. Only the extent to which a plant exhibited product variety showed conventional trade-off characteristics, being negatively correlated with rankings on added value per employee £ and the rate of new product introduction. This implies that, provided individual operating units can be organised so that each is focused on a relatively narrow product range, trade-offs can be avoided.

KEYWORDS

Operations management, manufacturing strategy, operating trade-offs, manufacturing plants, UK Best Factory Awards Database.

INTRODUCTION

It is generally accepted by manufacturing managers that operations management performance has a major impact on product cost, product quality, speed of delivery and delivery reliability. However, there is only limited empirical evidence in support of this and the precise nature of the interactions between the various elements of operating and business performance is still not fully understood.

In an attempt to provide a better understanding of how the manufacturing function can be used to support corporate objectives Wickham Skinner [1] developed the framework that is the basis of modern operating strategy. This was based on the premise that there are many ways to compete apart from cost and that each manufacturing unit should focus on doing those few things well that are critical to the achievement of the corporate mission. Underlying his ideas is the concept of strategic trade-offs: the achievement of high levels of performance on one factor can only be obtained at the expense of performance on one or more other factors. An implication of the trade-off concept is that a number of companies can compete in the same market, each meeting the specific needs of a segment of that market.

In recent years the existence of trade-offs has been questioned. Schonberger [2] has been the most notable of these critics, stating that, for the modern manufacturing company, trade-offs no longer exist. He argues that the factors leading to excellent performance on one factor also lead to excellent performance on the other factors. Therefore, world class companies will be able to out-perform their competitors on every aspect of performance. An implication of this is that there is a single generic manufacturing strategy, to become world class, which all manufacturers should be pursuing.

The determination of which of these two schools of thought is correct carries considerable implications for operating strategy. Surprisingly, little rigorous empirical research has been carried out to determine which of the two viewpoints is the more valid. The current research attempts to correct this deficiency.. A new model has been developed which integrates many features of the existing interpretations of the nature of trade-offs. Using a database of 782 UK manufacturing plants, the validity of this model has been tested statistically

LITERATURE REVIEW

During the early development of operations management as a discipline the emphasis was on cost efficiency with little attention being paid to the impact of operations management on customer service levels.

This emphasis on cost reduction alone started to change with Wickham Skinner's article "Manufacturing - Missing Link in Corporate Strategy" [1]. In this article he demonstrated the importance of operations management in determining corporate performance and provided a framework for matching manufacturing strategy with the corporate strategy. He developed these ideas further in his article "The Focused Factory" [3]. In this article he argued that a plant cannot perform well on every yardstick and that each manufacturing unit should focus on a few performance measures, trading these off against performance measures which are less important.

Since Skinner's original article it has been assumed by most manufacturers that improved performance on one factor can only be achieved by trading this off against reduced performance on one or more other factors. Further support for the existence of trade-offs between different performance areas has been provided by a number of writers [4-8]. These authors have refined Skinner's original ideas and have identified the following main performance areas between which trade-offs might be expected to exist.

Quality consistency
Quality specification
Lead time
Delivery reliability
Cost
Flexibility
Innovativeness

While most writers agree that these represent the key performance areas some writers [9,10] have criticised the lack of generally accepted definitions of these key concepts.

Further support for the concept of trade-offs has been provided by Porter [11]. In his book, "Competitive Strategy", Porter argues that the strategies of cost leadership and differentiation are mutually exclusive. However, several authors have criticised this view [12-14], arguing that it is possible for organisations to excel at differentiation and low cost at the same time.

Schonberger [2,15] has questioned the trade-off model proposed by Skinner, arguing that some companies are able to simultaneously improve on all aspects of performance. For these companies there are no trade-offs. Schroeder et al [16] have shown that many companies, particularly Japanese companies are capable of producing extremely high quality products at extremely low costs. Numerous authors [17-21] have shown how investment in quality improvement programmes can lead to simultaneous improvements in quality consistency and cost efficiency.

Skinner [10] and New [22] have responded to this argument by saying that although the nature of trade-offs is constantly changing, some trade-offs still remain. New is extremely critical of the position adopted by Schonberger and presents an analysis which shows that although modern manufacturing techniques have eliminated the traditional trade-offs between quality consistency and cost, customer lead time and delivery reliability, the trade-offs between quality specification and cost, product variety and cost still remain. Skinner amplifies on the trade-off aspects of his original ideas, arguing that the nature of the correlation between performance factors changes over time. He therefore suggests that these relationships should be referred to not as trade-offs but as performance relationships.

Although an understanding of the nature of the trade-offs between the various measures of operating performance is extremely important, very little empirical work has been done to establish the nature of these trade-offs. In the papers described above little is presented to support each author's views, other than selective anecdotal evidence.

In an attempt to provide an explanation of the dynamic nature of trade-offs, Ferdows and De Meyer [23] have developed what they refer to as the sand cone model. This is based on the proposition that competences are cumulative rather than mutually exclusive. They suggest that lasting improvements in performance always involve the same sequence in the performance improvement process. First quality is improved. Then, while improvements in quality continue, reliability is improved. Next, while improvements in these two performance areas improve further, flexibility is improved. Finally, while improvements in these three performance areas continue, cost efficiency is improved. These ideas have been developed further by Roth [24] in her work on competitive regression theory.

Empirical research to test the validity of the various trade-off models is rather limited. Filippini, Forza and Vinelli [25]have tried to provide some empirical data regarding the trade-off issue by analysing the compatibility/trade-off between different types of performance for a sample of 42 plants drawn from the metal mechanical industries. However, some errors in their method of analysis have been identified, invalidating their conclusions [26]. Re-analysis of their data provides some support for the hypothesis that high levels of quality consistency are associated with short, reliable lead times.

Schroeder et al [27] have reached similar conclusions using data from 120 plants. They have developed a network theory of plant performance in which conformance quality and cycle time are the drivers of fast delivery, on-time delivery, cost and flexibility. Statistical analysis of their data showed that high levels of conformance quality and short cycle times are associated with short, reliable lead times and high flexibility but not low cost.

PREVIOUS SURVEYS OF MANUFACTURING PERFORMANCE

One of the first surveys which attempted to statistically analyse the relationships between different aspects of business performance was the PIMS survey (Profit Impact of Marketing Strategy) [28]. This considered individual strategic business units, the smallest sub-unit of a company with profit responsibility, and developed regression equations linking measures of financial performance to internal characteristics of the Strategic Business Unit (SBU).

A survey more specifically focused on manufacturing performance is the Global Manufacturing Futures survey [29]. This operates at company level and is primarily concerned with monitoring changes in manufacturing priorities in Europe, Japan and the United States. However, Ferdows and De Meyer [23] have used the Futures Survey data to determine correlations between selected operating performance measures.

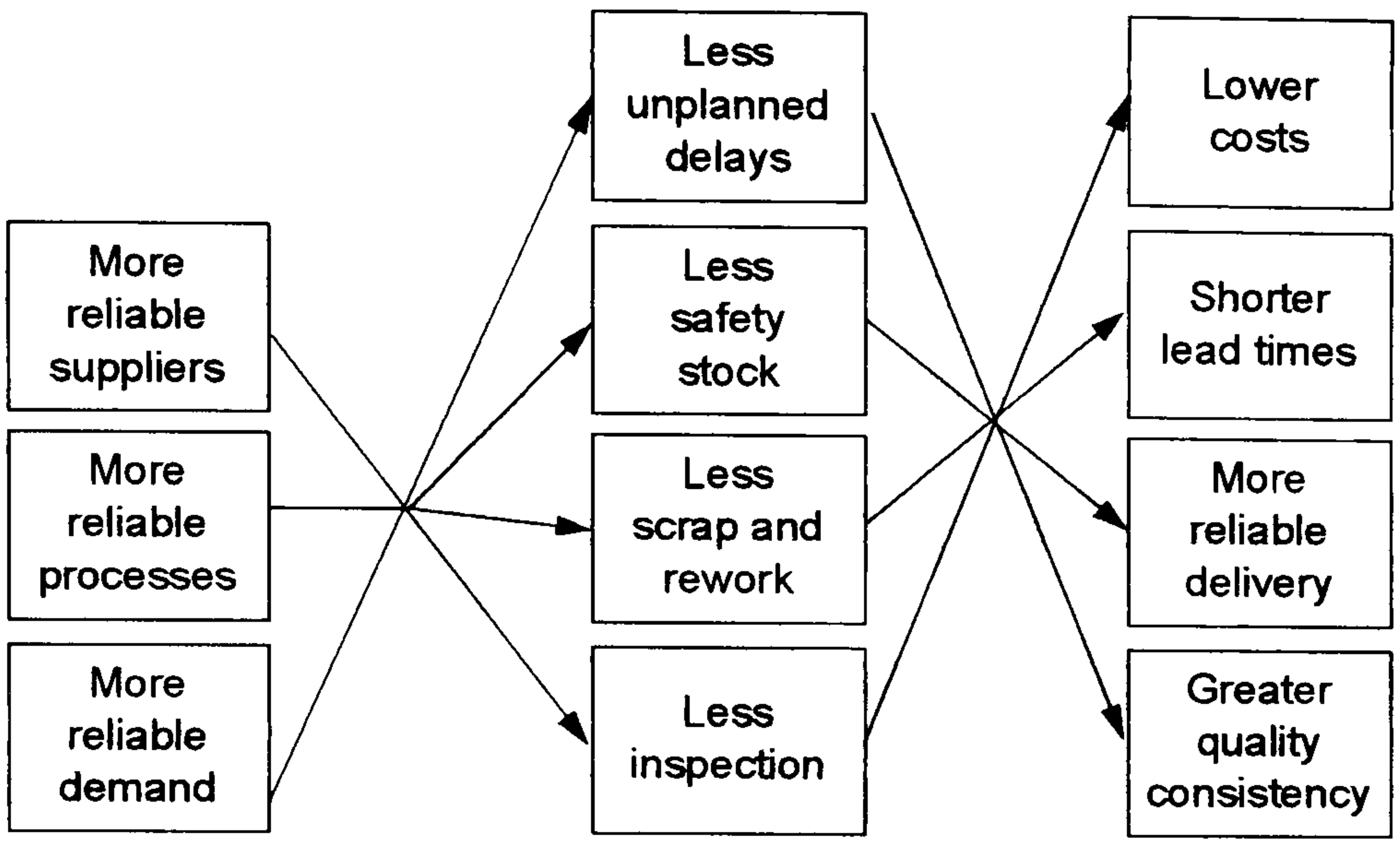
A more recent survey conducted by Voss [30,31] used interviews at manufacturing plants throughout Europe to construct indices of practice and performance for each plant. This survey demonstrated a positive correlation between a plant's index of best practice and its index of operating performance.

