AN INVESTIGATION INTO AGILE MANUFACTURING DESIGN

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Baba Isaiah, Omo Atologun, Omo Maria, continue to
Rest in peace in the blossom of the Lord Almighty!

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LIST OF ABBREVIATIONS

AA	Aggregate agility (total scores on competitive objectives)
AGVs	Automated guided vehicles
AMTs	Advanced manufacturing technologies
AP	Aggregate business performance
ASRS	Automated storage and retrieval systems
CAD	Computer aided design
CAM	Computer aided manufacture
CAPP	Computer Aided Process Planning
CD	Change drivers
CE	Concurrent engineering
CNC	Computer numerical control
EDI	Electronic data Interchange
ERP	Enterprise Resource Planning
FMS	Flexible Manufacturing Systems
IMS	Intelligent Manufacturing Systems
IT	Information technology
JIT	Just in Time
MRP	Material Requirements Planning
MRPII	Manufacturing Resource Planning
OEMs	Original equipment manufacturers
OPT	Optimised Production Technology
PDM	Product Data Managers
POS	Point of sale
QFD	Quality function deployment
SMED	Single Minute Exchange of Dies
TQM	Total Quality Management
WWW	World Wide Web

GLOSSARY OF TERMS

Agile	To be agile means quick moving, nimble, active, resourceful and adaptable in character.
Agile manufacturing	It is a manufacturing operations strategy characterised by significant emphasis on structures and systems for routine adaptation to change as a means of surviving market instability.
Agile manufacturing design	Packaging and deploying appropriate tools and methods for enhancement of competitive advantage in unstable markets.
Agile supply chains	Supplier relationship that is more collaborative than contractual, designed more for co-development and manufacture as a means of mobilising global resources real time to tap temporal opportunities.
Agility	The ability to thrive and prosper in a market characterised by continuous change and to respond quickly to emerging developments driven by customer based valuing of products. For the empirical purposes of this study, agility was defined as simultaneous attainment of a wide range of competitive objectives ranging from low cost to leadership in new technology products.
Agility enablers	They consist of tools and methods that should be identified and justified as enablers of competitive advantage for companies competing in unstable markets.
Business performance measures	They are the reward for enterprise earned by a company from its stakeholders. They consist mainly of financial measures such as sales turnover and net profit and non-financial measures such as customer loyalty and market share.
Change drivers	They consist of developments outside the company such as technological advance. They affect internal operations and competitive position but nothing can be done to influence them except to be anticipatory and adaptable.
Competitive objectives	They consist of the package of values delivered to the customer. They include low cost, quality, speed, product options, reliability, leading edge features and flexibility.
Cosmetic customisation	A contingency option in mass customisation where products are differentiated based on appearance, colour, packaging and other aesthetic features that have no significant added value.

Environmental performance	A measure of the extent to which a company has succeeded in profiting from the perturbing influences of change drivers.
Flexible automation	Machines that could be manipulated, retooled and changed over to perform a range of operations. To make machines more efficient, complete off-line retool kits have become more prominent.
Intelligent automation	Machines supported by advanced network communications and distributed computer systems so that they can be programmed to conduct a wide range of machining and assembly tasks without the time and effort entailed in flexible automation.
Leadership in new technology	A manufacturing competitive objective of delivering products that seem to be ahead of their time in terms of leading edge additions to product features
Lean production	This is a manufacturing operations strategy characterised by significant emphasis on structures and systems for frugal use of scarce resources and attainment of level schedules
Lean supply chains	Supplier relationship that is more contractual than collaborative, designed more for outsourcing and distribution than for co-development and manufacture, and structured to ensure level schedule rather than tap temporal opportunities
Limited automation	A manufacturing system in which machining, assembly, inspection and packaging operations are largely manual
Limited customisation	A contingency option in mass customisation where products have a restricted range of options and features, more or less like mass production of standard products
Limited empowerment	An organisational system where employees suffer from limited initiatives, training, skills, involvement, commitment and co-operation as a means of getting things done efficiently
Mass automation	Machines that had been rigidly specified to perform a particular operation and cannot be retooled or re-programmed to do anything else. They often consist of large capacity machines used for high volume manufacture of standard products over a long period.
Mass customisation	This is an approach to competitive manufacturing characterised by continuous enrichment of customers by varying and extending the range of available product options.
Operational flexibility	Operational flexibility is the extent to which production resources can be mobilised, shed or reassigned real time without significant penalties such as time and redundancy.

Team based empowerment	A work system in which assignment of authority and responsibility relies more on peer consensus and co-operation than seniority.
Technology differentiation	A strategy for technology adoption in which technologies such as MRP, TQM, JIT, OPT and CE were perceived as options to choose from and substitute rather than learning from them incrementally and positively.
Technology integration	A strategy for technology adoption in which technologies such as MRP, TQM, JIT, OPT and CE were perceived as mutually beneficial and amenable to modular and incremental learning and integration. It is like going for the best of all worlds
Total empowerment	A work system that relies on the dignity and ingenuity of employees and therefore empowers them through training, teaming, involvement and commitment
Traditional supply chains	Conditional alliance practices which were based more on agency relationships and used by multi-national companies such as General Motors and IBM in the early 1970s to penetrate new markets especially in emerging economies
Training based empowerment	An organisational system where employees undergo series of continuous training and skill development as a means of boosting their competence and acquiring emerging skills for keeping in constant tune with changing technology and customer requirements.
Transparent customisation	A contingency option in mass customisation where products have a wide range of optional features with significant added value such as new technical functions.
Virtual cells	An approach to the design of manufacturing facilities in which product lines and cells have porous boundaries. This is in terms of inter-line movement of machines, work in process and operating capacity as a means of adjusting capacity to momentary changes in order size requirements for any line of production
Volume flexibility	Ability to manufacture small and large batches as well as small and large volumes equally efficiently.

CHAPTER ONE

INTRODUCTION

This introductory chapter discusses the meaning and essence of agile manufacturing. In addition, it reports the aims of the research and the questions and hypotheses to be investigated. Finally, the chapter examines the research protocol as the formal processes, procedures and methods adopted for the conduct of research.

1.1. MEANING AND ESSENCE OF AGILE MANUFACTURING

Companies' efforts to improve efficiency, effectiveness and responsiveness of their manufacturing systems were discernible in the emergence of computerised planning and control systems such as Material Requirements Planning (MRP), and manual engineering techniques such as Total Quality Management (TQM), Just in Time (JIT) and continuous improvement (Yusuf, 1996; Karlsson, 1996; Maskell, 2001). However, unprecedented instability now threatens the responsiveness of formal planning systems, which rely on historical data and a relatively high degree of market stability. As well, manual engineering techniques such as TQM and Just in Time systems focused exceedingly on continuous improvement of internal work processes even as external change drivers required an equal amount of emphasis. In order to remain competitive, manufacturers have to look more outwards and ensure dynamic response to developments in technology, materials and customer preferences. In this regard, structures and systems for seamless exchange of information and knowledge on replicable designs and world-class competencies are inevitable. The challenge of agile manufacturing design therefore is to put in place structures and systems supportive to timely delivery of innovative products ahead of competitors (Sheridan, 1993; Dale, 1995; Gould, 1997; Bodine, 1998; Gunasekaran, 1998, Sharifi and Zhang, 2001).

Crucial to this challenge is the need to master change through transparent added value to current products and customers as a means of surviving intense competition and market instability (Dale, 1995; Lampel and Mintzberg, 1996; Gilmore and Pine, 1997). In the circumstance, the manufacture of a few standard products as in mass production or sequential introduction of families of related products in rapid succession would not guarantee profits and market share (Pine II, et al., 1993; Lampel and Mintzberg, 1996). In addition, exclusive reliance on continuous improvement and inventory management driven mainly by low cost and level schedule objectives would not achieve significant results (Lewis, 2000; Power et. al., 2001). Although such techniques are necessary, they are inadequate for competing in unstable markets because they can lead to a fragile balance of resource capacities, which cripples robustness to accommodate change and explore windows of temporal opportunities (Sheridan, 1998; Quintana, 1998; Bartezzaghi, 1999).

As a means of remaining competitive, agile manufacturing stresses excellence on a wide range of competitive objectives rather than cost or quality alone. Most importantly, it emphasises being first to market with leading edge customised products, delivered at the cost of mass production. Such products should surpass customer expectations and be able to derail competitors plans to the extent that the products become change agents. Agility in manufacturing is therefore "the ability to produce a broad range of low cost, high quality products with short lead times in varying lot sizes and built to individual customer specifications" as a means of "surviving and prospering in a competitive environment of continuous and unpredictable change" (Fliedner and Vokurka, 1997; Gunasekaran, 1998). As an operations strategy, agile manufacturing can therefore be defined as a business-wide mindset characterised by significant emphasis on routinely adaptable structures and infrastructures and enhanced access to global competencies as a means of achieving greater responsiveness to rapidly changing customer requirements.

Several ideas on the methods and techniques of achieving the above stated goals are readily available in the literature (Sheridan, 1993; Oliver, et. al., 1996; Gunasekaran, 1998; Gunasekaran, 1999; Gagnon, 1999; Sharifi and Zhang, 2001; Fawcett and Myers, 2001). The methods and techniques include mass customisation, supply chain networking, manufacturing automation, employee empowerment and technology utilisation. What remains is to identify from the methods and techniques, deployable best practices for agile manufacturing. Before this can be done, current manufacturing practices need to be explored so that bits of agile manufacturing methods and techniques are identified and tested for their individual and collective impacts on competitive and business objectives. Hence, the design challenge is to identify, justify and deploy such methods and techniques.

1.2 AIMS OF RESEARCH

This research aims to identify agile manufacturing enablers of competitive advantage that can be deployed collectively as a means of remaining competitive and profitable in markets characterised by rapid changes. The enablers so identified are therefore the resource competencies for enhancing competitive advantage in the rapidly changing global economy (Sheridan, 1993; Gagnon, 1999; Fawcett and Myers, 2001). They will be articulated as the building blocks for agile manufacturing.

As building blocks for agile manufacturing, the resource competencies will be identified from a range of current practices in companies and tested for significant impacts on competitive and business performance objectives. The goal is to:

"... Identify correctly the distinctive capabilities that a firm can exploit for competitive advantage and then to put in place the right mix...that must lead to higher levels of performance alongside certain competitive dimensions..." (Fawcett and Myers, 2001:66).

Therefore, the study sets to identify the right mix of enabling competencies for competitive advantage under intensely competitive and unstable markets faced by agile manufacturers. The choice of research aims was influenced by several factors. They include the evolving nature of agile manufacturing, the attendant consequences of which include limited understanding and adoption of deployable enablers as well as paucity of empirical work caused perhaps by risk aversion by researchers.

Accordingly, the study investigates current practices amongst companies with a view to identify practices consistent with the principles of agile manufacturing whilst leading to superior competitive advantage. The study, which is expected to clear the way for further empirical work in agile manufacturing, has three aims as follows.

1. Justify the need for agile manufacturing.
2. Identify and justify agile manufacturing enablers of competitive advantage.
3. Identify and address any potential limitations of agile manufacturing enablers of competitive advantage.

The following seven questions emanated from the three research aims.

a. Do environmental change drivers impact significantly on business performance?
b. Does higher attainment of a wider range of competitive objectives moderate the impact on environmental change drivers on business performance?
c. What alternative practices are deployable as enablers of competitive advantage?
d. Which of the alternative manufacturing practices can be identified as agile manufacturing enablers of competitive objectives and business performance?
e. Does adoption of agile manufacturing enablers lead to superior outcomes?
f. To what extent are pressures for agile manufacturing as well as agile manufacturing enablers of competitive advantage relevant to all companies?
g. What problems arise from adoption of agile manufacturing enablers? What solutions?

The core terms in the preceding research questions such as change drivers, agility enablers, competitive objectives and business performance are explained in chapters two and three.

1.3 RESEARCH HYPOTHESES

In order to answer the preceding questions, five research hypotheses were proposed based on expected relationship amongst four concepts which are central to the debate on agile manufacturing. The concepts are change drivers, competitive objectives as a measure of agility, agility enablers of competitive advantage and business performance.

In accordance with the aims of the research, five hypotheses were proposed to test relationships amongst the four concepts as a means of answering the research questions. The five hypotheses proposed for the study are as follows.

1. There is a strong relationship between change drivers, competitive objectives and business performance.

2. Companies that pay simultaneous attention to a wide range of manufacturing competitive objectives will outperform the competition.

3. Attainment of manufacturing competitive objectives and business performance is directly related to the level of adoption of agile manufacturing enablers.

4. Demographic and industrial contingencies determine the need for agile manufacturing design and its potential impacts on competitive objectives and business performance.

5 Virtual cells enhance operational flexibility, which in turn determine attainment of volume flexibility as a competitive objective.

The hypotheses were tested based on data from a survey by questionnaire. The results confirmed that market instability was real and that the agility enablers have superior impacts on competitive and business performance objectives. However, the agility enablers did not significantly influence volume flexibility. Four in-depth case studies were conducted with a view to test the validity of survey results whilst using Hypothesis 5 to explore the exact needs of volume flexibility within the framework of agile manufacturing.

In order to ensure that the findings of the study are valid and reliable, the formal processes and procedures that are often applied in the conduct of social enquiries (research protocol) were studied before a choice on method was made.

1.4. RESEARCH PROTOCOL

Protocol is concerned with a choice of method from available options in the conduct of social enquiries. There are two main dimensions of research protocol (Eisenhardt, 1990; Gill and Johnson, 1997; Filippini, 1997). The first is a choice between deductive and inductive research. Deductive research involves the development of a theoretical and conceptual framework prior to its testing through empirical observation. In contrast, inductive research moves from empirical observation towards the construction and explanation of models and theories. The deductive method is also known as the hypothetico-deductive or the positivist/rational approach. It emphasises empirical validation and conclusions that can be generalised, based on observable facts derived from reliable measurements (Bryman, 1988: 40-41).

In spite of this distinction, the essential differences between deductive and inductive research has narrowed down, and a combination of approach has become increasingly popular (Gummesson, 1991; Yin, 1994; Filippini, 1997). Gummesson (1991: 8) argued that rather than confining research to a certain ideology, a mixed method approach serves to provide a greater degree of understanding depending on the specific aspect of the research subject being investigated. It was further argued that an exploratory study can employ whatever methods of collection and analysis are appropriate to the problem at hand, and if possible attempt to satisfy the demands of methodological pluralism by using contrasting but complementing approaches.

For the study of an evolving and poorly understood concept such as agile manufacturing, the deductive approach should be appropriate in focusing the study, gauging practitioners' opinions to identify little bits of agile practices and exploring relationships amongst concepts and variables (Gummesson, 1991; Filippini, 1997). Therefore, the research was underpinned by a conceptual framework, which was used as a theory of method (Pettigrew, 1990). Research hypotheses were formulated using the framework as a template. The hypotheses were tested based on the evidence provided by observed and analysed data. In order to capture more data and explain emerging results, four case studies were conducted.

The second dimension of research protocol involves considerations over type, source and method of data collection and analysis (Filippini, 1997; Collins and Cordon, 1997). The issues involved often boil down to an appropriate choice of data collection method from amongst direct observation, survey by questionnaire, simulation, documentary data, active participation, interviews or combinations of two or three (Filippini, 1997). Each of the methods has unique limitations under different research and demographic settings, and a researcher should use an appropriate method based on constraints over access, sample size, time, personnel and money. In most works however, discussions on the second dimension of the research protocol is often limited to making a choice between quantitative and qualitative approaches (Bryman, 1988; Gill and Johnson, 1997).

Technically, however, the distinction between the quantitative and qualitative approaches has become increasingly unpopular. Irrespective of whether a research is deductive or inductive, researchers now use both methods in order to enhance validity of results (Eisenhardt, 1989; Gummesson, 1991; Gill and Johnson, 1997). To this extent, the quantitative and qualitative approaches are supportive, and each may be useful for some purpose but useless for some other purposes (Filippini, 1997).

Accordingly, the study combined both quantitative and qualitative methods of research protocol. Research hypotheses were investigated through an industrial survey by questionnaire. The results were tested for contextual validity based on data from four in-depth case studies. The initial conceptual framework was extended to address a surprise finding from the survey results via case studies (Gummesson, 1991; Nachmias & Nachmias, 1992). Gill and Johnson (1997) recognised that the research process is not a clear-cut sequence of procedures following a neat pattern but a messy interaction between the conceptual and empirical world, deduction and induction occurring at the same time. In doing this, a researcher should not be influenced exclusively by the initial literature search but instead should be immersed in the data, which should speak using systematic analysis.

As philosophical restrictions in research protocol have narrowed down, research quality has become more important. This is in terms of operationalising concepts and reducing ambiguities, minimising sample and non-response biases, screening data, identifying useful cause and effect relationships, and ensuring that results are generalisable and replicable (Bryman, 1998). This study realised the concerns for research quality and therefore adhered to scientific methods in the planning and conduct of data collection and analysis.

Further details of procedures evoked to ensure research quality are reported in the survey reports in chapter 4 and the case study reports in chapter 5, especially in section 4.1 to 4.5 and section 5.1 and 5.2. They include tests such as construct validity, respondent bias and normal distribution. Above all, research activities were conducted as an interactive process. This started from literature review through to formulation of conceptual framework, proposition of research hypotheses, conduct of industrial surveys and case studies, documentation, conference presentation of interim results and writing up of the thesis.

1.5. STRUCTURE OF THE THESIS

The research is reported in six chapters. Chapter 2 reports the types of manufacturing systems that have emerged over time in response to higher levels of market instability and product complexity. Following next was a review of the literature of agile manufacturing with a focus on its meaning, driving forces and change initiatives. Thereafter, five dimensions of competence building in manufacturing were discussed with a view to identify contingency models from which agility enablers could be deciphered and justified. Finally, Chapter 2 presents a critique of the agility enablers and a discussion of the main issues in the lean versus agility debate.

Chapter 3 proposes a conceptual framework and research hypotheses. The conceptual framework specified expected relationships amongst four concepts, which emanated from the literature review reported in chapter 2. The four concepts namely change drivers, agility enablers, competitive objectives and business performance, as well as expected relationships amongst them were justified. Based on the relationships specified in the conceptual framework, five research hypotheses were put forward for investigation.

As a follow up to Chapter 3, Chapter 4 reports the activities, the methods and the results of a survey by questionnaire, which was conducted to test the validity of the five research hypotheses. The formal processes undertaken in questionnaire design and administration, questionnaire administration and data analysis were reported. The methods and procedures of data analysis and the empirical results were reported fully. The roles of several statistical methods used in the study were specified. They include correlation tests of the relationship amongst change drivers, agility enablers, competitive objectives and business performance, as well as factor analysis as a method of data reduction of research variables into a few principal dimensions or models. In addition, regression and path analyses were conducted to test the relationships amongst the principal dimensions or models of research variables identified through factor analysis. Furthermore, mean difference tests amongst sub-samples of companies were reported.

The empirical results in Chapter 5 were followed in chapter 6 by a report of four industrial case studies. It reports the objectives of the study. This is in addition to the methods, activities and tools involved in negotiating access to the companies as well as for data collection and data analysis. Chapter 5 also presents case-by-case summary of reports on the five companies studied. This was followed by inferences, which were made alongside the main themes and concepts under study.

Finally, Chapter 6 presents a summary and conclusions of the study. This includes its significant contributions to knowledge on the agility enablers as deployable tools and methods for advancing competitive advantage. Chapter 6 also presents a critique of methodology and results as well as suggestions for further research.

CHAPTER TWO

LITERATURE REVIEW

This chapter reports the findings of a literature search on agile and competitive manufacturing. The search was structured to achieve the following aims.

a. Justify the emergence of manufacturing systems due to changing market pressures;
b. Make a clear distinction between lean production and agile manufacturing;
c. Reveal recent threats to lean production and provide support for agile manufacturing.
d. Identify the enabling competencies deployable for agile manufacturing design.

In accordance with the aims specified above, the literature search commenced with a discussion of the types of manufacturing systems that have emerged over time as a means of coping with higher degrees of market instability and product complexity. Thereafter, the treatise focused on the concept of agile manufacturing. A working definition of agile manufacturing was adopted, and followed by a discussion of agility drivers, dimensions, change requirements, enabling competencies and a critique of agile manufacturing.

Agile manufacturing enablers of competitive advantage were identified from a study of five dimensions of competence building and their associated operational practices, which were suggested in the literature on agile manufacturing and the wider literature on competitive manufacturing. The five dimensions of competence building studied were mass customisation, supply chain networking, manufacturing automation, technology utilisation and employee empowerment. For each of the five dimensions, contingency practices analogous to or poles apart from the suggestions prevalent in the literature of agile manufacturing were identified. In accordance with the overriding aim of this study, the literature review argued that high adoption of practices analogous to the suggestions of agile manufacturing would lead to higher competitive and business performance outcomes.

2.1. TYPES OF MANUFACTURING SYSTEMS

This section discusses and relates five major types of manufacturing systems that have emerged over time as alternative operations models for coping with increasing levels of market instability and product complexity. Such increases in market instability and product complexity compel new competitive initiatives and success factors. They include an extension of competitive objectives beyond low cost and quality objectives as well as extension of business performance objectives beyond short-term financial ratios and profit objectives (Blenkinsop and Burns, 1992; Flynn et. al., 1995a; De Toni et. al., 1997; Ward et. al., 1998; Ettlie, 1998). Accordingly, in order to marshal new enabling competencies for competition and long-term survival, companies often tinker with their business, operational and technological structures and infrastructure (Sweeney, 1991; Mills et al, 1995; Buzacott, 1995; Termini, 1996; Bartezzaghi, 1999). Accordingly, it has been argued that:

"Those companies who design business strategies that acknowledge the presence of uncertainty and provide mechanisms for pro-actively tackling it are ... ahead of competitors..." (Mason-Jones et. al., 2000).

Bhattacharya (1996) also opined that:

"*Manufacturing systems are having to deal with a major increase in variability and uncertainty... which disrupt even the best-laid strategic plans and lead manufacturing managers to continuously fire-fight, leaving little time, or inclination, for improvement... Procedures needs be established which continuously monitor the causal factors of turbulence and proactively identify the need to "reinvent" the manufacturing system....*"

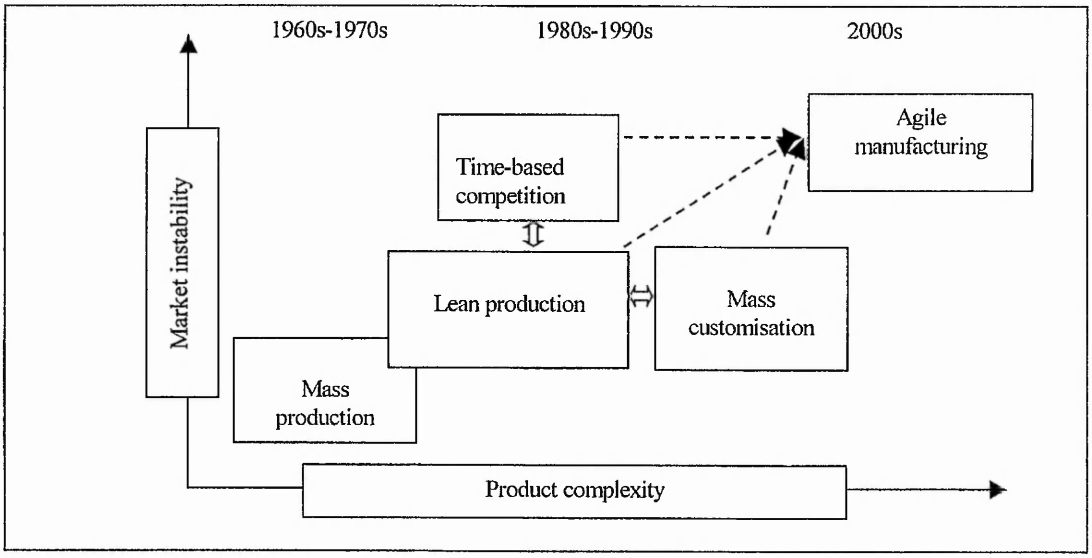


Figure 2.1 Major types of manufacturing systems

Accordingly, unique operations models or paradigms such as mass production, lean production and agile manufacturing emerged out of the need for continuous reinvention of manufacturing systems over time (Buzacott, 1995; Bartezzaghi, 1999). As the systems emerged in rapid succession, an evolutionary time frame has been identified (Crowe, 1992; Yusuf, 1996; Termini, 1996). Termini (1996:11) identified four phases defined as: traditional manufacturing (1960s-1970s), focused factories (1980s), flexible and lean manufacturing (1990s) and agile manufacturing (2000). Over this evolutionary time frame, Crowe (1992) noted that overriding themes guiding manufacturing system design shifted from productivity in the 1970s, to quality in the 1980s and flexibility in the 1990s. In accordance with the shift in overriding themes, companies in the UK have advanced rapidly from mass production, in preference for flexible capabilities, new ways of customising products and adding new technology to make them smarter (DTI, 1995).

A 25-year study of Volvo (Karlsson, 1996) attested to rapid changes in the operational characteristics of manufacturing systems subsequent to increases in the levels of market instability and product complexity. The study revealed how priorities changed from getting rid of the driven line, to quality through worker responsibility, lean and world class, lean and flexible, and to economies of scope. More recently, unprecedented increases in market instability and product complexity suggest a further shift of emphasis towards manufacturing agility (Richards, 1996; Singletary and Winchester, 1998). Figure 2.1 shows the main types of systems that emerged over time to address varying degrees of market instability and product complexity.

Market instability consists of social, economic, industrial, political, demographic, technological and environmental factors that affect business and manufacturing operations but over which a company has no influence whatsoever (DTI, 1995, Bhattacharya, 1996; Dean et al, 1999). Recent examples of major, largely unforeseen disruptions to the external business environment of UK manufacturing include environmental legislation, introduction of preferred supplier status, EU directives, rising value of the pound and economic liberalization (Bhattacharya, 1996). Market instability also arises from market drift and valued products and technologies rapidly becoming commodities (DTI, 1995).

Market instability causes dramatic shortening of product life cycles and lifetime earnings whilst making investment in tools and technologies very expensive and risky (Hill and Chambers, 1991). In this context, adoption of a new operations system such as agile manufacturing would enable timely response to changing requirements through rapid customisation of leading technology products, which is crucial to effective competition in global markets (Browne et at, 1995; DTI, 1995; Termini, 1996; Pandya et al. 1997).

In addition to market instability, Figure 2.1 shows product complexity as the second dimension of change leading to rapid emergence of manufacturing systems. Product complexity arises from modern civilisation, which makes customers' tastes and preferences more customised and finicky, as well as intelligent products that demand superior design quality. Subsequent to higher degrees of product complexity, systematic advance in the operational capabilities of manufacturing systems, and in effect, a transformation from mass production towards agile manufacturing, is inevitable. This argument does not negate the current role of mass production in some relatively stable markets where products are more functional than innovative. Neither does it challenge the success of lean production in product markets where the efficiency of physical production as a means of reducing cost and ensuring adherence to an agreed delivery schedule is more important than customisation and new technology. In any case, agile manufacturing provides a better means of accommodating several expectations of modern products and choosy customers, some of which were outlined as follows by Goldman (Sheridan, 1996):

a. *"Variable combinations of hardware, information, and services";*
b. *"Easily reconfigurable and upgradeable";*
c. *"Customised for individual requirements in arbitrary order quantities";*
d. *"A continually changing array of models within longer-lived families";*
e. *"Fragment mass product markets into niche markets";*
f. *"Continually add value for current customers"; and,*
g. *"Continuous rather than single-instance sales relationships".*

The choice of manufacturing system is determined by the levels of market instability and product complexity on the two axes in Figure 2.1. At the highest levels on the two axes, agile manufacturing emerges as a dominant operations management system. It is characterised by the use of intelligent technologies, empowered work force and virtual resource coalitions as a means of accommodating several requirements of modern products and customers. The main features of some of the systems shown in Figure 2.1 are summarised next, with a focus on how their weaknesses relative to higher levels of market instability, product complexity and some other change drivers threatened their relevancies.

Mass production, which involves production of a few standard products in large volumes, emerged as a means of responding to unprecedented surge in global demand after the Second World War. It thrives on large and stable markets characterised by long product life cycles and relatively simple products. Mass production remained most popular up to the 1970s (Buzacott, 1995; Singletary and Winchester, 1996; 1998; Bartezzaghi, 1999).

The mass production plant often consists of large capacity machines tended by largely unskilled labour force (Womack et al, 1990; Willis, 1998). Operations are characterised by labour specialisation, work fragmentation, strict formal procedures, interchangeable parts, hierarchical organisation, extensive distribution systems and closed-loop planning (Womack et al, 1990; Karlsson and Ahlstrom, 1992; Singletary and Winchester, 1996). In order to minimise internal and external disruptions, computerised software tools such as Material Requirements Planning (MRP) and Manufacturing Resource Planning (MRPII) were developed as a means of realigning plans, inputs and schedules with expected market demand over a period (Hicks and Stecke, 1995; Yusuf, 1996).

Mass production was effective in terms of low cost and economies of scale. However, its efficiency was threatened by problems of timely and dynamic response (Maskel, 1994; Hakanson, 1994; Filippini, 1997). Consequently, the need to improve responsiveness and widen the range of product options gave way to business, operational and technological changes now known collectively as lean production (Womack et al, 1990; Karlsson, 1996).

Lean production was proposed in a worldwide study of the automobiles industry to describe the practices introduced by Japanese manufacturers in the 1980's as a means of reducing wastes and costs whilst enhancing quality assurance (Womack et al, 1990; Richards, 1996). Lean production harps more on synchronised production flows, just in time purchasing and scheduling, and continuous improvement of operations processes (Karlsson and Ahlstrom, 1992; Sohal, 1996; Lewis, 2000; Mason-Jones et. al., 2000).

Lean production remains popular and its benefits have been demonstrated in several works (Womack et. al., 1990; Womack and Jones, 1994; Sohal, 1996; Sriparavastu and Gupta, 1997). However, several limitations arise from overriding emphasis placed on frugal use of resources and elimination of activities with no direct value-added (Smeds, 1994; Flynn et al, 1995b; Ramaparu et al, 1995; Emiliani, 1998; Adeleye et. al., 2000; Lewis, 2000). This leads to a fragile structure that potentially limits responsive adaptation to temporal opportunities and threats in inherently unstable markets (Ramaparu, 1995; Katayama and Bennett, 1996). The following are some of the limitations of lean production.

a. Lean production originated from Japan, which is renowned for a culture of community farming and social collectivity. This is in addition to a sense of frugality in using resources, which was compelled by a small land mass and associated high population density (Young 1992; Karlsson and Ahlstrom 1992). In essence, it is tenable that lean production is cultural to Japan and much less applicable as a universal basis of competition especially in contexts that required manoeuvring and re-orientation of structures and infrastructures ahead of market and competitive triggers.
b. Lean production focuses remarkably on continuous improvement of operations processes with a view to gain cost and quality advantage and maintain level schedules. In essence, lean production is process-focused and looks more inwards for competitive advantage, even as external pressures arising from market instability demanded more adaptable and responsive structures and systems (Katayama and Bennett, 1996)
c. Lean production outsources core component parts and inventories on contractual basis. However, the secrets of modern intelligent products are now hidden in their modularised component parts (Browne et al. 1995). Accordingly, component manufacturers would accumulate dominant market power through enhanced value-added in contrast to assembly operations (Lewis, 2000). To remain competitive, more rather than less in-house manufacture of components, perhaps through agile collaborative networks will be crucial for enhanced competitive advantage.
d. Reports abound that workers perceive lean practices such as cross training, job transfers and process discipline as exploitative, with an attendant loss of interest in factory jobs (Young, 1992; Cusumano, 1994; Yasin and Wafa, 1996).
e. Lean production launches families of related products in rapid succession, which are targeted on mass markets. Lean production therefore encourages rapid obsolescence whilst agile manufacturing emphasises customer specified designs as well as product upgrade and reuse (Cusumano, 1994; Fitzgerald, 1995; Termini, 1996).
f. Lean factories, with their characteristic intolerance for marginal capacity, might accommodate rather poorly to oscillations in volumes of demand, growth opportunities and market distress (Bartezzaghi, 1999). In this regard, agile manufacturing suggests intelligent automation and strategic alliances as a means of speedy replication of custom designs, compressing lead times and gaining the advantages of rapid technological advance without its associated investment.
g. Conservative use of resources retards employment and growth, with an attendant risk of a depression arising from lower economic multiplier effects (Bartezzaghi, 1999). As an alternative, agile manufacturing proposes structures for routine adaptation so that jobs, sales and profits are relatively stable.

h. Traditional lean advantages such as inter-changeable workforce, master-servant supplier relationships and just-in-time deliveries across the road, might be limited in global operations (Young, 1992; Martin et al, 1994). As an alternative, agile manufacturing harps on specialist knowledge as well as circular networks of co-developers and manufacturers rather than hierarchical networks for outsourcing. Moreover, Japanese depression has reduced the willingness of suppliers to accept JIT supplies and poor bargains (Herrett et al. 1998). In essence, the cost advantage often associated with lean supply chains may persist no longer.
i. Frequent small deliveries across the road have led to social problems of traffic congestion, which threaten the environment (Cusumano 1994).
j. Several advantages are unique to Japan. They include a culture of managing through compelled by a small land mass and a spirit of collectivity compelled by defeat in the Second World War (Young, 1992). In addition, Japanese economic advantage of the 1980's including a stable domestic demand and abundant third party funds made Japanese interest rates a third of world market rates. All these accounted for Japanese industrial success, not only the wizardry of lean principles (Ghemawat, 1985).

The preceding discussion reveals that lean production focuses on process improvement as a means of reducing waste and synchronising production flows. However, unprecedented increases in market instability and product complexity extend the search for productivity and competitiveness beyond excellence in shop floor operations driven principally by low cost and level schedule objectives. The threats to lean production as enumerated above are indicative of the need to respond more quickly to changing customer requirements.

In this regard, at higher levels of market instability, attainment of competitive objectives should extend beyond cost and quality to time-based responsiveness, product customisation and technology leadership (DTI, 1995; Tang and Yam, 1996; Vokurka and Fliedner, 1997; Vokurka and Fliedner, 1998; Ward et. al., 1998). The essence of agile manufacturing therefore is to advance simultaneously on a much wider range of competitive objectives than preceding systems such as mass production, lean production, time based competition and mass customisation. Indeed, the agility campaign was motivated in the US by concerns that systems were deficient in widening the range of manufacturing objectives as a means of enhancing national competitiveness (Booth and Hammer, 1995; Bertezzaghi, 1999).