The Lean Enterprise Benchmarking Report produced by Andersen Consulting [32] compared 18 automotive components plants, 9 of which were located in Japan and 9 in the UK. Although no statistical evidence is provided, their results appear to support the no trade-offs view. The best performing plants achieved high quality and productivity in spite of high product variety and a rapidly changing product range. In 1995 a further survey was published [33], covering 71 automotive components plants in 9 countries. Again no statistical evidence was provided but in their conclusions they stated that product complexity showed no correlation with productivity in the case of seats and brakes but that there was a negative correlation in the case of exhausts. They also stated that there was a negative correlation between quality specification and productivity.

THE PROPOSED MODEL

In an attempt to differentiate between those elements of performance that involve trade-offs and those which are mutually enhancing the following model has been developed. Almost regardless of strategy a primary concern of operations management is to increase reliability. The aim is not just to increase product reliability but also process reliability and supplier reliability. Each improvement in reliability leads to less scrap and rework and less unplanned delays permitting less inspection and less safety stock. This, in turn, leads to lower costs, shorter lead times, more reliable delivery and greater quality consistency. Provided that improvements are a result of greater reliability it should be possible to simultaneously shorten lead times, increase delivery reliability, increase quality consistency and reduce costs. This is illustrated in Figure 1.

Figure 1 Impact of improved reliability on operating performance



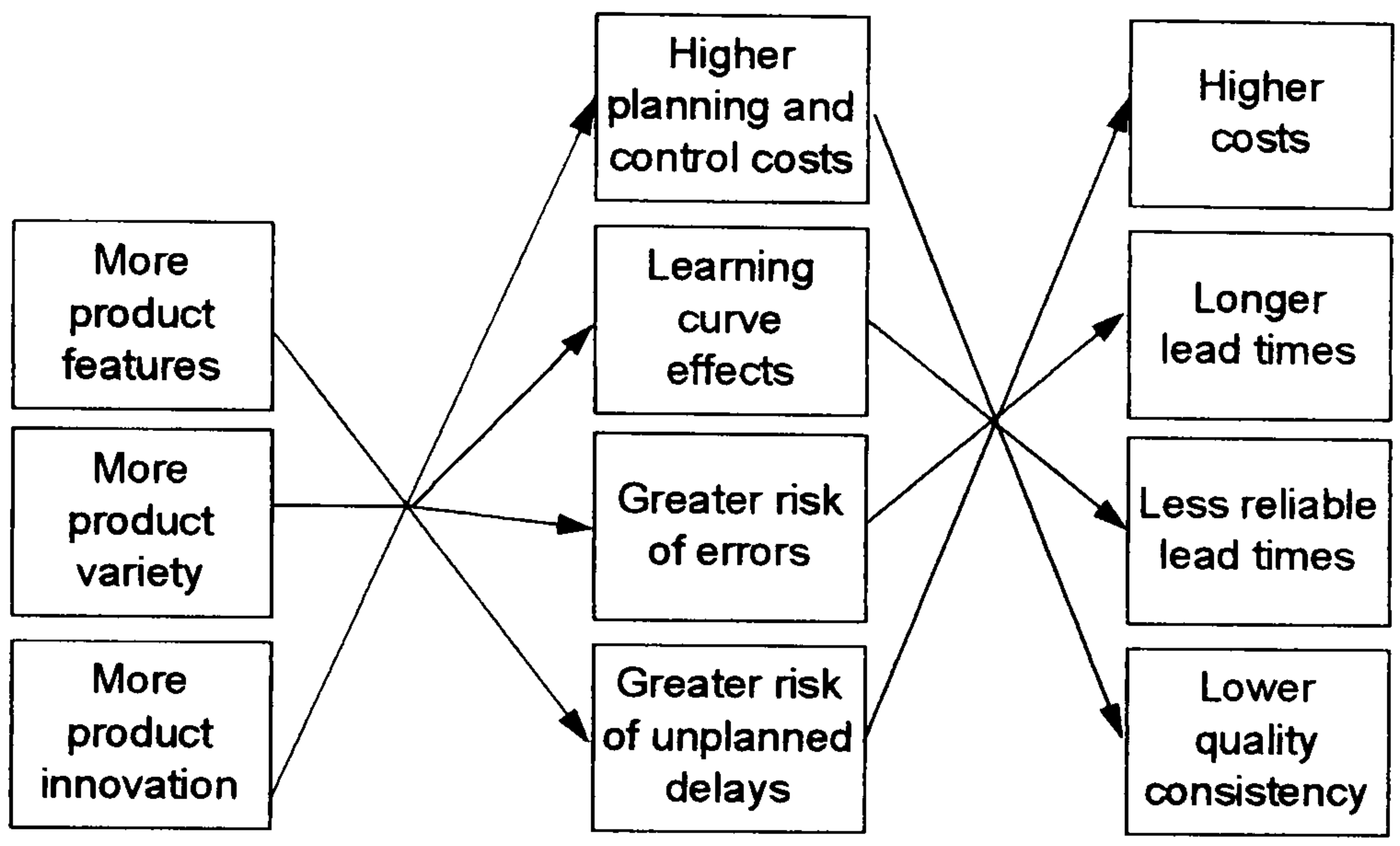
On the other hand, although the need to increase reliability is likely to be common to all manufacturing strategies there are also some strategic choices to be made. There is the question of what level of quality specification to offer. There are two issues here. Offering a greater number of product features, using more expensive materials, providing higher levels of precision all increase costs. It is not possible to manufacture a Rolls Royce car for the same cost as a Citroen 2CV. Additionally, producing a wide variety of different quality specifications in the same plant increases process complexity, increasing the likelihood of producing to the wrong quality specification, of unplanned delays and of scheduling errors with the consequence of poorer quality consistency, longer lead times and poorer delivery reliability. It is important at this point to differentiate between plant performance and corporate performance. A company can avoid the adverse effects of a wide variety of quality specification levels by having a number of different plants, each focused on a narrow quality range.

Companies are under considerable pressure to produce a wider variety of product variants, more colours, more flavours and more optional features. Greater variety within the same plant means greater complexity. While a well-managed plant designed to handle product variety may be able to minimise the impact of product variety on cost, quality consistency, lead time and delivery reliability, this impact is unlikely to be zero or negative.

Companies are also under pressure to introduce new products at a greater rate than in the past. Inevitably, during the early stages of the launch of a new product, problems will be encountered, leading to higher costs, longer lead times and poorer delivery reliability than would have been the case if the plant had continued to produce its existing products. Research on learning curve effects by Hayes and Wheelwright [4] shows a clear negative correlation between the total number of units produced and average manufacturing cost.

The nature of these performance relationships is illustrated in Figure 2.

Figure 2 Factors Affecting Performance



What strategic options do these performance relationships offer at plant level? A plant could concentrate solely on improving reliability. This is likely to lead to production of a narrow range of standard products that are changed infrequently. This strategy should provide fast, reliable delivery, consistent quality and low manufacturing costs. It will be most effective in stable, mature industries where order-winning criteria are price and availability. Alternative strategies might be to provide products with more features or a higher specification than the competition, to offer a wider variety of products or to introduce new products at a faster rate. Each of these strategies offers the customer something extra but, from our earlier discussion, it is likely that this will be at the expense of cost, quality consistency or delivery.

In summary, then, a modified trade-off theory is proposed in which some trade-offs have disappeared but those that remain still require us to make strategic choices. This is in contrast to Schonberger's position. He says that there are no trade-offs: it is actually possible to offer a wide product range, frequently introducing new products while still out-performing the competition on cost, quality and delivery. If this were correct then there would only be one strategy for any organisation, to continuously improve on every performance measure, out-performing the competition on everything.

RESEARCH METHOD

In order to establish the nature of the trade-offs between different types of manufacturing performance the UK Best Factory Award database for 1993-95 was used. This database contains information on approximately 800 manufacturing plants participating in the competition to select the Best Factory in the UK during the 3 year period 1993-95. This competition is organised by the *Management Today* magazine and is administered by the Cranfield School of Management. Each plant wishing to take part completes a 14 page questionnaire providing a comprehensive profile of each plant's characteristics and performance. This is the source of the information contained in the database.

As participation in the Best Factory Award survey is voluntary there is a risk that participants are not representative of the population of all UK manufacturing plants. This is, of course, a concern in any survey in which participation is not compulsory. Even when the initial sample is carefully selected to ensure that it is fully representative, there will be a proportion of non-respondents, leading to the risk of bias in the final sample. However, a particular concern with the Best Factory Award survey is that the participants are likely to be above average performers. The main reason for taking part in the survey is to obtain the bench-marking report issued to all participants and this should be attractive to plants at all levels of performance. However, because of the award element, it still seems likely that the absolute performance levels of the plants surveyed will be untypical of performance levels for the total population of plants in the UK. The research presented in this paper is concerned with testing whether achievement of excellence on one performance measure affects the likelihood of achieving high levels of performance on other measures. The Best Factory Awards plants are likely to include a higher proportion of plants achieving excellence on at least one performance measure than would be the case for a completely random sample but such data will still be suitable for the hypotheses being tested. On the other hand, average levels of performance within the database must be interpreted with care and are unlikely to be unbiased estimates of average performance levels for the whole population of UK manufacturing plants.

Another concern with the Best Factory Awards data is that respondents might exaggerate their performance in order to increase their chances of winning an award. This would be counter-productive for two reasons. Firstly, all plants short-listed for an award are visited by a panel of judges. During this visit, any discrepancy between actual performance and the performance claimed in the questionnaire would be identified and could lead to disqualification. Secondly, the main benefit to participating plants is the benchmarking report. Any plant that had submitted incorrect information would find that the benchmarking report was meaningless. In fact, the evidence from over 100 factory visits is that the accuracy of the questionnaire data is extremely high.

The following aspects of performance were considered in the analysis.

Area of performance	Measure used
Manufacturing cost	Added value per £ of employee cost
Quality consistency	Customer returns as a percentage of output
Lead time	Average lead time quoted to customer
Delivery reliability	% of items delivered on time
Rate of new product introduction	Number of new products introduced in the last 5 years as a % of 'live' products
Product variety	Number of different products currently 'live' in the plant

If the trade-off model developed earlier is correct then the following propositions should be true.

1. Rankings of plants relative to competitors on added value per employee £, quality consistency, speed of delivery and delivery reliability will be positively correlated. In particular, plants which achieve a better than average performance level for their industry on one of these factors will also achieve a better than average performance on the other factors.

2. The extent of product variety within a plant will be negatively correlated with rankings relative to competitors on added value per employee £, quality consistency, speed of delivery, delivery reliability and the rate of new product introduction. In other words, plants which manufacture a wide variety of products cannot expect to be competitive on the factors mentioned in comparison with plants manufacturing a narrower product range.

3. The ranking of a plant on rate of new product introduction will be negatively correlated with its ranking on added value per employee £, quality consistency, speed of delivery, delivery reliability and degree of product variety relative to its competitors. In other words, plants that are highly innovative are unlikely to be competitive on these factors in comparison with plants producing established products.

Each of the propositions above relates to the performance of a plant in comparison with other plants in the same industry. Consequently, the 782 plants were grouped into the following 6 categories.

Industrial category	Number of plants in sample
1. Capital equipment	50
2. Engineering	209
3. Electrical and electronics	99
4. Chemicals and pharmaceuticals	122
5. Food, drink and tobacco	77
6. Miscellaneous	225
	782

The plants in each industrial category were then ranked for each performance factor, good performance being given a high ranking and poor performance a low ranking. Rankings were determined separately for each of the three years to allow for any general improvements in performance over time. To allow for differences in the number of plants in each category, each rank was expressed as a percentage of the total number of non-zero entries in that category. This ensured that the lowest rank in each category was always 100, regardless of the number of plants in that category while the interval between successive ranks varied depending on the number of plants in the category. For example, for a category containing 100 plants the interval between successive ranks would be 1 and the plant with the best performance would receive a rank of 1. For a category containing only 20 plants the interval between successive ranks would be 5 and the plant with the best performance would receive a rank of 5. Correlation coefficients were then calculated for each pair of performance factors and the correlation coefficients tested for significance.

ANALYSIS OF THE RESULTS

The results of the correlation analysis are summarised in Table 1.

Table 1 Correlation coefficients between performance measures

	Quality Consist.	Lead time	Del. rel.	Innovn. rate	Product variety
Man. cost	0.07	0.09*	0.09*	0.11**	-0.16***
p	(0.12)	(0.02)	(0.05)	(0.005)	(0.000)
Qual. consist.		0.17***	0.19***	0.10*	-0.02
p		(0.000)	(0.000)	(0.02)	(0.55)
Lead time			0.28***	0.13***	-0.08*
p			(0.000)	(0.001)	(0.04)
Del. rel.				0.13**	-0.12**
p				(0.005)	(0.007)
Innovn. rate					-0.64***
p					(0.000)

*** = significance level of 0.001
** = significance level of 0.01
* = significance level of 0.05

This shows that nearly all of the pairs of performance measure rankings have correlation coefficients that are significant at the 0.05 level or better. The extent to which these results support the propositions put forward earlier is discussed below.

Proposition 1

This states that performance rankings on added value per employee £, quality consistency, speed of delivery and delivery reliability relative to competitors will be positively correlated. The results provide strong support for this. Rankings for added value per employee $, quality consistency, speed of delivery and delivery reliability are all positively correlated. Table 2 summarises the statistical significance of the correlation coefficients for each pair of variables.

Table 2 Statistical significance of correlation coefficients

	Quality Consistency	Lead Time	Delivery Reliability
Manufacturing Cost	not sig.	.002	.05
Quality Consistency		.000	.000
Lead Time			.000

Five out of the six pairs of variables show statistically significant correlations. The strongest correlations are between rankings on quality consistency, speed of delivery and delivery reliability. As the model predicts, those competences which lead to high levels of quality consistency also lead to speed of delivery and reliability of delivery so that plants which are above average on quality consistency are also above average on speed of delivery and above average on delivery reliability. There is a less strong, though still statistically significant, correlation between rankings on added value per employee £, speed of delivery and delivery reliability. This suggests that, while there are many factors which simultaneously increase added value per employee £, increase speed of delivery and increase delivery reliability, there are other factors, not identified in the model, which affect added value per employee £ without affecting speed of delivery and delivery reliability and vice-versa.

Surprisingly the correlation between rankings on added value per employee £ and quality consistency is not statistically significant. This contradicts what is predicted by the model and suggests that the factors leading to high levels of added value per employee £ are different to the factors leading to high levels of quality consistency. This requires further investigation. Schroeder et al [27] found a similar lack of correlation between cost and quality conformance and suggested that it may be due to the strong influence on cost of differences in levels of capital investment and plant size.

Proposition 2

This states that the extent of product variety within a plant will be negatively correlated with performance rankings relative to competitors on added value per employee £, quality consistency, speed of delivery, delivery reliability and the rate of new product introduction.

Table 3 Correlations with Product Variety

	Correlation Coefficient	Significance level
Manufacturing cost	-0.16	0.000
Quality consistency	-0.02	not sig.
Lead time	-0.08	0.04
Delivery reliability	-0.12	0.007
New product innovation rate	-0.64	0.000

The results in Table 3 provide support for this proposition. Ranking on degree of product variety shows statistically significant negative correlations with rankings on added value per employee £, speed of delivery, delivery reliability and the rate of new product introduction. This is consistent with the model and also agrees with conventional wisdom on manufacturing focus. Plants that manufacture a wide range of products are likely to perform less well on added value per employee £, speed of delivery and delivery reliability. Also, there is a strong negative correlation between rankings on degree of product variety and rankings on the rate of introduction of new products. In other words plants with a wide product range are likely to introduce new products at a slower rate than plants with a narrow product range.

One result that is not consistent with the model is the lack of significant correlation between rankings on degree of product variety and quality consistency. This is difficult to understand, as greater product variety would be expected to lead to greater operating complexity and greater problems of control. These in turn could be expected to lead to lower levels of quality consistency. This is an area requiring further investigation.

Proposition 3

This proposition states that the ranking of a plant on rate of new product introduction will be negatively correlated with its ranking on added value per employee £, quality consistency, speed of delivery, delivery reliability and degree of product variety relative to its competitors.

Table 4   Correlations with New Product Innovation Rates

	Correlation coefficient	Significance level
Manufacturing cost	+0.11	0.005
Quality consistency	+0.10	0.02
Lead time	+0.13	0.001
Delivery reliability	+0.13	0.005
Product variety	-0.64	0.000

Table 4 shows that there is little support for this proposition with the exception of the strong negative correlation between rankings on new product innovation rate and degree of product variety. In fact rankings on the rate at which new products are introduced shows a statistically significant positive correlation with rankings on added value per £, quality consistency, speed of delivery and delivery reliability. An explanation of this might be that introduction of new products often provides the opportunity to upgrade equipment and processes at the same time and it may be this that is leading to the improved performance in these factors. Further research is needed to establish the mechanisms, which lead to these positive correlations so that these can be incorporated into the model presented earlier.

CONCLUSIONS

A model has been developed which attempts to explain the mechanisms which link the different measures of operating performance at plant level. Analysis of the UK Best Factory Awards database provides a fair degree of support for this model. With the exception of product variety and the level of product specification (not dealt with in this paper), rankings on most measures of operating performance show significant positive correlations with each other. Not only is there an absence of trade-offs, good performance on one measure seems to lead to good performance on other measures. Although the degree of product variety would appear to be the exception to this at plant level, organisations might still be able to achieve high levels of overall product variety without adversely affecting other performance measures by focusing each of their plants on a different segment of their total product range.

While the model presented earlier goes some way towards explaining the trade-offs observed in empirical data, there are still some interactions that the model cannot explain. In particular, the factors which determine added value per employee £ are more complex than this simple model implies. As mentioned earlier, Schroeder et al [27] have suggested that this may be due to the influence of levels of capital investment and differences in plant size. Further research is needed to identify other factors that might influence added value per employee £. Multiple regression analysis could then be used to separate out the effects of the different factors.

Another area requiring further investigation is the effect of high rates of new product introduction on the other performance measures. Here the problem is not that the expected correlations cannot be identified but that the observed correlations are the reverse of those predicted by the model. As discussed earlier, one explanation of this is that introduction of new products provides the opportunity for the introduction of new technology and operating methods. Further research is needed to separate the effects of new technology and process choice from the learning curve effects that apply when a new product is introduced.

It should also be emphasised that the model presented here is essentially a static one. It considers relationships between different performance measures at a particular point in time. However, what is also important is the nature of dynamic changes. In order to achieve a higher rate of improvement in one performance measure, what changes in the rates of improvement in other performance measures will be necessary? This is complicated by the fact that, in the average plant, most measures of performance improve to some extent over time. The question is whether an above average rate of improvement in one performance measure is generally associated with a below average rate of improvement in certain other performance measures. In order to test this, it will be necessary to monitor changes in operating performance measures over time for a sample of manufacturing plants and determine the correlations between the relative rates of improvement.

While the development of this model is still at a very early stage, some tentative implications for managers can be drawn. Existing operations improvement programmes tend to focus on the elimination of waste in all its forms. This is still important, but equally important and complementary to the elimination of waste are the elimination of uncertainty and unreliability from the system. Much of the surplus stock, labour and capital equipment in the operating system is there as a consequence of uncertainty and unreliability. Causes of this include unreliable delivery by suppliers, variability in processing times and high defect rates. If attention is directed to the identification and elimination of uncertainty and unreliability from the system then it should be possible to simultaneously reduce manufacturing costs, customer returns and speed of delivery and increase delivery reliability.

The research also confirms existing thinking on manufacturing focus [3, 4, 34]. Plants with a narrow product range tend to perform better on most measures of operating performance than plants with a wide product range. However, New [35] has suggested that, in future, focus will occur at the level of the manufacturing cell rather than at plant level. The implications of this for the current research is that when plants are organised in self-contained manufacturing cells, the negative correlation observed in this research between degree of product variety and good performance on added value per employee £, speed of delivery and delivery reliability will cease to exist. Provided that there is focus at cell level the degree of focus at plant level will have little effect on overall levels of operating performance. Further research is needed to establish whether this is, in fact, the case.

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This research was conducted using the Cranfield University School of Management/*Management Today* Best Factory Award Database with the permission of Professor C.C. New and M. Szwejczewski.

Appendix 8

Process Variability and its Effect on Plant Performance

This paper was jointly authored by John Mapes, Marek Szwejczewski and Colin New. It appeared in the International Journal of Operations and Production Management, Volume 12, Number 7, 2000, pages 792-808.

PROCESS VARIABILITY AND ITS EFFECT ON PLANT PERFORMANCE

KEYWORDS

Manufacturing, plant performance, process variability, performance drivers

ABSTRACT

This report presents the preliminary findings of a research study to determine the factors which enable a manufacturing plant to simultaneously achieve high labour productivity, fast, reliable delivery and high quality consistency. The conclusions are based on analysis of a database containing details of 953 manufacturing plants in the UK. Based on the performance measures mentioned above, a composite performance measure was calculated for each plant in the database. The plants were then divided into groups of high performers, medium performers and low performers. Using statistical analysis, those differences between the high and low-performing plants that were significant were identified. The main factors differentiating high-performing plants from the rest were those associated with low process variability, high schedule stability and more reliable deliveries by suppliers.

LITERATURE REVIEW

The purpose of this research was to determine those characteristics that enable plants to achieve high levels of operating performance at plant level across a wide range of measures. Much of the existing work in this area has concentrated on the interactions between the performance measures themselves.