2.2 AGILE MANUFACTURING

This section reviews the literature on agile manufacturing. It focuses on its meaning, evolution, drivers, dimensions and enabling competencies. The review adopts agile manufacturing as a change strategy. Therefore, it focuses on the tools and methods that enable competitive advantage in response to market instability and product complexity.

The concept of agile manufacturing originated in 1991 from the Agility Forum, which was a joint initiative of US government, industry and academics. The Forum was organised to work out a long-term strategy by which US manufacturers could cope with global competition (Esmail and Saggu, 1996; Singletary and Winchester, 1998).

The Agility Forum (Kidd, 1994; Gunneson, 1997) defined agility as

> *"The ability to thrive and prosper in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer based valuing of products"*

Several other definitions abound in the literature but three are stated here (Goldman et al, 1995; Booth and Hammer, 1995; Richards, 1996; Gould, 1997; Harrison, 1997).

1. *"The ability to produce a broad range of low cost, high quality products with short lead times in varying lot sizes and built to individual customer specifications"* (Fliedner and Vokurka, 1997)
2. *"The capability of an enterprise to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services"* (Gunasekaran, 1998).
3. *"Agility is dynamic, context specific, aggressively change embracing, and growth oriented. It is not about improving efficiency, cutting costs, or battering down the business hatches to ride out fearsome competitiveness storms. It is about succeeding and winning profits, market share and customers in the very centre of competitive storms that many companies now fear"* (Goldman, et al, 1995)

These definitions suggest that agility in manufacturing demands an untiring ability to place competitive requirements in context, seize initiatives and invent new product features ahead of competitors (Richards, 1996; Gould, 1997; Litsikas, 1997). This is in order to excel on a wide range of competitive and business objectives such as cost, flexibility, product customisation, technology leader, profitability, market share and customer loyalty.

2.3. DRIVERS OF AGILE MANUFACTURING

In section 2.1, two dimensions of change drivers that often compel the emergence of new systems including agile manufacturing were categorised into market instability and product complexity. The following discussion further breaks down the two dimensions of change drivers in more details. This discussion is in order to identify the drivers of agile manufacturing including competitive pressures in the US where the concept originated.

The US government had a covert military interest in the agile manufacturing campaign, given that the Department of Defence sponsored the Agility Forum. The government was concerned with industrial efficiency and productivity as congress pressured it to award weapons contracts to US manufacturers. This was in addition to concerns for flexibility as defence goods industries converted to commercial production after the cold war (Esmail and Saggu, 1996; Gould, 1997).

In addition to the military interest, the US government and industry were bewildered with a persisting recession, which eventually hit its lowest point in 1991 (Hamel and Prahalad, 1994). Consequently, the Agility Forum stressed the need for US manufacturers, over 60 percent of which were small and medium sized companies, to network capabilities for global competition (Booth and Hammer, 1995; White et al, 1999). In addition, lean techniques such as multi-skilling and continuous improvement were deemed inappropriate in the US. Workers deplored practices such as frequent interchange of position, process discipline and never-ending pressures and targets for continuous improvement (Young, 1992; Yasin and Wafa, 1996).

Another driver of agile manufacturing was multiplicity of operations planning and control technologies towards the end of the 1980's and the associated problems over choice and application. By the late 1980s, several manufacturing systems and technologies had evolved, and many had become the popular three letter acronyms such as MRP, TQM and JIT (Wallace, 1992). Each of them had become increasing inadequate in addressing the multi faceted challenges of manufacturing even as companies became confused over choice and application (Wallace, 1992). Agile manufacturing would therefore have evolved as an umbrella system that integrates and synthesises preceding systems as a means of delivering on a much wider range of competitive objectives. Such integration provides a means of building an operations management foundation that would last (Aggarwal, 1985). Accordingly, Gunneson (1997: 3) articulated agile manufacturing as a means of achieving modular integration of technologies including complete mastery of lean production and concurrent engineering techniques.

In addition, advances in IT motivated extended enterprise thinking within which companies were to co-operate and operate as seamless chains of resource coalitions for the manufacture of complex products (Baldwin and Clark, 1997; Feitzinger and Lee, 1997). The nature and operational mechanics of such chains are explained in Section 2.6.1.

Largely, the most compelling drivers of agile manufacturing are market instability caused by globalisation, changing customer requirements, product complexity, falling product life cycles, and emergence of best practice (Kidd, 1994, Gunneson, 1997; Bartezzaghi, 1999).

The foregoing review shows that agile manufacturing is not about continuous improvement but fundamental re-design of capabilities, systems and processes as a means of advancing simultaneously on a wide range of competitive objectives without significant trade-offs. Nevertheless, agile manufacturing enablers of competitive advantage were yet to be identified and justified (Sheridan, 1993, Singletary and Winchester, 1998; Sharifi and Zhang, 2001; Hoek et. al., 2001). For this purpose, the next section explores contingency alternatives on five core dimensions of competence building in manufacturing. This is with a view to identify and justify agile manufacturing enablers of competitive advantage.

2.4. IDENTIFYING AGILE MANUFACTURING ENABLERS.

Agile manufacturing enablers of competitive advantage were identified from a study of five dimensions of competence building that were most frequently discussed in the literature (Hayes and Pisano, 1994; Browne et al., 1995; Ahmed, 1996; Oliver, 1996; Bodine, 1998; Gunasekaran, 1998; Gagnon, 1999; Gordon and Sohal, 2001; Fawcett and Myers, 2001). The five dimensions are mass customisation, supply chain networking, manufacturing automation, employee empowerment and technology utilisation.

Contingency options on each of the five dimensions of competence building were tested for harmony with the five principles of agile manufacturing proposed by the Agility Forum

(Goldman and Nagel, 1992; Kidd, 1994; Sheridan, 1998). The principles are customer enrichment through mass customisation, enterprise-wide co-operation for enhanced competitiveness, organising to master change through routinely adaptable structures and systems, and leveraging the impact of people, information and technology in order to boost organisational knowledge. Expatiating further on the principles of agile manufacturing, Yusuf et. al. (1999) identified four concepts namely core competence management, virtual enterprise, capacity for reconfiguration, and knowledge driven enterprise. Closely related, Booth and Hammer (1995) specified five generic parameters of a plan for agility. They are organising to thrive on change, leveraging the impact of people and information, devising prompt solutions to customer problems, enterprise-wide co-operation, and integrating social values into decision-making.

Contingency options in competence building were also tested for compatibility with the engineering and social process requirements specified in the literature of agile manufacturing (Deitz, 1995; Lee, 1998; Gunasekaran, 1998). The engineering requirement concerns the design of systems and products (Lee, 1998), whilst the social process prerequisite involves relationships with customers, employees, suppliers and competitors as joint stakeholders in the supply chain (Youssef, 1992). The engineering and social process requirements can be difficult to attain all at once but a balance is essential so that one does not inhibit the other (Tracy et al., 1994). The engineering and social process requirements involve questions pertaining to what product features, by which process, by whom, and where in terms of global manufacturing (Thomke and Reinertsen, 1998).

A study of internal and external dimensions of change initiatives also provides a means of identifying agile manufacturing enablers. Internal change initiatives will be agile if they enable internal competition and employee empowerment whilst external change initiatives will be agile as well if they emphasise supply chain development efforts and information networking (Fliedner and Vokurka, 1997). In other words, agile change initiatives should harp on global networking, collaborative product development, process reconfiguration, and an empowered workforce (Booth and Hammer, 1995; Willis, 1998). Relatedly, Gehani (1995) also identified the following practical change initiatives for becoming agile, which may not be new as a set of ideas but might be difficult to implement in companies .

i. Empowerment of front line workers, with the goal of eliminating unnecessary inspection and supervision that take more time than the process of adding value.
ii. Formation of concept to cash, cross-functional and inter-enterprise project teams.

iii. Modular integration of available operations technologies such as MRPII and JIT.

iv. Improvement of product competence and final configuration at the point of sale.

v. Product succession planning, based on incrementally improved base run products

vi. Enterprise wide integration of learning, with focus on organisations' longitudinal histories and experiences.

The following sub-sections report contingency practices on each of the five dimensions of competence building in manufacturing. Those practices that bore the greatest resemblance with agile principles and change initiatives as specified in the preceding paragraphs were deciphered as agility enablers of competitive advantage. As a basis for the conduct of field studies, the contingency practices identified are robust and valid, having been published in the proceedings of an international conference (Adeleye et. al., 2001).

2.5 MASS CUSTOMISATION

Customer enrichment through mass customisation has been articulated as a means of adding value to current products and customers. It involves tracking and devising unique solutions for individual customer's requirements (Dale, 1995; Booth and Hammer, 1995). In other words, mass customisation means offering a wide range of product options in parallel and targeting them to different niche markets and customers (Fitzgerald, 1995). This is unlike mass production, which tenders a few standard products for everyone (Pine and Davis, 1993). It also differs from lean product development, which upgrades and offers families of related products in rapid succession (McGrath et. al., 1992; Pine II et. al., 1993; Cusumano, 1994; Oliver et. al., 1996; Adeleye et. al., 2000; Power et. al., 2001).

As an enabler of competitive advantage, mass customisation preceded agile manufacturing. However, its practice has become inefficient as 80 percent of product offerings now contribute only 20 percent of profits (Pine II et al, 1993; Trueman and Jobber, 1995). Accordingly, several ideas aimed at making mass customisation profitable and sustainable abound in the literature (Stalk and Webber, 1993; Feitzinger and Lee, 1997; Fawcett and Myers, 2001). Such ideas include "market relatedness", which means targeting the core products that created a company's success. This is in addition to making mass customisation more responsive to transitions in customer values and leading edge of technology (Maruka and Halliday, 1993; Trueman and Jobber, 1995; Sull, 1999). Some other suggestions include component modularity as a way of enhancing postponement of customisation to the point of sale (Feitzinger and Lee, 1997) and the profit impact of mass customisation (Yeh & Chu, 1991). Accordingly, Sheridan (1998) opined:

"Companies... need to think in terms of design for mass customisation, with an emphasis on commonality of parts and postponement of final configuration... final operations, assembly, testing and packaging are done very near to the customer at the point of sale".

The extent and intensity of mass customisation differs across product markets depending perhaps on the extent to which products are functional or innovative (Fisher, 1997). Accordingly, a continuum ranging from pure standardisation to pure customisation has been identified (Lampel and Mintzberg, 1996). In addition, Gilmore and Pine 11 (1997) discussed four faces of mass customisation as contingency options. They are cosmetic, collaborative, adaptive and transparent. At the extreme end of pure standardisation, little or none of the operations of design, fabrication, assembly and distribution is customised, whereas they are all customised at the other extreme of pure or transparent customisation, where every product solution tends to be technically unique. Cosmetic customisation differentiates mainly on packaging and appearance as a means of making standard products appear differentiated in the eyes of customers. Cosmetic customisation is also useful in differentiating packaging quality and targeting them to a range of income groups.

Cosmetic customisation as explained in the preceding paragraph will be inconsistent with transparent customisation as a concerted strategy of survival in markets characterised by changing and complex customer requirements (Maruka and Halliday, 1993; Pine II et al, 1993; Stalk and Webber, 1993; Fawcett and Myers, 2001). As a contingency option in mass customisation, transparent customisation is more close-knit to the expectations of the literature of agile manufacturing. This is in terms of accommodating to changing customer requirements through customer-led product solutions. Nevertheless, the resource capabilities required for transparent customisation are beyond single companies but within the reach of networked companies operating as virtual resource coalitions (Browne, 1995; Lee and Lau, 1999; Perry and Sohal, 2001).

Accordingly, a discussion of supply chain networking follows as the second dimension of manufacturing competence building from which agility enablers can be identified.

2.6. SUPPLY CHAIN NETWORKING

Supply chain networking, which involves building co-operative relationships with customers, suppliers and competitors, has become crucial in mobilising resource capabilities across company boundaries and delivering superior solutions ahead of competitors (Fisher, 1997; Kasarda and Rondinelli, 1998; Power and Sohal, 2001).

"Companies of all sizes are developing strategic partnerships because so many different critical technologies are required to create today's sophisticated products that no one company can maintain leadership in all of them" (Kasarda and Rondinelli, 1998).

Supply chain networking also preceded agile manufacturing. Supply chain networking became popular in the early 1970's and 1980's as mass producers such as General Motors and IBM employed it for market penetration, outsourcing and distribution (Sachwald, 1998; Badaracco, 1991). Such earlier networks are different from newly emerging process dependent networks that share critical manufacturing capabilities while competing (Goldman and Nagel, 1992; Ashley, 1997a,b). Sharing and seamless flow of physical and non-physical assets amongst companies would lead to pooling synergy and optimise total assets that are potentially available to companies (Upton and McAfee, 1996; Kasarda, and Rondinelli, 1998). When fully realised, networking companies would allocate core modules of production amongst themselves, based on their relative competencies (Venkatraman and Henderson, 1998; Lee and Lau, 1999).

Several factors motivate supply chain networking. The first is advances in information and Internet technologies, which enable mutual and real time access to information, data and files amongst companies spatially distributed across the globe (Goldman and Nagel, 1995; Warkentin, 1997). Although IT applications initially evolved to support secure and evidential transfers of trading reports, cash and other assets and obligations by multi-national companies, recently applications have extended to logistics management, design, scheduling and manufacture (Mutsaers et al, 1998, Soliman and Youssef, 2001).

Secondly, the advent of just in time practices with emphasis on smaller volumes of transactions motivates supply chain networking. This is because of the need to monitor real-time and as an integrated routine process, the volumes of transactions that were specified, executed and delivered. In addition, efforts to widen the range of product options available to customers motivated manufacturers to seek direct linkage to customers as well as direct control and sometimes part ownership of suppliers and distributors (Womack et al, 1990; Badaracco, 1991; Browne et al, 1995).

The third motivator of supply chain networking is product complexity, which compels focusing strategies (Quinn, 1992). As products and customer specifications become more complex, companies strive to focus on only a narrow aspect of the total supply chain where competitive advantage is greatest whilst networking with other companies to complete the supply chain. This requires that companies work with equal vigour and commitment to add the greatest values (Upton and McAfee, 1996; Feitzinger and Lee, 1997; Bhatt, 2000).

Accordingly, in addition to commercial collaboration in outsourcing and distribution, knowledge sharing on critical competences in design and manufacturing has become a vital tool of competition (Gunneson, 1997). Hence, entire supply chains rather than individual companies are emerging as the unit of analysis in the new competitive game plan. Success in the new competitive game plan required that companies surrender their capabilities to their supply chains and become connected to the global resource base through modern IT. Networking promotes shared views, employee awareness and tracking of customer expectations. It also reduces errors and time cycles in product and process development efforts (Bhatt, 2000; Perry and Sohal, 2001).

Conceptually, a range of contingency models in supply chain networking can be identified. They include conditional alliances employed for market penetration by global conglomerates, lean supply chains for outsourcing and distribution as a means of ensuring a level schedule, and agile supply chains renowned for global leverage of manufacturing competencies (Gray, 1990; Badaracco, 1991; Russ and Camp, 1997, Fisher, 1997; Prater, 2001; Boardman and Clegg, 2001; Christopher and Towill, 2001).

The model of supply chain adopted by a company can be an important determinant of competitive advantage. This is because it influences access to real time data and knowledge, and the attendant ease of mobilising global resources to tap temporal windows of opportunities (Goldman et. al., 1995; Gadient et. al., 1997; Mason Jones et. al., 2000; Yusuf et. al., 2001; Hoek et. al., 2001; Kehoe and Boughton, 2001; Power et. al., 2001).

The lean supply chain as articulated in several works is the most dominant form of supply chain networking in the literature (Womack et al., 1990; Womack and Jones, 1994; Herrett et. al., 1998; Hoek et. al., 2000; Mason-Jones et. al., 2000). More suitable in a relatively stable market, the lean supply chain emphasises long-term contracts for outsourcing and distribution, with a view to secure cost and quality gains whilst also committing suppliers and customers to planned JIT supplies and schedules (Fisher, 1997; Naylor et. al., 1999; Christopher and Towill, 2001). In order to facilitate these objectives, inspection, coaching and financial support for suppliers and distributors were popular (Womack et al., 1990; Womack and Jones, 1994). However, manufacturing process dependency, opportunistic collaboration and virtual integration as a means of exploring temporal opportunities are limited (Mason-Jones et. al., 2000, Hoek et. al., 2000; Power et. al., 2001).

Accordingly, the agile supply chain is underpinned by global exchange of manufacturing competencies through the Internet. It enables timely mobilisation of world-class resources as a means of responding to emerging customer expectations ahead of the competition (Goldman et al, 1995; Upton and McAfee, 1996; Lee and Lau, 1999; Perry and Sohal, 2001; Boardman and Clegg, 2001; Christopher and Towill, 2001). In this regard, the agile supply chain is nearer to the expectations of agile manufacturing in terms of delivering transparently customised products ahead of competitors and at the cost of mass production. In the light of unprecedented market instability and product complexity, the agile supply chain has the potential to enhance attainment of a wide range of competitive and business objectives (Lewis, 2000, Hoek et. al., 2000; Power et. al., 2001).

Whereas until recently supply chain networking refers almost exclusively to long-term supplier relationships, an equal amount of downstream collaboration with customers and lateral co-operation with competitors has become increasingly important (Lee and Lau, 1999; Hoek et al, 2001; Boardman and Clegg, 2001; Christopher and Towill, 2001; Power et. al., 2001). Indeed, an agile supply chain should integrate the entire gamut of manufacturing and logistics operations into a seamless flow. Supply chain agility can therefore be explained as a measure of the extent to which the entire gamut of upstream and downstream operations is integrated and supportive of the following pivotal objectives of agile manufacturing (Goldman, et al, 1995; Lee and Lau, 1999; Hoek et al; 2001; Kehoe and Boughton, 2001). The objectives are:

1. Continually add value to current products and customers ahead of competitors;
2. Striving to achieve mass customisation at the cost of mass production;
3. Master change and uncertainty through enhanced access to global resources;
4. Post higher profits and market share irrespective of market instability.

2.6.1. THE NATURE OF AN AGILE SUPPLY CHAIN

The agile supply chain consists of legally separate and spatially distributed companies engaging in collaborative design and manufacture, with the aid of Internet-based information technologies (Goldman et al, 1995; Davenport, 1998; Soliman and Youssef, 2001; Boardman and Clegg, 2001; Christopher and Towill, 2001). With client-server systems, the design units of a range of companies using CAD/CAM software could remotely access the same design files and contribute knowledge simultaneously. As well, files can be transmitted to manufacturers located in other parts of the world for simultaneous upgrading or prototyping. Knowledge generation, codification, sharing and application to product design, manufacture and logistics as a means of exploiting profitable opportunities in a volatile marketplace is the major goal (Soliman and Youssef, 2001; Kehoe and Boughton, 2001; power et. al., 2001; Yusuf and Gunasekaran, 2002).

Besides the use of advanced IT applications, the nature of an agile supply chain can be analysed in terms of the reach and range of activities covered by networking (Browne et al, 1995; Lee and Lau, 1999; Kehoe & Boughton, 2001). Figure 2.2 illustrates the reach and range approach. On the vertical axis, information reach extends from personal to anywhere whilst on the horizontal axis, the range of activities widens from electronic messaging to Internet-based integration. Accordingly, as shown in Figure 2.2, supply chain agility increases as the degree of freedom in networking widens from bill of material controls to purchasing efficiency and to demand and capacity planning.

Figure 2.2 also shows that although computer-based data integration can reach to anywhere, Internet-based integration may be limited to customers or suppliers alone, and without any significant global reach. However, an agile supply chain should extend to the highest levels on both dimensions of reach and range. At the highest levels of attainment of both dimensions, the conduct of internal operations will be transparent virtually, and local teams of employees can think globally and take initiatives with similar but distributed process teams. To this extent, responsiveness to changing competitive requirement becomes easier to master as a routine process with little penalties in time, cost and quality.

In addition to high attainment of the two dimensions of reach and range in Figure 2.2, supply chain agility can be measured on three inter-dependent dimensions of customer interaction, asset configuration and knowledge leverage (Venkatraman and Henderson, 1998). The challenge of an agile supply chain will be to improve and ensure balance across the three inter-dependent dimensions shown in Column 1 of Figure 2.3. Relative scores on the three dimensions provide a basis for testing maturity towards agile supply chains.

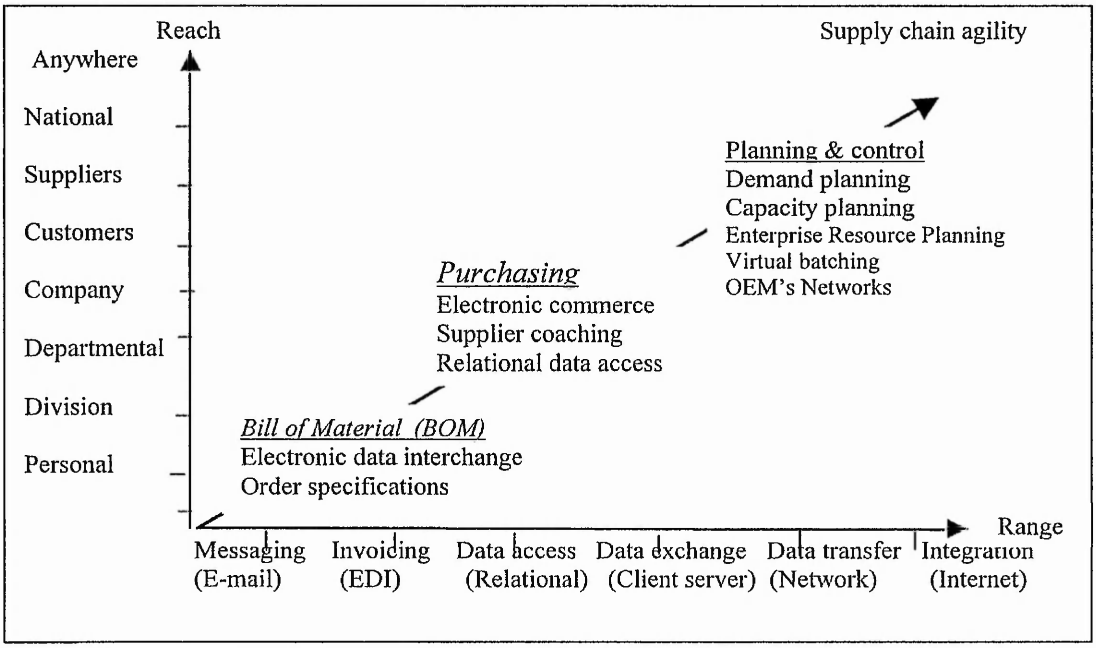


Figure 2.2 Reach and Range analysis of supply chain, integration (Browne et al, 1995).

Customer interaction involves reaching out to spatially distributed customers, working with customers towards dynamic customisation for clusters of unique preferences and establishing communities of customers. At the highest level of customer interaction, a company owns customer communities as a means of making transparent customisation more sustainable. This is due to the advantages of customer-inputs to product upgrades rather than seeking variety as an end in itself. In addition, there is the potential benefits of market concentration in terms of getting unique customer communities committed to long-term contracts of supply, which are called off in small volumes over time (Chen et al., 1992). As such, the incidence and destructive impacts of the "Forrester's effect" can be minimised (Chandra and Kumar, 2000). Without close interaction with customers, mismatches between production volume/ mix and customer expectations often arise, and however marginal, they potentially cause panic and speculation up and down the supply chain. The attendant consequence is that production plans and schedules are based on false and distorted market data, which causes another round of mismatch that is bigger in magnitude and accelerating the initial effect.

The asset configuration dimension of supply chain agility also matures from emphasis on outsourcing of inputs to delegation of business processes to seamless resource coalitions.

The members of such resource coalitions contribute and share competencies from a network of global resources whilst nurturing their individual limited area of focus.

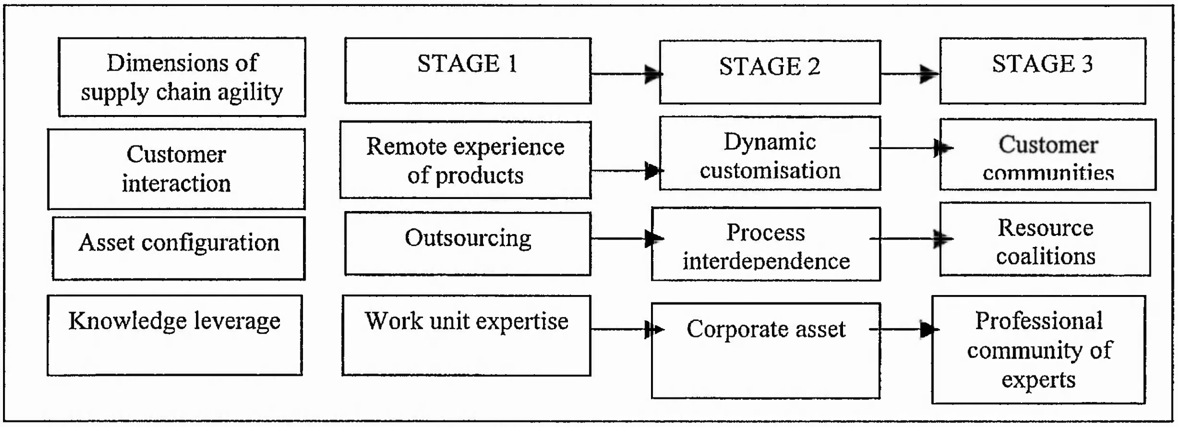


Figure 2.3. Three stages of supply chain maturity (Venkatraman & Henderson, 1998).

Finally, Figure 2.3 shows that on the knowledge leverage dimension of supply chain agility, competence building advances from significant emphasis on work unit expertise to free flow of tacit knowledge across work units as a corporate asset. Ultimately at the third stage, knowledge flows freely amongst distributed companies who are joint stakeholders in the processes of conceiving, creating and delivering value. At this stage, a company aims to leverage competencies not only amongst its own employees, work units and teams, but also within a global professional community of experts.

Across the three stages of maturity towards agile supply chains, the target focus of action would extend from task units, to organisation units and to inter-organisational units. As well, performance objectives would mature from operating efficiency to economic value added and survival prospects (Venkatraman and Henderson, 1998).

Closely related to the three dimensions of supply chain maturity, four dimensions of agile supply chain practices have been identified (Hoek et al, 2001; Boardman and Clegg, 2001; Christopher and Towill, 2001; Power et. al., 2001). Figure 2.4 reveals the dimensions as customer sensitivity, virtual integration, process integration and network integration.

Customer sensitivity obliges quick response to customer requirements while network integration requires that companies in the supply chain have a common identity, which can range from commitment to agile practices, compatibility of structure, compatibility of information architecture and collaborative competencies. Furthermore, virtual integration demands that companies trade more in information and knowledge rather than inventories, and surrender to the Internet, all knowledge and competencies, which remain largely protected. Lastly, process integration suggests that networking companies delegate core modules of production amongst themselves based on their relative competencies. This requirement of process integration differs from contract manufacturing, which can potentially increase cost through hierarchies of non value- adding commercial margins.

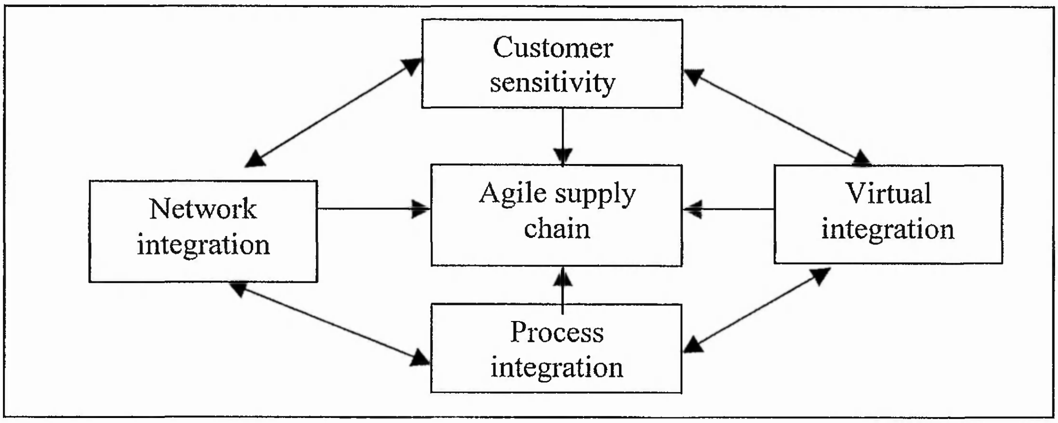


Figure 2.4 Elements of an agile supply chain (Hoek et al, 2001)

An agile supply chain should embody the four elements of supply chain networking. However, the virtual element, which is perhaps the greatest innovation in agile manufacturing, is largely absent in most supply chains (Hoek et. al., 2001; Hoek, 2001; Power et. al., 2001; Christopher and Towill, 2001). Figure 2.1.6.3 presents the elements as customer sensitivity, virtual integration, process integration and network integration.

Customer sensitivity means that supply chain networking initiatives should enable quick response to customer requirements based on point of sale data capture and transmission. To this end, manufacturing processes require integration and specialisation based on relative core competencies of networking companies. The element of network integration requires that companies operate as confederation of partners equally committed to agile practices as a means of leveraging competencies for leading and transparent customisation of products. The fourth element, which is virtual integration, goes beyond network integration and demands that companies surrender to the Internet all knowledge and competencies, which remained largely protected. Three out of the four elements are concerned with integration as a means of aiding customer sensitivity, which is the fourth element.

The foregoing discussion signifies that an agile supply chain has a high degree of integration, which is facilitated by Internet-based information and communication technologies. Consequently, an agile supply network could consist of several spatially distributed units of a company. Such units may include a component design unit in Greenwich, Headquarters office in Chicago, assembly plant in Lagos and several other independent partners, each engaging in rapid and transparent customisation of core modules of products (Sheridan, 1996; Lee and Lau, 1999; Christopher and Towill, 2001).

Crucial to the agile supply chain as described above are multi-level teams of local and remotely distributed workers, who interact, conceive and commit their companies to temporal opportunities without the luxury of waiting for inhibiting approvals from superior personnel. Such employees would require empowerment through training, teaming and re-orientation towards reliance on peer consensus rather than superior authority. Following next is a discussion of employee empowerment as the third dimension of competence building in manufacturing from which agility enablers can be identified.

2.7. EMPLOYEE EMPOWERMENT

The literature of agile manufacturing (Burgess, 1994; Gunneson, 1997), lean production (Womack, et al, 1990; Smeds, 1994; Sohal, 1996) and other related studies (Levary, 1992; Quinn, 1992; Forsythe, 1997; Fawcett and Myers, 2001) agreed that employee empowerment is crucial for companies in unstable markets. The consensus is that companies change from vertical to lateral structures in which consensus among professionals and work groups become superior to formal authority (Quinn, 1992). A lateral organisation empowers professionals and shop floor employees. It also potentially halts the separation of doers from thinkers whilst minimising several divisive interfaces that polarises structures, depletes resources and inhibits timely response (Ohnae, 1982; Burgess, 1994; Gunneson, 1997). Employee empowerment therefore requires a complete realignment of power relations within which managers emphasise interdisciplinary collaboration and leadership, shared values and motivation for knowledge diversity (Joyce and McGee, 1997; Forsythe, 1997; Fawcett and Myers, 2001).

Empowerment can be discussed from three main dimensions. They are training that targets work content improvement and teaming that fosters joint authority and responsibility for decisions and actions in work groups (Saraph and Sebastin, 1992; Niepce and Molleman, 1996; Forsythe, 1997). The third is involvement in decision-making including methods of work and motivation as well as determination of remuneration and other perquisites (Pennathur, 1999; Maskell, 2001). The training dimension also requires providing workers with appropriate knowledge, skills and tools necessary to manipulate and operate intelligent machines and technologies. This is in addition to putting in place concurrent engineering structures that enable employees to operate in self-directing, self-communicating and self-organising teams. Furthermore, empowerment suggests that workers are able to influence decisions about their job performance, work environment and company's future (Upton and McAfee, 1996; Pennathur et al., 1999).

The ease of realigning power relations within existing organisation structures as well as the relative efficacy of decision-making based on peer consensus and position-power under situations of sporadic change is dicey. However, employee empowerment has been proposed as the principal assets in making a plant truly flexible, notwithstanding loads of intelligence possessed by advanced manufacturing systems (Upton, 1995; Pinochet et al., 1996). For workers to perform effectively, a considerable amount of training and retraining is required in the following areas (Zhang and Zhang, 1995; Pennathur et al., 1999).

- Managing shared resources for productivity and reusability;
- Interpersonal skills for teaming and peer leadership;
- Information science and proficiency in applications software;
- Systems orientation that emphasises the global impact of local decisions and actions;
- Technology evaluation, utilisation and trouble shooting;
- Multi- skilling especially in operations before and after own workbench; and
- Problem-solving skills.

Teaming, which requires that employees work relationships are co-operative and collaborative, is another important dimension of empowerment. Team practices and dispositions facilitate job assignment, execution and delivery because they support parallel and integrative conduct of activities involved in design, engineering and manufacture (Goldman and Nagel, 1992; Gadient et. al., 1997; Forsythe, 1997; Pennathur, A. et al., 1999). A team culture would be easier to nurture in a plant that has embraced teaming as an organisation system underpinned by the principles of multi-dimensional collaboration that is inherent in concurrent engineering (Zhang and Zhang, 1995; Forsythe, 1997; Yan and Jiang, 1999; Fawcett and Myers, 2001). A team-based concurrent engineering structure empowers employees individually and collectively, and therefore enhances the knowledge base available for profitable and sustainable mass customisation (Pant et al, 1994;

Ganapathy and Goh, 1997; Yan and Jiang, 1999). Moreover, most operations will be run as mini-companies, each with its own sense of identity and loyalty (Huq, 1992; Bratton, 1993; Castellano et al., 1999). Accordingly, smaller groups of employees will be responsible for resources and results, and management attention would shift from individual or functional work units to project teams. The cost of supervision would fall.