One of the earliest writers on this subject was Wickham Skinner (1969, 1974). He developed the concept of strategic trade-offs: achievement of high levels of performance on one factor can only be achieved at the expense of performance on one or more other factors

Further support for the existence of trade-offs between different performance areas was provided by Hayes and Wheelwright, Richardson, Taylor and Gordon, Rosenfield, Shapiro and Bohn, Fine and Hax, Wacker. These authors refined Skinner's original ideas and identified the following main performance areas between which trade-offs might be expected to exist.

Quality consistency
Quality specification
Lead-time
Delivery reliability
Cost
Flexibility
Innovativeness

However, in recent years the existence of trade-offs has been questioned. Schonberger (1986) has been the most notable of these critics, stating that, for the modern manufacturing company, trade-offs no longer exist. He argues that the factors leading to excellent performance on one factor also lead to excellent performance on the other factors. Therefore, world class companies are able to out-perform their competitors on every aspect of performance

In support of this, Schroeder, Sakakibara, Flynn and Flynn have shown that many companies, particularly Japanese companies are capable of producing extremely high quality products at extremely low costs. Numerous authors [Deming, Juran et al, Crosby, Garvin, Skinner (1986)] have shown how investment in quality improvement programmes can lead to simultaneous improvements in quality consistency and cost efficiency.

In an attempt to provide an explanation of the dynamic nature of trade-offs, Ferdows and De Meyer have developed what they refer to as the sand cone model. This is based on the proposition that competences are cumulative rather than mutually exclusive. They suggest that lasting improvements in performance always involve the same sequence in the performance improvement process. First quality is improved. Then, while improvements in quality continue, reliability is improved. Next, while improvements in these two performance areas improve further, flexibility is improved. Finally, while improvements in these three performance areas continue, cost efficiency is improved.

The ideas of Ferdows and De Meyer have been developed further by Roth et al (1996) in her work on competitive progression theory. This theory proposes:

"Sustainable combinative competitive capabilities accumulate in a sequential progression forward - from quality to delivery to flexibility to price leadership - over an innovative cycle leading to strategic agility; combinative competitive capabilities on quality, delivery, flexibility, and price leadership."

Most of the researchers who have developed trade-off models have given little attention to the precise mechanisms within plants that would lead to performance factors being either mutually supportive or involving trade-offs. A number of other researchers, however, have concentrated their attention on those factors that are the drivers of operating performance at plant level.

A view expressed by many of these researchers is that low throughput time is the most important driver, being closely associated with high levels of quality consistency and productivity and with fast, reliable delivery. Schmenner (1988) reported the results of a survey that demonstrated that the single most important determinant of improved factory productivity was reduced throughput time. He says "while throughput time does not improve productivity by itself, it stimulates a host of complementary actions and tactics within the factory that, in turn, improve productivity".

Stalk (1988) and Stalk and Hout (1990) introduced the concept of time-based competition, demonstrating how low throughput times provide organisations with a major source of competitive advantage. Drucker in "The Emerging Theory of Manufacturing" argues that the key measure for the new manufacturing accounting is time. Benefit is whatever reduces that time. Plossl (1991) states, "In manufacturing operations all benefits will be directly proportional to the speed of flow of materials and information".

Schonberger (1996) identifies another, related factor, high stock turns, as the main determinant of business performance. This view has been supported by Shingo (1988), Hall (1983, 1987) and Ohno (1988).

However, short throughput times and high stock turns are intermediate measures. They lead to improvements in external performance but they are themselves the consequence of earlier actions by the organisation.

These earlier actions are likely to be associated with the development in high-performing plants of operating systems that are much more stable and reliable than those in low-performing plants. This will lead to less stock and shorter manufacturing lead times in the high-performing plants. This will, in turn, lead to faster, more reliable delivery, greater quality consistency and lower unit costs. In other words, the fundamental drivers that lead to simultaneous improvements in productivity, customer lead time, delivery reliability and quality consistency are all aspects of reduced variability and uncertainty within the operating system. The main ways of achieving reduced variability and uncertainty are listed below.

<u>Increased adherence to schedule</u>

Unplanned changes to the production schedule have a number of adverse effects. The jobs that have been displaced are delayed, increasing average throughput times and work in process stocks. The changes are usually non-optimal and frequently increase the amount of time spent on set-ups and changeovers. The consequence is reduced productivity and further increases in throughput times. The end results are higher costs, longer lead times and late deliveries.

The less uncertainty there is with regard to future customer requirements, the availability of raw materials and bought-in components and the processing times for each stage in manufacture, the easier it is for plants to adhere to the planned schedule. In a survey of UK plants by Armistead and Mapes two of the most important determinants of high levels of operational efficiency and customer service were sharing of production schedules with customers and suppliers. Sharing information in this way reduces uncertainty and enables increases in the degree of adherence to schedule at every stage along the supply chain.

Reduced process time variability

The greater the variability in the processing times of the individual manufacturing stages the more complex is the task of co-ordinating these stages. The traditional way of dealing with process time variability is to introduce work in process buffers between the stages. This ensures that longer than expected processing times at the earlier stages of manufacture do not lead to the later stages running out of work. However, it increases the average manufacturing throughput time and does nothing to reduce the variability in throughput time. The overall effect is to increase costs, to increase customer lead times and to reduce delivery reliability.

Increased reliability of supplier deliveries

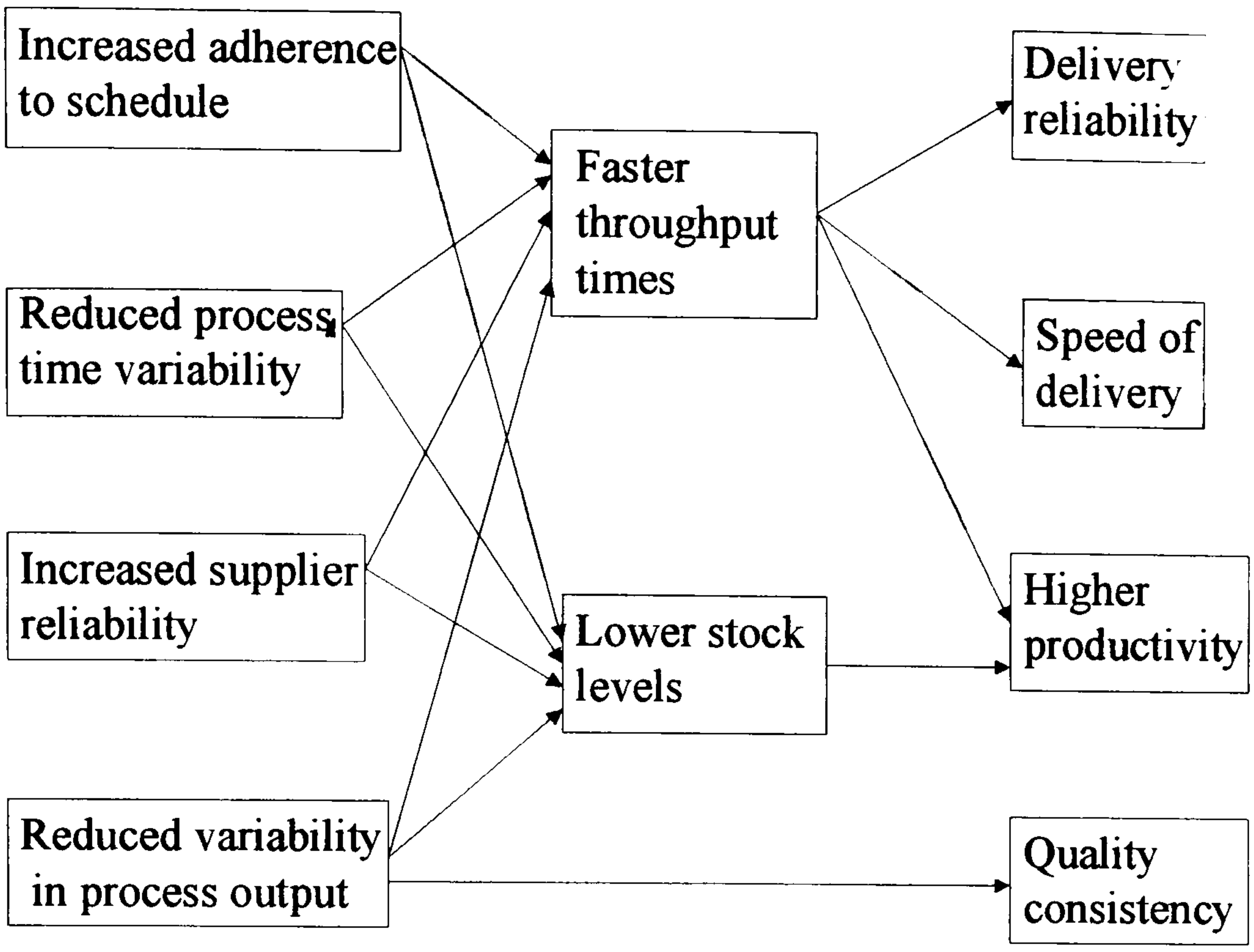
By using suppliers who can provide on-time delivery of items of the correct quality and in the correct quantities then there will be fewer unplanned delays due to non-availability or rejection of raw materials. This not only reduces average throughput time and increases delivery reliability, it also reduces the amount of raw materials stock that needs to be held.

Reduced process output variability

The lower the variability in the output of each stage in the manufacturing process, the higher the proportion of output that is within specification, in other words, the lower the scrap rate. Not only will this reduce the likelihood of defective product reaching the customer, it will also reduce the cost of scrap and rework. Also fewer delays due to rejected components will occur so that average throughput rates and delivery reliability will also improve.

The relationship between these factors and the external measures of operating performance are shown in Figure 1.

Figure 1: Drivers of Plant Performance



A number of researchers have published results that support elements of this model. Schonberger (1982) and Hall (1983) both identify three factors that are prerequisites for reducing throughput times and inventory levels. These are

Stabilising the master schedule
Cutting variation in process times
Getting suppliers to deliver in smaller lot sizes

The first two of these are performance drivers identified in the proposed model. The third would be classified as an intermediate measure within the model. Only when supplier reliability has been improved can customers risk deliveries of raw materials in smaller quantities, leading in turn to lower stock levels.

Newman, Hanson and Maffei (1993) also provide support for the model, claiming that reducing uncertainty and increasing flexibility enable capacity, inventory and throughput time to be cut. A number of authors have confirmed this through simulation studies. [Crawford and Cox (1991), Zangwill (1992), Huang, Rees and Taylor (1983), Swenseth, Muralidhar and Wilson (1993), Lee and Seah (1988)]. Wacker (1987) showed that the levels of customer service, productivity and quality achieved by a plant are related and that the degree of the relationship depends on the extent to which the plant can reduce throughput time. This, in turn, is associated with specific estimates of system parameters associated with consistency and predictability. Hafner (1991) showed that reducing the coefficient of variability of the processing and inter-arrival times had the same effect on throughput times as an increase in capacity.