In industries faced by unprecedented market instability and product complexity, teams of empowered employees will be indispensable in servicing agile supply chains and mobilising global competencies (Pant et al, 1994; Yan and Jiang, 1999). Nevertheless, reports abound that team practices in lean production have become unwieldy, exploitative and punitive due to significant emphasis on heavyweight leadership, seniority-based pay, peer-surveillance and unending pressures for continuous improvement. In this context, teaming perhaps strip workers of their personal rights, specialist skills and autonomy rather than empower them (Young, 1992; Karlsson and Ahlstrom, 1992; Forza, 1996; Warkentin, 1997). The aforementioned problems are avoidable in agile plants where operations are more decentralised and less line oriented. Instead, operations are project and niche market-based and also virtual in character (Saraph and Sebastian, 1992; Yang and Lee, 1996; Forsythe, 1997; Warkentin, 1997; Henry, 1998).

In addition to training and teaming, employee involvement is another important dimension of empowerment. It manifests itself in several ways including the following (Young, 1992; Pennathur et al., 1999; Castellano et al, 1999):

- Stoppage of production flow on observation of any anomalies;
- Free exchange of positions and work re-allocation, perhaps hourly or daily;
- Adaptation of work teams to variations in job duties and in the production flow;
- Commitment to continuous improvement and innovation;
- Influence over recruitment into autonomous teams and cells;
- Free exchange of knowledge and suggestions for improvement;
- A pull system which determines pace of work on the line rather than in the office;
- Open communication through tacit support for informal contacts and social exchanges amongst employees as well as the use of modern means of open communication such as in-plant walkie-talkie, electronic public folders and bulletin board systems, and;
- Better opportunity to influence top management decisions.

Employee involvement should enable higher levels of fulfilment, pride from workmanship, satisfaction and self-actualisation, which in turn ought to ensure loyalty and commitment to work and company. Employees' commitment, up to willingness to sink or swim with the company to which they have invested their career and future is a principal asset for companies facing intense competitive pressures and market instability.

Accordingly, empowered employees are the principal assets in the agile factory (Goldman and Nagel, 1992; Upton, 1995; Forsythe, 1997; Fawcett and Myers, 2001). They are the core enablers of competitive advantage as advances in technology and best practices transform job structures and extend workers' scope of discretion and responsibility (Saraph and Sebastian, 1992; Hayes and Pisano, 1994; Browne et al, 1995). For these reasons, a wide range of training programmes especially in operations before and after own workstation, technology application, system monitoring, and cooperative ethics are imperative (Goldman and Nagel, 1992; Zhang and Zhang, 1995; Upton, 1995; Kirk and Tebaldi, 1997; Fawcett and Myers, 2001).

The relative emphasis placed on each of training, teaming, involvement and commitment as dimensions of employee empowerment and as determinants of agile competitive advantage would differ widely in practice. Empowerment scores could be insignificant for all the four dimensions, higher for only one or two dimensions or substantial for all the four dimensions. In order to cope effectively with the challenge of change as well as marshal the skills required to operate intelligent machines and deliver transparently customised solutions ahead of competitors, empowerment should be multi-dimensional and total. Therefore, maximum deployment of employees' knowledge capabilities is crucial as a means of boosting the ability to manipulate intelligent machines (Goldman and Nagel, 1992; Fawcett and Myers, 2001).

Following next is a discussion of manufacturing automation as the fourth dimension of manufacturing competence building from which agility enablers can be identified.

2.8. MANUFACTURING AUTOMATION

Manufacturing automation refers to the total gamut of operations, which can be performed by plants and equipment with minimal human intervention. It can also mean the range of different machining and assembly operations that a particular machine or plant could be manipulated to execute (Roger, 1985; Pinochet et al, 1996). The evidence abounds that automation enhances capability and reliability of manufacturing systems by reducing costs, human fatigue and risk of error in repetitive operations such as welding, painting and material selection (Womack et al, 1990; Edwards, 1996).

However, based on the level of human intervention required by a machine and the range of operations that a machine can be manipulated to execute, three contingency alternatives in manufacturing automation can be identified. They are mass automation, flexible automation, and intelligent automation (Kirk and Tebaldi, 1997; Kusiak and He, 1997; Bodine, 1998). In mass automation, machines had been in-built to perform specific operations and cannot be altered, retooled or re-programmed to do anything else. On the other hand, flexible automation has an advantage of being adaptable and able to perform a wider range of operations, although valuable time is spent to retool and change over.

In spite of the benefits of flexible automation, it is most suitable for relatively simple machining and assembly tasks especially in high volume repetitive batch processes rather than for continuous reconfiguration and customisation of products (Kusiak and He, 1997). Intelligent automation is largely computer-controlled, with closed-loop feedback systems and in-built diagnostic capability (Waters, 1996). They operate as integrated but independent networks of computer numerically controlled (CNC) machines, feeders, controllers, actuators and sensors connected by conveyors (Lee, et al., 1997; Kusiak and He, 1997; Bodine, 1998). Supported by advanced network communications and distributed computer systems, they can be programmed to conduct a wide range of machining and assembly tasks without the time and effort entailed in flexible manufacturing systems.

Parametric CAD/CAM system, which is used in early production planning, is also an important component of intelligent automation. For example, the Pro/Engineer CAD/CAM system speeds up the manufacture of prototypes and Pro-manufacturing links generic set of tool paths to generic family-table of products (Kohler, 1993). Some other components of intelligent automation include automated guided vehicles, automatic storage and retrieval systems, automated material handling, direct numerical control, computer numerical control, surface mounting technology and mobile robotics (Kirk and Tebaldi, 1997).

When intelligent machine networks are complemented by modern means of material storage and retrieval, loading and unloading as well as surface mounting, a factory or cell can be described as operationally mobile. Intelligence and mobility are crucial for speedy customisation and replication of the core modules of intelligent products at little or no extra cost (Zammuto and O'Connor, 1992; Zhang and Zhang, 1995; Kusiak and He, 1997).

In the light of shrinking life cycles and intense mass customisation that tend to fragment and reduce order quantities and life cycle profits, intelligent and versatile machines are the strength of the agile factory. This is because reproduction costs of products manufactured by intelligent machines are not volume sensitive (Browne et al, 1995).

According to Browne et al (1995):

"By the late seventies and eighties, the concept of FMS was widely publicised. The system that resulted serviced an environment where product life had fallen below manufacturing facilities life. It was becoming increasingly difficult to justify dedicated single-product automated manufacturing facilities. FMS exhibited a relatively high degree of transient flexibility compared to hard automation... This state of flexibility must not be confused with the emerging requirements imposed on manufacturing facilities by developments in product life cycles and customisation"

In spite of its potentials, intelligent automation remains poorly adopted and therefore requires strategy in order to enhance its adoption (Maskell, 1994; Kirk and Tebaldi, 1997). First, the goal of intelligent automation is dynamic reconfiguration as a means of responding to changing specifications and achieving mass customisation at the cost of mass production (Deitz, 1995; Small, 1995; Kusiak and He, 1997; Willis, 1998). To this end, companies are advancing systematically through three technical options in automation (Kirk and Tebaldi, 1997, Kohler, 1993). They are: a centralised system, a system of electronic control stations that supplement a centralised system, and independent but co-operative modules of electronic control stations. Towards agile manufacturing design, steady advance from the first to the last is desirable (Kohler, 1993; Song and Nagi, 1997).

Another element of automation strategy is that intelligent automation requires a considerable amount of knowledge work especially in re-programming machines for several one of a kind production situations (Zhang and Zhang, 1995; Kirk and Tebaldi, 1997; Dailami and Redford, 1998). This is unlike traditional automation of repetitive processes where knowledge work is not significant (Womack and Jones, 1990: 94; Kohler, 1993; Bodine, 1998).

Finally, advances towards intelligent automation can be in discreet steps. The most basic step is cellular layout of machines based on related jobs or parts families (Vakharia and Kaku, 1993; Small, 1995; Sheridan, 1998). A cell generally consists of one or two stand-alone CNC machines, complemented by ancillary equipment such as robotic parts handlers (Gadient et al., 1997). Once a cellular design has been implemented, a range of simple machining and assembly tasks can be automated selectively based on the exact needs of individual cells (Pandiarajan and Patun, 1994; Kusiak and He, 1997; Bodine, 1998). Therefore, the range and intensity of automation, flexibility, machine intelligence and operational mobility in material handling would vary across cells.

The impacts of cellular design on competitive advantage have been demonstrated (Wemmerlov and Hyer, 1989; Brussel and Bongaerts, 1999; Chambers and Nicholson, 2000). Cellular design leads to smaller work-systems to which employees are more committed (Small, 1995). It also promotes interaction amongst equipment, workstations and product modules, with attendant improvement in ability to trap problems at source, conduct parallel operations and flex capacity (Kirk and Tebaldi, 1997; Lee et al., 1997; Lee, 1998; Brussel and Bongaerts, 1999).

The foregoing discussion reveals that manufacturing automation influences competitive advantage. Three contingency options in manufacturing automation were discussed in the preceding paragraphs out of which intelligent automation appeared more suitable for plants engaging in transparent customisation. This discussion of intelligent automation as an agility enabler revealed five core elements, which are cellular design, a wider range of automated processes, machine flexibility, machine intelligence and plant mobility.

In addition to mass customisation, supply chain networking, employee empowerment and manufacturing automation, technology utilisation was proposed earlier as the fifth dimension of competence building. The issues involved in technology utilisation including contingency options from which a fifth agility enabler can be identified are discussed next.

2.9. TECHNOLOGY ADOPTION

The literature suggests that companies adopt and learn incrementally from a wide range of technologies as a means of enhancing competitive advantage (Aggarwal, 1985; Wallace, 1992; Youssef, 1992b; Zammuto, 1992; Samitt and Barry, 1993; Zachary and Richman, 1993; Gunneson, 1997; Gerard et al., 1999; Soliman, 2001). Technology integration, in terms of "modular integration" and "assimilation of lessons learnt" in a wide range of emerging technologies such as MRP, JIT, TQM, CE and OPT was proposed as a core enabler of agile competitive advantage (Youssef, 1992b; Gunneson, 1997; Singletary and Winchester, 1998). Therefore, towards agile manufacturing design, intelligent synthesis of tools and methods such as MRP, MRPII, ERP, JIT, TQM, EDI and CE are indispensable for competing and satisfying customers' requirements from all fronts. However, several companies perceive technologies as alternatives even as joint deployment could be a complex process (Youssef, 1992b Wallace, 1992).

Technologies consist of several techniques, which are often adopted and implemented with a view to improve manufacturing practice, management systems and the entire gamut of plant and logistics operations. In essence, technologies include human-centred techniques such as concurrent engineering (CE), JIT and TQM, as well as integrated hardware and software-based technologies like CAD/CAM and CAPP. If properly synthesised and implemented incrementally, they can boost process capabilities for speedy customisation and delivery of advanced product solutions (Youssef, 1992b; Soliman, 2001).

Several researchers have articulated adoption or synthesis of multiple technologies as an essential requirement of agile manufacturing design (Gunneson, 1997; Singletary and Winchester, 1998). Indeed, multiplicity of operations techniques by the late 1980's (Aggarwal, 1985; Wallace, 1992) could have motivated the emphasis placed by the agility movement on synthesis of technology. As managers were frustrated over choice and application of technology (Aggarwal, 1980; Wallace, 1992), it was crucial to connect and learn incrementally from the range of available options (Samitt and Barry, 1993; Duck, 1993; Goldman and Nagel, 1995; Harrison and Storey, 1996). In this sense, agile manufacturing supports systematic learning and mastery of several techniques of lean production and concurrent engineering and the lessons they offered (Goldman and Nagel, 1992; Gunneson, 1997). The synthesis of several technologies is imperative for systematic and co-ordinated response to market instability (Singletary and Winchester, 1998).

Accordingly, Duck (1993) made a case for

"...connection and balancing of all the pieces of improvement programmes that had been implemented in isolation..."

Exactly what combinations of technologies are appropriate for a company would depend on contextual factors including location, industry, size, technology, strategy, resource capabilities and goals (Spina, 1996). For instance, speed and new technology leadership can be crucial competitive objectives in Western Europe as against low cost in Eastern Europe. The range of technologies adopted and implemented will therefore be determined by the relative importance and relevance of competitive objectives in different situations and times (Burgess, 1994; Vokurka and Fliedner, 1998).

Technology can be classified into operations technology and information technology. The two components are becoming largely integrated as most machines and logistics operations now rely on a considerable amount of computer-based information networking. The integration of operations technologies with IT especially digital electronic and Internet technologies, enable machines and several other distributed manufacturing entities to seamlessly relate, reconfigure and share the same set of physical resources (Pant, Rattner and Hsu, 1994). Information technologies include personal computers, Local Area Networks (LANs) and relational data base systems. Some others are Electronic Data Interchange (EDI), e-mail, imaging systems, product data managers (PDM) and client server networks (Kumar and Motwani, 1995; Forsythe, 1997).

As for information technologies, operations technologies also consist predominantly of MRP, MRPII, ERP, TQM, JIT, CE, QFD, CAD/CAM and CAPP. Most of the technologies evolved in pursuit of different competitive objectives but the goals may not be mutually exclusive. Nevertheless, if adoption of multiple operations technology were to create agile competitive advantage, the technologies would require considerable amount of modification and smoothening of interfaces. Some operations technologies are discussed.

2.9.1. OPERATIONS TECHNOLOGIES

Material Requirements Planning (MRP) was developed in the late 1960's and early 1970's to support the planning and ordering of material and components as dictated by forecasts of future demand based on historical data (Maskel, 1994). MRP effectively integrated inventory management, purchasing, work order tracking, and bill of material control as a means of ensuring a high level of product delivery. However, MRP lacked the reactive ability to track down short-term variations in capacity and orders (McGrath et al, 1992; Yusuf, 1996). In addition, MRP exerted little influence on resources other than materials and components. Yet, it relied on complex and expensive hardware and software (Ronen and Pass, 1992).

Accordingly, Manufacturing Resource Planning (MRPII) evolved in the late 1970's to address the inadequacies of MRP. MRPII was also a computerised planning system that feeds back the records of actual completed work into the next manufacturing cycle (McGrath et al, 1992; Maskel, 1994). However, its influence extended beyond material requirements to accommodate other vital resources within the manufacturing function. Nevertheless, MRPII did not exert significant influence on resources outside the manufacturing function and in effect, the entire gamut of company operations were not fully integrated. Enterprise resource Planning (ERP) later emerged as a means of integrating all enterprise operations including finance, logistics and sales (Yusuf, 1996).

MRP, MRPII and ERP systems were quite effective in capturing history, inventory, material needs and other static information. The resulting effectiveness in the flow of work ensured that the goals of high volumes and least costs were met. Nevertheless, the systems are deficient in dynamic and interactive feedback that inherently unstable competitive environments demanded (Berry and Hill, 1992; Maskel, 1994; Hakanson, 1994). Several other problems include perception of MRP, MRPII and ERP as computer systems rather than business systems, poor linkage with other functions, and inadequate commitment of time and funds to user education and training (Maskel, 1994; Yusuf, 1996). Far more importantly, in a market faced by shrinking product life cycles and rapid customisation, the need arose to track demand, resource requirements, revenue and costs based on product life cycles (Browne et al, 1995; Gunneson, 1997). Accordingly, by the middle 1980s, significant attention had shifted to process improvement technologies such as JIT and TQM. Organised around shop-floor operators, they target cost, quality and speedy response to changing product requirements (Maskel, 1994; Willis, 1998).

TQM emphasises statistical process control, process standardisation and effective leadership as a means of reducing scrap, rework, stress to machines, and warranty costs (Dean & Bowen, 1994; Elmuti and Aldiab, 1995). To this extent, TQM has the potential to reduce deviations between plans and actual results with attendant improvement in the accuracy of MRP, MRPII and ERP systems.

However, some adaptation is important in order to reverse the claim that (Obert, 1996: 90):

"Total quality management methods should be very useful for strategies emphasising incremental or evolutionary refinements of organisational products and processes but less applicable to fast-moving organisations whose strategies require risk-taking, creativity, or quantum changes in short periods of time".

As markets become unstable and success requires quantum changes at short time intervals, TQM should focus more on reduction of scrap, rework and warranty costs so that its benefits are more tangible and measurable. In addition, more emphasis on worker empowerment and virtual collaboration is imperative rather than emphasis on top-bottom leadership and process standardisation (Niven, 1993; Reeves and Bednar, 1994; Dean & Bowen, 1994; Gunneson, 1997). Within the framework of agile manufacturing design, the primary objectives of TQM should be conformance to specification, tangibility of value added to new products and extent of transparent customisation (Reeves and Bednar, 1994). Besides TQM, JIT is another important component of agile technologies. It aims to smoothen operations flow with a view to reduce operating costs and deviations.

The Just-in-time (JIT) concept originated in the late 1980's from the efforts of Japanese companies to raise productivity, reduce waste, increase product variety and cope with global competition (Samson, 1991; Meredith, 1992; Willis, 1998). JIT consists of new process and organisational design methods underpinned by the basic principle of minimising waste in all forms by replenishing inventory buffers and scheduling work just in time on receipt of customer orders. JIT also emphasises continuous improvement of work processes, shorter cycle times, synchronised production flows and level schedules.

JIT is structured on Kanban cards, which provide the signal for new movements of stocks including work in progress. This is in addition to a tiered network of contracts with suppliers and distributors, multiple training and rotation of employees and a teaming orientation (McGrath et al, 1992; Harrison and Storey, 1996).

The success of JIT has been demonstrated (Zachary and Richman, 1993; White et al., 1999). Through JIT, Toyota reduced time needed to produce a car from 15 days to one day (Meredith, 1992: 529). JIT is consistent with TQM and it has been instrumental in sharpening its focus (Samson, 1991; Flynn et al., 1995b). In addition, through its emphasis on decentralised shop floor control, JIT can reduce errors inherent in MRP, MRPII and ERP systems (Samson, 1991; Wallace, 1992).

However, JIT is most applicable to repetitive linear flow systems for manufacturing relatively standard products (Meredith, 1992: 547; Sheridan, 1998). Furthermore, it is founded on a fragile balance of inputs and capacities (Sohal, 1996). As a result, JIT may be unsuccessful in markets characterised by rapidly changing customer and product specifications (Meredith, 1992; Ramarapu, 1995). In such situations, disruptions caused by factors such as unionism and supply chain bottlenecks would make zero inventory, zero marginal capacity and sole contracts of supply risky and inapplicable.

For JIT to be relevant to agile manufacturing design, it is mandatory to distinguish between things that are superfluous and those that can cripple robustness in a turbulent competitive environment and therefore become lean on growth (Bartezzaghi, 1999). This is because full capacity and inventory utilisation might lead to critical resource shortages (Sheridan, 1998; Quintana, 1998). Therefore, a minimal strategic investment in marginal capacity, a large chunk of which can be in intelligent automation and logistics flexibility will pay for itself through routine adaptation to surges in demand (DTI, 1995; Upton, 1995; Suri, 1998). What is required might not be a pure lean model, which focuses essentially on waste elimination without commensurate attention to routine adaptation in mobilising resources and in the routing and sequence of work (Suri, 1998; Sheridan, 1998).

Several other operations technologies such as CE, QFD, OPT, CAD/CAM, CIM and CAPP are also relevant (Aggarwal, 1985; Zammuto and O'Connor, 1992; Zachary and Richman, 1993; Bodine, 1998; Gerard et. al., 1999). They are relatively new technologies that could be modified to work harmoniously in support of the operations of an agile plant. For instance, although concurrent engineering has been used traditionally for parallel and integrative conduct of design and manufacture (Goldman and Nagel, 1992; Zhang and Zhang, 1995), applications seem largely limited to product development (Agrell, 1994). Therefore, concurrent engineering requires significant extension to process planning and production scheduling as well as the whole range of extended enterprise logistics (Paashius and Boer, 1997; Yan and Jiang, 1999; Gerard et. al., 1999).

Likewise, Optimised Production Technology (OPT) is expected to be an important component of agile technologies (Aggarwal, 1985; Gunneson, 1997). In the light of the complex and multi-dimensional nature of operations involved in speedy and transparent mass customisation, OPT will be invaluable in identifying potential conflicts and smoothening interfaces amongst and across machines, workers, cells and spatially distributed teams. As an operations technology, OPT is useful in identifying and isolating resource bottlenecks with a view to improve line balancing and maximise capacity utilisation (Aggarwal, 1985; Gunneson, 1997).

In addition to the afore-mentioned operations technologies, Computer Integrated Manufacturing is also important as a means of tracking and co-ordinating complex and multi-dimensional operations in the agile plant and its associated supply chain. CIM is not new as a tool for tying the various components of a company into a single cohesive system, ensuring timely access to information as well as effective top level planning and co-ordination (Malhotra and Jayaraman, 1992; Yang and Lee, 1996; Yan and Jiang, 1999).

However, CIM architectures follow the vertical control principles in financial accounting where speed, volume and top management control take pre-eminence (Ronen and Pass, 1992). In contrast, lateral architectures are required to (Ronen and Pass, 1992: 50):

"Typically manage and control, concurrently, the manufacturing process of hundreds of products, each of which has its own bill of material (BOM)... "

Lateral CIM architectures enable automatic and simultaneous upgrade of transactions in all books and locations. They also provide intelligence for cells to be continually reconfigured for batches of products currently being processed (Hatvany, 1985; Davenport, 1998).

In addition to the operations technologies, information technologies are also essential to agile manufacturing design. They are discussed next.

2.9.2. INFORMATION TECHNOLOGIES

This section suggests some information technologies (IT) for agile manufacturing. Quite unlike in mass production where timely availability of internal data on stocks and orders is the principal resource, readily available information amongst networks of collaborating companies is principal in agile manufacturing. Indeed, researchers tend to agree on the requisite IT for agile manufacturing (Pant, et al, 1994; Jung, et al., 1996; Song and Nagi, 1997; Warkentin et al, 1997; Gadient and Hines, 1997). The requisite IT should enable seamless flow of information as well as support responsive adaptation and integration across functions, cells and supply chain networks (Pant et al, 1994; Ronen and Pass, 1992). It should in addition reduce any expenses and difficulties inhibiting effective workings of teams, cells and supply networks separated by time and space (Warkentin et al, 1997).

Appropriate IT applications include Electronic Data Interchange facilities (EDI) such as electronic mail, radiophone, telephone and fax (Mutsaers, 1998). EDI applications originated to facilitate secure and evidential transfers of trading and operations data of multi-national companies (Nolan, 1979). However, they remain useful for data communication amongst multi-product cells and plants in agile manufacturing.

Nevertheless, effective integration amongst multi-product cells demand advanced IT applications with wider utility than Electronic Data Interchange (EDI). Therefore, new IT capabilities in terms of faster and robust transfer, reach and automatic upgrades of technical files across time and space amongst supply chain networks are crucial (Mutsaers, 1998). Accordingly, advanced digital electronic and internet-based communication technologies are a requisite (Goldman and Nagel, 1992; Pant et al, 1994; Song and Nagi, 1997). They enable distributed entities to relate real time and seamlessly (Pant, et al, 1994).

Advanced IT applications for faster flow of information include imaging systems, fourth generation languages and enterprise-wide product data managers PDM and Electronic Document Management. Some others yet are Local Area Networks (LANs), Bulletin Board systems, Internet Usenet and client server networks. (Warkentin, 1997; Forsythe, 1997). Most advanced applications are integrated and linked to the Internet. They therefore enable parallel information flow within a global decision space, in which information from other isolated units are integrated (Pant, et al, 1994).

In general, advances in network-based information technology have significantly facilitated the development and application of operations technology, intensity of customisation and depth of supply chain integration (Ronen and Pass, 1992; Yang and Lee, 1996; Jung et al, 1996; Davenport, 1998). However, compatibility and security problems limit virtual networking as a vital aspect of agile manufacturing (Hicks and Stecke, 1995; Gadient and Hines, 1997; Davenport, 1998). Such problems threaten accuracy, consistency and robustness as original designs are distributed over space and time (Harrison, 1997). Therefore, further improvement in interface requirements and Integrated Product Data Management models would facilitate networking (Gadient and Hines, 1997; Song and Nagi, 1997). More importantly, access to the WWW is imperative. It enables membership of a global network with enhanced access to information (Brabston and McNamara, 1998).

A number of operations and information technologies have been outlined including their roles in enhancing competitive advantage. The long list of technologies suggests that companies would at best adopt some few technologies that are more relevant to their operations. This in turn implies that contingency options would vary widely and be difficult to track in practice (Youssef, 1992b). However, it suffices for this research to argue that integration rather than substitution of technologies will enhance the ability to devise and deliver best in the world solutions as a means of surviving market instability. Such technologies include planning and control systems such as MRP, MRPII and ERP, human engineering systems such as JIT, CE and TQM and advanced systems such as CAD/CAM, CAPP and CIM for speedy execution of design and manufacture.

Several technologies and the modifications required to make them relevant to agile manufacturing have been highlighted. It was argued that MRP, MRPII and ERP systems should track resources, revenues and costs based on the entire life cycles of products. In addition, it was suggested that TQM, JIT and OPT should permit some reasonable amount of marginal capacity whilst identifying and isolating bottleneck resources and processes. The best way forward in technology utilisation is beyond the scope of this thesis. Nevertheless, it was expected that modular integration of a wider range, rather than a narrower range of operations and information technologies should lead to incremental learning. This is expected to enhance attainment of competitive objectives and business performance. In this regard, technology integration is imperative.

2.10 A CRITIQUE OF AGILE MANUFACTURING

Agile manufacturing has limitations just like other preceding manufacturing systems. However, much of the limitations arise from the pattern of discussion in the literature. Contrary to the dominant pattern of its discussion, manufacturing competitiveness and performance do not depend exclusively on external factors, but also on internal factors such as history, internal work processes, local context and redundancies. Most of these internal factors were addressed by JIT, TQM and OPT (Bartezzaghi, 1999). However, research effort is required on what and how preceding systems could be modified and integrated into agile manufacturing rather than the weight of emphasis being placed on agile manufacturing as a clean break.

Moreover, although market turbulence and customer shifts truly suggest agile manufacturing as a universally applicable approach to system design, some companies still compete in relatively peaceful and stable markets. In such markets, products are more like commodities. Therefore, demand is more predictable, technological changes are easier to accommodate and threats of new entrants are minimal (Bartezzaghi, 1999). As product life cycles are relatively long, cost reduction remains the principal determinant of strategy and manufacturing system design (Bartezzaghi, 1999; Mason-Jones et. al., 2000).

Accordingly, pressures for agile manufacturing would differ across product markets. Therefore, contingency and transitional models for determining the required levels of agility in different industries, markets and product groups become necessary. Such models will be invaluable in motivating practice and research, given that agile manufacturing is still widely believed to be an emerging concept, and having little application in industry (Katayama and Bennett, 1996). In order to encourage adoption of agile manufacturing, the time was ripe to direct research effort towards identification of deployable enablers of competitive advantage. To this end, research needs not present agile manufacturing as radically different from what companies are doing presently. It is sufficient for companies to track new challenges in the competitive environment and identify best practices in mastering such challenges in order to ensure stable profits and market share (Bhattacharya, 1996; Oliver et. al., 1996; Mason-Jones, 2000).

Another critique of agile manufacturing is that in spite of academic input to its evolution, its literature is largely descriptive and deficient in prescriptive intervention programmes. In addition, empirical evidence on the depth of environmental pressures in industrial sectors as well as the competitive outcomes of agile manufacturing over preceding systems were rare in the literature. For these reasons, agile manufacturing has not significantly penetrated mainstream engineering and management literature as well as the collective consciousness of European practitioners (Burgess, 1994: 23). The need therefore arises to search for clues on current practices in manufacturing competence building with a view to identify and justify agile manufacturing enablers of competitive advantage (Ashley, 1997a, b, Harrison, 1997; Sheridan, 1998).

Lastly, the social benefits of agile manufacturing require more theoretical and empirical articulation so that legal and political leaders do not wrongly perceive agile networks as monopolistic gang ups. The social benefits include advances in the pleasure of life through custom production at the cost of mass production. Agile manufacturing also emphasises routine responsiveness to market instability as a means of ensuring stable jobs, turnover and profits amidst market chaos. Furthermore, agile manufacturing stresses the need to develop human capital as assets. It therefore rejects downsizing by which companies grow smaller than better, with attendant loss of jobs, incomes and economic multiplier effects

(Hamel and Prahalad, 1994). Yet, agile manufacturing supports ambitious rather than conservative use of advanced technologies with a view to make products smarter and improve the pleasure of life. As well, the emphasis on virtual resource coalitions culminate into global factories, with an attendant potential for common industrial and political interests in global security. The aforementioned benefits of agile manufacturing are overtly attractive. Nevertheless, their realisation in practice through the agility enablers as identified earlier in this thesis might be difficult. The subsequent paragraphs present a critique of the agility enablers.

The potential benefits of the agility enablers over and above other alternative options in manufacturing competence building were discussed in Sections 2.4-2.92. However, the agility enablers have several limitations as well as implications for practice and research. This is in terms of their relevance to different product markets and problems of adoption and implementation without which it might be difficult to study their essence and impacts on competitive and business performance objectives. The potential limitations of the five agility enablers identified earlier are discussed in the following paragraphs.

2.11. A CRITIQUE OF AGILITY ENABLERS

Five agility enablers were identified. The first was transparent customisation, which emerged from the practice of mass customisation. Whereas mass customisation has been popular as a means of boosting market share and customer loyalty, it has become inefficient by adding more to costs than to revenues even as 80 percent of products now contribute 20 percent of profits (Lampel and Mintzberg, 1996). This is the essence of transparent customisation where value-added to technical functionality and options become more important than aesthetic appeal. However, even as this study proposes transparent customisation as beneficial, its relevance will be limited by differences in product markets such that in relatively stable markets where products are more functional than innovative, customisation would at best be cosmetic. In addition, the degree of freedom to customise products might be restricted in small scale companies that may have limited access to knowledgeable skills and intelligent machines required for intense customisation. In spite of these limitations, the need arises for companies to add more value to products through some degree of customisation as a means of boosting profits and retaining market share.

In support of transparent customisation, tremendous attention focuses on the development of seamless supply chains as a means of speeding up design and manufacturing cycle times. To this end, the agile supply chain was identified and discussed in 2.6.1 in terms of its superiority over and above other forms of supply chain networking. The agile supply chain was justified in terms of companies' ability to mobilise global resources and respond to sporadic changes in customer requirements through manufacturing process dependency rather than exclusive emphasis on outsourcing, JIT supplies and inventory positioning in the lean supply chain. Accordingly, the agile supply chain is innovative in terms of significant emphasis on internet-based technologies as a means of enhancing access to global resources. However, the supporting technologies and business practices such as co-operation amongst competitors suffer from several problems including compatibility, high cost and poor adoption (Davenport, 1998; Power and Sohal, 2001; Hoek et. al., 2001). Therefore, models for figuring out the appropriate supply chain in different markets whilst identifying and evaluating alternative supply chain practices are required (Fisher, 1997).

Intelligent automation was another agility enabler identified in Section 2.8. It implies the use of versatile machines supported by a considerable degree of computer power as a means of enhancing speedy customisation of leading edge technology products (Gadient et. al., 1997; Bodine, 1998; Gunasekaran, 1999). In practice however, several plants use flexible manufacturing systems, which consist of machines that could be retooled manually by skilled operatives to perform a wide range of machining and assembly operations (Edwards, 1996). Most of the ideas in studies of agile automation such as graphical simulation, mobile robotics, flexible parts feeders, modular grippers and assembly hardware seem more relevant to capital intensive plants including automobiles where tremendous input goes into the design and manufacture of state of the art products. In commodity or standard products sectors such as food processing, which involve large-scale manufacture of a few standardised or customised products, automation would be relatively rigid or at best flexible (Edwards, 1996). Several other factors that may limit the adoption of intelligent automation include small scale of operations, dangers of system collapse, high cost of intelligent machines and supporting software. In any case, as intense competitive pressures force more companies to turn traditional commodity products into high value innovative products, intelligent automation will become more popular (Dale, 1995; Ashley, 1997b). Albeit, the scale of operations should be large enough whilst the product needs to be sufficiently innovative with long-term custom appeal in order to generate additional profit to cover the cost of investment in intelligent machines. Accordingly, further research is required on the appropriateness of mass, flexible and intelligent manufacturing systems in different product markets.

Technology integration was also identified as an agility enabler because of the potential benefits of incremental learning emanating from seamless access to several new ideas. However, new technologies affect the structure of jobs and work relationships whilst they take time to be fully integrated into the production process. Employees may therefore be less inclined to adapt existing operational systems especially where new skills are required. In a study of the timing of technological adaptations, Tyre and Orlikowski (1994) found that in the light of new competitive pressures companies occasionally re-examine existing technologies and make important modifications, but that regular use of new technologies was not consistent with the kind of mental and physical effort required to develop and implement new ideas. Worse still, beyond studies of integrated JIT/TQM and integrated MRP/JIT, there is little knowledge of best practice in technology integration (Ahmed et. al., 1996; Sriparavastu and Gupta, 1997). Accordingly, frequent adaptation of work process to embrace modules of new technologies will be a complex process involving money, time and new skills. Especially during this period of rapid technological change, training, adaptation, assimilation and consolidation are crucial challenges. These are in addition to compatibility problems and associated problems of robustness and accuracy amongst several modules of new technologies (Davenport, 1998). In all these, technology integration will be easier to manage and beneficial if it aims to respond to abrupt pressures imposed by rapid technological change within a policy of timed and continuous process of modification and accommodation of new technologies (Tyre and Orlikowski, 1994).

Employee empowerment has also been discussed from three main dimensions of training, teaming and involvement in decision-making. Empowerment arises from the need for knowledgeable and committed employees who would embrace organisational adaptation to new competitive pressures and technologies whilst championing new projects and partnerships initiatives from start to finish. However, the discussion of employee empowerment in this study was not exhaustive because it did not elaborate on other factors such as remuneration, motivation, job security and limitations arising from ownership structures in sole and family owned manufacturing companies. Some other issues include relative emphasis to place on cross- training, time lost to team activities, prevalence of top-bottom structures in several companies and the reported success of heavyweight leaders in Japanese companies (Young, 1992; Pennathur et. al., 1999). In addition, a paper already published from this research found that training and teaming as two core dimensions of employee empowerment had non-complementary effects on competitive objectives especially at higher levels of plant automation (Adeleye et. al., 2000a). The study therefore asked whether knowledgeable employees would be positively disposed to lateral team practices. It also wondered if a seemingly British culture of limited interest in third party affairs would not threaten operational efficiency of team-based plants. However, this study's focus on total employee empowerment calls attention to the paucity of in-depth studies of human factors in agile manufacturing (Forsythe, 1997; Gunasekaran, 1998).