Oliver, Delbridge, Jones and Lowe (1994) found that the percentage variation from schedule during the month prior to delivery was only 5.5 per cent for world class manufacturing plants in comparison with 11.9 per cent for other plants. They conclude that demand stability and environmental uncertainty more generally may, however, be important as the most significant indicators of leanness - inventory levels - are heavily driven by uncertainty in one form or another. Bennett and Forrester (1994) showed that schedule uncertainty in high variety - high volume plants causes higher inventories, longer lead times and less reliable delivery. Harrison (1996) observed a similar effect at an auto parts supplier.

Zachery and Richman (1993) argue that JIT emphasises variability reduction whereas CIM emphasises variability handling. They say that CIM should only be introduced once variability has been reduced as far as possible by other means.

We can therefore state the following tentative hypothesis based on the model proposed in Figure 1.

Manufacturing plants that are able to simultaneously achieve high levels of productivity, quality consistency, and delivery reliability and short customer lead times will show the following characteristics in comparison with other plants.

- greater adherence to schedule
- lower process time variability
- more frequent deliveries by suppliers
- more reliable deliveries by suppliers
- lower scrap rates
- lower stock levels
- lower average throughput times

RESEARCH METHODOLOGY

In order to test whether this hypothesis is correct a database was used containing information on 953 plants for which questionnaires had been submitted as part of the UK Best Factories Award during the period 1993-1996. This database contains information on all manufacturing plants participating in the competition to select the Best Factory in the UK during the 4-year period 1993-96. This competition is organised by the Management Today magazine and is administered by the Cranfield School of Management. Each plant wishing to take part completes a 14-page questionnaire providing a comprehensive profile of each plant's characteristics and performance. This is the source of the information contained in the database.

The 953 plants in the database were grouped into the following 6 categories.

Industrial category	Number of plants in sample
1. Capital equipment	56
2. Engineering	278
3. Electrical and electronics	140
4. Chemicals and pharmaceuticals	158
5. Food, drink and tobacco	99
6. Miscellaneous	22
	953

The plants in each industrial category were then ranked for 4 performance factors, good performance being given a high ranking (close to 1) and poor performance a low ranking (close to 100). Rankings were determined separately for each of the four years to allow for any general improvements in performance over time. To allow for differences in the number of plants in each category, each rank was expressed as a percentage of the total number of non-zero entries in that category. This ensured that the lowest rank in each category was always 100, regardless of the number of plants in that category while the interval between successive ranks varied depending on the number of plants in the category. For example, for a category containing 100 plants the interval between successive ranks would be 1 and the plant with the best performance would receive a rank of 1. For a category containing only 50 plants the interval between successive ranks would be 2 and the plant with the best performance would receive a rank of 2. Each plant was given a score based on its ranking relative to other plants in its industry on a number of different performance measures.

For the purposes of this exercise it was decided that the emphasis should be on those measures of operating performance that are most directly under the control of operations managers. Profitability and other financial measures were rejected, as they are difficult to assess at plant level, being heavily dependent on transfer prices between plants. Such measures are also determined by the activities of many functions, not just operations. A survey of the literature suggested that there is general agreement that the following measures of performance are most directly under the control of operations management personnel at plant level.

Productivity
Quality consistency
Customer lead times
Delivery reliability

While this list cannot claim to be comprehensive, it was felt that an understanding of the drivers of these performance measures would be a useful first step. Subsequent research could then extend this understanding to encompass a wider-ranging and more comprehensive set of performance measures.

The next problem was to identify suitable quantitative measures of each of these aspects of performance that were reasonably objective and could be readily derived from the information in the database. It was also important that the measures used should provide a valid basis for comparisons between plants.

Productivity

Identifying a common measure for productivity for all plants in the database is difficult because of differences in the valuation of inputs and outputs between plants. The only productivity measure that could readily be derived from the responses to the Best Factory Award questionnaire was manufacturing added value per £ of employee cost and so this was used.

Quality consistency

Three measures of quality consistency were available. These were as follows,

% scrap or % below ideal yield rate
% first time pass rate
% customer returns or complaints

The first two of these measures were thought to be internal performance drivers rather than external measures of quality consistency and so the measure of quality consistency used was % customer returns or complaints in the last 12 months.

Customer lead times

The Best Factory Awards questionnaire provides three measures of lead-time.

What is the shortest lead-time quoted to the customers in days?
What is the average lead-time quoted to the customers in days?
What is the longest lead-time quoted to the customers in days?

It could be argued that a more appropriate measure would have been based on actual customer lead times being achieved. It was felt that this could confuse speed of delivery and reliability of delivery. Customers tend to choose suppliers on the lead-time quoted (speed of delivery) and the likelihood of that lead-time being achieved (reliability of delivery). For this research, therefore, average customer lead-time quoted was used as the measure of lead-time. The average was used as it represented the most typical customer lead-time for that plant.

Delivery reliability

Two measures of delivery reliability were available.

% service level ex-finished stock
% delivery on time.

As both measures are aspects of delivery reliability, both might have been used in the analysis. However, the two measures have different characteristics. Plants that make for stock are, to some extent, de-coupling the relationship between delivery performance and the other aspects of performance. Ex-stock performance will be almost entirely a function of the plant's ability to predict customer requirements and the amount of finished stock that they hold. Percentage delivery on time is much more directly affected by the other aspects of plant performance and so this was the measure that was used.

For each performance measure a high ranking (close to 1) meant good performance. What was meant by good performance on each factor is indicated below.

Productivity	High manufacturing added value per £ of employee cost
Quality consistency	Low % customer returns or complaints in the last 12 months
Customer lead times	Low average lead-time quoted to customers
Delivery reliability	High % of items delivered on time

The rankings were then added to give a composite performance score (COMP) with all measures being given the same weighting. The value of this composite performance score was then used to divide the complete set of plants into three equal-sized groups of high performers, medium performers and low performers. The values of the COMP scores necessary to ensure that the three groups were of equal size were as follows.

Group 1 (high performers): COMP<217.0
Group 2 (medium performers): COMP between 217.0 and 297.5
Group 3 (low performers): COMP>297.5

COMPARISON OF HIGH AND LOW-PERFORMING PLANTS

The next step in the research was to identify differences in performance between those plants whose overall ranking on operating performance measures was high (Group 1), and low (Group 3). The expectation was that those factors for which the differences in the means were significant would be consistent with the hypothesis stated earlier. However, it was considered that all significant differences between high and low-performing plants should be identified as this might suggest further alterations and improvements to the model presented earlier. Therefore, for the complete set of 191 questionnaire variables in the database, the means and standard deviations of each questionnaire variable were calculated for the two groups. Differences between each pair of means were then tested for significance: the larger the absolute value of the Z-value, the greater the significance. A Z-value of at least 2.58 is needed for a difference to be statistically significant at the 0.01 level and this was set as the minimum level for significance.

In the model developed in this paper, four performance drivers and two intermediate measures have been identified; all of which should be associated with high levels of operating performance.

Performance drivers:	High adherence to schedule Low process time variability High reliability of delivery by suppliers Low variability in process output
Intermediate measures:	Faster throughput times Lower stock levels

We would expect performance on these factors to be significantly better for high-performing plants than for low-performing plants. The actual results are summarised below.

High adherence to schedule

High-performing plants achieved an average adherence to schedule of 93.3% while low-performing plants only achieved an average adherence to schedule of 76.0%. This represents a difference of 4.0 standard errors, which is significant at the 0.00006 level, providing strong evidence for the proposed model.

Low process time variability

Unfortunately the database does not provide a direct measure of process time variability. However, respondents are asked to rate their plant out of 10 (10 = perfect, 1 = poor) on process dependability, that is, the extent to which planned production and actual production match in terms of quantity and timing. High-performing plants achieved an average score of 8.13 while low-performing plants achieved an average score of 6.95. This represents a difference of 6.72 standard errors, which is very highly significant (significance level 0.00000). Obviously, this is a subjective rather than an objective measure but it does provide limited support for the proposed hypothesis.

High reliability of delivery by suppliers

For high-performing plants 90.9% of deliveries by their suppliers were on time while the corresponding figure for low-performing plants was 81.0%. This represents a difference of 3.84 standard errors, which is significant at the 0.0001 level.

Low variability in process output

The Best Factory Awards questionnaire includes two measures of process output variability. These are scrap rate and first time pass rate. As one of the components of the basis for classifying the plants into categories was % customer returns it would not, perhaps, be too surprising that plants in the high performance category had lower scrap rates than plants in the low performance category. This is confirmed by the results. The scrap rate for the high-performing plants was 1.7% while the scrap rate for the low-performing plants was 9.2%. This represents a difference of -6.56 standard errors, which is very highly significant (significance level 0.00000). However, the difference in the first time pass rates for the two groups of plants was surprisingly low. High-performing plants achieved a first time pass rate of 95.0% and low-performing plants achieved a first time pass rate of 92.5%. This is a difference of only 1.52 standard errors, which is not statistically significant (significance level 0.13).

Lower stock levels

Table I compares weeks of usage for each category of stock for Groups 1 and 3.

Table I: Stock Levels in Weeks of Usage for Groups 1 and 3

Description	Group 1 (high perf.)	Group 3 (low perf.)	Z-value	Significance of difference in means
raw materials	4.08	9.02	-4.18	0.0000
bought out components	5.74	7.95	-1.9	0.056
work in process	3.75	6.12	-2.28	0.023
finished goods	5.18	4.67	0.49	0.624

This provides mixed support for the proposition that high-performing plants operate with less stock than low-performing plants. While the differences in raw materials stock are highly significant, there is no significant difference in the levels of finished goods stocks. In fact, low-performing plants have slightly less weeks of finished goods stock than high-performing plants.

Faster throughput times

Table II compares processing lead times for high and low-performing plants.

Table II: Comparison of Processing and Manufacturing Lead Times in Days for Groups 1 and 3

Description	Group 1 (high perf.)	Group 3 (high perf.)	Z-value	Significance of difference in means
Shortest man LT	2.76	7.78	-3.33	0.0009
Av. Man. LT	6.57	17.85	-5.20	0.0000
Longest man. LT	17.11	37.29	-4.24	0.0000
Av. Processing time (hrs.)	19.29	59.25	-2.25	0.024
Av. Assy. LT	2.82	9.22	-4.66	0.0000
Longest assy. LT	6.26	19.75	-4.73	0.0000

With one exception, the differences have significance levels in excess of 0.001. Even in the case of average processing time the difference is still fairly significant but does not meet our minimum requirement for significance of Z = 2.58.

OTHER DIFFERENCES BETWEEN HIGH AND LOW-PERFORMING PLANTS

Overall, then, there is substantial support for the proposed hypothesis. Are there other differences between high-performing and low-performing plants that might throw further light on the key performance drivers?

Differences in measurement of reliability and uncertainty levels

One area where a difference was observed was in the extent to which plants measured current levels of reliability. Table III shows the percentages of plants in each of the three groups that measure each aspect of performance.

Table III: Percentage of Plants Measuring Each Aspect of Performance

Performance Measure	Group 1 (high perf.)	Group 3 (low perf.)	Z-value	Sig.
% supplier delivery on time	72.9	63.3	1.17	0.242
output volume	99.1	99.2	-0.08	-0.936
schedule adherence	84.6	67.7	2.87	0.004
ex-stock availability	88.0	67.6	3.18	0.001
due date reliability	100.0	100.0	0	1
stock record accuracy	92.6	75.0	4.23	0
scrap rate	100.0	98.0	1.74	0.082
time on rework	61.0	56.4	0.80	0.424
time spent on changeovers	59.4	53.4	1.03	0.303
customer returns	98.6	91.2	2.92	0.004
first time pass rate	79.1	55.0	3.82	0.0002

Five of these measures show differences between the percentages that are significant at the 0.01 level and all are concerned with some aspect of the reliability and predictability of processes and procedures.

Labour costs

Table IV shows the differences in labour costs as a percentage of total manufacturing costs.

Table IV: Labour Costs as a Percentage of Total Manufacturing Costs

Description	Group 1 (high perf.)	Group 3 (low perf.)	Z-value	Significance of difference in means
Direct labour	10.73	15.83	-5.91	0.0000
Indirect labour	3.24	6.05	-5.84	0.0000
other labour	5.73	9.22	-4.30	0.0000

These results provide strong evidence that high-performing plants spend a lower percentage of their manufacturing costs on labour than low-performing plants. There could, of course, be many other reasons for the difference. The levels of capital intensity could be different, for example. However, this particular reason is unlikely, as there is no significant difference in the percentage of manufacturing costs devoted to depreciation for high and low-performing plants.

Differences in ratings on world class performance

As part of the questionnaire, plants are asked to rate themselves on a scale from 1 (poor) to 10 (perfect) on a number of indicators usually associated with world class performance. Mean ratings for the complete set of factors are shown in Table V.

Table V: Differences in World Class Rating Assessments between Groups 1 and 3

Factor	Group 1 (high perf.)	Group 3 (low perf.)	Z-value	Significance of difference in means
Process dependability	8.13	6.95	6.72	.000000
Throughput efficiency	7.92	6.77	6.45	.000000
Change as a way of life	7.82	6.62	6.10	.000000
Labour flexibility	7.99	6.83	5.94	.000000
Emphasis on process eng.	7.98	6.87	5.79	.000000
Employee involvement in Continuous Improvement	7.23	6.17	5.15	.000000
Plant cleanliness	7.77	6.92	5.07	.000000
Documentation accuracy	8.42	7.51	4.69	.000003
Use of labour brainpower	7.28	6.34	4.65	.000003
Training	7.29	6.34	4.47	.000006

All of these differences are very highly significant. Either the high-performing plants are consistently more generous in their ratings than the low-performing plants or the high-performing plants are genuinely better at all of these factors. The former is unlikely as Voss et al in their surveys, Made in Britain (Voss, 1994) and Made in Europe (Voss, 1995), found the reverse to be true. They found that it was the badly performing plants with poor practices in place that were unjustifiably optimistic about their performance. The most significant difference between high and low-performing plants is for process dependability. This is in agreement with the model developed in this paper.

Deliveries to customers

Category 1 plants were much more precise about delivery dates promised to customers with a much higher percentage of cases where delivery was for a specific time of day (Z= 4.09) and a much smaller percentage where delivery was for a specific week ending date (Z= -2.73).

Emphasis on performance improvement

While there is no significant difference in the percentage of each type of plant with formal problem solving groups, the percentage of production employees involved in these groups is significantly higher for Category 1 plants (Z= 3.69).

Capacity utilisation

Category 1 plants use their capacity more productively.

Table VI: Comparison of capacity usage for Groups 1 and 3

Item	Z-value	Significance of difference in means
% of capacity used for changeovers	-3.37	0.0008
% of capacity used for reprocessing	-2.85	0.0044

Surprisingly, differences in actual changeover times are less distinct. None of the differences in average changeover times showed a significant difference at the 0.01 level.

Levels of unpredictability

One question in the survey asks plants to assess the unpredictability of various aspects of their business environment. With only one exception, there was no significant difference in the degree of unpredictability of the environments in which high-performing and low-performing plants operate. In other words, the observed differences in performance between high and low-performing plants are not due to high-performing plants operating in business areas, which are mature and non-volatile. The exception was raw material/component availability for which low-performing plants gave a higher estimate of unpredictability (Z= -2.93, significance level = 0.003). This is consistent with our expectations. One of the ways in which plants are likely to reduce uncertainty is to form closer links with suppliers. One of the benefits of this should be less unpredictability about availability of raw materials and bought out components.

DIFFERENCES IN CHARACTERISTICS OF HIGH AND LOW-PERFORMING PLANTS

One concern in this type of analysis is that the differences being observed between the plants are merely a consequence of the types of plants in the two groups being different. In other words we might not be comparing like with like. For example, high-performing plants might all be making a few, simple products in high volume; whereas low-performing plants might be making very complex products with every product having a different specification. A number of potential differences were identified and the results are displayed in Tables VII and VIII. Table VII considers nominal variables.

Differences in the frequency distributions of these variables were compared using the chi-squared test. Table VIII considers ordered variables. Differences in these variables were compared by testing the significance of differences in the means of the two.

Table VII: Differences between Nominal Variables for Groups 1 and 3

Description	Significance
Who owns the plant?	0.001
No. of plants owned by parent company	not sig.
Is no. of employees above or below 500?	not sig.
Industrial category	not sig.

Table VIII: Differences between Ordered Variables for Groups 1 and 3

Description	Significance of differences in means
Area of plant	0.080
No. of employees	0.865
% of output as capital goods	0.165
% of output as intermediate goods	0.042
% of output as consumer goods	0.317
total items at product level	0.303
No. of components in main product	0.234
No. of customers who are third parties	0.168
No. of customers who are own company distribution points	0.503
No. of customers who are other plants within company	0.697

Only one of these variables, the distribution of plant ownership, shows a difference that is statistically significant at the 0.01 level. The differences in ownership can be seen in Table IX, which shows the distribution of ownership for all three groups.

Table IX: % Distribution of Plant Ownership for Groups 1 to 3

Owner	Group 1 (high perf.)	Group 2 (medium perf.)	Group 3 (low perf.)
UK	50.7	62.9	72.2
Continental Europe	18.7	11.3	6.0
Japanese	4.0	2.0	1.3
US	14.7	16.7	9.9
Other foreign	2.7	4.0	6.0
Joint UK/foreign	9.3	3.3	4.6

This table indicates that high-performing plants are far less likely to be entirely UK owned than low-performing plants. This is consistent with the results of the Made in Europe survey conducted by Voss et al (1995). They found that, in all countries surveyed, including the UK, foreign-owned sites out-performed domestically-owned sites at every level. This could mean that UK plants perform less well than their foreign counterparts or it could be that companies with high performance are more likely to be operating internationally rather than locally.

CONCLUSIONS

The results obtained provide support for the hypothesis that high-performing plants utilise processes and procedures that have lower levels of variability and uncertainty than low-performing plants. There is general support for most elements of the model that has been proposed. All of the performance drivers in the model (high adherence to schedule, low process time variability, high reliability of delivery by suppliers, low variability in process output) are significantly higher for high-performing plants than for low-performing plants. Of the two intermediate measures (faster throughput times and lower stock levels), throughput times are significantly shorter for high-performing plants. However, the differences in stock levels between high and low-performing plants are not as great as might be expected. In particular the difference between the number of weeks of finished goods stocks held by high and low-performing plants is not statistically significant.
It was also surprising that the difference in first time pass rates for high and low-performing plants was not statistically significant. This is contrary to what would be predicted by the proposed model.

High and low-performing plants were not significantly different in size, in the complexity and volume of products made or in type of industry. However, high-performing plants were more likely to be owned by a foreign parent company.

SUGGESTIONS FOR FURTHER RESEARCH

While the results presented in this paper provide general support for the proposed model, there are still some anomalies that require further research. The most important topic requiring further investigation is the relationship between the performance drivers in the model and plant stock levels. Also, the reasons for the small difference in first time pass rates for high and low-performing plants would merit further investigation. In developing the model, the set of external performance measures included was deliberately restricted. Further research is needed to extend the model to encompass a wider-ranging and more comprehensive set of external performance measures.

The research described in this paper looks at the performance of the plants surveyed at a particular point in time. However, the model presented can be interpreted dynamically. It implies that as plants progressively reduce their levels of variability and uncertainty, simultaneous improvements in labour productivity, speed and reliability of delivery and quality consistency will be observed. In order to test this, longitudinal studies could be carried out on a few plants, monitoring changes in variability, uncertainty and operating performance over time. There are some practical difficulties with longitudinal studies, as they would need to be extended over several years. However, even when studied over a short period, the insights gained from the detailed observation of a small number of plants would help to establish more precisely the mechanisms whereby reductions in levels of variability and uncertainty lead to improved operating performance. This should enable the model presented to be further improved.

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Appendix 9

Best Factory Awards Questionnaire

Management Today
Best Factory Awards Audit 1996
In Association with Cranfield School of Management

Best Factory Awards Audit

This self-administered Best Factory audit report has been developed by Cranfield School of Management. The audit is designed to help businesses view their manufacturing operations in relation to international standards of excellence and thus enable them to initiate in-house action plans in order to achieve world class manufacturing standards.

The scheme is endorsed by the Department of Trade and Industry, Confederation of British Industry, The Institute of Management, Engineering Employers Federation, Institution of Electrical Engineers, and The Industrial Society.

Management Today Best Factory Awards

All plant audit questionnaires will be analysed and an individual feedback report will be prepared for each participating plant which identifies key areas for possible future action. In addition a number of the best performing plants will be selected for a site visit and a more extensive physical audit by the Best Factory Awards team of assessors from Management Today and Cranfield School of Management.

Winners will be announced at the Management Today Best Factory Awards lunch at The Savoy, Strand, London WC2 on October 31, 1996 where the following awards will be presented:

The Engineering Industry Award
The Electronics Industry Award
The Process Industry Award
The Household Products Industry Award
The Best Small Company Award
The Most Improved Factory Award
The Judges Special Award
The Factory of The Year Award

Completing the Audit

The audit forms have been designed for simplicity in completion but in order to ensure comparability across plants detailed definitions are supplied where necessary: please read these carefully before completing the appropriate sections.

Please complete the audit form exactly as set out without amalgamating answers or entering ranges. Failure to complete the questionnaire fully may prevent you from being shortlisted and will make your feedback difficult to interpret.

We believe and sincerely hope that your company will benefit from completion of the actual audit itself so please do not be daunted by the level of information required.