In general, several elements of the agility enablers remained largely idealistic in that they were yet be properly defined, operationalised into detailed tools and metrics, and widely adopted by companies (Gunasekaran, 1998; Sharifi and Zhang, 2001; Hoek et. al., 2001). Accordingly, as only a cluster of companies would have implemented only a small number of variables that constitute only a few of the five agility enablers, problems of fit between model and data were not unexpected. Moreover, as trade-offs amongst competitive objectives persisted in companies (New, 1992, Ward et. al., 1998; Silveira and Slack, 2001), the adopted definition of agile manufacturing in this study as simultaneous advance on a wide range of competitive objectives, created statistical dilemma. For instance, a single measure of agility derivable by factoring companies' scores on competitive objectives did not converge until some companies were screened out (see Table 4.17).

The preceding paragraphs present a critique of agile manufacturing and agility enablers, which were identified earlier in this study as a means of coping with unprecedented market instability and product complexity. In spite of the criticisms, studies of agility enablers were rare in the literature, perhaps due to low adoption of agile practices in industry and risk aversion by researchers. Although the agility enablers identified in this study are far from exhaustive, the dimensions highlighted can pivot further studies. However, more details of the dimensions of the agility enablers are required. This is by way of minute operational details of the enablers and some others yet to be identified. In addition, the agility enablers may not be equally relevant and easy to implement across industries because of differences in product characteristics, competitive priorities, scale of operation and type of business (Hormozi, 2001).

Accordingly, the agility enablers are indicative of appropriate change initiatives, the intensity of which should depend on the magnitude of the impact of environmental change drivers that threaten attainment of competitive objectives and business performance measures. However, as intense competition and market turbulence forces more companies to strive to turn traditionally functional products into innovative products as a means of boosting competitiveness, change initiatives that mimic the agility enablers would become more popular. In order to further articulate the business drivers behind the agility enablers, the following section discusses some of the main issues in the lean/ agile debate.

2.12. LEAN VERSUS AGILITY DEBATE

Several people whose inputs were sought at various stages of this research wondered if agile manufacturing was not a buzzword and whether it differed significantly from lean production. As well, although researchers have highlighted some differences between lean and agile (Karlsson and Ahlstrom, 1992; Hamel and Prahalad, 1994; Booth and Hammer, 1995, Richards, 1996; Yusuf et. al., 2002), some other writers either used the two concepts interchangeably or called for their integration (Bodine, 1998; Quintana, 1998; Naylor, 1999; Mason-Jones et. al., 2000). Accordingly, the main issues in the lean/ agile debate required elaboration especially the differences and common grounds. This section discusses the main issues borrowing largely from an on-coming journal publication from this research, which highlighted the main differences between lean production and agile manufacturing (Yusuf et. al., 2002). In addition, the discussion drew knowledge from the distinction between functional products and innovative products as a basis for figuring out the right supply chain for a product (Fisher, 1997; Mason-Jones, et. al., 2000).

Whereas lean production seeks cost efficiency through continuous improvement and synchronous production flows, agile manufacturing seeks responsive adaptation by leveraging the resources of chains of companies for speedy and transparent customisation. Accordingly, lean production and agile manufacturing differ in their competitive drivers, operational tools and mechanisms as well as interactions amongst people, teams and machines (Booth and Hammer, 1995; Fitzgerald, 1995; Richards, 1996; Fisher, 1997; Willis, 1998; Mason-Jones et. al., 2000; Christopher and Towill, 2001). The following quotations sharpen the distinguishing features (Mason-Jones et. al., 2000).

"Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market" whilst *"Leanness means developing a value stream to eliminate all waste, including time, and to ensure a level schedule"* (Naylor, 1999).

"Lean or world class manufacturing is being very good at doing the things you can control. Agile manufacturing deals with things we cannot control" (Maskell, 2001).

Whereas lean methods offer customers good quality products at low price by removing inventory and waste from manufacturing, agile manufacturing is a strategy for entering *niche markets rapidly and being able to cater for the specific needs of ever more demanding customers on an individual basis* (Robertson and Jones, 1999).

The main differences can be outlined as follows (Booth and Hammer, 1995).

- Lean production is an enhancement of mass production whereas agile manufacturing implies breaking out of mass production age and producing in diverse configurations.
- Agile manufacturing strives to serve ever-smaller niche markets and unique customers at the same cost with mass and lean producers. In contrast, lean production seeks waste reduction and a level flow of operations in a relatively stable market.
- Accordingly, agile manufacturing seeks opportunistic coalitions of companies sharing manufacturing facilities and knowledge as a means of enhancing responsiveness whilst lean production emphasises just in time inventory and scheduling management in addition to long-term contractual obligations with customers and suppliers.

A paper published from this research (Yusuf et. al., 2002) addressed the main issues in the lean/ agile debate. In twelve headings, the paper discussed differences in market conditions, competitive priorities, core operating capabilities, management style, operations control, IT architecture, logistics, work organisation, machine characteristics, nature of automation, core training requirements and overriding limitations of lean and agile. The paper argued for instance that:

"The ultimate goal of lean production is to increase productivity, enhance quality, shorten lead times and reduce costs" whilst: *"The decisive goal of agile manufacturing is to ...develop capabilities for managing continuous change in customer requirements as a routine, ...and be able to produce anything in any volume, at the cost of mass production"*

Fisher's (1997) distinction between commodity products and innovative products as a basis for devising the appropriate supply chain for a product also provides a handy basis for discussing the lean/ agile debate. Fisher argued that commodity products markets are relatively stable whilst innovative product markets are relatively unstable. Accordingly, supply chains in the former should seek efficiency in physical distribution in support of a low cost strategy. In contrast, supply chains for innovative products, that is, agile supply chains should be driven by responsiveness, as products' life cycles are lower.

However, Fisher (1997) recognised that companies could "turn traditionally functional products into innovative products in order to achieve higher profits" and that the very newness of innovative products "forces companies to introduce a steady stream of newer innovations". Nevertheless, little is known about the turning point at which a company should transit from functional products to innovative products and subsequently migrate from the lean supply chain to the responsive and agile supply chain.

In this migration from the lean to the agile supply chain, the most important issue is where to position inventory, capacity and core value adding activities. These can be positioned near the plant, the supplier, the competitor or the customer (Fisher, 1997; Mason-Jones, 2000). A decision is required that suits either the need to respond to a volatile market through an agile supply chain or maintain a level schedule through a lean supply chain (Naylor et. al., 1997; Mason-Jones, 2000). Accordingly, Fisher (1997) concurred that:

"The critical decision to be made about inventory and capacity are not about minimising costs but about where in the chain to position inventory and available production capacity in order to hedge against uncertain demand."

In the light of this discussion, the need to implement the agile supply chain is greater with innovative products. However, two products that are physically the same can, through differences in the product strategy of plants be manufactured as a functional or innovative product. As well, in the innovative or high value products sectors such as automobiles, a car such as the "MINI" that services the basic needs of a car user can be described as functional whereas Alfa Romeo will be innovative as it has a range of additional features.

Indeed, Fisher (1997) recognised that a company can gravitate from the functional to the innovative and conversely without realising that anything has changed. In essence, the two types of supply chains- lean and agile may be relevant to the operations of a company even as the agile supply chain would become more relevant as companies strive to nurture functional products into innovative products. Not only this, the objectives of low cost and responsiveness pursued respectively by the lean and the agile supply chain may not be mutually exclusive. Indeed the agility of a supply chain could be defined as the extent to which a supply chain improves simultaneously on the two objectives.

Accordingly, as the two pivotal objectives of efficiency and responsiveness sought individually by the lean and the agile supply chains appear to be not mutually exclusive, the main issue in the lean/ agile debate seems to be identification of common grounds. This includes the efficacy of a total supply chain that combines the lean and agile paradigms (Mason-Jones et. al., 2000). However, a lean process must be engineered first and then adapted by removing specific constraints and capacity limitations. A simple axiom (Womack and Jones, 1990) that a lean organisation design must come before high-tech process automation that agile manufacturing epitomises also justifies the need to focus the lean and agile debate on common grounds. The following quotations demonstrate that lean and agile methods are not mutually exclusive.

"Agility is about developing tactical capabilities: superior concept to cash speeds. First, you need to have gone as far as you can with leanness. It is about hockey, not ballet. But you need to learn ballet first!" Harrison (1997)

"To approach agile manufacturing requires that the company already be world-class and using lean manufacturing methods. This is a starting point. You can only build agility on a firm foundation." Maskell (2001)

"Agile manufacturing is based on lean production, although there may be some apparent contradictions between the stability required for low cost and the flexibility required for agility. Agile manufacturing comprises the characteristics of lean production, extended to encompass ..." (Robertson and Jones, 1999).

"Interestingly, our case studies also indicates a connection between lean and agile approaches...Company A's strategic intent was to improve responsiveness rather than to eliminate waste. ... This strategy... led to an outcome of increased leanness and improved responsiveness to customers... By viewing manufacturing in the context of the supply chain as a whole, it is possible to see how agile manufacturing can subsume the paradigm of lean production." (McCullen and Towill, 2001).

The foregoing discussion indicates that in spite of the differences between lean production and agile manufacturing, they have common grounds. They both pursue customer driven and team focused strategies of survival under increasingly difficult competitive conditions. In such conditions, agile manufacturing should deliver on the efficiency of lean production as an indispensable addition to responsive adaptation (Tracy et al, 1994; Mason-Jones et. al., 2000; Power and Sohal, 2001). Agile manufacturing can optimise current processes through structures and systems that enable timely, temporal and costless mobilisation and shedding of marginal capacities as windows of opportunity open and close. In this regard, Naylor (1999) called for:

"... Combination of the lean and agile paradigms within a total supply chain strategy ... so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream ... "

In an effort to apply lean and agile methods to their operations, British Telecom (BT) tries to distinguish between physical network connection and service delivery over the network (Robertson and Jones, 1999). The former does not require customisation and therefore lends itself to a lean engineering approach, whilst service delivery is packet-based for individual customer requirements at short notice using agile manufacturing approach.

The path for integration of lean and agile has been specified. Lean demands more adaptability (Katayama and Bennett, 1996) whilst agile requires complete mastery of the levels of efficiency already attained in lean production (Gunneson, 1997: 3). Nevertheless, between resources, structures and processes that are superfluous and should be identified and eliminated, as against those whose elimination can cripple robustness and become lean on growth, a clear distinction is mandatory (Harrison, 1997; Bartezzaghi, 1999).

This section discussed the main issues in the lean/ agile debate. The main differences were highlighted. In particular, lean stresses cost efficiency and level schedule whilst agile harps on global resource mobilisation and responsive adaptation. In addition, a distinction was made between functional products and innovative products as a basis for figuring out the appropriate supply chain (lean or agile) for a product. However, it was argued that products and companies could gravitate between functional and innovative and that the pivotal objectives of the lean and agile supply chains are therefore not mutually exclusive. Accordingly, it was posited that identification of common grounds has become the main issue in the lean/ agile debate. Following next is a study of the nature of competitive objectives. They are the targets to which change initiatives such as lean and agile supply chains are directed. The direction of change in the attainment of competitive objectives therefore provides a means of assessing the impacts of agile change initiatives.

2.13. THE NATURE OF COMPETITIVE OBJECTIVES

Competitive objectives of manufacturing are several and can be listed according to fancy. They include low cost, quality, dependability, speed, volume flexibility, product customisation and leadership in new technology [New, 1992; Vokurka, R. and Fliedner 1997; Ward et. al., 1998; Gordon and Sohal, 2001]. Ideally, a company would strive towards simultaneous attainment of a wide range of competitive objectives even as the trade off syndrome persists in most companies (New, 1992; Ward et. al., 1998; Silveira and Slack, 2001). However, innovative methods such as JIT, concurrent engineering and AMTs have led to significant advances in cost, quality and speed. They also facilitate a shift in the position of competitive trade-off from most of the basic objectives such as cost and quality to higher order objectives such as speed and product customisation (Ward, 1998; Silveira and Slack, 2001; Gordon and Sohal, 2001).

In the light of rapid changes in market requirements, relative emphasis placed on competitive objectives is crucial to business performance (Vokurka and Fliedner, 1997; Vokurka and Fliedner 1998; Willis, 1998; Lau, 2002). This is in addition to systematic extension of competitive objectives beyond cost and quality to higher order objectives such as volume flexibility, product customisation and leadership in new technology (Hamel and Prahalad, 1994; Hayes and Pisano, 1994; Voss 1995; Vokurka and Fliedner, 1998; Ling X 2000; Lau, 2002). Ultimately, a company should improve its agility in terms of enhanced ability to compete from all fronts simultaneously.

Low cost is the most basic competitive objective. It seeks cost savings through economies of scale, baseline products with relatively stable life cycles, standardised machines, regular equipment maintenance, maximum labour utilisation, lower overhead costs, long production runs, and right first time practices (Edwards, 1996; Silveira and Slack, 2001). The quality objective follows low cost. It emphasises product confidence through quality assurance, parts availability, serviceability, user serviceable designs, guarantees, warrantees, and incremental additions to product features. Innovative programmes such as JIT, TQM, QFD, SMED, continuous improvement, concurrent engineering and automated process control of quality have succeeded in reducing traditional trade-offs between cost and quality (Flynn et. al., 1995; Hackman and Wageman, 1995; Edwards, 1996; Ganapathy, 1997; Emiliani, 1998; Sheridan, 1998; Curkovic et. al., 2000).

Next to cost and quality is dependability. It means adherence to and compliance with the terms and conditions earlier agreed with or expected by the customer. Such terms include continuous realisation of fair or agreed prices as well as delivery dates or call-off quantities. Dependability is influenced by relative stability in sourcing inputs, synchronised operational processes and production flows as well as machine, equipment and personnel reliability. Dependability also requires just in time improvement in ethical and contractual obligations as well as designs and terms (Ling X, 2000). The emphasis on dependability has increased due to a higher incidence of machine breakdowns in automated systems as well as unprecedented instability in the competitive environment (Edwards, 1996; Gordon and Sohal, 2001).

While it is important for manufacturers to deliver on low cost, quality and dependability objectives, unprecedented instability in the business environment has focused attention on speed and product customisation (Browne et. al., 1995; Bhattacharya, 1996; Sheridan, 1998; Suri, 1998; Gordon and Sohal, 2001). Speed means timely fulfilment of scheduled orders and developing new solutions ahead of competitors. Speed is influenced by machine efficiency, automation of routine processes and use of concurrent multidisciplinary project teams (Parthasarthy and Sethi, 1993; Tersine and Hummingbird, 1995; Bhattacharya, 1996; Ashley, 1997a, b; Suri, 1998). Enhanced operations speed also requires elimination of adversarial relationships, destructive interfaces, queues, breakdowns, incompetence and nonchalance in supply chains, operations processes, equipment and systems (Joyce and McGee, 1997; Gunneson, 1997; Forsythe, 1997; Gordon and Sohal, 2001). Information technology has become the main tool for advancing speed as plant operatives could access requirements real time, just as customers' databases can be penetrated remotely for information on stocks and potential orders. Accordingly, routing, batching and scheduling can be initiated in real time.

Closely related to speed is the competitive objective of product customisation. It seeks to satisfy unique customer needs, accommodate design change at ease, and support a wider range of product configurations as a means of competing in mass and niche markets (Sheridan 1993; Booth and Harmer, 1995; Bodine, 1998; Chambers and Nicholson, 2000). If nurtured through agile supply chain networks, the potential to add value to current products and customers is crucial for surviving market instability (Dove et. al., 1996; Paashuis and Boer, 1997; Perry and Sohal, 2001; Pratter et. al., 2001). However, several companies seek product variety as an end in itself rather than as a competitive strategy for surviving market instability (Pine II, et al., 1993; Trueman and Jobber, 1995; Lampel and Mintzberg, 1996; Tang and Yam, 1996). This leads to little or no transparent enhancements in customised offerings, which result to inefficiency as 80 percent of product offerings account for only 20 percent of profits (Stalk and Webber, 1993; Dale, 1995; Fitzgerald, 1995; Lampel and Mintzberg, 1996).

For product customisation to be profitable and sustainable, not only should it be attainable without trade-offs in cost, quality and speed, it needs to be complimented by two related competitive objectives of volume flexibility and leadership in new technology. Leadership in new technology means adding new features that appear to be ahead of their time to existing products, and in a manner that derail competitors' plans. This is the essence of agility enablers such as agile supply chains, intelligent automation and employee empowerment, as the means of mobilising best in the world competencies, enhancing replicable designs and committing teams of knowledge workers to unparalleled innovation.

As product customisation becomes intensified, order size requirements per custom product will tend to fall. However, a company should be able to vary capacity and manufacture any size of orders at the same unit cost. This is volume flexibility, whose significance arises from increasing product fragmentation with attendant decrease in order size quantities. Furthermore, a mass product may be customised for low volume supplies in specific market niches just as the basic features of a low volume customised product can be standardised for mass production (Maruka and Halliday, 1993; Pine II, et al, 1993; Thomke and Reinertsein, 1998). Accordingly, volume flexibility is the ability to change gears swiftly and intermittently from standard to custom product lines, to manufacture any order quantities, and adjust capacity at no extra cost to accommodate sporadic demand changes.

The Factory of the Future report (DTI, 1995) attested to the importance of volume flexibility. It was reported that CEOs of UK's industries identified a blend of elasticity (volume flexibility) and leadership in new technology as their dream and assured path to future survival. Yet, while the latter has been widely discussed, the same cannot be said about how to cope with variable order size requirements. The evidence of little emphasis on volume flexibility shows in only casual reference to it in the literature even as such references were based on seasonal demand fluctuations that could be planned for (Dixon, 1992; Upton, 1994; Silveira and Slack, 2001). In practice as well, volume flexibility remained least recognised as a crucial but most difficult to attain objective. In a recent study, companies ranked it as the least important and consequently, operational competencies for volume flexibility were near zero (Sharifi and Zhang, 2001). Nevertheless, flexible operational competencies, which facilitate responsiveness to demand fluctuations and dynamic upgrades of leading-edge products have been instrumental in warding off foreign competition (DTI, 1995).

Volume flexibility can be the most difficult competitive objective. Whereas supply chain networking can lead to cost savings, quality improvement, speedy deliveries and rapid customisation, competence in volume flexibility seems to depend more on factory floor efficiency and flexibility. The most important are routing and batching flexibility so that custom orders can be processed in parallel. Enhanced capability for volume flexibility would depend more on workers skills and the ease of mobilising, shedding and reconfiguring vital production resources and much less on intelligent machines and technologies [Upton, 1995; Willis, 1998].

Whereas advanced manufacturing systems such as NC machines have been useful in improving manufacturing cycle times and enhancing timely delivery of leading edge technology products, the same cannot be said about endless adjustments in levels of output (Vakharia and Kaku, 1993; Spina et. al., 1996; Soliman and Youssef, 2001; Silveira and Slack, 2001). The former has been largely achieved by means of improved hardware designs such as quick release mechanisms, cartridge-tooling assemblies and CNC machines. Nevertheless, although advanced machines and improved information processing enhance product customisation, they still have not made it possible to efficiently manufacture different quantities (Voss and Freeman, 1994).

In the light of the foregoing discussion, it was expected that the agility enablers would impact widely on competitive objectives but perhaps much less on volume flexibility. The study also expected that positive influence on the competitive objectives would translate into significant gains in business performance measures.

The impacts of competitive objectives on business performance measures have been reported in a number of works (Swamidass and Newell, 1987; Droge et. al., 1994; Ling X, 2000; Gordon and Sohal, 2001; Lau, 2002). Such studies exclusively used financial measures of business performance mainly sales turnover, net profit, ratio of operating income to assets and return on investment (Whybark, 1997; Ettlie, 1998; McGahan, 1999; Ling X., 2000). Financial measures are popular as short-term indicators of potential reward to investors. However, they may be inadequate as indicators of the level of activities, long-term survival and investment justification in situations of continuous change. Accordingly, a balanced score card of performance measures-financial, market and environmental are crucial in evaluating the impacts of change initiatives (Blenkinsop and Burns, 1992; Flynn et. al., 1995a; De Toni et. al., 1997; Ettlie, 1998). Section 3.2 reported six business objectives on which the impacts of agility enablers were tested. They had been used frequently in prior related studies (Flynn et. al., 1995b; De Toni et. al., 1997; Ettlie, 1998; De Toni and Tonchia, 2001).

2.14. SUMMARY AND CONCLUSION

Several issues involved in agile manufacturing as a competitive strategy were discussed in this review of the literature. The evolution of manufacturing systems, attributes of lean production and agile manufacturing, the drivers of agile manufacturing and identification of the enabling competencies deployable for agile manufacturing were presented. The main issues are summarised as follows.

Frequent changes in competitive and success factors faced by companies and the appropriateness of changes introduced into the operational characteristics of manufacturing systems determines competitive advantage. In this respect, increases in market instability and product complexity was employed to demonstrate the evolution of mass, lean, time-based competition, mass customisation and agile manufacturing. It was argued that tactical search for better performance justifies an integrative design, driven by the need to achieve simultaneously, the individual competitive objectives sought by preceding systems.

Thereafter, the threats to lean production were discussed in relation to the drivers of agile manufacturing. Whereas lean production focuses mainly on process improvement and excellence in shop floor mechanics, unprecedented instability and complexity in the business environment compels extension of the search for enablers of competitive advantage beyond excellence in shop floor mechanics and supply chain practices dedicated to outsourcing and distribution. In this regard, companies need to pool competencies and operate as virtual networks of resource coalitions for product development and manufacture. Accordingly, several drivers of agile manufacturing were outlined. They include a covert military interest by the US government, worker-induced problems associated with lean production, intensity of market pressures and developments in IT.

The review outlined several definitions of agility. A goal-based operational definition of agility, which best suits the study's empirical objectives was adopted. Agility was defined as simultaneous excellence on a wide range of competitive objectives such as cost, quality, speed, dependability, flexibility and customisation. This is expected to result to better business performance outcomes.

Two dimensions of agile initiatives were highlighted as a means of attaining simultaneous excellence in competitive and business performance outcomes. The dimensions are the engineering/ design dimension, and the social process dimension. The first dimension involves activities related to the design of manufacturing systems and the design of components whilst the social process dimension concerns customer, employee and supplier relationships. From the two dimensions, five enabling competencies were identified, which could be deployed as building blocks for agile manufacturing. The enabling competencies or agility enablers are transparent customisation, agile supply chains, intelligent automation, total employee empowerment and technology integration.

The five agility enablers were identified from a range of contingency models of current practices in product customisation, supply chain networking, manufacturing process automation, employee empowerment and technology utilisation. For instance, current practice in product customisation ranges from pure standardisation to transparent customisation. In the former, little of design, fabrication, assembly and logistics operations are customised, whereas in the later, all are customised and products technically unique.

As for supply chain networking, three contingency models of current practice were deducted from the literature. They are traditional supply chains, lean supply chains, and agile supply chains. Quite unlike the traditional chain employed by global conglomerates for market penetration and the lean supply chain networks of master-servant contractual obligations, the agile chain is underpinned by global exchange of manufacturing competencies. The latter is underpinned by access to global resources as a means of providing first to market solutions and gaining competitive advantage.

Next to supply chain networking, employee empowerment was discussed from the main dimensions of training, which targets work content improvement, and teaming, which fosters joint responsibility in work groups. The former means providing workers with the knowledge, skills and tools necessary to manipulate and operate advanced machines, whilst the latter means putting in place structures that enable employees to operate in self-directing and self-organising teams. Furthermore, empowerment suggests that workers are able to influence decisions about their job performance, work environment and the company's future. Total employee empowerment, which means integrating all dimensions such as training, teaming and involvement, is the third enabler of agile manufacturing.

Manufacturing automation in terms of the total gamut of operations or the range of different machining and assembly tasks that a particular machine or plant could be manipulated to execute, was discussed as another enabler of competitive advantage. Based on the level of human intervention required by machines and the range of operations that machines can be manipulated to execute, three general types of manufacturing automation were identified. They are mass automation, flexible automation, and intelligent automation. The third was identified as most appropriate to agile manufacturing design. This is in the light of the emphasis on transparent customisation and the fact that the reproduction costs of products manufactured by software-based intelligent machines are not volume sensitive. It was argued that intelligent automation requires higher scores on cellular design, range of automated processes, machine flexibility, machine intelligence and operational mobility.

Technology utilisation was discussed as the fifth agility enabler of competitive advantage. It was argued that multiplicity of operations technologies by the late 1980's frustrated managers over choice and application, and made it imperative to connect and learn incrementally from the range of available options. Consequently, several researchers have articulated adoption or synthesis of multiple technologies as an essential requirement of agile manufacturing. Technology was classified into two dimensions- operations technology and information technology. Some components of each dimension, including their essence and essential modifications in order to fit into agile manufacturing were highlighted. The conclusion was reached that irrespective of their numbers and range, technology is a "good" rather than a commodity, and that more should be preferred to less.

The review also presented a critique of agile manufacturing, most of which emanates from the pattern of literature development. In was stressed that contrary to the weight of emphasis placed on market turbulence, internal factors most of which were collectively addressed by JIT, TQM and OPT are also important. Therefore, it was suggested that research effort is required on what and how preceding systems could be integrated into agile manufacturing design rather than current emphasis on agility as a clean break. Agility could well mean the ease of integrating preceding systems for incremental learning. The integrative and incremental learning approach has the potential to provoke more research and industrial interest in agile manufacturing, in the search for best practice. By this approach, agile manufacturing would appear not to be radically different from what several companies have tried in the past or are trying presently or contemplating.

Finally, the nature of competitive and business performance objectives was discussed. It was argued that companies should advance from lower order to higher order competitive objectives, the most difficult of which could be volume flexibility.

Three conclusions emanate from the preceding literature review. First, agile manufacturing is indispensable as a means of enhancing competitive advantage. This is in the light of unprecedented market instability, which manifests in several ways such as complex customer requirements, companies attempt to outdo themselves, shrinking product life cycles and sporadic customer shifts. In this regard, the emphasis which agile manufacturing places on responsive adaptation would counter the destabilising influence of competitive pressures on business performance outcomes.

In the light of the first conclusion, what then are the enabling competencies by which the negative impacts of market and competitive pressures can be neutralised? Five enabling competencies otherwise described in this study as agility enablers were identified from a range of alternative practices in manufacturing competence building. The five agility enablers are transparent customisation, agile supply chains, intelligent automation, total employee empowerment and technology integration. Therefore, the second conclusion emanating from literature review is that the five agility enablers should be building blocks for agile manufacturing design. The agility enablers would require joint deployment so that they create positive multiplier effects.

The third conclusion stemming forth from literature review is that empirical research is inevitable in order to demonstrate the magnitude of market pressures as a driver of agile manufacturing. In addition, empirical research is important as a means of identifying and justifying agile manufacturing enablers of competitive advantage.

In the light of the third conclusion emanating from the literature review, this study set to identify and justify agile manufacturing enablers of competitive advantage. As a guide for the empirical investigations, chapter 3 reports a proposed conceptual framework of expected relationships amongst four concepts, which emanated from the literature review. The concepts are change drivers, competitive objectives, business performance and agility enablers. Research hypotheses were formulated to test the specified relationships amongst the four concepts.

CHAPTER THREE

CONCEPTUAL FRAMEWORK AND HYPOTHESES

This chapter reports a proposed conceptual framework of expected relationship amongst four concepts emanating from the literature review. Research hypotheses were proposed based on the conceptual framework. The four concepts in the conceptual framework are change drivers, competitive objectives, agility enablers and business performance. The conceptual framework is invaluable as a clear theory of method and as a rational guide for empirical studies (Pettigrew, 1990; Nachmias & Nachmias, 1992). In the light of limited empirical knowledge, an exploratory conceptual framework as used in several works will be invaluable in specifying relationships amongst concepts that reveal the exact nature and benefits of agile manufacturing (Burgess, 1994; Gunasekaran, 1998, 1999; Sharifi and Zhang, 2001; Hoek et al, 2001). Conceptual frameworks are also useful as the basis for drafting research hypotheses (Pettigrew, 1990; Nachmias & Nachmias, 1992).

3.1 CONCEPTUAL FRAMEWORK

This section specifies a relationship amongst four concepts emanating from the preceding literature review. The concepts are change drivers, business performance, competitive objectives and agility enablers. In Figure 3.1, the four concepts are shown by four boxes. The direction of cause and effect amongst the boxes were indicated by arrows. The conceptual framework pivots the research and provides the basis for generating hypotheses and crafting research instruments. The conceptual framework was used as a theory of method to focus the study and guide the investigation of relationships amongst concepts under study (Pettigrew, 1990; Goldman and Nagel, 1992; Burgess, 1994).

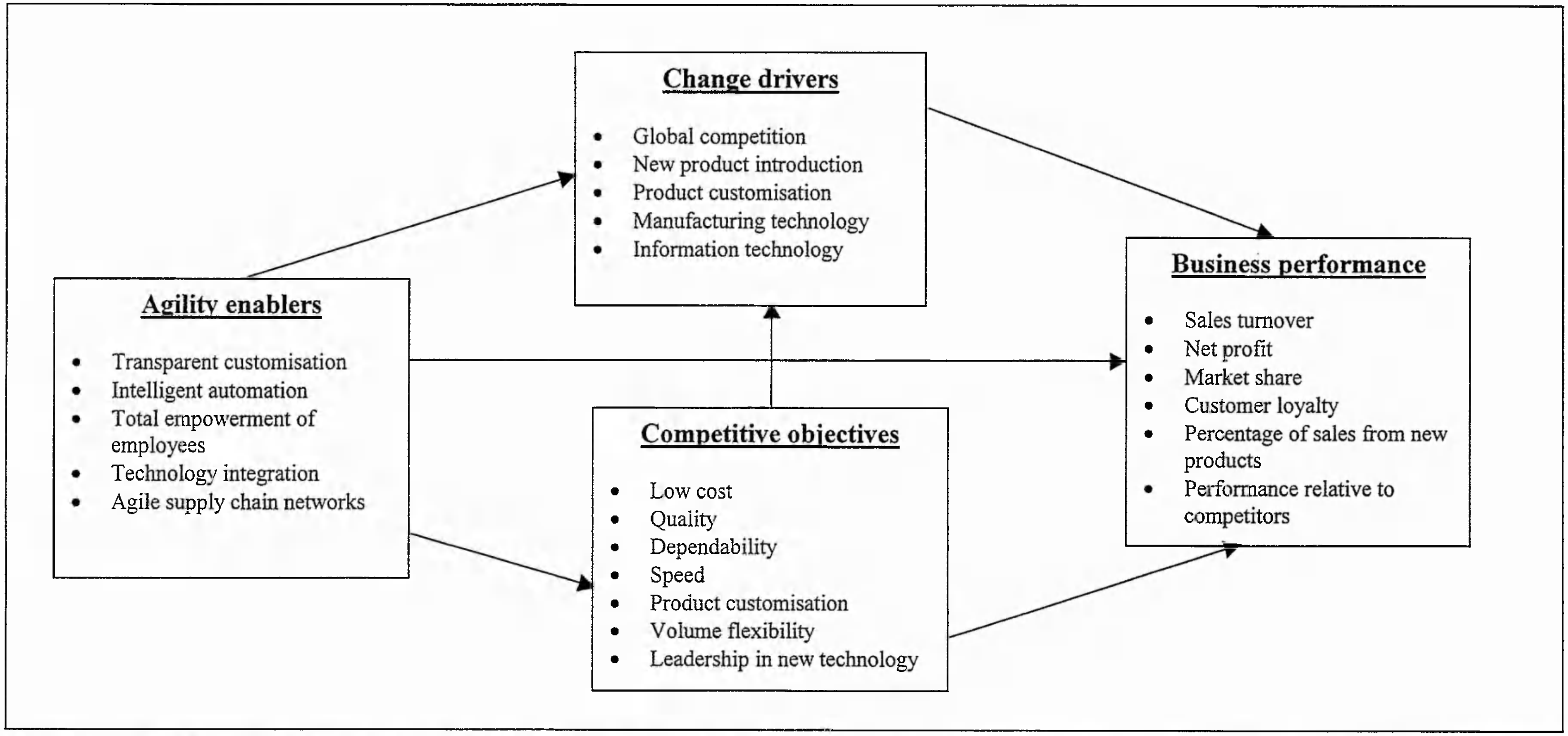
The directional arrow between the two boxes labelled respectively as change drivers and business performance shows that the former impacts on the latter. The need to master the perturbing influence of environmental change drivers on business performance provides the basis for agile manufacturing (Dove et al, 1996; Richards, 1996; Bartezzaghi, 1999; Mason-Jones et. al., 2000). The third box in Figure 3.1 was named competitive objectives. Companies need to improve on a wide range of competitive objectives as a means of defending business performance measures against the perturbing influence of the change drivers. In order to improve upon competitive objectives, appropriate competencies that enable competitive advantage need to be identified and deployed (Stalk et al, 1992; Gagnon, 1999; Gunasekaran, 1999, Sharifi and Zhang, 2001). Such competencies were labelled as agility enablers in Figure 3.1.

The conceptual framework in Figure 3.1 relates the four main concepts of change drivers, competitive objectives, business performance and agile manufacturing enablers, with a view to answer the following questions.

a. Do change drivers impact significantly on business performance?
b. Does attainment of competitive objectives affect the impact of environmental change drivers on business performance?
c. What resource competencies enable competitive advantage?
d. Could such resource competencies be classified as agile or non-agile?
e. Is agile manufacturing relevant to a wide range of companies?
f. What problems inhibit simultaneous attainment of competitive objectives?

The box labelled as change drivers is the originating point for discussing the conceptual framework. Change drivers have two broad dimensions, which were identified earlier in the literature review (Figure 2.1) as market instability and product complexity. The intensity of pressures imposed by these two dimensions of change drivers impacts negatively on business performance outcomes. This negative impact in turn recommends higher attainment of competitive objectives, which is made possible through significant adoption of the agility enablers (Gunasekaran, 1998; Ling X., 2000; Sharifi and Zhang, 2001). In other words, an increase in the strength of the change drivers justifies the deployment of the agility enablers as a means of boosting competitive objectives and business performance. Section 3.3 illustrates this relationship.

Five change drivers were extracted from the literature and investigated in terms of the magnitude of their impacts on business performance. The five change drivers are intensity of global competition (Vokurka and Fliedner, 1998), developments in manufacturing technology (Wallace, 1992), advances in IT (Goldman et al, 1995), increasing emphasis on custom products (Booth and Hammer, 1995) and a fast pace of introducing new products (Brown et al, 1995). The impacts of these change drivers on business performance compel the adoption and implementation of the agility enablers listed in Figure 3.1 as a means of advancing competitive objectives and business performance measures. The relationships amongst the concepts are discussed further in section 3.2.



Note: Between the four boxes, twelve arrows are possible. However, in empirical studies (Flynn et. al. 1995; Anderson et. al., 1995), entity relationships shown by arrows are those that fit reality and the data set more accurately and can hence be justified empirically. In contrast, all possible entity relationships can be indicated in a purely theoretical work (Sharifi and Zhang, 2001), which consists of ideas of a general nature and requires no empirical justification.

Figure 3.1 Conceptual framework

The box labelled as business performance is the second step in discussing the conceptual framework. Business performance provides the barometer for measuring business success. The nature of business performance was explored by studying the direction of change in six broad-based measures of that were more frequently discussed in the literature (Blenkinsop and Burns, 1992; White, 1996; Ling X. Li, 2000). The six measures are sales turnover, net profit, market share, proportion of sales turnover from new products, customer loyalty based on repeat orders, and performance relative to competitors. Most research works (Droge and Vickery, 1994; White, 1996; Ling X. Li, 2000) employed only financial measures of business performance such as sales turnover, net profit and return on investment. Financial measures, exclusive of non-financial measures such as market share and customer loyalty or retention might be inadequate for assessing overall strength and survival prospects in industries faced by unprecedented market instability.

The third box represents competitive objectives and it is the third focal point in discussing the conceptual framework. Competitive objectives are the goals sought by a manufacturing plant in terms of the set of values delivered to customers. Seven competitive objectives that are more commonly discussed were compiled from the literature (Vokurka and Fliedner, 1997; Ward, 1998; Yusuf et al, 1999; Ling X. Li, 2000; Silveira and Slack, 2001). They are low cost, quality, speed, dependability, product customisation, volume flexibility, and leadership in new technology products. This study expects that simultaneous attention to a wide range of competitive objectives will enhance the ability to cushion the impacts of the change drivers whilst also boosting business performance. The need to deliver simultaneously on a wider range of competitive objectives including product customisation and volume flexibility gives rise to the agility enablers. The need to identify and deploy agility enablers as a means of boosting the attainment of a wide range of competitive objectives has been stressed (Ferdows and De Meyer, 1990; Vokurka and Fliedner, 1997; Ling X. Li, 2000). In other words, if agility enablers were correctly identified and deployed, it should be possible to minimise trade-offs amongst competitive objectives and compete from all fronts (New, 1992; Ward et. al., 1998; Silveira and Slack, 2001). The ability to compete from all fronts is invaluable in shielding business performance measures from the perturbing influence of the change drivers, irrespective of their forms (Gunasekaran, 1998; Ling X. Li, 2000; Sharifi and Zhang, 2001).

The fourth box named as agility enablers is the fourth focal point in discussing the conceptual framework. The agility enablers are the resource competencies for boosting competitive objectives in markets characterised by sporadic changes and therefore requiring a significant amount of agile intervention. The need to identify and justify appropriate enablers of competitive objectives in today's unstable markets have been articulated in several works (Stalk et al, 1992; Sheridan, 1993; Gagnon, 1999; Fawcett and Myers, 2001). According to Fawcett and Myers (2001:66):

"The challenge is to identify correctly the distinctive capabilities that a firm can exploit for competitive advantage and then to put in place the right mix...that must lead to higher levels of performance alongside certain competitive dimensions..."

To this end, in the literature review conducted earlier, five agility enablers were deciphered from fifteen contingency options that emanated from a discussion of five dimensions of competence building in manufacturing. The five agility enablers are transparent customisation, agile supply chains, total employee empowerment, intelligent automation and technology integration (Gardiner, 1996; Ashley, 1997a, b; Gunasekaran, 1998; Gunasekaran, 1999). This study agues that adoption and implementation of the five agility enablers will improve attainment of manufacturing competitive objectives, and in turn defend business performance outcomes against the perturbing influence of environmental change drivers. Justification of the conceptual framework is important as a valid basis for drafting research hypotheses, collecting data and making inferences.

3.2. JUSTIFICATION OF THE CONCEPTUAL FRAMEWORK

Figure 3.1 shows the conceptual framework of how this research explains and develops the relationships amongst the several factors that have been identified from the literature as important to the discussion of agile manufacturing. The conceptual framework flows logically from the documentation of previous research in the problem area (chapter 2). The discussion in this section focuses on variable role definition as well as the explanation and illustration of the reason underlying the specified relationships. The arrows shown are those that the researcher perceives as more likely to reflect and fit empirical reality. This is the practice in empirical studies that are structured on guiding conceptual frameworks (Flynn et. al., 1995; Anderson et. al., 1995). Empirical data to be provided in chapter 4 will attest to the validity of the directional arrows shown in Figure 3.1. The validity of the directional arrows (as against imaginable reverse arrows) can be confirmed based on the difference between empirical correlation and regression coefficients as the measures of relationship and direction of impact between two variables (Anderson et. al., 1995). If the directional arrows are valid as specified, the difference between the correlation and regression coefficients should be no more than 0.1, and alternative reverse arrows would hence be deemed to fail the test of empirical reality (see page 120).

The term "Change drivers" is the starting or originating point for the conceptual framework. Change drivers consist of all sources of instability, uncertainty and turbulence in the business environment, which are exogenous or externally determined (Section 2.1 and 2.3). In other words, change drivers constitute an independent variable in Figure 3.1. Throughout history, manufacturers have been confronted with change drivers in their business environment. For example, Bhattacharya (1996) reports on an engineering company that fell victim of the change drivers after two years of significant investment in the redesign and implementation of product-focused manufacturing cells. Although such cells would have aided internal efficiency, they were perhaps too rigid whilst business conditions changed fast. According to Bhattacharya (1996):

"The company found that over a period of two years there was a fall in performance along key indicators... Analysis showed that the cell design had become misaligned when compared against the prevailing conditions and original objectives. The effect of such misalignment was felt as turbulence in the manufacturing pipeline, and its identification and measurement can provide key input into redesigning a robust system."

A study of the Factory of the Future (DTI, 1995) found that:

"External change drivers affecting companies today are extremely significant, very rapid and... largely out of their control. Recent examples of major unforeseen disruptions to the external business environment include the long and deep recession, the end of the cold war and the reunification of Germany, environmental legislation, the introduction of preferred supplier status, EU directives and market drift- the trend for today's product to become tomorrow's commodity."

These change drivers have become more continuous and sporadic, and they rather than differences in internal efficiency have been recognised as the cause of most failures in manufacturing (Sharifi and Zhang, 2001)

In other words, according to Browne et. al (1995):

"... Performance measures now reflect some of the external pressures placed on the manufacturing enterprise"

The foregoing argument that performance measures now reflect some of the external pressures placed on manufacturing enterprises justifies the arrow that shoots out from change drivers towards business performance (Figure 3.1). This arrow implies that the change drivers exercise a direct impact on business performance, and hence, business performance is a dependent variable. Ordinarily, as shown in the following illustration, the impact of change drivers on business performance is expected to be negative, as the impact will be to reduce the performance (DTI, 1995; Sharifi and Zhang, 2001).

This study illustrates the relationship between change drivers and business performance as follows, using two hypothetical companies A and B. The former operates in the UK whilst the latter is based in Eastern Europe. Assume that a new EU directive (a change driver) makes pharmaceutical products freely tradable within the EU. This singular EU policy becomes a change driver in the nature of global competition (Figure 3.1). Perhaps due to lower labour costs in Eastern Europe, Company B may have a cost advantage over Company A, even as Company B may wish to trade in the UK because the residents have a higher purchasing power, which could fetch higher sales turnover and net profit.

Accordingly, assume that Company B now enters the UK market with the cheaper but equally effective tablet formulation in the field of HIV. The activities of Company B therefore become a change driver to Company A, when viewed from the perspectives of globalisation, foreign competition and new product introduction. Thus, the change driver that has a negative impact on company A has a positive impact on company B. It is not always that what is negative for one company is positive for another. In this foregoing illustration however, company B is being seen as a foreign competitor and the concern herein is for how Company A could respond to such situations through the agility enablers.

By the time this cheaper but equally effective tablet formulation enters the UK pharmaceuticals market, competitive objectives in Company B including cost, quality and speed would tend to remain at their present levels as if nothing has changed in the market. Market share in Company B, which is a core dimension of business performance, will be the first victim of the EU-induced activities of Company A as customers drift to the newly introduced cheaper but equally effective tablet formulation. Following next will be a decline in customer loyalty, sales turnover, net profit and long-term survival prospects.

Accordingly, in Figure 3.1, an arrow that shoots out from the change drivers to competitive objectives rather than business performance may not fit reality. This is from the point of view of the UK Company A whose survival prospects, rather than that of Company B, lies in the centre of this illustration. As well, a reverse arrow between the change drivers and business performance, which implies a reversal of the direction of the foregoing illustration, may be less valid if confronted with empirical data. For example, it seems inconceivable to think that business performance in Company A would determine a change driver such as this illustrative example of EU-induced global competition.

Besides the EU-induced global competition, assume that technological advances have led to a new tablet forming machine that is amenable to complete off-line retooling, as well as a data communication software for real-time monitoring of inventory requirements being readily available in the UK market. These also are externally induced change drivers in the form of advances in manufacturing and information technology. The new tablet forming machine has the capability to completely eliminate down-time associated with machine set-up, and in effect, change over across a wide range of product lines in the course of a day potentially becomes possible at no extra cost. Such benefits are also accruable from, the new data communication software, which can facilitate just in time scheduling and the efficiency of physical distribution whilst reducing space and inventory costs.

The availability of these new technologies in the market does not on their own and in any way effect competitive objectives and business performance measures in Company A or Company B. The impact is felt on profits when an unknown company buys these technologies and utilises them to compress its own manufacturing cycle time, and is therefore more able to lower cost and time to market. Such activities will be felt in Company A and B by way of lost market share, sales turnover and profits as customers shift to the unknown company that has become more efficient. From this perspective therefore, the arrow that shoots out from change drivers towards business performance is justifiable. A reverse arrow between change drivers and business performance, which would imply a reversal of the foregoing illustration, may not fit empirical reality well. For example, an argument that working tools (agility enablers) determines harvest quantity or output (business performance) appears more sensible than a counter argument that harvest quantity determines the tools applied.

In the earlier illustration of the relationship between change drivers and business performance using EU-induced global competition, Company A was a victim of change. In the second illustration of technological advance, Companies A and B were both casualties of change because they were inept.

In order to recapture lost market share, sales turnover and profits in companies that have become victims and casualties of change, it is important to improve on current of attainment of competitive objectives. For instance, Company A may have to lower cost and prices to the levels of the newly relocated competitor from Eastern Europe. This is achievable for example by sourcing core inputs from Eastern Europe. Alternatively, Company A may package and target to the customers, a wider range of competitive objectives such as a speedy delivery, better quality and dependability. If the attainment of competitive objectives could match or surpass the levels of Company B, Company A could recapture lost grounds in market share, sales turnover and profits. This is the sense in which an arrow shoots out from competitive objectives towards business performance. The relationship is expected to be positive, in that a positive change in delivery speed (competitive objective) would motivate customers to buy more and lead to a positive change in market share, sales turnover and net profit. The need to widen competitive objectives whilst also striving for simultaneous advance was stressed in section 2.13.

The foregoing discussion shows that business performance is exposed to opposing impacts from externally determined change drivers and internally determined competitive objectives. It is also logical to infer From the preceding illustration that as higher attainment of competitive objectives by Company A leads to lost market share and sales being recaptured, the impacts of change drivers such as the EU policy becomes increasingly ineffectual. In other words, a tripartite relationship exists amongst change drivers, competitive objectives and business performance.

As markets become more competitive and the change drivers more difficult to predict and plan for, companies need to widen the range of competitive objectives as a means of boosting business performance whilst warding off the pressures from change drivers. To this end, development of appropriate enabling competencies is required.

Accordingly, Browne et. al. (1995) argued that:

"In the current situation... the basis of competition... is excellence in core competencies"

To this end, Robertson and Jones (1999) stressed that:

"The *emphasis is on the design of a complete enterprise that is flexible, adaptable, and has the ability to thrive in a continuously changing business environment where markets consist of radically changing niches serving increasingly sophisticated customer demand.*"

This is the essence of the box labelled agility enablers, from which three arrows shoots out towards the change drivers, competitive objectives and business performance (see Figure 3.1). It was argued in section 2.4 that the agility enablers are agile manufacturing structures and systems for tackling the change drivers and boost competitive objectives and business performance. The agility enablers consist of (Gunasekaran, 1998):

"*... A few enabling technologies... information and communication infrastructure, and organisational and behavioural changes* that is *critical to successfully accomplishing....*"

Five dimensions of agility enablers were identified in sections 2.4-2.9 and listed in Figure 3.1. The agility enablers were identified from five dimensions of competence building that was most commonly discussed in the literature of competitive manufacturing (Gunasekaran, 1999; Vernadat, 1999; Maskell, 2001).

The agility enablers are expected to have a direct effect on the change drivers, business objectives and business performance. Assume that the UK Company A that was used earlier to illustrate EU-induced global competition now embarks on a programme of agile manufacturing as a mean of regaining lost market share, sales turnover and profits. The company may adopt transparent customisation as a new way of making its products smarter through continuous streams of innovation (DTI, 1995; Fisher, 1997). They may target single dose packages for midday administration, blister packs for users in nursing homes and soluble tablets. It is for this similar purpose that in the food processing industry, every product now comes in a bewildering variety of sizes, packs, variations, diet, low sodium, decaffeinated, kid's size, and so forth. A wider range of options delight customers and creates the potential for higher sales, market share and profits. What is important however, is the uniqueness or transparency of innovation contained in each product option. This is the point made in section 2.5 against cosmetic customisation and lean product development that adds more to costs than to revenue (Pine II et al, 1993; Gilmore and Pine II, 1997).

In support of this strategy, a company may adopt intelligent automation by way of investing in machines that could be programmed to perform a much wider range of machining and assembly operations without the machine change over costs that characterised flexible automation. Compressed time subsequent to the utilisation of intelligent machines would compress manufacturing cycle times whilst making it less expensive to widen the range of product options. Furthermore, a company may initiate an agile supply chain for opportunistic response to temporal windows of opportunities in the business environment whilst also empowering employees from all dimensions. These are in addition to technology utilisation as a means of improving plant and logistics operations. The implementation of the afore-mentioned agility enablers, will through several measures of operational efficiency such as manufacturing cycle time, operational flexibility, routing flexibility and rate of production, translate to a higher attainment of competitive objectives.

It is therefore tenable to state that attainment of competitive objectives and business performance is directly related to the level of adoption of agility enablers. This is the sense in which Sarkis (2001) argues that the agility enablers have the potential:

"...To reduce the toll of change on production cost, product quality, product availability, organisational viability, and innovation leadership"

Accordingly, the arrows that originate from the agility enablers and joins the boxes named change drivers, competitive objectives and business performance are justifiable. In contrast, a reverse arrow from the three boxes and shooting towards the agility enablers, which would imply a reversal of the arguments canvassed in the preceding paragraphs, might be less valid. For example, an argument that working tools (agility enablers) determines harvest quantity or output (business performance) appears more sensible than a counter argument that harvest quantity determines the tools applied. This latter argument would tend to be less valid if confronted with empirical reality.

The foregoing discussion clarifies the role of the agility enablers. Through the agility enablers as a means of reducing the toll of change on competitive objectives such as production cost, product quality, product availability, innovation leadership and organisational viability, the expected negative impact of the change drivers on business performance could of course become positive. As such, a company that is significantly innovative and takes pre-emptive measures in anticipating of the change drivers such as the EU-induced challenge of global competition would profit rather than become a victim or hostage. In this sense, the impact of the change drivers on the operations of a company that is significantly agile, innovative and pro-active could approach +100 percent, whilst in contrast, it would approximate –100 percent for its competitors. Accordingly, companies' scores on a Likert Scale ranging from say –5 (Highly negative) to +5 (Highly positive) can be described alternatively as a measure of environmental performance.

The two arrows linking competitive objectives to change drivers and business performance also require some articulation. The arrow linking competitive objectives to the change drivers means that higher attainment of a wider range of competitive objectives influences the impact of the change drivers. For example, if the UK Company A has developed appropriate resource competencies by which it could compete effectively from all fronts, Company B would have no business in the UK. Indeed, it would be Company A expanding to Eastern Europe after the EU globalisation policy whilst also making business in the UK unprofitable for Company B. On the other hand, the arrow linking competitive objectives to business performance, is much easier to explain and studies of this relationship abound in the literature on manufacturing strategy and productivity (Droge et. al., 1994; Ling, 2000). Put simply, any cost-savings such as through economic use of space or materials would ultimately reach the end customer through lower prices (low cost leadership), which in turn implies higher sales, market share and profits. The same applies to quality as a competitive objective. Enhancements in quality motivate customer confidence in a product, and through higher sales, profits and market share are elevated.

The arguments presented in the preceding paragraphs justify the four concepts and the six directional arrows that populate Figure 3.1. It is possible to extent to twelve the six arrows in Figure 3.1, as in general, n entities can be linked by: n x (n-1) arrows. However, the six arrows proposed are those that could be meaningful in this context and therefore be valid when confronted with empirical reality. In purely theoretical works such as Sharifi and Zhang (2001), which discussed ideas of a general nature without empirical input, the number of arrows amongst entities can be maximised. However, in empirical works such as Flynn et. al., (1995a), directional arrows indicating entity relationships were limited to those that data could validate.

Sharifi and Zhang (2001) proposed a model of agility, which validates the framework proposed in this study. The model consists of three elements defined as follows:

1. *Agility drivers are the changes/ pressures from the business environment that necessitate a company to search for new ways of running its business in order to maintain its competitive advantage.*
2. *Agility capabilities are the essential capabilities that the company needs in order to positively respond to and take advantage of the changes.*
3. *Agility providers are the means by which the capabilities could be obtained.*

The framework proposed in Figure 3.1 has some limitations. First, as a single study for PhD, it could not investigate the minute details of the four concepts. In addition, the framework lacks prior empirical validation whilst the various terms used were yet to have widely acceptable definitions. Accordingly (Sarkis, 2001):

"A more robust, theoretical foundation is still a necessary requirement in aiding the transformation of agility and its principles into a science... the theoretical foundations of agility have yet to be explored and this may be a barrier to agility's progression, at least from the scientific viewpoint... The first barrier is... definitional... the second barrier... is the lack of paradigms to characterise the field of agility".

Nevertheless, these limitations (Sarkis, 2001):

"Should not serve as a barrier for advancement... Agility is an emerging theory... the lack of definition/ theory should not be a hindrance in making advances..."

The foregoing discussion justified the conceptual framework in Figure 3.1. Deriving from the discussion, the following five hypotheses were proposed for investigation.

3.3 RESEARCH HYPOTHESES

Five hypotheses were proposed to investigate the specified relationships amongst the four concepts of change drivers, agility enablers, competitive objectives and business performance. The first hypothesis explored the relationship between environmental change drivers and business performance. In order to neutralise the impacts of environmental change drivers on business performance, higher attainment of competitive objectives, which is in turn determined by specific enabling competencies (agility enablers), are a requisite. Based on the expected relationships, the following five hypotheses that were listed earlier in Chapter 1 were proposed for investigation. The study commenced initially with four hypotheses. However, a fifth hypothesis was proposed later as a means of studying a "research dilemma" that emerged from the results of the survey by questionnaire (Collins and Gordon, 1997). This research dilemma borders on the agility enablers, which did not impact significantly on the competitive objective of volume flexibility. The fifth hypothesis was therefore proposed to study the exact nature and requirements of volume flexibility within the framework of agile manufacturing design.

Based from the relationships specified by directional arrows in the conceptual framework in Figure 3.1, the following five hypotheses were proposed for investigation.

1 There is a strong relationship between change drivers, competitive objectives and business performance.

2 Companies that pay simultaneous attention to a wide range of manufacturing competitive objectives will outperform the competition.

3 Attainment of manufacturing competitive objectives is directly related to the level of adoption of agile manufacturing enablers.

4 Demographic and industrial contingencies determine the need for agile manufacturing and its potential impacts on competitive advantage.

5 Virtual cells enhance operational flexibility, which in turn determine attainment of volume flexibility as a competitive objective.

Hypothesis 1 argued that a relationship exists between environmental change drivers competitive objectives and business performance. These relationships make agile manufacturing design inevitable. Agile manufacturing is underpinned by the assertion that market instability impacts negatively on business performance, and that agile manufacturing provides the means of mastering the undesirable impacts of the change drivers (Richards, 1996; Dove et al, 1996; Bartezzaghi, 1999; Mason-Jones et. al., 2000). Accordingly, companies that recognise the significance of the change drivers will be more positively disposed towards agile manufacturing design as a means of profiting from change and uncertainty. In the light of the argument that a relationship exists between change drivers and business performance, which that makes agile manufacturing inevitable, the need arises to test for differences in business performance outcomes across agile and non-agile companies.

Hypothesis 2 followed from hypothesis 1. It opined that companies that pay simultaneous attention to a wide range of manufacturing competitive objectives would outperform the competition. If the perturbing influence of environmental change drivers on business performance truly justifies agile manufacturing design, the need arises for a framework for measuring agility. Accordingly, having defined agility earlier in sections 1.1 and 2.2 as simultaneous attainment of competitive objectives, Hypothesis 2 aimed to test whether emphasis on a wider range of competitive objectives enhances business performance more than focusing on a narrower range of competitive objectives such as low cost and quality. Although focusing strategies and the trade-off syndrome persist in several companies (New, 1992; Ward et. al., 1998; Gordon and Sohal, 2001; Silveira and Slack, 2001), agile manufacturing pursues simultaneous attainment of competitive objectives (Spina et. al., 1996; Fliedner and Vokurka, 1997). In essence, hypothesis 2 tests whether broad-based competition as proposed in agile manufacturing is more desirable than focusing strategies such as low-cost competition (McGahan, 1999).

Hypothesis 3 was the main hypothesis of the research. It was proposed to identify and justify agile manufacturing enablers of competitive advantage. If the impacts of change drivers justify agile manufacturing design (Hypothesis 1), and if simultaneous attainment of competitive objectives (agility) enhances business performance (Hypothesis 2), agile manufacturing enablers of competitive advantage need to be identified and justified. This is the essence of Hypothesis 3 and of course the central objective of the study.

The main challenge in competitive manufacturing is identification of the resource competencies for keeping in constant tune with the market and the customer, as a means of enhancing competitive advantage and long-term survival (Gagnon, 1997). Fawcett and Myers (2001:66) hammered on the need to:

"... Identify correctly the distinctive capabilities that a firm can exploit for competitive advantage and then to put in place the right mix...that must lead to higher levels of performance alongside certain competitive dimensions..."

This challenge of identifying distinctive capabilities persists in agile manufacturing even as researchers recognised the need to identify and justify deployable enablers of competitive advantage in inherently unstable markets (Sheridan, 1993; 1996; 1998; Gunasekaran, 1998;

1999; Gagnon, 1999; Sharifi and Zhang, 2001; Hoek et al., 2001). Hypothesis 3, which is the focus of the research aims to identify and justify agility enablers.

Hypothesis 4 proposed that demographic contingencies determine the need for agile manufacturing and its potential impacts on competitive advantage. In essence, Hypothesis 4 sought to test the extent to which the results emerging from Hypotheses 1 and 3 apply widely to companies irrespective of size, product groups and other demographic factors. Hypothesis 4 is hence underpinned by the inclination towards highly volatile markets such as automobiles in the discussion of agile manufacturing (Levary, 1992; Richards, 1996).

The need therefore arises to test the extent to which the impact of environmental change drivers that compel agile manufacturing is significant across a wide range of demographic sub-samples of companies. Likewise, it is important to test whether the expected impacts of agility enablers to be identified based on Hypothesis 3 apply equally across demographic groups. This is the sense in which Harrison (1997) argued that the time was ripe to search for clues on the relevance of agile manufacturing to the UK but that the search should be industry specific. Nevertheless, it is tenable that change drivers such as global competition, rapid customisation and new product introduction may have no industrial bounds and that the results of the study will be devoid of demographic limitations. Accordingly, irrespective of demographic contingencies, a company that recognises the destabilising influence of the change drivers will be more favourably disposed towards the agility enablers as a means of profiting from change and enhancing survival (Richards, 1996; Dove et al, 1996; Bartezzaghi, 1999; Mason-Jones et. al., 2000).

Lastly, Hypothesis 5 was proposed as a means of studying the unique nature of volume flexibility as a competitive objective that is potentially most difficult to influence by the agility enablers. Earlier in Hypothesis 3, it was proposed that attainment of manufacturing competitive objectives is directly related to the level of adoption of agile manufacturing enablers. Nevertheless, the evidence abounds that competitive trade-offs persist and that volume flexibility might be least influenced by the agility enablers (New, 1992; Ward et. al., 1998; Silveira and Slack, 2001). Although several innovations in manufacturing such as application of cost of quality programmes, advanced manufacturing technologies and cellular design significantly impact on cost savings and customisation, volume flexibility is an exception. This is in terms of the ability to flex capacity and vary production volumes at no extra cost (Wemmerlov and Hyer, 1989; Vakharia and Kaku, 1993; Chambers and

Nicholson, 2000). Accordingly, reports abound that companies' current attainment of volume flexibility tends towards zero (Hill and Chambers, 1991; Sharifi and Zhang, 2001).

Hypothesis 5 therefore provides a means of revealing the potential threat posed by volume flexibility in relation to the goal of simultaneous attainment of competitive objectives, subsequent to the deployment of agility enablers. The hypothesis also tests the validity of virtual cells as a means of improving volume flexibility.

In this chapter, a conceptual framework of relationships amongst four concepts that underpin agile manufacturing design was proposed. The concepts are change drivers, agility enablers, competitive objectives and business performance. The model was employed to argue that change drivers impact on business performance and that higher attainment of competitive objectives, which is achievable through the implementation of agility enablers of competitive advantage could neutralise the perturbing influence of environmental change drivers. This is the central thesis of the study, and all hypotheses proposed for investigation were ancillary to it.

Following next in Chapter 4 is the report of a survey by questionnaire. The survey was designed to gauge practitioners' opinions on the impact of change drivers, implementation of elements of the agility enablers, and attainment of competitive and business performance objectives. Multiple instruments were crafted to collect data, and the data were used to test the validity of the five hypotheses proposed earlier by the researcher.

CHAPTER FOUR

SURVEY BY QUESTIONNAIRE

This chapter reports the planning and administration of a survey by questionnaire and the results emanating there from. The survey gathered data with a view to exploring and testing the relationships specified in the conceptual framework and research hypotheses. It obtained data on environmental change drivers, alternative practices in competence building and attainment of competitive and business performance objectives. In terms of the number of concepts and variables studied, the survey is extensive as agile manufacturing lacks prior empirical work to build upon or depart from. A survey by questionnaire provides a means of collecting data from several companies on an emerging concept such as agile manufacturing. An industrial surveys by questionnaire can be complemented by in-depth case studies.

A survey by questionnaire provides a means of collecting data, which are analysed to reveal the nature of new concepts or entities, and to test relationships, similarities or differences amongst them (Collins and Cordon, 1997). A survey by questionnaire often has three aims, which are exploration and measurement of new concepts, confirmatory studies, and descriptive studies that aim not to test or build a theory (Filippini, 1997:665). Most researches in manufacturing operations are descriptive whilst exploratory and confirmatory studies are rare (Filippini, 1997). This survey is exploratory. It sets to identify competence-building practices that are compatible with agile manufacturing principles whilst at the same time leading to higher levels of business performance.

The survey data was designed to provide the basis for answering research questions and testing the research hypotheses proposed earlier in sections 1.2 and 1.3. In order to reduce error and enhance validity of results, formal procedures of survey design, administration and data analyses were applied (Nachmias & Nachmias, 1992; Collins and Cordon, 1997).

This chapter is organised as follows. A sub-section is allocated to each of company selection, questionnaire design and administration, data validation, demographic, and descriptive statistics. Inferential statistics follow next, with sub-divisions reporting the various statistical tests conducted. A final sub-section discusses the research hypotheses.

4.1. QUESTIONNAIRE DESIGN AND ADMINISTRATION

A questionnaire was designed with a view to collect data on the four main concepts of change drivers, business performance, competitive objectives and agility enablers. The four concepts, which underpinned the conceptual framework discussed earlier in Section 3.1, provided the basis for deriving the survey questions. The conceptual framework was published before the relationships contained therein were employed as the basis for crafting research instruments and designing the questionnaire (Adeleye et al, 1999).

The survey questions underwent rigorous evaluation by the supervisory team. The researcher also sought informal inputs from Trent Surveys, a commercial outfit of the university. Thereafter, the questionnaire was administered to six colleagues, two lecturers and two friends outside the university. They were asked to complete the questions as if they were CEOs, and to provide feedback on clarity, flow and time taken. The internal pilot test indicated an average of about nine minutes completion time. The lessons learnt from the internal pilot test such as the need for straightforward questions, were incorporated into the pilot test.

Five hundred copies of the questionnaire were distributed for pilot test. The pilot questionnaire consisted of 86 questions, most of which were matrix and required only a tick. Nevertheless, only 45 questionnaires were returned, out of which 19 were deemed valid and 26 invalid. Several questionnaires were returned as undeliverable by the post. Twelve companies claimed not to be in manufacturing, two companies claimed to be non-British and one company returned blank. A study of the 19 valid returns showed that some questions were poorly grasped whilst some respondents lost patience or concentration.

The pilot study results were discussed with the supervisors and some changes were made towards the final questionnaire. First, The YAHOO UK on-line, from which companies addresses were compiled, was replaced by Financial Analysis Made Easy (FAME). In addition, the questions were made more concise and reduced from 85 to 60 in order to encourage more responses by companies during the final administration of the questionnaire. Reduction of the number of questions limited the number of variables used to measure concepts to between five and eight per concept. Such reduction restricts available data and this is a major disadvantage of surveys by questionnaire.

The nineteen valid responses from the pilot study were retained for data analysis. However, a few of the pilot responses were modified to tally with the final questionnaire. For example, based on sales turnover and number of employee, most of the nineteen pilot respondents were small-scale companies. In addition, questions on the application of technology were changed from ordinal categories in the pilot survey to nominal "Yes" or "No" categories in the final survey. Therefore, with due apology, a four-item repeat-questionnaire was mailed again to nineteen companies returning valid pilot responses.

The pilot and final questionnaires were administered mainly by post, followed up by telephone calls. They were also sent to a few companies as e- mails through their web sites.

The relative advantages of the postal over the telephone or Internet questionnaire have been discussed (Nachmias and Nachmias, 1992, Layder, 1993; Bhatt, 2000). The post is not too expensive and perhaps, it compels an obligation to pass a posted questionnaire alongside other mails addressed to the CEO. This is quite unlike passing a questionnaire through a web site, which was intended mainly for commercial enquiries or sending a questionnaire as unsolicited e-mails that could be easily deleted.

However, postal questionnaires often suffer from problems of low response rate, perhaps due to pressure of work or lack of interest. In this study of a new and poorly understood concept of agile manufacturing, several methods were applied to boost the response rate. The "funnel sequence" of starting survey questions from wider issues at market and industry levels before narrowing down to company level details was applied (Sudman & Bradburn, 1983). In addition, the "total design method" was deployed. It consists of an 18-step process for avoiding bad formatting, illogical sequence, repetition, threatening, and double barrel questions (Nachmias & Nachmias, 1992). Therefore, attention was paid to good formatting, logical sequence, and simplicity so that respondents could spare the time and interest required for accurate information. The questions were simple and easy to complete within eight to ten minutes, and without recourse to documents or records. Most questions required just a tick on a five-point Likert Scale.

In order to further improve on the response rate, reminder questionnaires were sent at the end of the third, fifth and eight week of sending out the questionnaires. Follow up telephone calls were also made. University official envelopes were used while post-paid and self-addressed return envelopes were enclosed. In addition, the researcher hid his identity as a student. The covering letter to the questionnaire and all follow up written contacts carried the name and signature of the Departmental Research Coordinator.

The survey questions captured perceptual data using relative scores on a 1-5 Likert Scale (Anderson et. al., 1995; Flynn et. al., 1995a; Hoek et. al., 2001). For most of the questions, One (1) stood for "Highly negative", "Least important" or "Sharp decrease". As well, Three (3) represented "Neutral" or "Modest" whilst Five (5) meant "Highly positive", "Most important" or "Sharp increase". Although the validity of relative scales in relation to absolute scales has been questioned, their use in the conduct of social and organisation research has however become popular. For example, Ward et al (1998) argued that:

"data do not support the often stated believe that objective questions requiring absolute estimates necessarily yield better results than measures constructed from relative scales".

Nevertheless, in using relative scales, this study accepts the limitations identified by Gordon and Sohal (2001:238). As such, this research assumes that every factor, increase or decrease has equal weight or importance and that changes in factors had equal impact across companies and over time. It also assumes that direction is as important as magnitude of change and that changes had equal impact regardless of current attainment or base.

4.2. COMPANY SELECTION

The survey questionnaire was distributed to 600 companies. They were selected randomly from a database of UK manufacturing companies named Financial Analysis Made Easy (FAME). Attention was paid to fair spread of companies across turnover sizes and industries. Wide spread of companies was considered important in order to reduce external validity problems, which are often associated with industry-specific studies (Curkovic et al, 2000). More importantly, wide spread of companies across size and industry facilitated tests of the extent to which agile manufacturing is universally applicable.