Eligibility

The entry unit for the awards is a manufacturing plant in the UK. A "plant" is defined as a relatively self contained unit with its own management staff which may be identified either by separate facilities, by separate product types, or by a separate management structure. Several "plants" may operate at the same physical location or site and may share some facilities.

Confidentiality

All information contained in the audit reports or obtained during site visits will be regarded as confidential. As soon as audit reports are received by Cranfield they will be identified by code number only. No company specific information will be released or used for any purpose other than the evaluation process without the express consent of the applicant.

Office Use Only Audit Ref.	

ALL QUESTIONS RELATE TO THE SINGLE PLANT TO BE AUDITED EXCEPT WHERE SPECIFIED OTHERWISE

A: THE PLANT PROFILE

A1 **Is the plant owned by (Please tick one box only)**

A Publicly Quoted UK Parent Company	☐ 1	
A Privately Owned UK Parent Company	☐ 2	
A Continental European Parent Company	☐ 3	
A Japanese Parent Company	☐ 4	
A US Parent Company	☐ 5	
Other Foreign Parent Company	☐ 6	
Joint UK/Foreign Parent Company	☐ 7	1

A2. **How many plants does the parent company control worldwide? (Please tick one box only)**

1 only	☐ 1	
2	☐ 2	
3	☐ 3	
4	☐ 4	
5	☐ 5	
6 - 10	☐ 6	
11 - 20	☐ 7	
more than 20	☐ 8	2

A3. **Does your TOTAL number of COMPANY employees exceed 500? (including <u>all plants</u>, holding company employees etc.)**

Yes ☐ 1 No ☐ 2 3

A4. **What is the total area of the plant buildings?**

Square Feet ☐ Or Square Metres ☐ 4

B: NATURE OF MANUFACTURING OPERATIONS

B1. **What proportion of the plant's output (at manufacturing cost) falls into these four categories (a,b,c,d below):**

(a) Sales Catalogue item ☐ % 5

For what proportion of this output is the customer lead time determined by:

1.	The Customer	%	6
2.	Yourself as supplier	%	7
3.	Negotiation	%	
		100%	

(b) Sales Catalogue with Customer Choice Options ☐ % 8

For what proportion of this output is the customer lead time determined by:

1.	The Customer	%	9
2.	Yourself as supplier	%	10
3.	Negotiation	%	
		100%	

(c) Customer specific design to repeat orders ☐ % 11

For what proportion of this output is the customer lead time determined by:

1.	The Customer	%	12
2.	Yourself as supplier	%	13
3.	Negotiation	%	
		100%	

(d) Unique Customer specific design ☐ % 14

For what proportion of this output is the customer lead time determined by:

1.	The Customer	%	15
2.	Yourself as supplier	%	16

3. Negotiation

%
100%

Total (a) + (b) + (c) + (d) = 100%

B2. What proportion of the plant's output (at manufacturing cost) falls into the following categories:

Capital Goods	(equipment used by other businesses as capital assets)	%	17
Intermediate Goods	(components, supplies etc. used by other businesses to produce their products)	%	18
Consumer Goods	(products for sale to the user, general public)	%	19
		100%	

B3 Complexity Factors

B3.(a) How many different item records are currently 'live' (in use) within the plant?

At product level (as sold to customers) [ ] 20

At manufactured component, bulk intermediate or sub-assembly level (do not include finished products or raw materials) [ ] 21

At bought out component or sub-assembly level (as purchased from suppliers but <u>not</u> including raw materials) [ ] 22

At purchased raw material level for processing by yourselves [ ] 23

B3.(b) How many <u>different</u> manufactured components, purchased items or purchased assemblies are there in the product which has the largest output (at manufacturing cost) in the plant? [ ] 24

B3.(c) In relation to <u>all</u> products produced in the plant over the last year:

How many products were in continuous production in the plant? (runners) [ ] 25

How many different product types (of known design) were produced intermittently/from time to time in the plant? (repeaters) [ ] 26

How many different product types (of initially unknown design) were produced in the course of the year in the plant? [ ] 27

B4. Manufacturing lead times and customer delivery lead times
(N.B. 1 week = 7 days is assumed)
We have separated manufacturing lead times into 3 stages:

1. Material procurement	2. Component or intermediate bulk manufacture	3. Final assembly or packaging
e.g: External purchasing of • Raw materials • Components • Ingredients • Packaging	e.g: • Individual component production • Bulk product manufacture pre-packaging • Piece part knitting/cutting	e.g: • Mechanical assembly • Food packaging • Garment making up

For the product which has the largest output (at manufacturing cost) in the plant:

B4. (a) What is the planned procurement lead time for the main (or most significantly constraining) bought out item/material: [ ] Days 28

B4. (b) Answer this section if as part of the manufacturing lead time you manufacture components, intermediate or bulk products.

(i) What is the planned component (or intermediate/bulk product) manufacturing lead time for:

The shortest manufacturing lead time		Days	29
The average manufacturing lead time		Days	30
The longest significant manufacturing lead time		Days	31

(ii) For the average (or typical) component (or intermediate) given above: what is the actual processing time (i.e. time in/on a machine or being hand processed) for the normal production batch quantity of the item? This time should represent the minimum elapsed time in which the batch could be manufactured in an empty factory without ANY queuing, waiting or transport time (It will usually be close to the standard hour content of the batch).

Processing time for the Average lead time item	Hours	32

(iii) How many hours per week does the component or bulk manufacture part of the plant normally work?
e.g.: 5 days x 8hrs/day = 40 hours/week

	Hours per week	33

B4.(c) Answer this question if as part of the manufacturing lead time you carry out assembly or packaging operations.
(i) What is the planned assembly (or final packing) lead time for:

The average assembly lead time item	Days	34
The longest significant assembly lead time item	Days	35

B5. What are the quoted Customer Delivery lead times over all products produced:

The shortest customer lead time quoted	Days	36
The average customer lead time quoted	Days	37
The longest customer lead time quoted	Days	38

B6. What proportion of the plant's total output (at manufacturing cost) is supplied to customers (in this question manufacturing lead time is the total component/intermediate and final assembly/packaging lead time):

Off the shelf (ex-finished goods stock)	(A)	%	39
On a quoted lead time shorter than the actual manufacturing lead time (i.e. assemble-to-order, pack-to-order)	(B)	%	40
On a quoted lead time equal to or longer than the actual manufacturing lead time (through engineering design work or backlog for example)	(C)	%	41
Total output of plant	(A)+(B)+(C)=	100%	

B7. For the proportion of output supplied on a quoted lead time (category B and/or C above):

B7.(a) For what proportion of the output supplied on a quoted delivery date is this date mainly determined by:

Customer requirements	%	42
Capacity/scheduling constraints in your plant	%	43
Material availability in the supply chain	%	44
Design availability	%	45
Total output supplied on a quoted lead time	100%	

B7. (b) What does a quoted delivery date to a customer (supplied on a quoted lead time) mean in your plant?

	% of output	
Specific week ending date	%	46
Specific day date	%	47
Specific time(s) of day (delivery slot)	%	48
Other (please specify)	%	49
	100%	

B7. (c) What are the major factors which facilitate good delivery performance in your plant:
(Please rank from 1-7, where 1=most important and 7=least important)

	Rank (1-7)	
Excess capacity		50
A reliable supply chain		51
Workforce flexibility		52
Reliable processes		53
Quick changeovers		54
Responsive planning and control system		55
Other (please specify)		56

B8. **Set-up and Changeover Times**

How long does a typical changeover between products or batches take? e.g: time to reset line, tools/dies, clean and recharge etc.

	Minutes			
	Shortest	Average	Longest	
In Component/Intermediate Manufacture				57,58,59
In Assembly/Packaging				60,61,62

B9.(a) **Number of customers**
How many different customers does your plant ship to:

	Number	
Third party customers	%	63
Your own company distribution points	%	64
Other plants within your own company	%	65

B9.(b) **What percentage of turnover by value do they represent?**

	% of turnover	
Third party customers	%	66
Your own company distribution points	%	67
Other plants within your own company	%	68

B10.(a) **Number of suppliers**
How many suppliers do/did you have for manufacturing purposes:

	Number	
Currently		69
In 1994		70
In 1992		71

B10(b) **What proportion of your suppliers currently deliver to you:**

Daily	%	72
Twice weekly	%	73
Weekly	%	74
Monthly	%	75
Less frequently than monthly	%	76
	100%	

B10.(c) **Do you formally measure the delivery performance of your suppliers?**

Yes [ ] 1 No [ ] 2 77

If yes what is the current overall delivery performance?

[ ] % on time 78

C: COST STRUCTURE

C1. **The Manufacturing Cost Structure: Please give the breakdown for your most recently <u>completed</u> budget year, giving a figure for each separate section wherever possible:**

Tick the appropriate box to indicate the <u>units</u> in which your cost structure is expressed below:
(Tick one): £000's [ ] **£millions** [ ]

Bought out raw materials	(a)		79
Purchased components, assemblies & packaging	(b)		80
Energy costs	(c)		81
Bought out services (rent, rates, equipment hire etc.)	(d)		82
Direct labour	(e)		83
Indirect factory labour	(f)		84
All other labour (including staff and managerial)	(g)		85
Depreciation charges	(h)		86
Other	(i)		87
Total value of manufacturing output at cost (sum of (a) to (i)			88

Other costs associated with this output (design, marketing etc.)		89
Net profit before Interest and Tax		90
Sales Value of this output		91

Amount owing to your suppliers at the end of the most recently completed budget year		92

Total value of manufacturing output at cost expected:		
- in current budget year		93
- in next budget year		94

C2. **How has the unit cost for the product which has the largest output (at manufacturing cost) changed over the last two years:**

Unit cost has: (please tick one box only)

Decreased by	More than 20%		1	
	10 - 19%		2	
	5 - 9%		3	
	Less than 5%		4	
Remained the same			5	
Increased by	Less than 5%		6	
	5 - 9%		7	
	10 - 19%		8	
	More than 20%		9	95

D: INVENTORY PROFILE

Please give details relating to the most recent complete budget year:

D1(a) What was the average level of inventory investment for the following five categories:

Tick the appropriate box to indicate the units in which your average inventory value is expressed below:

Tick one: £000's ☐

£millions ☐

	£ Average value over year	Weeks of Usage	
Raw Materials			96,97
Bought out Components and Assemblies etc.			98,99
Work in Process including: • Components/intermediates in manufacture • Finished components or intermediates awaiting assembly or packing • Assembly/Packing			100,101
Finished Goods Ready for Sale			102,103

D1.(b) If your business is highly seasonal what degree of deviation + or - is there around the above figures

\+
\- % 104

D2. How has this inventory profile changed over the last two years:

Average Inventory has: (Please tick one box only)

Decreased by	More than 50%		1
	25 - 50%		2
	10 - 24%		3
	Less than 10%		4
Remained the same			5
Increased by	Less than 10%		6
	10 - 24%		7
	25 - 50%		8
	More than 50%		9

105

E: EMPLOYEE PROFILE

E1. **Current Profile across the Plant (in terms of Full Time Equivalent employees, include all temporary or contract employees):**

			No. of FTE's	
Plant Management & Supervisory		(a)		106
Technical Support	Manufacturing, Industrial and/or Process Engineering, support staff	(b)		107
Materials Management	Planning, Scheduling, Order Processing Production and Inventory Control, Purchasing, Warehouse Operations	(c)		108
Quality Management	Quality Control, Management and Audit	(d)		109
Other Indirect Support	(please specify here)	(e)		110
Direct Value Adding Production Employees	Component or Intermediate Manufacturing, Assembly and/or packaging	(f)		111
Total Production Related (a+b+c+d+e+f=g)		(g)		112
Design	Product Design and Development			113
Other	All other support activities including: Personnel Accounting etc.			114
Total Employees				115

E2. What proportion of Direct Value Adding Production Employees (see f above) are temporary or contract employees? [%] 116

E3. For Total Production related employees (see g above):

EMPLOYEE PROFILE		Numbers of employees	
(a) By Age	Under 30 yrs	%	117
	30 - 40	%	118
	41 - 50	%	119
	Over 50	%	120

(b) Average Length of Service:	Years	121
(c) Average Rate of Absenteeism:	%	122
(d) Average Annual Turnover Rate:	%	123

E3. (e) Over the last two years Total Employee numbers have:
(Please tick one box only)

Decreased by more than 20%	1	
Decreased by less than 20%	2	
Remained static	3	
Increased by less than 20%	4	
Increased by more than 20%	5	124

E4. What is the average number of days training received per employee per year?