The study focused on a plant within a company as the unit of analysis. The companies were asked to answer survey questions having in mind a most valued plant, in terms of contribution to sales profitability and overall survival prospects. The questionnaires were addressed to CEOs because they were deemed to have better knowledge of the companies.

Out of the 600 companies sampled, 118 companies completed and returned a copy of the survey questionnaire (see Appendix 1). Out of the 118 questionnaires returned, 110 were fully completed and the answers were logical and consistent. The 110 questionnaires were deemed as valid and usable for the study whilst the remaining nine questionnaires were excluded. Although the poorly completed questionnaires still provide some data, researchers often exclude such questionnaires in order to reduce the incidence of missing data in statistical analysis as well as the reliability of results (Gill and Johnson, 1997). Table 4.1 provides details of response rates across product groups. The number of sampled companies ranged from 150 in industrial and agricultural, to fifty in personal and fashion products. Table 4.1 reports the sample, response and usable percentage rates per product group of the 600 companies studied. The percentage rates per product group are close-knit, meaning that company selection was devoid of demographic bias.

Product groups	Sample	Rate %	Response	Rate %	Usable	Rate %
Automobile and automotive	80	13.33	17	21.25	17	21.25
Computer and allied equipment	65	10.83	11	16.92	11	16.92
Personal and fashion products	50	8.33	10	20.0	10	20.0
Electrical and electronics equipment	75	12.50	17	12.75	17	12.75
Food, chemical & pharmaceuticals	85	14.17	13	11.05	11	12.94
Industrial and agricultural equipment	150	25.00	31	20.66	27	17.33
Aircraft and ship-building	80	13.33	17	13.6	17	13.6
Any others (please specify)	15	2.5	2	13.33	-	
Totals	600	99.99	118	19.66	110	18.16

Table 4.1 Analysis of response rates across product groups

4.3. DATA VALIDITY AND RELIABILITY TESTS

The quality of an empirical study depends on the validity and reliability of instruments (Bryman, 1988; Gill and Johnson, 1997:91). Validity requires that instruments or variables should correctly measure the concepts under study. It also means that identical results should emanate if research processes were repeated, and that results should be applicable without contextual limitations- external validity (Shannon and Davenport, 2001).

In order to ensure conceptual validity of questionnaire items, data collection was preceded by in-depth literature review. Subsequently, a guiding conceptual framework was proposed on which research hypotheses were specified. In addition, some control questions were put in the questionnaire (Gill and Johnson, 1997) just as responses to some questions such as sales turnover were compared against published data. Above all, completed questionnaires were scrutinised for consistency and fullness prior to data analysis.

The Statistical software package named Statistical Package for Social Sciences (SPSS) 10.0 for Windows was used for data analysis. The SPSS is simple, interactive and rich in alternative methods of data analysis (Yusuf, 1996; Shannon and Davenport, 2001; Hoek, 2001). The SPSS 10.0 for Windows has a data editor, which is the medium for inputting, coding and defining data prior to analysis. The Data Editor has a Variables tab that makes it possible to view and define variable attributes such as data types and descriptive variable and value labels. The SPSS also has an output media on which statistical results are automatically generated based on commands specified by the user.

The "analyse" command has a scale menu with a sub-menu for reliability tests. The most important is the Cronbach's coefficient Alpha, which tests the reliability of data collected through multiple scales, which are often summed up to define concepts. Some other results of the Alpha test procedure include the mean, standard deviation, a table of analysis of variance and inter-item correlations between pairs of variables.

The "analyse" command of the SPSS 10.0 for Windows has a range of statistical options. They include the mean, correlation, regression, factor analysis and sub-sample mean difference tests. The SPSS software suggests the data types such as nominal, ordinal and scale that are more suitable for each of the statistical options. The software is also rich in graphical tools such as histogram, box plots, pie charts and interactive bar charts, which enhance visual appreciation of empirical relationships and differences.

In order to test whether the results emerging from the data will be devoid of chance, the data collected were tested for significant differences across random sub-samples of companies. First, the first 55 and the last 55 responses received from companies and entered into the research data file as they arrived were compared. Second, odd numbered and even numbered responses in the research data file were classified and compared. In both cases, the Kolmogorov-Smirnov (K-S) Z tests of the SPSS software was applied. The K-S Z test computes the largest difference between two distributions as the basis for testing if two samples originate from the same population.

QUESTIONNAIRE ITEMS	Most Extreme Differences			K-S statistics	Sig.
	Absolute	Positive	Negative		
Unique technical functions	.061	.061	-.039	.318	1.000
Packaging and appearance	.184	.184	.000	.949	.329
Customers' ability to pay	.173	.047	-.173	.884	.415
Basic product features	.067	.067	-.065	.345	1.000
Dominant design customised at POS	.184	.184	-.006	.946	.332
New technology to customers	.077	.077	-.044	.397	.997
Impact on profit	.106	.106	-.040	.543	.930
Number of technologies used	.180	.000	-.180	.943	.336
Cellular layout of machines	.069	.020	-.069	.360	.999
Job- based production	.193	.193	.000	1.013	.257
Range of automated processes	.095	.095	-.039	.499	.964
Plant mobility (AGV's and robots)	.083	.019	-.083	.437	.991
Intelligent CNC machines	.083	.020	-.083	.437	.991
Flexible manufacturing systems	.159	.088	-.159	.828	.500
Autonomy over methods and tools	.221	.000	-.221	1.126	.158
Project based team structures	.086	.086	.000	.446	.988
Flow of knowledge	.132	.132	-.061	.694	.722
Workers' commitment to job and company	.035	.035	-.011	.184	1.000
Workers' involvement in decision making	.158	.000	-.158	.824	.505
Training and skill development	.130	.000	-.130	.678	.747
Interaction with competitors	.133	.133	.000	.697	.716
Customer involvement	.085	.085	-.020	.444	.989
Supplier integration	.120	.048	-.120	.631	.821
Protection of core capabilities	.040	.000	-.040	.208	1.000
Exchange of core competencies	.040	.040	.000	.208	1.000
Alliances motivated by poor performance	.099	.099	-.069	.520	.950
Alliances among complementary equals	.106	.106	-.060	.555	.918
Computer-based data integration	.177	.042	-.177	.929	.354
Knowledge sharing on design & manufacture	.132	.132	-.061	.694	.722
Product customisation	.192	.192	.000	1.002	.268
Volume flexibility	.123	.123	.000	.643	.802
Low cost	.126	.053	-.126	.662	.773
Leading technology products	.136	.036	-.136	.711	.693
Speed to market	.064	.059	-.064	.334	1.000
Quality	.097	.097	.000	.506	.960
Dependability	.051	.051	.000	.267	1.000
Impact of change in man tech	.197	.000	-.197	1.021	.248
Impact of change in info tech	.189	.189	.000	.971	.302
Impact of rapid introduction of new products	.087	.000	-.087	.452	.987
Impact of emphasis on make to order	.100	.000	-.100	.522	.948
Effect of rise in global competition	.078	.024	-.078	.410	.996
Direction of change in sales turnover	.229	.000	-.229	1.200	.112
Direction of change in net profit	.248	.000	-.248	1.300	.068
Direction of change in market share	.181	.000	-.181	.950	.327
Proportion of turnover from new products	.095	.095	-.027	.496	.967
Customer loyalty	.069	.016	-.069	.361	.999
Performance relative to competitors	.069	.069	-.052	.364	.999

Table 4.2 Test of significant differences between early and late respondents

QUESTIONNAIRE ITEMS	Most Extreme Differences			K-S statistic	Significance
	Absolute	Positive	Negative	of difference	(p)
Unique technical functions	.078	.023	-.078	.389	.998
Packaging and appearance	.104	.029	-.104	.514	.954
Customers' ability to pay	.181	.000	-.181	.890	.406
Basic product features	.071	.071	-.056	.354	1.000
Dominant design customised at POS	.074	.074	-.004	.368	.999
New technology to customers	.139	.000	-.139	.693	.722
Impact on profit	.115	.000	-.115	.566	.906
Number of technologies used	.111	.024	-.111	.557	.916
Cellular layout of machines	.139	.035	-.139	.695	.719
Job- based production	.123	.123	.000	.617	.841
Range of automated processes	.053	.026	-.053	.265	1.000
Plant mobility (AGV's and robots)	.031	.031	.000	.154	1.000
Intelligent CNC machines	.134	.134	-.063	.676	.751
Flexible manufacturing systems	.104	.104	-.012	.521	.949
Autonomy over methods and tools	.071	.000	-.071	.345	1.000
Project based team structures	.111	.000	-.111	.555	.918
Flow of knowledge	.091	.091	-.091	.456	.986
Workers' commitment to job and company	.031	.000	-.031	.158	1.000
Workers' involvement in decision making	.113	.113	-.054	.569	.903
Training and skill development	.116	.029	-.116	.583	.886
Interaction with competitors	.181	.181	.000	.911	.377
Customer involvement	.207	.000	-.207	1.042	.228
Supplier integration	.246	.000	-.246	1.241	.092
Protection of core capabilities	.180	.180	-.012	.906	.385
Exchange of core competencies	.180	.012	-.180	.906	.385
Alliances motivated by poor performance	.058	.058	-.049	.294	1.000
Alliances among complementary equals	.140	.140	-.032	.705	.703
Computer-based data integration	.057	.000	-.057	.288	1.000
Knowledge sharing on design & manufacture	.091	.091	-.091	.456	.986
Product customisation	.095	.095	-.056	.474	.978
Volume flexibility	.222	.000	-.222	1.112	.169
Low cost	.057	.051	-.057	.286	1.000
Leading technology products	.141	.063	-.141	.711	.693
Speed to market	.108	.045	-.108	.539	.933
Quality	.056	.033	-.056	.280	1.000
Dependability	.092	.000	-.092	.465	.982
Impact of change in man tech	.117	.015	-.117	.581	.888
Impact of change in info tech	.044	.000	-.044	.219	1.000
Impact of rapid introduction of new products	.012	.012	-.005	.062	1.000
Impact of emphasis on make to order	.059	.059	-.032	.294	1.000
Effect of rise in global competition	.105	.105	.000	.527	.944
Sales turnover	.118	.118	.000	.594	.872
Net profit	.069	.069	-.024	.347	1.000
Market share	.014	.000	-.014	.068	1.000
Proportion of turnover from new products	.062	.062	.000	.310	1.000
Customer loyalty	.021	.019	-.021	.107	1.000
Performance relative to competitors	.056	.056	-.021	.284	1.000

Table 4.3 Differences between even and odd numbered respondents

For some variables, the cumulative distribution for one group exceeded the cumulative distribution for the other group and vice versa. In Tables 4.2 and 4.3, the column labeled absolute lists the largest difference between the two cumulative distribution functions. The last two columns report the K-S statistics of difference and their p levels. All p-values are greater than 0.05, meaning that the differences do not differ from zero. The tests therefore confirm that differences in the data collected from early and late respondents as well as between odd and even numbered responses in the research data file were not significantly different from zero. This means that the results emerging from the data will be valid and devoid of chance.

Having confirmed statistically that the questionnaire data are devoid of random effects, reliability tests were conducted as a measure of the internal consistency of research instruments employed to measure concepts. For the instruments measuring a concept to be reliable, they should be highly correlated. Cronbach's coefficient alpha, which computes an average of all possible split-half estimates, is the most widely used test of internal consistency (Bryman and Cramer, 1994; Sriparavastu and Gupta, 1997; Henry, 1998; Flynn et. al., 1995a). Moreover, data reliability requires that instruments measuring the same concept should be sufficiently different from other instruments. They should load separately in a factor analysis (Malhotra and Grover, 1998; Shannon and Davenport, 2001: 120).

Reliability tests were conducted for instruments that were summed up to measure agility (total attainment of competitive objectives), impact of change drivers and business performance. Reliability test results for business performance (BP) are reported in Table 4.4. The first part of Table 4.4 shows the correlation matrix for each paired measure of business performance (BP). The coefficients were evenly distributed and none was negative. The second part of Table 4.4 shows inter-item statistics, the last column of which demonstrates the change in coefficient Alpha if a measure of BP was excluded. A high Cronbach's alpha of 0.7241 indicates a high level of reliability of BP measures. In addition, a Hotelling's T^2 of 17.0587 and an F-statistic of 3.2865, both at $p= 0.0085$, show that the mean scores and variances of the individual measures of BP differed significantly.

The coefficient Alpha for attainment of competitive objectives as a measure of agility was rather low at 0.41. This is because companies were yet to master trade-offs amongst the competitive objectives, which were therefore disharmonious with one another. The split-half method of grouping instruments into two compatible sub-groups was tried. The procedure generated Alpha values of 0.67 for one group consisting of two instruments namely volume flexibility and product customisation, whilst an Alpha value of 0.61 was computed for the other group comprising of five instruments. Alpha tests of all other multiple scales employed to measure concepts confirmed reliability. The only exception was bases of product differentiation or mass customisation, the Alpha value being 0.4195.

R E L I A B I L I T Y   A N A L Y S I S   - S C A L E   (A L P H A)

Correlation Matrix

	REVENUE	NETPROF	MKTSHARE	NPRSALES	CLOYALTY
REVENUE	1.0000				
NETPROF	.6833	1.0000			
MKTSHARE	.4331	.3236	1.0000		
NPRSALES	.1108	.1255	.3503	1.0000	
CLOYALTY	.3304	.2595	.4098	.2626	1.0000
PERFCOMP	.1505	.2619	.4679	.1253	.3759

	PERFCOMP
PERFCOMP	1.0000

N of Cases = 109

Item-total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Alpha if Item Deleted
REVENUE	17.9909	8.3577	.5366	.5549	.6600
NETPROF	18.2091	8.2770	.5156	.4980	.6676
MKTSHARE	18.1909	8.9449	.6070	.4343	.6469
NPRSALES	17.9636	9.9620	.2636	.1566	.7441
CLOYALTY	18.1000	9.5037	.4832	.2673	.6806
PERFCOMP	18.1364	9.8253	.3879	.3134	.7049

Hotelling's T-Squared = 17.0587   F = 3.2865   Prob. = .0085
Degrees of Freedom: Numerator = 5   Denominator = 105

Reliability Coefficients   6 items

Alpha = .7241   Standardized item alpha = .7307

Table 4.4 Alpha reliability test of the measures of business performance

Finally, validity test was conducted for a combination of all instruments measured on 1-5 multiple scales. An Alpha coefficient of 0.7052 was computed. This means that the conceptual framework proposed in Figure 3.3 and the hypotheses crafted from them are consistent whilst the survey instruments extracted from them are also true determinants of the concepts studied. Table 4.7 shows Alpha coefficients computed for instruments used to measure concepts. They were within the range of 0.5 and 0.6, which is acceptable for exploratory studies (Anderson et al, 1995; Ward et al, 1998).

For a poorly understood multi-dimensional concept such as agility, positive and negative correlations amongst instruments as well as alpha coefficients averaging 0.5 should be understandable (Shannon and Davenport, 2001: 126). Even then, the data on agility enablers, which is the crux of the study were not aggregated but factored.

Research concepts		Alpha coefficients
Conceptual measures of five dimensions of competence building	Manufacturing automation	0.681
	Employee empowerment	0.746
	Supply chain networking	0.501
	Mass customisation	0.419
	Technology utilisation	0.648
Competitive objectives (split-half)		0.67/ 0.61
Change drivers		0.558
Business performance		0.724
All instruments combined		0.705

Table 4.7 Alpha reliability coefficients of concepts measured on multiple scales

4.4. DESCRIPTIVE AND DISTRIBUTION STATISTICS

This section reports the distribution of scores on observed variables around their mean. Whereas a mean score is the prototypical value of an observed variable, the standard deviation is a measure of dispersion around the mean. In a normal distribution, 68 percent and 95 percent of cases should fall within one and two standard deviations respectively (Diamantopoulos and Schlegelmilch, 1997; Shannon and Davenport, 2001).

For instruments measured on 1-5 Likert scales, a mean score close to one (1) means least important, negative or sharp decrease whereas a mean score close to five (5) implies most important, positive or sharp increase. As well, a mean score close to three (3) stands for modest or neutral. Table 4.4 reports summary statistics of research instruments measured on 1-5 Likert Scales. The mean scores reveal the prototypical values of the instruments just as the standard deviations reveal the extent to which the mean scores are typical.

RESEARCH VARIABLES		Cases	Min	Max	Mean	Standard Deviation	Skewness	Kurtosis
Mass customisation	Unique technical functions	109	1	5	3.80	1.15	-.850	-.021
	Packaging and appearance	107	1	5	2.71	1.24	.121	-.945
	Customers' ability to pay	105	1	5	3.10	1.21	-.153	-.830
	Basic product features	106	1	5	3.77	1.12	-.799	.149
	Dominant design customized at POS	106	1	5	3.25	1.10	-.286	-.506
	New technology to customers	108	1	5	3.51	1.13	-.556	-.355
	Impact on profit	105	1	5	3.56	.97	-.565	.287
Range of technologies used		110	1	11	5.92	2.54	.063	-.881
Manufacturing automation	Cellular layout of machines	109	1	5	3.09	1.26	-.204	-.935
	Job- based production	110	1	5	3.74	1.34	-.765	-.592
	Range of automated processes	110	1	5	2.26	1.13	.548	-.386
	Plant mobility (AGV's and robots)	110	1	4	1.29	.63	2.212	4.373
	Intelligent CNC machines	110	1	5	1.35	.81	2.557	6.301
	Flexible manufacturing systems	109	1	5	2.85	1.28	-.069	-1.117
Employee empowerment	Autonomy over methods and tools	104	1	5	3.13	1.48	-.108	-1.154
	Project based team structures	109	1	5	4.17	1.25	-1.256	.487
	Flow of knowledge	110	1	5	2.67	1.02	-.139	-.486
	Workers' commitment	110	1	5	4.31	1.10	-1.320	.813
	Workers' involvement in decisions	109	1	5	3.61	1.26	-.341	-.651
	Training and skill development	109	1	5	4.03	1.29	-.992	-.109
Supply chain networking	Interaction with competitors	110	1	5	2.85	1.31	.026	-.960
	Customer involvement	110	1	5	4.23	.91	-1.300	1.836
	Supplier integration	110	1	5	3.48	1.05	-.195	-.608
	Exchange of core competencies	110	1.00	5.00	2.54	1.23	.389	-.657
	Alliances motivated by poor perf.	110	1	5	2.67	1.06	-.159	-.834
	Alliances among equals	110	1	5	3.36	.96	-.148	.050
	Computer-based data integration	110	1	5	2.28	1.21	.509	-.687
	Knowledge sharing on manufacture	110	1	5	2.67	1.02	-.139	-.486

Table 4.6 Descriptive and distribution statistics (Continues on the next page…)

RESEARCH VARIABLES		Cases	Min	Max	Mean	Standard Deviation	Skewness	Kurtosis
Competitive objectives	Product customisation	109	1	5	3.86	1.32	-.892	-.433
	Volume flexibility	109	1	5	3.95	1.20	-1.065	.277
	Low cost	109	1	5	3.58	1.14	-.378	-.610
	Leading technology products	109	1	5	3.39	1.17	-.279	-.732
	Speed to market	109	1	5	3.37	1.30	-.377	-.935
	Quality	109	3	5	4.62	.56	-1.127	.302
	Dependability	109	2	5	4.43	.70	-.978	.366
Total score on competitive objective		106	19.00	35.00	27.22	3.27	.014	-.363
Change drivers	Manufacturing technology	107	1	5	3.75	1.21	-.403	-.644
	Information technology	106	1	5	4.28	1.11	-1.264	.657
	Rapid introduction of new products	107	1	5	3.09	1.41	-.066	-.961
	Emphasis on custom production	109	1	5	3.90	1.35	-.832	-.437
	Effect of rise in global competition	109	1	5	3.08	1.54	-.079	-1.304
Total score on change drivers		105	5.00	25.00	17.99	3.98	-.598	.689
Business performance	Direction of change in sales turnover	109	1	5	3.73	1.00	-.923	.539
	Direction of change in net profit	109	1	5	3.51	1.05	-.855	-.175
	Direction of change in market share	109	2	5	3.53	.80	-.036	-.413
	Percentage sales from new products	109	1	5	3.75	.96	-.312	-.554
	Customer loyalty (repeat orders)	109	1	5	3.62	.79	-.342	.373
	Performance relative to competitors	109	1	5	3.58	.82	-.423	.201
Total scores on business performance		109	11.00	28.00	21.72	3.53	-.340	-.339
Future plans	IT-based knowledge leverage	106	2	5	4.14	.86	-.650	-.427
	Team based organization	104	1	5	3.78	.92	-.371	.030
	Adaptable tools & processes	104	1	5	3.95	.87	-.616	.253
	Supply chain integration	109	1	5	3.48	1.05	-.195	-.608

Table 4.6 Descriptive and distribution statistics

Table 4.6 shows that out of five change drivers studied, information technology (IT) has the highest mean score of 4.28 whilst global competition (GC) has the lowest mean score of 3.08. The mean scores were greater than the middle point of three on the 1-5 Likert

Scale. This means in effect that the companies under study seem to have converted the impacts of information technology and global competition into positive gains. The mean scores also show that information technology and global competition were the strongest and weakest change drivers respectively.

Some other extreme mean scores are as follows. On competitive objectives, quality has the highest mean score of 4.62 as against 3.37 on speed. For business performance, the direction of change in sales turnover from new products had the highest mean scores of 3.75 as against the lowest mean score of 3.51 on the direction of change in net profit. The extreme mean scores computed for competitive objectives and business performance revealed some weaknesses in UK manufacturing. For instance, the companies returned lowest mean score on speed, which is of essence in gaining market share under intense competition. In contrast, they returned the highest mean score on quality which no longer guarantees competitive advantage (Levary, 1992; McGahan, 1999; Power and Sohal, 2001). For business performance measures, although the highest mean score of 3.75 on percentage sales from new products is beneficial and perhaps indicative of limited threat from global competition, the lowest mean score of 3.51 on net profit suggests that new product efforts are cost intensive and eating deeply into profits.

The mean scores on mass customisation, manufacturing automation, employee empowerment and supply chain networking varied widely as well. The mean scores, which derived from 1-5 Likert Scales with a mid-point of three, confirm this variation. For supply chain networking, the highest and lowest mean scores were: customer involvement (4.23) and computer-based data integration (2.28). For employee empowerment, the highest and lowest mean scores were: workers' commitment (4.31) and autonomy over methods and tools (3.13). On manufacturing automation, the highest and lowest mean scores were 3.74 and 1.29 for job-based production and plant mobility respectively. Lastly, for the bases of product differentiation as a measure of mass customisation, unique technical functions had the highest mean of 3.80 as against 2.71 on packaging and appearance.

The mean scores on the afore-mentioned dimensions of competence building revealed some inadequacies. The highest mean score of 3.80 on unique technical functions, as a basis for product differentiation seems to account for the highest mean score of 3.75 on percentage sales from new products as a measure of business performance. Nevertheless, the lowest mean scores on computer-based data integration (2.28), workers' autonomy (3.13) and plant mobility (1.29) suggest limited operational flexibility. This perhaps accounts in turn for the lowest mean score of 3.37 on speed (a competitive objective). In the circumstance, the highest mean score of 3.75 on percentage sales from new products (a measure of business performance) adds more to cost than to revenue. The attendant result is the lowest mean score of 3.51 on net profit as a performance measure.

Whereas the mean scores are prototypical, the standard deviations reveal differences amongst the respondent companies. Except for the most basic research instruments such as quality, dependability, customer involvement, market share and customer loyalty, the standard deviations were rather high. They ranged between one-half and one-third of the mean scores. High standard deviations reveal significant differences amongst companies, which recommend the use of factor analysis to identify distinctive categories.

Most parametric factor tests such as factor and regression analysis are underpinned by the assumption of normal distribution (Shannon and Davenport, 2001). The data collected for this study was therefore checked for departure from normality prior to the application of parametric tests. Measures of distribution, such as skewness and kurtosis, indicate how much a data varies from normal distribution. The normal distribution has a skewness value of zero, and in general, a skewness value greater than one indicates a departure from normality. As well, a distribution with significant positive skewness has a long right tail whilst a significant negative skewness is indicative of a long left tail. In addition, skewness values more than twice their standard errors indicate a departure from symmetry. The kurtosis also measures the clustering of observations around a central point. For a normal distribution, kurtosis is zero. Positive and negative kurtoses respectively indicate longer and shorter tails than in the normal distribution.

The skewness and kurtosis statistics in Table 4.6 do not depart significantly from between zero and one. In addition, there is a balanced distribution of positive and negative values within the range of zero and one. Two exceptional departures are plant mobility and machine intelligence. The skewness and kurtosis statistics were high and positive, which means that scores clustered on the lower end of the scale. Further tests aimed at justifying the use of parametric tests were conducted.

Although the mean, standard deviation and correlation are the most basic tools for statistical analysis, they are inadequate for measuring the behaviour and determinants of a multi-dimensional concept such as agility. For this reason, parametric techniques like the t-test, regression, analysis of variance (ANOVA), and factor analysis should be more powerful in exploring the nature and the competitive impacts of the agility enablers. Indeed, parametric techniques are now widely used to analyse ordinal data (Henry 1998; Ward et al, 1998; Vonderembse and Tracey, 1999; Curkovic, 2000; Lewis, 2000).

Parametric analysis assumes that observed variables are normally distributed and that analytic sub-samples have equal variances. Even then, modern statistical packages have alternative methods for data that fall short of the requirement of normal distribution. Above all, it has been reported that inferences based on parametric analysis of ordinal data will be valid if approximately 68, 95 and 99.7 percent of the individual values of observed variables fall respectively within one, two and three standard deviations from the mean (Diamantopoulos and Schlegelmilch, 1997: 106; Shannon and Davenport, 2001). This condition was met because for the research variables listed in Table 4.6, the scores by approximately 62, 96 and 100 percent of the companies studied fell respectively within one, two and three standard deviations of the mean scores.

In order to further justify the use of parametric analysis, tests of normality were also conducted using the stem and leaf diagrams (Bryman and Cramer, 1999: 131). Figure 4.1 consists of four visual plots for aggregate agility and business performance. First, the stem and leaf diagram of aggregate agility shows that for its individual measures, the largest number of between ten and nineteen observations clustered around the median value of 3 on a 1-5 Likert Scale. Consequently, the data is bell shaped, meaning that individual scores are evenly distributed around a prototypical measure of central tendency. Next, the associated histogram, which ascends and descends evenly with an encapsulating bell-shaped curve, also attests to normality. Thirdly, the normal Q-Q Plot of each of aggregate agility and performance show that standardised observed values, which are expressed in dots in Figure 4.1 are close-knit and evenly spread around the expected normal curves.

```
Stem-and-Leaf Plot of aggregate agility

 Frequency    Stem &  Leaf

     1.00        2 .  1
     4.00        2 .  2233
     2.00        2 .  55
     6.00        2 .  667777
    10.00        2 .  8888999999
     8.00        3 .  00001111
    19.00        3 .  2222233333333333333
    12.00        3 .  444455555555
     8.00        3 .  66677777
     7.00        3 .  8888899
     6.00        4 .  000011
     5.00        4 .  22333
     3.00        4 .  555
     2.00        4 .  67
     1.00        4 .  8

 Stem width:     10.00
 Each leaf:       1 case(s)
```

Figure 4.1 Normal plots of aggregated variables (Stem and leaf diagram of aggregate agility)

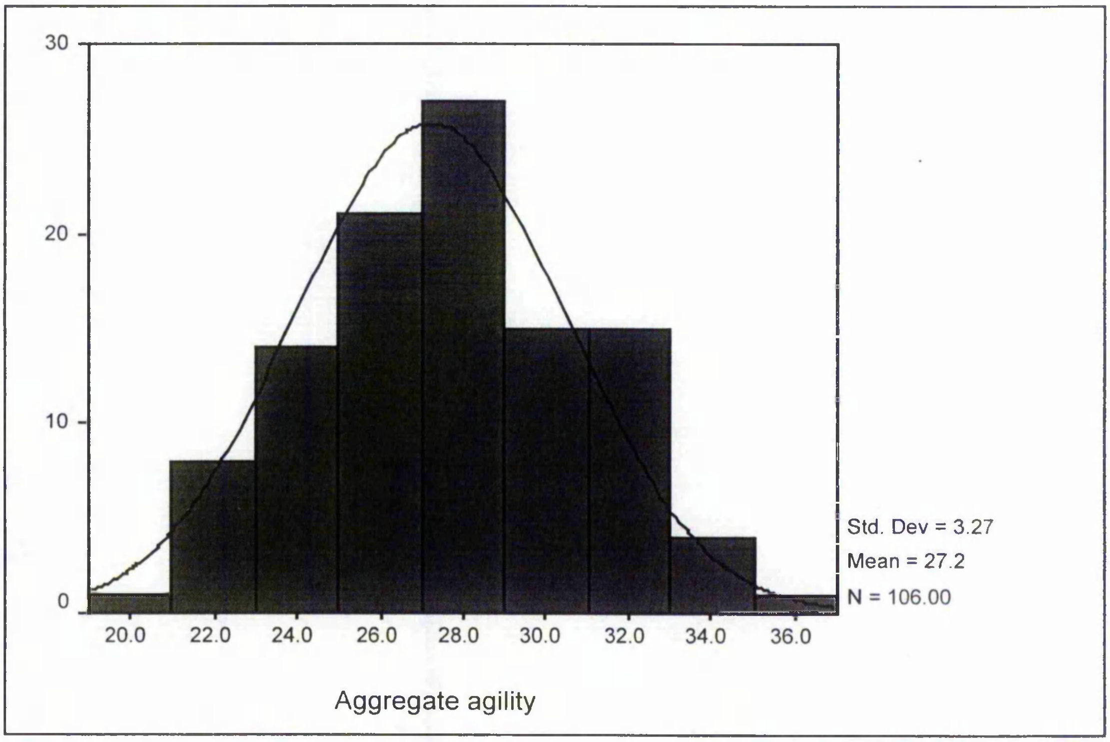


Figure 4.1. Normal plots of aggregated variables (Histogram of aggregate agility)

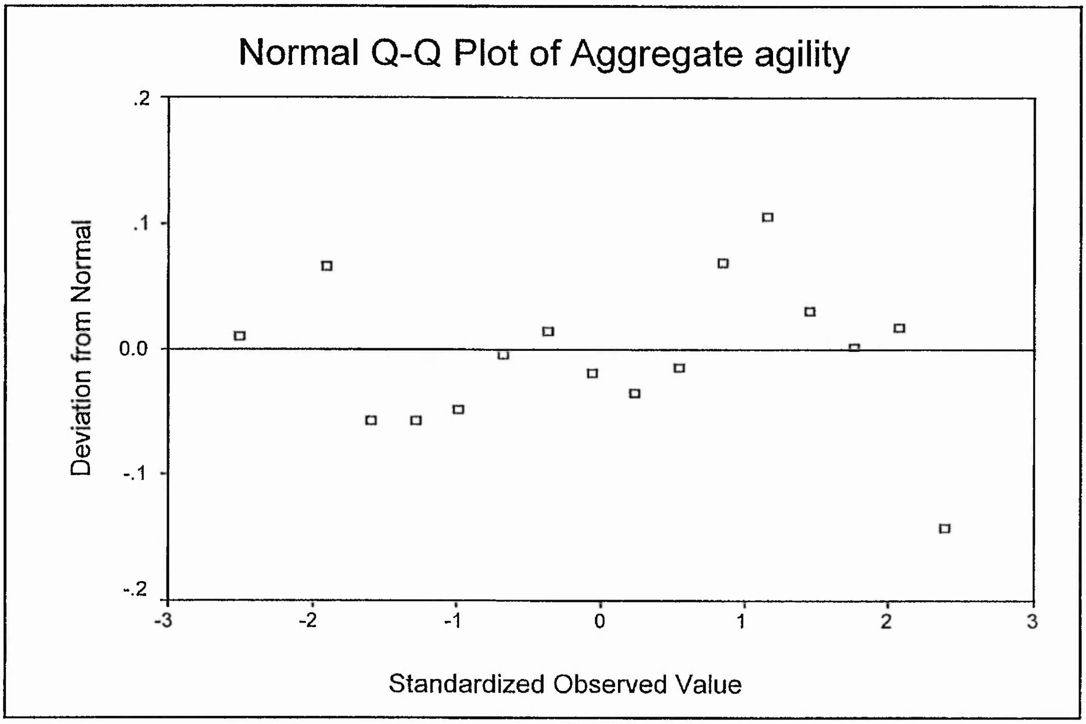


Figure 4.1 Normal plots of aggregated variables (Observed values of aggregate agility)

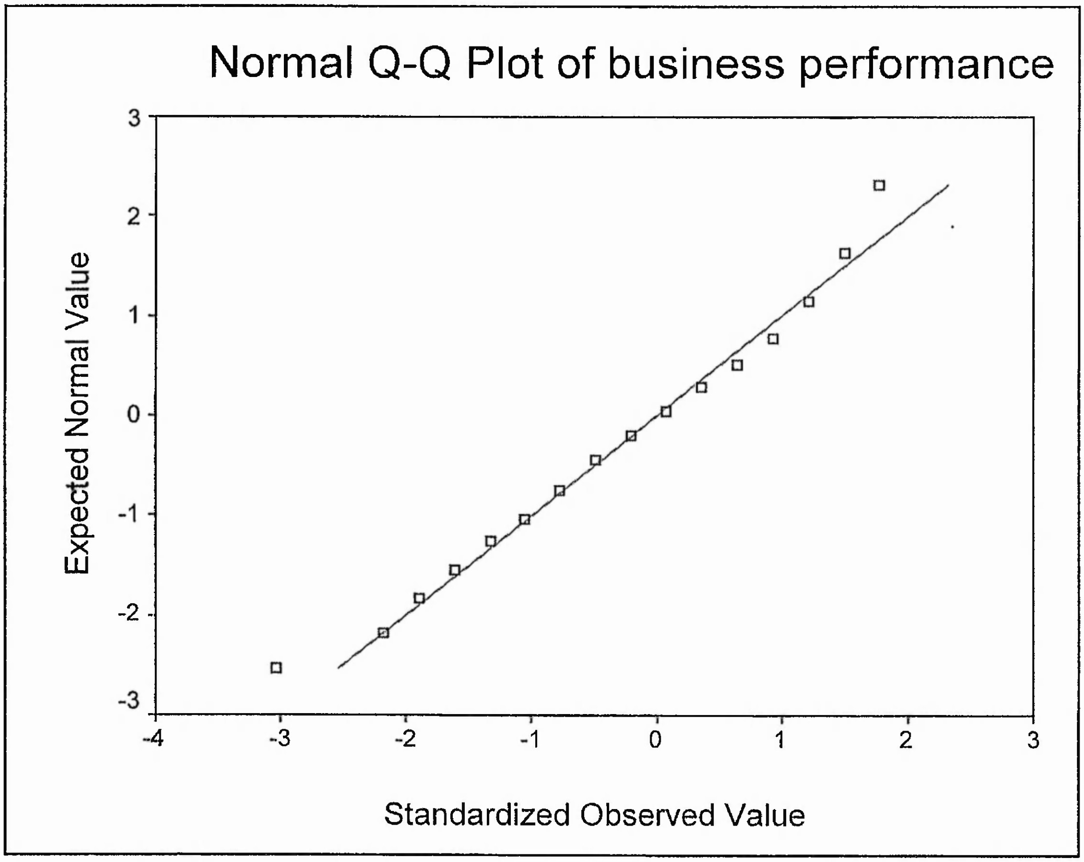


Figure 4.1 Normal plots of aggregated variables (Expected values of business performance)

4.5. DEMOGRAPHIC CHARACTERISTICS OF COMPANIES

This section reports the profile of companies studied. The questionnaire asked respondents to tick one out of six sales turnover and employment level groups. The sales turnover groups are: 0-10, 11-30, 31-50, 51-100, 101-300, and over 300 million pounds. As well, the following categories of number of employees were presented: 1- 50, 51-100, 101-200, 201-300, 301-500, and over 500. The sales turnover and number of employees categories were reconstituted into three categories in line with DTI classifications. Table 4.7 shows that based on sales turnover, 55, 22 and 25 percent are small, medium and large-scale companies respectively. The three broad groupings of turnover and employee levels have enough numbers of companies in each group, so that sub-sample tests are possible.

The respondents were also evenly distributed across seven product groups. The companies were asked to indicate the most important product line in their plant and complete the questions with respect to the product line specified. The distribution ranged from 23.9% in industrial/ agricultural equipment, to 9.2% in personal and fashion products.

Companies were also requested to choose one out of four options that described the pattern of competition facing the selected product line. This question is most important as a means of relating business and operational practices to the nature of market competition. Over 95 percent of the respondents were identified with either of two market classifications, which were described as perfect competitive and oligopolistic competitive. The term "perfect competitive" refers to a market where competition is more intense and made up of several companies of relatively equal strength. About 37.6 % of the companies were identified in the group. On the other hand, "oligopolistic competitive" describes a market in which some few large companies dominate, competition is less intense and customers are more docile (Fisher, 1997). About 57.7 % of the companies studied were in the second category.

Table 4.7 also reports on the percentage number of employees engaged in design, process engineering and manufacturing operations. This question was aimed at exploring the number of manufacturing and non-manufacturing related workers across systems. About 26.6% of companies have the lowest 30 percent of workforce in manufacturing related functions, as against 13.9% of companies having between 31% and 70% in such functions.

Finally, Table 4.7 reports official designation of respondents. About 26%, 18.4% and 19.4% of the questionnaires were completed by CEOs, heads of manufacturing and heads of other functions respectively. Following next are illustrations based on bar and pie charts. The bar charts in Figure 4.2 show that based on sales turnover and number of employees respectively, the largest number of respondent companies was small-scale whilst the lowest number of respondents was in the large-scale category. As well, the pie charts in Figure 4.3 show that companies were fairly equally distributed across seven product groups. On the other hand, Figure 4.3 shows that CEOs completed over 62 percent of questionnaires.

Total number of respondent companies =109	Frequency	Percentage
Size by number of employees		
Small scale (Up to 100)	58	53.2
Medium scale (100-400)	22	20.2
Large scale (Above 500)	29	26.6
Size by turnover		
Up to £10 million	60	55.0
£11- £30 million	24	22.0
Above £30 million	25	22.9
Nature of market and competition		
[1]Perfect competitive (many companies, relatively equal size)	41	37.6
[2]Oligopolistic competitive (a few large companies dominate)	56	57.7
Others unspecified	12	4.70
Total number of respondent companies =109	Frequency	Percentage
Employees in design, engineering and manufacture		
Low (Under 30 %)	29	26.6
Moderate (31-70%)	15	13.9
High (71-80%)	41	38.0
Very high (Above 80%)	23	21.3
Broad product groups		
Automobile and components	17	15.6
Personal and fashion, including textiles	10	9.2
Food, drink, chemical, and pharmaceuticals	11	10.1
Computer, office and communications	11	10.1
Electrical and electronics	17	15.6
Industrial, hospital and agricultural	26	23.9
Aircraft and ship-building	17	15.6
Official position of respondents		
Chief Executives	64	62.1
Head of Manufacturing	19	18.4
Others (Heads in other units)	20	19.4
[1] An economist's description of a market made up of several companies of equal size [2] An economist's description of a market in which a few large companies dominate.		

Table 4.7 Demographic characteristics of companies

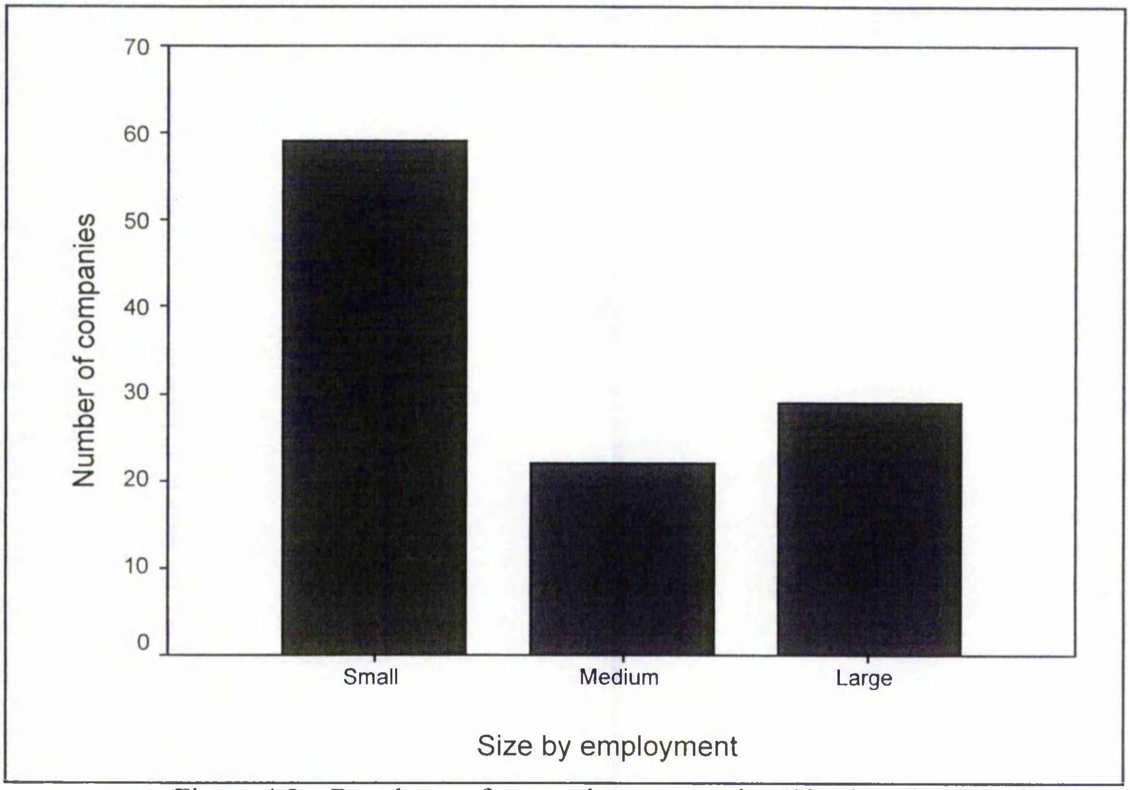


Figure 4.2a. Bar charts of respondent companies (Size based on employment level)

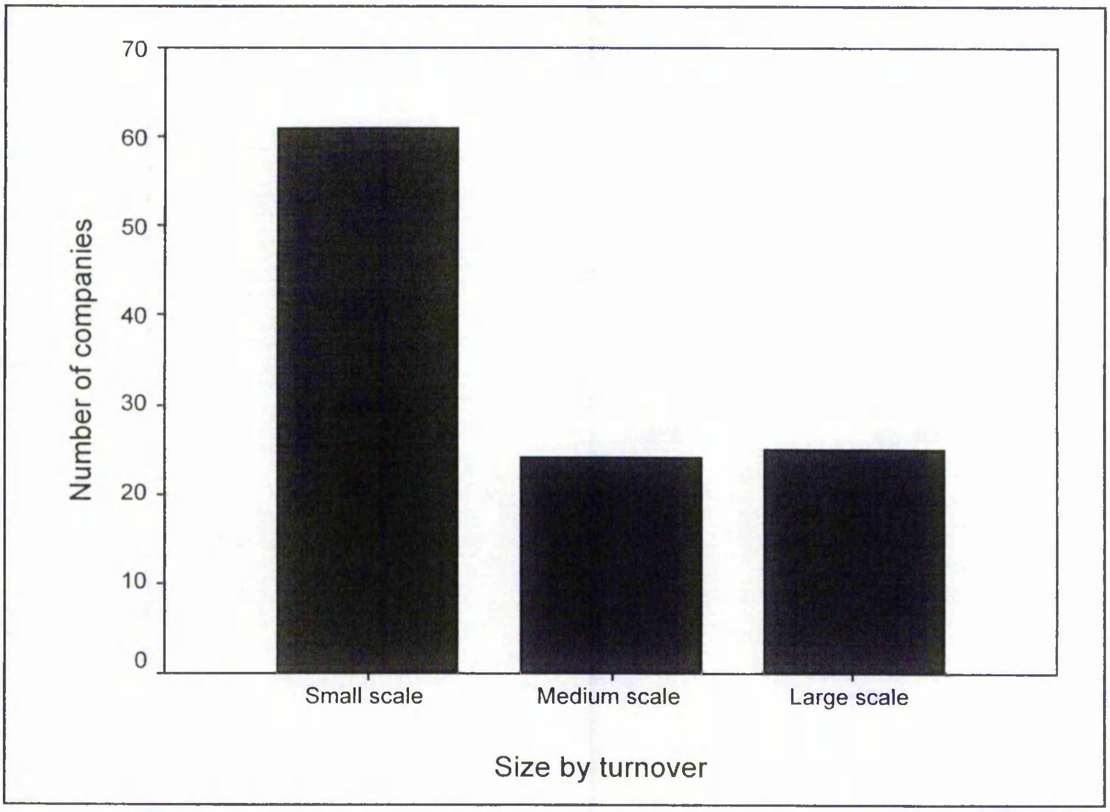


Figure 4.2b. Bar charts of respondent companies (Size based on sales turnover)

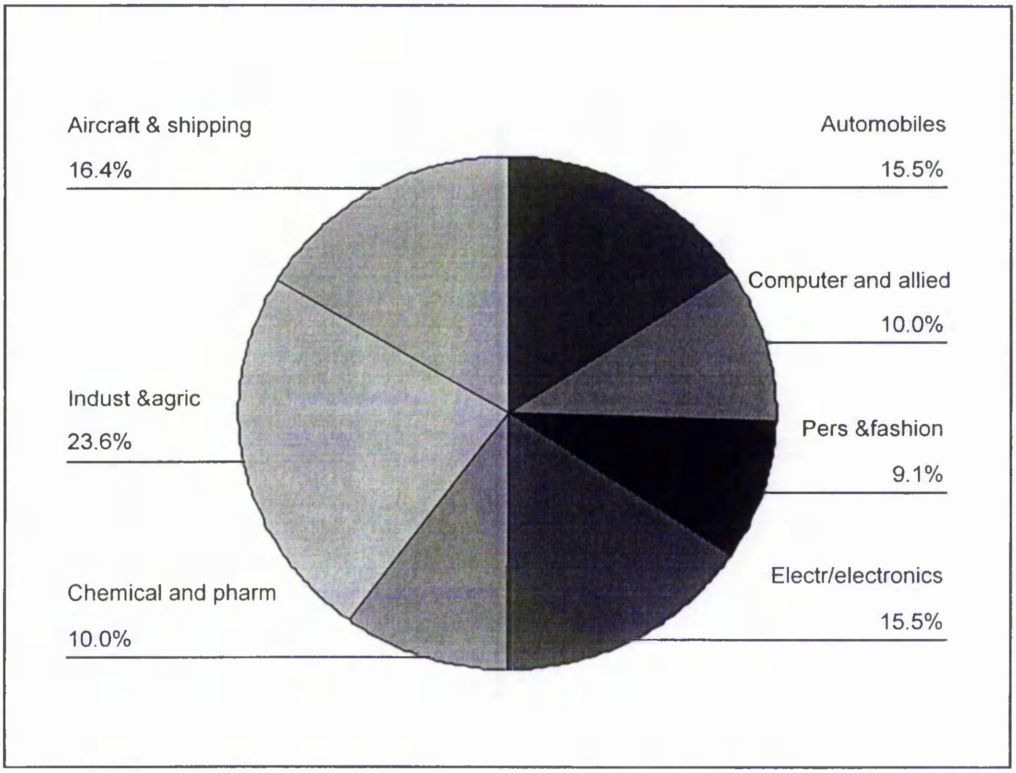


Figure 4.3 Pie chart of product groups

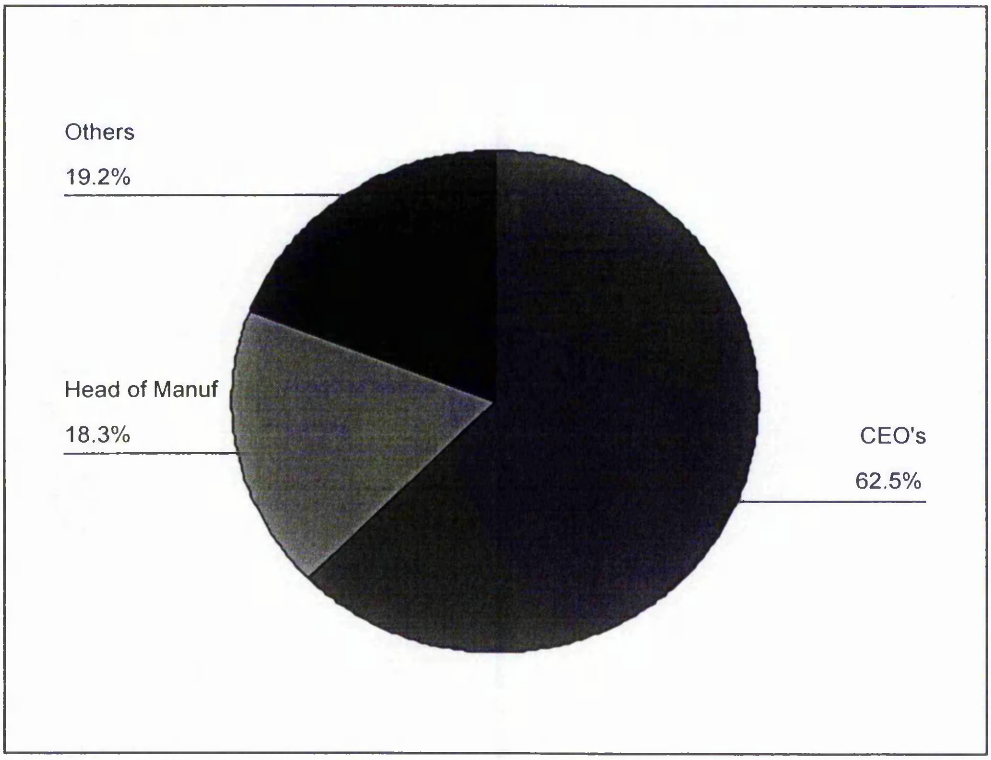


Figure 4.4 Pie chart of official position of respondents

4.6. STATISTICAL RESULTS

This section presents statistical tests of research hypotheses. The results are presented in the order of statistical methods applied. The first is correlation tests of relationships amongst conceptual measures of change drivers, competitive objectives as a measure of agility, and business performance. Second, the results of factor analysis, which was employed to reduce research variables to a few distinct dimensions, are reported. Thereafter, regression and path analyses of the reduced factor models are presented. Following next are tests of mean difference across two sub-samples classified as low and high adopters of agility enablers and between two sub-samples of the least successful and the most successful plants. Demographic limitations on the emerging results are explored. Next, research hypotheses are discussed relative to empirical results.

4.6.1. CORRELATION ANALYSIS

Correlation analysis was carried out to test Hypothesis 1, which states that there is a strong relationship amongst change drivers, competitive objectives and business performance. In order to test the relationship amongst the three concepts, companies' scores on the research instruments that measured each of the three concepts in Table 4.6 (Column 1) were summed up to derive aggregate scores on change drivers, competitive objectives and business performance. This was in order because the Alpha coefficients reported earlier in Table 4.7 showed a high degree of internal consistency.

	Aggregate agility (AA)	AA excluding volume flexibility	Aggregate performance (AP)
Impact of change drivers (CD)	0.230 (0.02)	Not required	0.402 (0.00)
Aggregate performance (AP)	-	0.226 (0.00)	-
Probability levels (p) of correlation coefficients are in parentheses			

Table 4.8 Correlation results of aggregated variables

Table 4.8 presents the correlation results. Change drivers (CD) and business performance (AP) had a correlation of 0.402 at $p<0.01$. In addition, CD and aggregate agility (AA) had a correlation of 0.230 at $p<0.05$. However, AP and AA did not correlate. The positive correlation of 0.402 at $p= 0.000$ between CD and AP is a measure of the potential benefit of paying significant attention to the change drivers that impact on aggregate business performance. The correlation coefficient between change drivers and business performance could range from –1 to +1. When a company pays significant attention to the change drivers and has succeeded in mastering their perturbing influence, and therefore profits from them, the relationship between the change drivers and business performance would tend towards +1. In contrast, when a company ignores the threats imposed by the change drivers and becomes a victim of change, the relationship between the change drivers and business performance would tend towards –1. The positive correlation shows in essence that companies that appreciate the potential impact of change drivers would put defensive mechanisms in place and attain higher levels of business performance. This is why Mason-Jones et. al., (2000) argued that:

"Companies that acknowledge the presence of uncertainty and provide mechanisms for pro-actively tackling it are rewarded... ahead of competitors... "

On the other hand, the correlation of 0.230 at p= 0.022 between CD and AA also shows that a positive relationship exists between agility (total attainment of competitive objectives) and the change drivers. In essence, higher attainment of competitive objectives as a measure of aggregate agility (AA) can effectively moderate the impact of CD on AP, as specified in the conceptual framework in Figure 3.1. However, the correlation of 0.42 between CD and AP is greater than the correlation of 0.230 between CD and AA by 0.172. In terms of the relationships specified in Figure 3.1, this difference suggests that collectively the change drivers have a stronger impact on business performance relative to the influence of competitive objectives on the change drivers. This shortfall of 0.172 requires higher attainment of competitive objectives, perhaps through agile manufacturing.

Not only should AA correlate with CD, it should also correlate with AP. Absence of correlation between AA and AP is an exception to elementary logic. This is because if CD and AP are correlated whilst CD and AA are also correlated, AA and AP should be correlated. Absence of correlation between AA and AP suggests that the measures of AA were engaged in a "war of attrition" or "trade-offs" in their collective relationship with AP. Hence, agility (total attainment of competitive objectives) did not impact strongly on AP. In order to detect the source of attrition, one measure of AA was isolated in turns and the rest were tested for correlation with AP. When volume flexibility as a measure of agility (AA) was isolated, AA and AP had a significant correlation of 0.226 at p=0.007.

The correlation tests imply that in order to boost business performance (BP), a higher level of agility in terms of higher scores on competitive objectives is desirable. Nevertheless, aggregate score on competitive objectives upon which the correlation tests were based, may not be as important as equal relative emphasis on all competitive objectives, in line with suggestions in the literature. In effect, if two competitive objectives were measured on a 1-5 Likert Scale, a company that scores 3 and 3 (total of 6) may outperform another company that scores 2 and 5 (total of seven) on the two competitive objectives

In order to test the validity of this assertion, companies were classified into two groups based on their range of mean scores on competitive objectives. The first group of companies who scored relatively equal scores on competitive objectives were classified as low range companies whilst the second group of companies returned relatively unequal scores on competitive objectives and they were classified as high range companies.

Chi-square tests revealed a stronger correlation of 0.403 at $p<0.007$ between CD and AP of the companies in the "low range" group. This is in contrast to a weaker correlation of 0.337 at $p<0.008$ between CD and AP of companies in the "high range" group. In addition, 15 significant correlation coefficients were computed between individual measures of CD and AA in the low range group. In contrast, for the "high range" group, only one significant correlation was computed, which is negative, between any paired measures of AA and AP. Furthermore, tests of mean difference showed that the low range group returned significantly higher mean scores on five out of seven competitive objectives studied. This is in addition to three measures of business performance.

Competitive objectives	Mean scores		T test	
	Low range (1.30)	High range (1.47)	t	p
Product customisation	4.26	3.57	3.03	0.03
Volume flexibility	4.17	3.79	1.77	0.079
Low cost	3.87	3.37	2.47	0.015
Leadership in new technology	3.89	3.03	4.36	0.000
Speed	3.80	3.05	3.38	0.001
Aggregate agility	29.09	25.89	5.65	0.000
Business performance				
Market share	3.65	2.67	5.32	0.000
% Sales from new products	3.20	3.02	1.56	0.070
Performance against competitors	3.68	2.93	4.01	0.003

Table 4.9 Differences between companies having low and high range of mean scores

The results showing a stronger relationship between aggregate agility and aggregate business performance of the low range group suggest that competitive objectives reinforce themselves when deployed with equal vigour without significant trade-off. They therefore culminate to superior outcomes in business performance. Table 4.9 shows the significant differences in the mean scores on five competitive objectives and three measures of business performance for the two groups having low range and wide range of mean scores. The table reveals that companies in the low range group significantly outperformed their counterparts in the high range group.

The results in Table 4.8, which shows strong relationship between change drivers and business performance, confirm that agile manufacturing is indispensable as a means of reducing the perturbing influence of the change drivers on business performance. In addition, the range of mean scores test reported in Table 4.9 confirms that companies that pay relatively equal attention to a wider range of competitive objectives will outperform their counterpart who focus on only a limited range of competitive objectives.
Analysis of variance (ANOVA) test also provided further evidence that simultaneous attention to a wider range of competitive objectives leads to higher business performance. The test was based on data derived from factor analysis. However, for purposes of parsimony, all factor analysis tests are reported in the next section. ANOVA tests compare the mean scores of a sub-sample against the mean score of all other sub-samples combined.

Further results to be provided later in Table 4.17 and Figure 4.5 reveal three models of competition namely agile, lean and mass customisation. Companies in the agile category pursued a much wider range of competitive objectives. Companies in that category therefore outperformed other companies classified as lean and mass customisation. The agile companies had superior scores on market share, performance relative to competitors and overall business performance.

Contrast Tests	Component (model) contrasts	Value of Contrast	Std. Error	t	Sig.
Market share	Agile model	.66	.32	2.045	.044
	Flexibility model	-.98	.36	-2.697	.008
	Lean model	.32	.36	.909	.366
Performance against competitors	Agile model	.46	.32	1.420	.159
	Flexibility model	-.92	.36	-2.530	.013
	Lean model	.46	.36	1.302	.196
Overall business performance	Agile model	1.9964	1.456	1.371	.174
	Flexibility model	-3.9293	1.648	-2.383	.019
	Lean model	1.9329	1.615	1.197	.235

Table 4.10 ANOVA contrast test of differences in market share

The ANOVA contrasts results are reported in Table 4.10. For every variable being tested for significant difference, contrast statistics are computed equal to the number of sub-samples. The contrasts values and their standard errors are reported in columns 3 and 4 respectively. This is followed by their ratios (t) in column 5 and probability (p) of significance in column 6. A positive t-value greater than 2.0 at $p<0.05$ indicates that a sub-sample is significantly superior to all other sub-samples. On the other hand, a negative t-value lower than -2.0 at $p<0.05$ indicates a significantly inferior sub-sample.

A significant t-value of 2.045 at 0.044 was computed for market share of the agile model. In contrast, all t-values of the lean model were lower than 2.0 at $p>0.05$ whilst all t-values of the flexibility model were lower than - 2.0 at $p>0.05$. This means in effect that at least on market share growth, the agile model is superior to the lean model and the flexibility model. The ANOVA procedure also generates a mean scores plot. Figure 4.5 presents a plot of mean scores on market share for the agile, lean and flexibility (mass customisation) models. It is evident that the mean score on market share was highest for the agile model whilst it is lowest for the flexibility model.

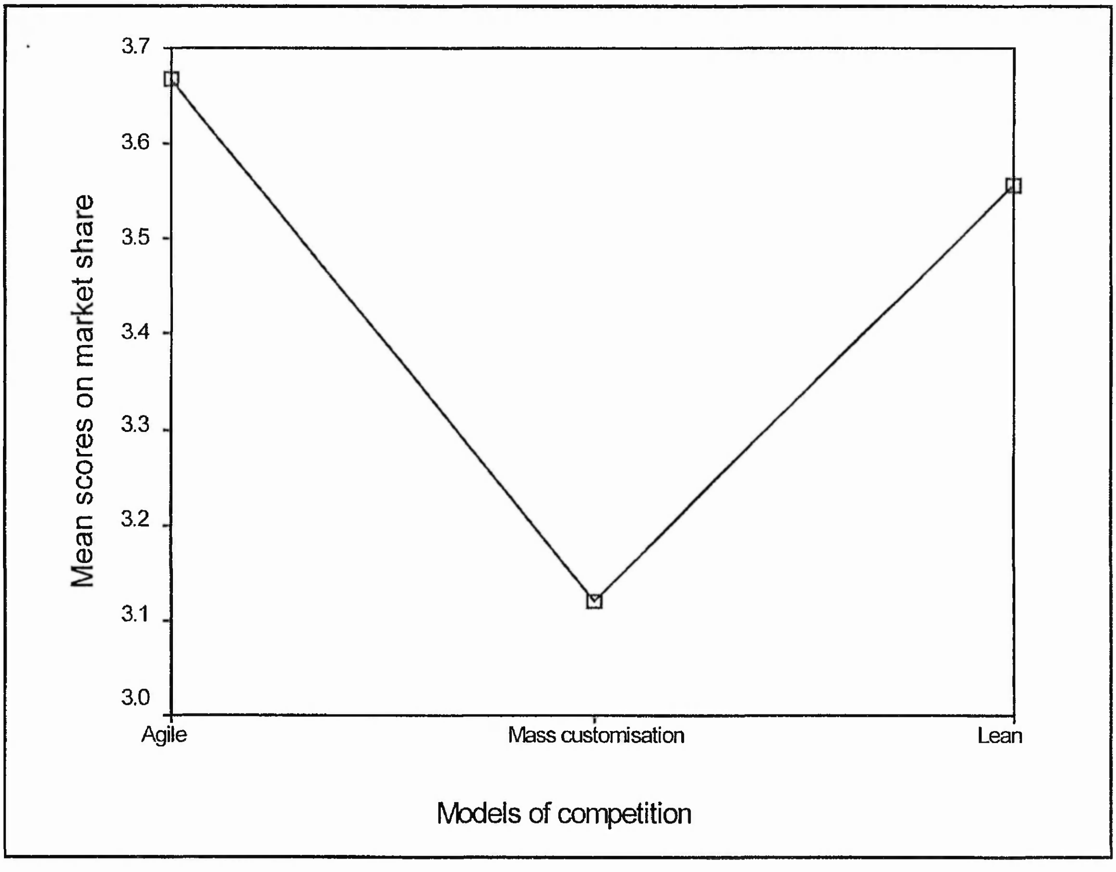


Figure 4.5 ANOVA mean scores plot of differences in market share

4.6.2. EXPLORATORY FACTOR ANALYSIS

In order to identify and explore the pattern of cause and effect amongst research concepts and variables, it is important to reduce the number of research instruments in a questionnaire survey to a few but independent core dimensions. This section introduces factor analysis as a data reduction method and presents the core dimensions of research variables that emerged from factor analysis. The interpretations given by the researcher to the emerging factor models of research variables were reported in Section 4.6.3 whilst section 4.6.4 explored their relationships using regression and path analyses. The relationships amongst the factor models were studied using regression and path analyses. The results were justified in section 4.6.5 together with examples of use.

Factor analysis was used to reduce research variables into a few principal factors. Each principal component, model or factor in a factor analysis consists of correlated variables, while the principal factors consist of core dimensions of practices that are far apart from one another. The weight of variables loaded in each factor component can be used to validate or refute a research hypothesis. More importantly, variable reduction through factor analysis facilitates further analysis such as multiple regression. The principal components method was used out of a range of other available options such as Alpha factoring in SPSS 10.0 for Windows. This is because the method forms uncorrelated linear combinations of observed variables, and therefore has the advantage of reducing multi-collinearity (variance inflation) prior to multiple regression tests. In this regard, the principal components method is most appropriate for the exploratory goal of research, which is to identify unique set of agile practices (agility enablers) from a wide range of contingency options in competence building for competitive manufacture. The principal components method is unlike the Alpha factoring method that maximises alpha reliability of factors and is hence, more suitable for definitions of concepts and variables rather than exploration of relationships.

It was argued earlier in chapter 3 that the variables constituting the five dimensions of competence building were yet to be widely adopted by companies. Therefore, the variables did not converge into useful and interpretable dimensions in a single factor solution. Therefore, for purposes of reducing research variables, the elements constituting each of the five dimensions of competence building were presented for separate factor tests rather than a single all-encompassing factor test. The following paragraphs justify the special use of factor analysis in this study.

All that one does in factor analysis is to impose a particular model on empirical data and find a solution that is most compatible with the data. To this end, researchers often run a single factor test incorporating all research variables but it is possible that a single factor test does not generate sufficient empirical support for a conceptual model. In a discussion of practical issues in factor analysis, Kim and Mueller (1978) identified situations where a single factor test incorporating all variables may be ambiguous and fail to provide a sufficient basis for making inferences. Such situations are more likely where variables are in definable clusters representing disparate conceptual dimensions and where "we must contend with the problems caused by an imperfect fit between the factor analytic model and the data" (Kim and Mueller, 1978:42). These are in addition to where factor analysis is used mainly as a heuristic means of sorting out major clusters amongst independent variables rather than studying interdependence amongst them. In these situations, what is important is (Kim and Mueller, 1978): "the criterion of interpretability and invariance" (page 42) so that "all of the finer points we have examined may become minor issues in comparison to the extra-factor analytic considerations" (page 70). "For many research problems the choice may be academic" (page 69) and "the final judgement has to rest on the reasonableness of the solution on the basis of current standards of scholarship in one's own field" (page 45). This current standard of scholarship in agile manufacturing is a "search for clues as to what may be possible" (Harrison, 1997), given that agility enablers were yet to be properly defined, tested and adopted (Hoek et. al., 2001; Sarkis, 2001).

Accordingly, whereas the variables constituting agility enablers were yet to be defined and justified, factor analysis provides a means of filtering through and reducing a large amount of data on competence building from which agility enablers can be identified. The data for this study were therefore teased out from five dimensions of competence building none of which was equally popular amongst companies. Consequently, the data were heterogeneous for a single factor test aimed at data reduction. Since a single factor solution was not feasible, each cluster of independent variables such as the variables measuring supply chain practices were presented in turns for factor analysis. On the other hand, competitive objectives and business performance measures as moderating and dependent variables were presented jointly for a factor test.

Faced perhaps by a similar problem of fit between data and model, Power et. al. (2001) polarised data into dependent and independent prior to the use of factor analysis for data reduction. Conceivably, in an effort to make data more amenable to single factor tests, researchers often engage in opportunistic screening of research sample and data. For instance, in a study of competitive priorities in manufacturing, Ward et. al. (1998) screened out 34 percent of the companies studied in order to obtain a more homogeneous data set. As well, Swamidass and Newell (1987) and Droge et. al. (1994) screened out a significant proportion of companies and variables which they described as "contaminating". This approach of fitting data may not be justifiable in studies of emerging and less mature concepts, and more so in a pioneer research that searches for clues on the efficacy of agile manufacturing. Accordingly, all the variables used to capture data on each of the five dimensions of competence building were factored in their natural clusters and reduced from an average of seven variables to three principal dimensions or factor models.

The most important results of factor analysis are explained as follows. A table of correlations shows the relationship between pairs of variables. A table also reports extraction communalities, which are computed as estimates of the variance in each variable that is accounted for within the factor solution. A value close to one indicates that the corresponding variable fits well to the factor solution. In contrast, a value close to zero indicates that a variable did not fit well, and should possibly be dropped.

In addition, a table of variances explained presents eigenvalues, variance explained by each factor, and cumulative variance explained by all factors in the solution. In a factor solution, principal components can be many but a few components with eigenvalues greater than one are retained as significant. A scree plot of variances explained within each principal factor can also be used as basis for factor retention or exclusion. The cut off point would be the principal factor after which the scree plot has a distinctive break and peters out. A good factor solution has only a few significant factors.

The component matrix is the third most important result of factor analysis. It reports factor loadings (correlation), that is, the influence or weight of each variable within each principal component in a factor solution. Results are interpreted based on a common thread amongst variables having large positive or negative loadings per factor.

The validity of factor analysis results was confirmed by cluster analysis, which has an additional benefit of identifying the number of respondents in a cluster or factor model. Four important results of the k-means option in cluster analysis, which were compared with factor analysis results, are as follows. A table of initial cluster centres classifies respondents based on their most dissimilar characteristics whilst a table of final cluster centres group respondents based on the unique feature of prototypical cases within each cluster. The initial cluster results derive from the most dissimilar characteristics across variables. They are therefore more useful for validating the results of principal components method in factor analysis because variables are less dependent. For purposes of parsimony, this thesis excludes the results of cluster analysis.