	On job training	Off job training		
New starters			Days	125,126
Existing employees			Days	127,128

E5. What percentage of the production employees can carry out more than 50% of the production tasks in their area ____ % 129

E6. (a) Employee Involvement
Do you run an employee suggestion scheme?

Yes ☐ 1 No ☐ 2 130

If yes what was the number of suggestions per employee per annum in 1995 ☐ 131

What type of reward was offered as part of the scheme (tick one box):

Substantial financial reward	1	
Small financial award	2	
Token reward only	3	
No reward	4	132

E6. (b) Are Production Employees involved in formal Problem Solving Groups?

Yes ☐ 1 No ☐ 2 133

If yes, what proportion of production employees are involved as a percentage of total production employees ____ % 134

Are groups (tick one box):

Temporary	1	
Permanent	2	
Both	3	135

How frequently do they meet (tick one box)

Daily	1	
2-3 times per week	2	
Weekly	3	
Less frequently	4	136

Are group leaders (Tick one box)

Appointed by management	1	
Elected by group	2	
Rotated within group	3	
Other	4	137

F: PRODUCT INNOVATION

A __significantly__ new product is one which the plant has __not__ made previously and which represents __more__ than a simple change of material, colour or design variant. For example, in garment manufacturing a pair of trousers made in a new material would __not__ be regarded as significant. However, if the trouser manufacturer started making overcoats this __would__ be regarded as significant for the plant.

F1. How long does it typically take to bring significant product innovation to market (from start of detail design to market launch)? [months] 138

F2.(a) How many significantly new products (not including material or minor model changes) have you launched in the last 5 years? [months] 139

F2.(b) Of these new products how many would you regard as:

Extensions to existing product range(s)		140
Totally new (to plant) product range(s)		141
Other (please specify)		142

F2.(c) How many significantly new products (not including material or minor model changes) do you expect to launch in the next 5 years? [ ] 143

F3. For those products made to a unique customer specific design,

What is the typical level of (please circle one of the numbers on the scale for each item)?

	Low				High	
Technological novelty	1	2	3	4	5	144
Specific Applications Engineering	1	2	3	4	5	145
Number of drawing changes required	1	2	3	4	5	146
Use of new materials	1	2	3	4	5	147

G: Management Information

Is this factor measured formally on a regular basis (Tick Yes or No for each factor). If yes then please give current levels unless otherwise requested:

Performance Factor

G1 Output Volume — Yes [ ] 1 No [ ] 2 — Output per Week [ ]
Units of Measurement [ ] 148,149,150

G2. Production schedule adherence — Yes [ ] 1 / No [ ] 2 — % Schedule Adherence: in 1994 [ ] Current [ ] 151,152,153

G3. Delivery Performance

(a) Ex-stock Availability (For items on ex-stock supply) — Yes [ ] 1 / No [ ] 2 / N/A [ ] 3 — Service Level ex-finished stock: in 1994 [ ] current [ ] 154,155,156

(b) Due-date Reliability (For items on quoted lead times) — Yes [ ] 1 / No [ ] 2 / N/A [ ] 3 — % Delivery 'on time': in 1994 [%] current [%] 157,158,159

G4. Inventory Record Accuracy — Yes [ ] 1 / No [ ] 2 — % Correct [%] 160,161

G5. Scrap or Yield Loss Rate — Yes [ ] 1 / No [ ] 2 — % Scrap or % below ideal yield rate: in 1994 [ ] current [ ] 162,163,164

G6. Time spent on Rework/Reprocessing — Yes [ ] 1 / No [ ] 2 — % Capacity used for Reprocessing [%] 165,166

G7. Time spent on Setting/Changeover — Yes [ ] 1 / No [ ] 2 — % Capacity used for Changeover [%] 167,168

G8. Customer returns (or complaints) for quality reasons — Yes [ ] 1 / No [ ] 2 — % Returns: in 1994 [%] current [%] 169,170,171

F9. First time pass rate at final test — Yes [ ] 1 / No [ ] 2 — Current [%] 172,173

H: Market Positioning

For the product group with the largest output (at manufacturing cost) in the plant:

H1. Please rank the following criteria in order of relative importance to the customer:
(1 = Greatest Importance, 7 = Least Importance)

	Rank (1 to 7)	
Quoted Delivery Lead Time		174
Reliability of Delivery Date or Service Level		175

Product Features or Performance		176
Technical Support		177
After Sales Service		178
Brand Image/Reputation		179
Price		180

H2. What relative emphasis do your <u>auditable</u> plans for the next two years place on each of the following areas in order to give your plant a competitive advantage? Please rank the areas in order of priority (1 = Great Importance, 7 = Least Importance)

	Rank (1 to 7)	
Rapid Product Design Change		181
Consistent Quality		182
Short Delivery Lead Times		183
Dependable Delivery Dates		184
After Sales Service		185
Improved Product Performance		186
Manufacturing Cost Reduction		187

H3. Over the next six months what is the degree of unpredictability for the following (please circle one number for each)

	Highly Predictable				Highly Unpredictable	
Customer demand levels	1	2	3	4	5	188
Competitor activity	1	2	3	4	5	189
Raw material prices	1	2	3	4	5	190
Raw material or component availability	1	2	3	4	5	191
Legislative environment	1	2	3	4	5	192

H4. The General Characteristics of your Plant:

Please score your plant out of 10 (10=Perfect, 1=Poor) on each of the following characteristics. Your score should reflect your view of your own plant in relation to what you think should be possible in your industry:

1. The plant is clean, tidy and uncluttered. A place for everything and everything in its place. [ ] 193

2. Plant performance is based upon the dependability of the process (not on output alone). Do the performance measures used relate to whether you did exactly what you said you would do in terms of quantity and timing? [ ] 194

3. The Process documentation is accurate, detailed and used. If a competent operator did it according to the process specification would it work? [ ] 195

4. Process Engineering is regarded as important to performance. Continuous effort is focused on process improvement. [ ] 196

5. Material moves very quickly through the process. Short throughput or lead times are important. [ ] 197

6. Employees have very broad work task definitions. High levels of labour flexibility across skill ranges. [ ] 198

7. <u>All</u> employees are committed to continuous improvement on <u>all</u> performance factors. [ ] 199

8. Training and competence is emphasised throughout the plant. High levels of cross training are present, skill matrices monitored. [ ] 200

9. Labour is primarily regarded as a source of brainpower not just muscle power. All the labour force is involved in process improvement. [ ] 201

10. Employees accept that change is a way of life and that learning "on the run" is the norm. [ ] 202

Total Score (Maximum 100) [ ]

H5.(a) Please give a brief description of the kinds of products which the plant manufactures e.g. plastic components for automotive industry, chemicals for pigment manufacture, domestic washing machines.

____
____
____
____

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H5.(b) Please give a brief description of the main manufacturing processes involved.

<u>Primary Processing Stages</u>
eg. Component machining, ingredient mixing, distillation, bulk chemical synthesis, fabric manufacture and processing, printed circuit board assembly.

____
____
____

<u>Secondary Processing Stages</u>
e.g. Product assembly, product packaging, cutting and finishing.

____
____

____

____

H6. **Please state briefly the areas in which you think your plant is particularly strong and indicate any major improvements which have been made over the last two years.**

____

____

____

____

____

H7.(a) **When manufacturing investment decisions are made do you differentiate between the rate of return required for Operational Investment (eg. buying a new machine or replacing an existing one) and Strategic Investment (eg. major capital investment in new technology or a new plant)?**

Yes (we do differentiate) [ ] 1 — No (we do not differentiate) [ ] 2 — 204

H7.(b) **What was the required rate of return for the two types of investment in the year 1995?**

If you use an Internal Rate of Return criterion:

IRR for Operational Investment	%	205
IRR for Strategic Investment	%	206

If you use a Payback Period criterion:

Payback for Operational Investment	months	207
Payback for Strategic Investment	months	208

PLANT AUDITED

Company Name ______________________________

Location ______________________________

Parent company name if different from above ______________________________

Plant address ______________________________
____
____
____

Name of company contact to whom feedback report will be sent and to whom queries can be directed
____

Position ______________________________

Telephone ______________________________

Fax number ______________________________

Have you entered the Best Factory Awards previously

(Please tick the relevant boxes)

1992 ☐ 1 1993 ☐ 2 1994 ☐ 3

1995 ☐ 4

Where did you hear about the Awards? ______________________________

CONFIDENTIALITY

Please be assured that immediately on receipt of your audit questionnaire this identification sheet is removed and the data is then identified solely by the Audit Reference Number which will be assigned to it. It would be very helpful if you could send with your application a product brochure so we can better understand your plant's product portfolio.

Please return your Best Factory Audit Form together with a product brochure (if available) to:

Professor Colin New, Management Today Best Factory Awards, Cranfield School of Management, Cranfield, Bedford, MK43 0AL

DEADLINE 15TH APRIL 1996

THANK YOU FOR YOUR TIME IN COMPLETING THIS PERFORMANCE AUDIT. WE HOPE THAT COMPLETING IT HAS RAISED SOME QUESTIONS FOR YOUR PLANT TO FOLLOW UP.

YOUR COMPARATIVE BENCHMARKING REPORT WILL BE RETURNED AS SOON AS THE ANALYSIS IS COMPLETE.

FINALISTS WILL BE SELECTED IN JULY 1996

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