Bases of mass customisation	Extraction communality	Transparent Customisation	Cosmetic Customisation	Limited Customisation
Unique technical functions	0.561	.721	-.166	.113
New technology to customers	0.701	.570	-.450	
Dominant design customised at POS	0.795	.570	-.299	-.158
Impact on profit	0.716	.519	.482	-.395
Customers' ability to pay	0.439	.135	.765	.437
Basic product features	0.528	.398	.208	.717
Packaging and appearance	0.657	.205	.538	-.608
Eigenvalues		1.658	1.470	1.269
Percentage of variance explained (62.81)		23.68	21.00	18.13

Table 4.11 Factor models of mass customisation

Supply chain practices	Extraction Communality	Agile supply chains	Traditional supply chains	Lean supply chains
Computer-based data integration	0.429	.669	-.108	-.306
Interaction with competitors	0.561	.639	-.132	
Knowledge sharing on design and manufacture	0.548	.570	.301	-.411
Alliances motivated by poor performance	0.658		.702	
Alliances with complementary equals	0.500	.412	.675	
Exchange of core competencies	0.626	.280	-.625	-.434
Customer involvement	0.554	.404	-.126	.618
Supplier integration	0.584	.471		.565
Eigenvalues		1.816	1.482	1.161
Percentage of variance explained (55.74)		22.70	18.53	14.51

Table 4.12 Factor models of supply chain networking

Measures of plant automation	Extraction communalities	Intelligent automation	Limited automation	Flexible automation[1]
Plant mobility (AGV's and robots)	0.640	.770	.132	-.439
Intelligent CNC machines	0.869	.748	.208	-.421
Range of automated processes	0.583	.705	-.276	.101
Flexible manufacturing systems	0.803	.648	-.246	.468
Cellular layout of machines	0.781	.592	.233	.486
Job- based production	0.699		.911	.193
Eigenvalues		2.421	1.082	0.872
Percentage of variance explained (72.90)		40.35	18.01	14.54
[1]Flexible automation was retained based on the scree plot leveling off after the third factor model				

Table 4.13 Factor models of manufacturing automation

The results of factor analysis are presented in Tables 4.11-4.18. Because of the large volume of SPSS output from factor analysis, the tables report only the more insightful data. This is the practice in most research reports (Henry, 1998; Ward, 1998; Vonderembse and Tracy, 1999; Lewis, 2000, Curkovic, 2000). In Tables 4.11-4.18, the first column lists the variables under study whilst the second column reports extraction communalities. The remaining columns report factor coefficients and the interpretative labels attached to factor models by the researcher. As well, the last two rows report eigenvalues and the percentage of variance in the variables under study that could be attributed to each of the factor models. The meanings of these statistics were explained earlier in this section. Inferences are based on extraction communalities, factor loadings, eigenvalues and percentage of variances explained. In order to clean up minute factor loadings, tidy up result, and simplify interpretation, loadings lower than an absolute value of 0.1 were suppressed. For the same reason, two factor solutions were rotated in order to focus on important variables (Child, 1970; Ward et. al., 1998; Curkovic et. al., 2000).

Measures of employee empowerment	Extraction communalities	Total empowerment	Training-based empowerment	Limited empowerment[1]
Workers' commitment to job & company	0.825	.760	-.323	.275
Workers' involvement in decision making	0.801	.740	.322	-.292
Project based team structures	0.757	.718	-.405	.349
Autonomy over methods and tools	0.737	.708		-.566
Training and skill development	0.944	.428	.790	.370
Eigenvalues		2.32	1.000	0.740
Percentage of variance explained (81.27)		46.47	20.00	14.80
[1]Limited empowerment was retained based on the scree plot which did not level off after the second factor				

Table 4.14 Factor models of employee empowerment

Use of technologies[1]	Extraction communalities	Technology integration	Technology differentiation[2]	
MRP, MRPII and ERP systems	0.578	.743	-.154	
Concurrent Engineering (CE)	0.630	.653		.272
Computer Integrated Manufacturing (CIM)	0.700	.575	-.293	.250
Just in time techniques (JIT)	0.480	.573	.216	-.506
Computer aided design and manufacture	0.502	.376	.374	
Client server & network computers	0.372	.248	.702	.211
Electronic data interchange	0.598	.382	.469	
Computer aided process planning	0.577	.414	-.458	.444
Total quality management (TQM)	0.289	.458	-.264	-.649
Eigenvalues		2.367	1.289	1.070
Percentage of variance explained (52.51)		26.30	14.32	11.89
1. Scores on "Use of technologies" were contrast coded as "Used" (5), "Not used" (-5) and standardised.				
2. For lack of a common thread and better interpretation, two components were combined as differentiators.				

Table 4.15 Factor models of technology utilisation

Competitive objectives	Extraction communalities	Time-based tech leader	Flexibility leader	Quality leader	Low-cost leader
Speed to market	0.781	.883			
Leading technology products	0.787	.860			
Volume flexibility	0.974		.872		.150
Product customisation	0.758	-.102	.861		-.166
Quality	0.782			.858	
Dependability	0.739			.841	
Low cost	0.720				.985
Eigenvalues		1.623	1.535	1.368	1.014
% of variance explained (84.19)		23.18	21.92	19.55	14.59
The factor solution was rotated (varimax) in order to converge loadings on the more important variables.					

Table 4.16 Factor models of competitive objectives

The extraction communalities were generally high. For all fifty-three research variables (instruments) which were presented in seven factor solutions, only eight out of fifty-three extraction communalities were lower than 0.50. Thirty extraction communalities were higher than 0.6, which means that a significant proportion of variance in research variables was explained within the factor solutions. The eigenvalues and percentages of variance explained were also high. Out of twenty-two principal factors in the seven factor solutions, twenty principal factors were retained based on minimum eigenvalues of 1.0. For the principal factors retained in Tables 4.13 and 4.14 based on the scree plot, about 60 percent of total variance were explained exclusive of the third models. The percentages of variance explained ranged between a minimum of 52.51 for technology utilisation and a maximum of 84.19 for competitive objectives. The lower limit of 52.51 do not depart significantly from 62.88 and 53.0 reported respectively by Curkovic (2000) in a study of quality and by Ward et al (1998) in a study of competitive priorities in manufacturing.

The factor results in Tables 4.11-4.15 indicate that survey data captured three contingency options on each of the five dimensions of competence building studied whilst the results in Tables 4.15 and 4.18 lend credence to four distinct categories of competitive objectives and three dimensions of business performance.

Competitive objectives	Factor models of competition			
	Extraction communality	Agile	Mass customisation	Lean
Dependability	0.606	0.693	-	0.381
New technology leadership	0.709	0.597	-0.543	
Speed to market	0.653	0.498	-0.494	-0.397
Custom production	0.753	0.372	0.673	-0.393
Volume flexibility	0.681	0.454	0.672	
Quality	0.699	0.565	-	0.628
Low cost	0.266	-	-	0.464
Eigenvalues higher than one		1.77	1.45	1.14
% of variance explained (62.29)		25.27	20.68	16.34

Table 4.17 Factor models of competition (restricted sample)

Measures of business performance	Dimensions of business performance			
	Extraction communality	Market share	Environmental performance	Sales profitability
Performance relative to competitors	0.472	.710	.102	-
Market share	0.544	.700	.142	.307
Customer loyalty based on repeat orders	0.697	.668	-	.241
Proportion of sales from new products	0.324	.487	-	-
Information technology	0.394	-	.726	.129
Rapid introduction of new products	0.824	.419	.595	-.410
Make to order products	0.702	-	.554	.128
Manufacturing technology	0.605	-.197	.551	.360
Global competition	0.241	.392	.489	-
Sales turnover	0.504	.287	.248	.825
Net profit	0.515	.316	.150	.761
Eigenvalues		3.201	1.359	1.262
Percentage of variance explained (52.93)		29.10	12.36	11.47
The solution was rotated (varimax) to converge loadings on the more important variables				

Table 4.18 Factor components of business performance

4.6.3. INTERPRETATION OF FACTOR MODELS

The summary results of seven exploratory factor tests, which were reported in the preceding Tables 4.11 to 4.18 generated twenty-two factor models. The first five of the seven factor solutions explored five core dimensions of competence building with a view to identify practices most compatible with the principles of agile manufacturing. Such practices were labelled as agility enablers in this study. The sixth factor model identified four dimensions of competitive objectives whilst the seventh dimension identified three dimensions of business performance. Factors models were interpreted and reported as follows based on variables having the higher factor loadings or in other words the more significant influences. The models to be interpreted are justified in the section 4.6.5.

Table 4.11 presents three models of mass customisation. The first model was populated by unique technical functions (0.721), making new technologies available to customers (0.570) and dominant design customised at the point of sale (0.570). Some other variables such as customers' ability to pay and packaging/ appearance were loaded marginally but positively. This model was deciphered as transparent customisation because of the high factor loadings of unique technical functions as well as making new technologies available to customers. Transparent customisation, in terms of new solutions that surpass customer expectations and keep competitors guessing, is crucial in an intensely competitive environment. The second factor was interpreted as cosmetic customisation because customers' ability to pay and packaging/ appearance had strongest influence. They were loaded respectively at 0.765 and 0.538. The third model was interpreted as limited customisation. With "Basic product features" exclusively loaded at 0.717, the model represents mass producers in the sample. Section 4.6.5 provides illustrative examples.

Three models of current practices in supply chain networking were identified in Table 4.12. The first factor has significantly high loadings on Computer-based data integration (0.669), Interaction with competitors (0.639) and Knowledge sharing on design and manufacture (0.570). All other variables were also moderately loaded at between 0.471 for supplier integration and 0.280 for exchange of core competencies. This factor was interpreted as agile supply chain by virtue of emphasis on computer-based data integration, interaction with competitors and leverage of manufacturing knowledge. Indeed the three variables are the building blocks for supply chain networking in agile manufacturing. They are the main additions to the literature of lean supply chains (Womack and Jones, 1990; Parkinson, 1999; Hoek et. al., 2001; Soliman and Youssef, 2001). "Alliances motivated by poor performance" was not loaded at all in the agile supply chain model because the agile supply chain operates as a routine opportunistic process.

The second model of supply chains was described as traditional. This is because of high negative loading of –0.625 for exchange of core competencies, alliance motivated by poor performance (0.702) and alliances amongst complementary equals (0.675). The variables that loaded in this model depict traditional supply chains, which are renowned for limited exchange of manufacturing knowledge as well as complex conditions on compatibility, compliance, contribution and attribution of gains and losses (Gunneson, 1997).

In the third model of supply chains, customer involvement and supplier integration had the highest loadings of 0.618 and 0.565 respectively. On the other hand, knowledge sharing on manufacture, computer-based data integration and exchange of core competencies had marginal but negative correlation. By virtue of the highest positive loadings of customer involvement and supplier integration, the model was interpreted as lean supply chains.

Table 4.13 also reports models of manufacturing automation. The first model had high and positive loadings ranging from 0.770 for plant mobility, 0.748 for intelligent machines, 0.705 for range of automated processes to 0.592 for cellular layout of machines. The high loadings on machine intelligence and plant mobility validate intelligent automation as discussed in the literature of agile manufacturing. In the second model, job based production was solely loaded at 0.911, followed by cellular layout of machines at 0.233. This second component was interpreted as limited automation. The third component in which cellular layout of machines and flexible manufacturing systems had the highest loadings of 0.486 and 0.468 respectively was interpreted as flexible automation.

As well, Table 4.14 reports models of employee empowerment. The first model had high loadings on all five variables studied, and was named as total empowerment model. This is in contrast to the second model described as training-based empowerment. Training was loaded at 0.790 whereas project-based team structure was negatively loaded at –0.405. In the third factor model, not one of the measures of empowerment was uniquely positive. Instead, autonomy over methods and tools was uniquely negative with a loading of –0.566. The model was interpreted as limited empowerment. The next section offers illustrations.

Table 4.15 reports models of technology application. One model in which all the nine operations and information technologies were loaded positively was named as technology integration. For companies in the model, technologies complement rather than substitute one another. This is the theoretical position in agile manufacturing. The other two models of technology utilisation were characterised by positive and negative loadings on some specific technologies. This means that technologies substitute rather than complement one another. The two models were combined and interpreted as technology differentiation.

There remain two more results of factor analysis. Table 4.16 reports four models of competition, which were derived from seven competitive objectives studied. The first model was decoded as time based technology leadership due to the high loadings of speed at 0.883 and leadership in new technology products at 0.860. This model represents intensely competitive situations where speedy delivery of leading technology products is more important than say cost efficiency. In the second model, volume flexibility loaded at 0.872 while custom production loaded at 0.861. The model was interpreted as mass customisation. It is of essence where customers frequently change product specification as well as the mix and volume of orders.

The third factor model was described as lean in the light of uniquely high loadings of 0.858 for quality and 0.841 for dependability. Quality and dependability in terms of commitment to level schedules are pivotal in lean production. They are also some of the most basic competitive requirements, which customers would not barter for anything else, even as manufacturers seek a wider range of competitive objectives. The fourth model was labelled as low cost leader due to remarkably high loading of low cost at 0.985. The model typifies mass producers amongst the companies studied, who compete principally on low cost. The factor models of competition did not identify an agile model, that is, a model that has positive and relatively high factor loadings on all competitive objectives.

In order to explore the possibility of identifying an agile model, the principle of data screening was applied (Swamidass and Newell, 1987; Droge et al, 1994). According to the principle, some variables or cases that weaken or restrict the success of a study could be screened out, especially if the results will still be widely applicable. In this regard, some companies were screened out based on speculations that volume flexibility and product customisation are the most advanced but difficult to attain competitive objectives (Hill and Chambers, 1991; Sharifi and Zhang, 2001). If companies undergo agile capability tests, most would fail on volume flexibility and product customisation. Therefore, thirteen companies scoring "Very Low" (1) on a 5-point Likert Scale that measured companies attainment of the competitive objectives of volume flexibility and product customisation were isolated and the factor test of competitive objectives was re-run.

Table 4.17 reports the results of the re-run factor tests of competitive objectives using the restricted sample of companies. The low cost model and the time-based technology model were suppressed, and in their place, one new model emerged in addition to the mass customisation and lean models. The new model was unique in that all factor coefficients of competitive objectives were high and none was negative. In effect, companies in the model paid relatively equal attention to all competitive objectives. The new model was interpreted as agile. However, custom production and volume flexibility that are the most crucial competitive objectives in agile manufacturing had the lowest factor loadings. Nevertheless, it was expected that companies in the agile model would be high performers.

Lastly, Table 4.18 reports factor components of business performance. The measures of the impacts of environmental change drivers and the measures of business performance were presented together for factor analysis. The scores on environmental change drivers were adopted as a measure of environmental performance in terms of the extent to which companies succeeded in transforming the perturbing influence of environmental change drivers into positive gains. This is permissible in the light of the strong correlation reported earlier in Table 4.8 between aggregate scores on the impact of change drivers and aggregate business performance. Moreover, Alpha tests showed that the individual measures of the two concepts of impact of change drivers and business performance were internally consistent. Eleven measures of business and environmental performance were reduced to three principal components by factor analysis. The first component was interpreted as market share due to sizeable factor loadings on non-financial performance measures such as customer loyalty and performance relative to competitors. As well, the second component factor had significantly high loadings on environmental performance measures. Finally, the third component was characterised by large loadings of 0.825 on sales turnover and 0.761 on net profit. It was deciphered as sales profitability.

Through factor analysis, a large number of research instruments that were used to capture data on competence building, competitive objectives and business performance were reduced to a few principal dimensions known as factor models in Section 4.6.2. This section reports the terms and interpretations attached to the factor models. Table 4.19 summarised the twenty factor models arising from seven factor analysis tests conducted. Five factor tests were conducted for each of the five dimensions of competence building, which were mass customisation, supply chain networking, manufacturing automation technology utilisation and employee empowerment. One factor test was conducted for competitive objectives from which four dimension namely cost leadership, quality leadership, time-based technology leadership and flexibility leadership emerged. Lastly, one factor test was also run for business performance measures. Three dimensions of business performance interpreted as sales profitability, market share and environmental performance emerged.

Research variables had been reduced to a few core dimensions in order to facilitate the study of relationships amongst them. Following next, Section 4.6.4 presents the results of regression and path analysis with a view to explore relationships amongst the core models of research variables generated from factor analysis. The fourteen models of competence building identified by factor analysis will be tested for significant relationship with four dimensions of competitive objectives and three models of business performance that also derived from factor analysis.

SUMMARY OF FACTOR MODELS [1, 2, 3]	
Contingency options in competence building	
1. Mass customisation	3. Manufacturing automation
a. Limited customisation	a. Rigid automation
b. Cosmetic customisation	b. Flexible automation
c. Transparent customisation	c. Intelligent automation
2. Supply chain networking	4. Employee empowerment
a. Traditional supply chains	a. Limited empowerment
b. Lean supply chains	b. Training based empowerment
c. Agile supply chains	c. Total empowerment
5. Technology utilisation	
a. Technology differentiation	
b. Technology integration	
Dimensions of competitive objectives	Dimensions business performance
a. Cost leadership	a. Sales profitability
b. Quality leadership	b. Market share
c. Time-based technology leadership	c. Environmental performance
d. Flexibility leadership	
[1] These terms derived from factor analysis of research variables in section 4.6.2.	
[2] See sections 2.4-2.9, 4.6.3 and 4.6.5 for explanation and justification of terms	
[3] See sections 4.6.4 and 4.6.6 for a study of relationships amongst the terms.	

Table 4.19 Summary of factor models

4.6.4 REGRESSION AND PATH ANALYSES OF THE IMPACTS OF AGILITY ENABLERS

Regression and path analyses were conducted in order to study the impacts of the factor models of competence building (including those that were already deciphered as agility enablers) on the competitive and business objectives identified by factor analysis. The aim was to study the impacts of agility enablers relative to the influence of other models that were interpreted and justified earlier in Section 4.6.3. It was expected that the models of competence building described earlier as agility enablers namely transparent customisation, agile supply chains, intelligent automation, total employee empowerment and technology integration will be stronger predictors of attainment of the core dimensions of competitive objectives and business performance.

Multiple regression analysis was employed to estimate the coefficients of the impacts of the agility enablers and non-agility enablers as independent variables as a means of predicting attainment of competitive objectives and business performance as dependent variables. For example, assume that a plant implements fifty percent positive change in transparent customisation and that the regression coefficient between transparent customisation (dependent variable) and flexibility leadership (dependent variable) is known. A percentage change in the attainment of flexibility leadership as a core dimension of competitive objectives can be determined. With multiple regression analysis, such relationships can be modelled. They can also be visualised through path analysis.

Path analysis presented a means of modelling and visualising the network of effects amongst the agility and non-agility enablers as independent variables on one hand and competitive and business objectives as independent variables on the other hand. It facilitates the comprehension and analysis of direct and indirect effects.

Regression analysis has several assumptions such as normal distribution, constant variance, and linear and independent observations. Several tests were conducted earlier as evidence of normal distribution and equal variance across sub-samples. To further satisfy the assumptions, the coefficients of factor models were standardised prior to regression tests.

The multiple regression procedure of SPSS 10.0 for Windows has a range of options. The stepwise forward option, which enters variables sequentially, was used as the basis for variable selection. The first variable that qualified for entry into the regression equation was the one with the largest partial correlation with the specified dependent variable. After the first variable was entered, the independent variable not in the equation that had the largest partial correlation was considered next. The procedure stopped when no more variables met the specified entry criterion, which in this study, was $p<0.05$. The stepwise forward procedure is conservative in terms of variable inclusion. In effect, it is most useful in preventing model over fit as well as hard to interpret and error-laden models. Indeed, for each independent variable in all regression tests, the Variance Inflation Factors (VIFs) as measures of multicollinearity were approximately 1.0. In essence, the VIFs were much lower than the acceptable upper limit of 10.0 (Flynn et al, 1995a).

Three results of multiple regression analysis are most relevant. They are a model summary, analysis of variance and a coefficients table. The model summary displays R, R^2, adjusted R^2, and the standard error. R is the correlation between the dependent and the independent variables. R-values range from -1 to 1, with larger values indicating stronger relationships. R^2 is the proportion of variation explained by the regression model. R^2 is often used to determine model fit. A small R^2 means that a model does not fit the data well.

The analysis of variance table computes regression sum of squares, the mean squares accounted for within the regression model, and the unexplained residual variation. An F-value reports the ratio of sum of squares and residual sum of squares. A model with a large sum of squares in comparison to the residual sum of squares computes a high F-value, which indicates that the model accounts for most of the variation in the dependent variable. In this study, R^2 and F values having $p<0.05$ were used as the criterion for model retention.

The coefficients table is the third most important result of regression analysis. The coefficients table reports unstandardized and standardized coefficients of independent variables. The standardized coefficients enable realistic comparison when independent variables are measured in different units. In this study, all research variables were measured perceptually whilst all factor coefficients derived from factor analyses were standardized prior to regression analysis. Nevertheless, in line with common practice in most research works, standardized regression coefficients were used in the analysis of regression results and in composing the path coefficients in Figure 4.6. The coefficients' table also computes t statistics. As a guide for making useful predictions, t values higher than 2.0, in addition to only a few independent variables having regression coefficients at $p<0.05$ are most useful. In essence, the coefficients of independent variables having t values greater than 2.0 and probability levels higher than 0.05 were retained in the path diagram of regression results.

Dependent variable	F	Sig.	R^2	VIF	Independent variable	Beta	t	Sig.
Overall survival prospects	17.01	0.000	0.442	1.111	Technology integration	0.260	3.159	0.002
				1.061	Flexibility leadership	0.331	3.987	0.000
				1.057	Time based tech leadership	0.369	4.456	0.000
				1.009	Quality leadership	0.393	4.853	0.000
Environmental performance	4.606	0.002	0.176	1.150	Technology integration	0.257	2.450	0.016
				1.181	Quality leadership	0.287	2.701	0.008
				1.072	Lean supply chains	0.215	2.071	0.041
Sales profitability	5.85	0.018	0.062	1.000	Total empowerment	0.248	2.419	0.018
Market share	2.972	0.036	0.093	1.126	Quality leadership	0.255	2.349	0.021
Flexibility leadership	4.345	0.007	0.125	1.092	Lean supply chains	0.236	2.305	0.023
				1.082	Technology integration	-0.248	-2.436	0.017
Time based technology leadership	16.56	0.000	0.353	1.102	Transparent customisation	0.593	6.70	0.000
				1.004	Intelligent automation	0.212	2.512	0.014
Quality leadership	5.398	0.000	0.233	1.070	Lean supply chains	0.203	2.116	0.037
				1.078	Flexible automation	-0.269	-2.785	0.007
				1.011	Total empowerment	0.309	3.309	0.001
				1.014	Training	-0.190	-2.035	0.045
Low cost leadership	4.610	0.012	0.091	1.000	Agile supply chains	0.169	2.552	0.035
				1.104	Limited automation	-0.259	-2.607	0.011

Table 4.20 Summary of regression results

Table 4.20 presents the summary of regression results. Column 1 lists the dependent variables for the regression models. Column 2 reports F-values all of which are shown in column 3 a significant at $p<0.05$. The F-value is a ratio of explained and unexplained variance in the dependent variable. Column 4 also reports R^2 values, which measure the magnitude of change in the dependent variable attributable to the independent variables. The R^2 values ranged from 0.062 (six percent) for sales profitability to 0.442 (forty-four percent) for overall survival prospects. The independent variables were also listed in column 6 followed by their beta values as regression coefficients, t-values and p values.

In order to capture cause and effect in a series of regression models, researchers often employ path analysis (Anderson et al, 1995; Flynn et al, 1995a). Three main steps involved in the application of path analysis to regression results are invoked in this study as follows.

First, the regression coefficients are decomposed into their direct, indirect and total effects, as shown in Table 4.21. A direct effect is the direct impact of an independent variable such as quality leadership (0.255) on a dependent variable such as market share in Table 4.21. However, when some variables such as quality and flexibility are both dependent and independent within a multiple regression model, indirect effects exist and they need to be identified. An indirect effect is the product of all intermediate or moderating effects between a pair of variables linked together by a series of moderating variables, that is, by a chain of path coefficients in a path diagram.

Dependent variable	Independent variable	Direct effect	Indirect effect	Total effect	Correlation	Unexplained effect
Overall survival prospects	Technology integration	0.268	-0.08	0.118	0.254[a]	0.136
	Flexibility leadership	0.331	-	0.331	0.284[a]	0.047
	Time based tech leadership	0.369	-	0.369	0.466[a]	0.097
	Quality leadership	0.393	-	0.393	0.341[a]	0.052
	Total empowerment	-	0.12	0.120	0.039	0.081
	Transparent customisation	-	0.22	0.220	0.330[b]	0.110
	Intelligent automation	-	0.08	0.08	0.230[b]	0.150
	Lean supply chains	-	0.158	0.158	0.267[b]	0.109
	Flexible automation	-	-0.11	-0.11	0.106	0.004
Environmental performance	Technology integration	0.257	-	0.257	0.263[a]	0.006
	Quality leadership	0.287	-	0.287	0.169	0.118
	Lean supply chains	0.215	0.06	0.275	0.230[a]	0.045
	Training based empowerment	-	-0.05	-0.05	0.131	0.081
Sales profitability	Total empowerment	0.248	-	0.248	0.216[b]	0.032
Market share	Quality leadership	0.255	-	0.255	0.185	0.070
	Flexible automation	-	-0.17	-0.17	0.155	0.015
Flexibility leadership	Lean supply chains	0.236	-	0.236	0.203[b]	0.033
	Technology integration	-0.248	-	-0.248	-0.173	0.075
Time based technology leadership	Transparent customisation	0.593	-	0.593	0.572[a]	0.021
	Intelligent automation	0.212	-	0.212	0.167	0.045
Quality leadership	Lean supply chains	0.203	-	0.203	0.081	0.122
	Flexible automation	-0.269	-	-0.269	0.180	0.089
	Total empowerment	0.309	-	0.309	0.318[a]	0.009
	Training based empowerment	-0.190	-	-0.190	-0.192	0.002
Low cost leadership	Agile supply chains	0.169	-	0.169	0.169[b]	0.000
	Limited automation	-0.259	-	-0.259	-0.322[a]	0.063

[a] Correlation coefficients significant at $p<0.011$; [b] Correlation coefficients significant at $p<0.05$

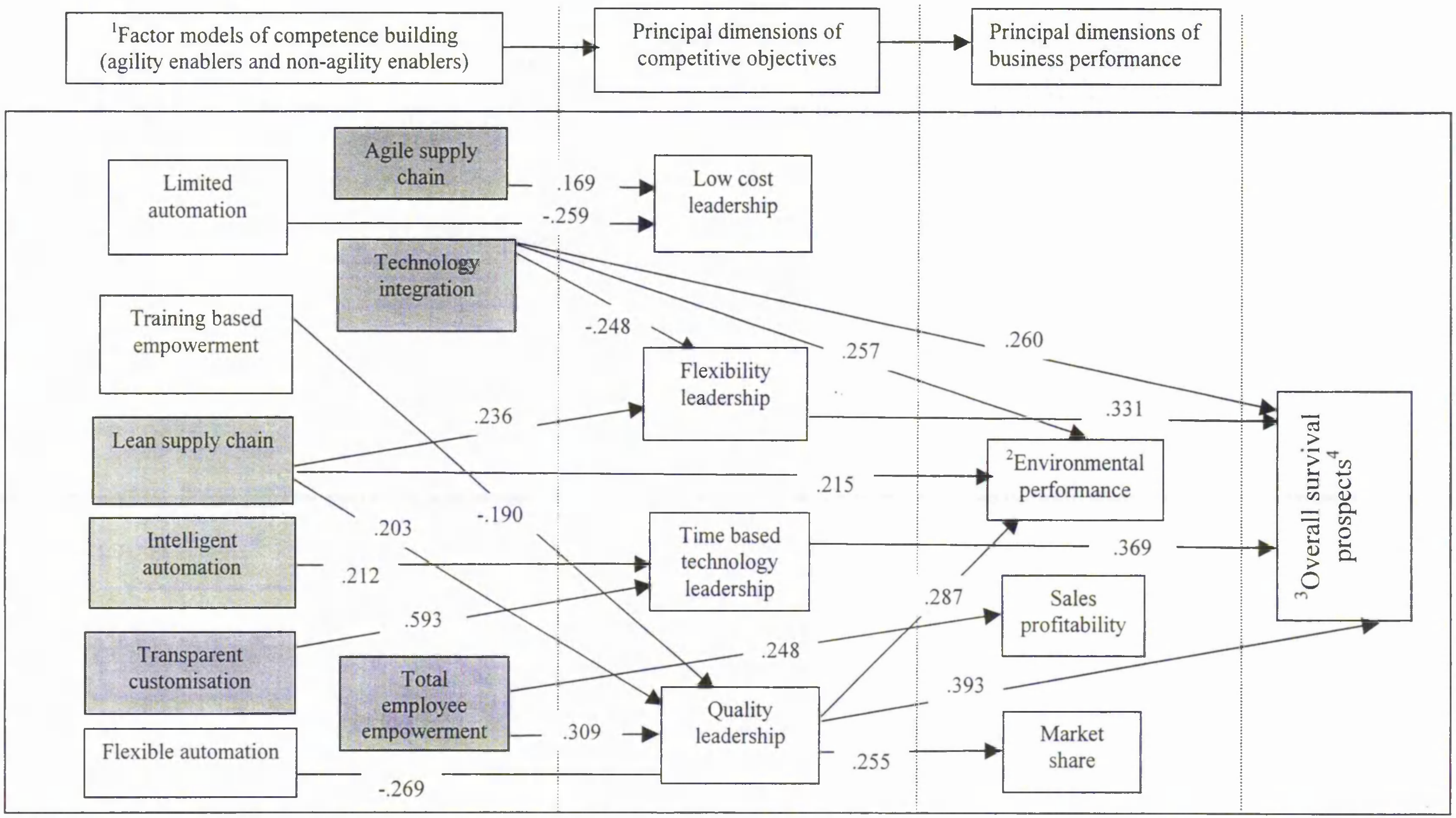
Table 4.21 Decomposition of regression coefficients

The second procedure in path analysis of multiple regression results is a test for differences between regression coefficients and correlation coefficients of every pair of variables studied. Such tests compute a statistic known as unexplained residual (column 7 of Table 4.21, which provides another means of knowing the extent to which the regression model was correctly specified (Flynn et al, 1995a). If correctly specified, the total effect (column 5) as the sum of direct and indirect effects (columns 3 and 4) between a pair of variables should be equal to the correlation coefficient (column 6) between the same pair of variables. For a set of variables such as the independent variables listed in column 2 of Table 4.21, the differences should not be generally greater than 0.1, as large differences would mean that the conceptual framework (Figure 3.1) that underpinned the study of relationships was poorly specified and invalid in terms of empirical reality (Flynn et al, 1995a). Column 7 of Table 4.21 shows the unexplained effects, all in the region of 0.1.

Having provided the evidence in the last paragraph that the conceptual framework was correctly specified, the third procedure in path analysis of multiple regression results is to draw a path diagram of empirical relationships. The path diagram should bear a semblance to the initial conceptual framework, and indeed validate it. The path diagram therefore consists of boxes representing the core dimensions of variables that defined the concepts under study, and are linked together by arrows shooting towards same direction. A box represents a variable (model) that impacts significantly on at least one other variable within the regression model. The arrows indicate the direction of impact while the corresponding coefficients indicated on the arrows reveal the strength of impact of the variable on the left (independent) on the variables on the right (dependent). Independent variables that have poor linkages with dependent variables and dependent variables that were not influenced by any independent variables are often excluded from a path diagram (Flynn et. al., 1995a).

Excluded independent variables were limited customisation, cosmetic customisation, traditional supply chain, limited empowerment and technology differentiation. They were excluded because they were irrelevant to the other variables even as all of them derived equally from factor analysis. Likewise, the path coefficients that label the directional arrows in the path diagram in Figure 4.6 are standardised regression coefficients that were significant at a probability level of 0.05 and therefore retained in the summary of regression results in Table 4.20.

Figure 4.6 reports the path diagram of significant relationships. Using dotted lines, the boxes were separated into three groups. The first group are the models of competence building identified earlier in section 4.6.2. It includes the agility enablers, which were highlighted. The second and the third group are the dimensions of competitive objectives and business performance respectively. The path coefficients shown on the arrows are the R^2 values reported earlier in Table 4.20. The path diagram has seventeen variables, nine of which were derived from the fourteen factor models of competence building (Table 4.11-4.15), whose regression coefficients were significant at $p<0.05$. In effect, the nine variables had at least one significant impact on a core dimension of competitive objectives or business performance. The remaining eight variables in the path diagram are the four dimensions of competitive objectives in Table 4.16 and the three dimensions of business performance in Table 4.19. They are all derived from factor analysis. This is in addition to one box named overall survival prospects. The box summed up standardised factor scores on sales profitability, market share and environmental performance. It is therefore an overall measure of the direction of change in overall company strength.



The five agility enablers under study plus the lean supply chain

1 Fourteen models of competence building were identified from factor analysis out of which the nine models shown above scaled through regression tests.
2 Companies' scores on the change drivers studied (Appendix 1), which ranged from negative to positive, were summed up as environmental performance.
3 "Overall survival prospects" was derived as a sum of standardised factor scores on environmental performance, sales profitability and market share.
4 Path coefficients of sales profitability, market share and environmental performance on overall survival prospects were not shown in the path diagram. This is because such path coefficients serve no useful empirical purpose given that the latter was derived directly from the earlier three.

Figure 4.6 Path diagram of regression results.

Five out of the nine factor models of competence building (agility enablers and non-agility enablers) whose impacts were significant and were therefore retained in the path diagram in Figure 4.6 were interpreted earlier in section 4.6.3 as agility enablers. Furthermore, all the impacts (path coefficients) of the five agility enablers on the dimensions of competitive objectives and business performance were positive and significant. For example, the agile supply chain has a path coefficient of 0.169 on low cost leadership. This means that a change initiative that raises the coefficients of the variables which defined the agile supply chain in Table 4.12 will cause a positive change in a plant's capability to manufacture at a lower cost and perhaps move closer towards becoming a low cost leader. The unit change towards agile supply chain practices will be multiplied by the path coefficient of 0.169 in order to determine the percentage change in low cost capability.

In addition to the five agility enablers, the model of competence building that was construed as the lean supply chain had a range of direct and indirect impacts, which were significant and positive. The lean supply chain therefore qualifies as an agility enabler. The other four models of competence building (non-agility enablers) had negative impacts on competitive objectives and business performance. The negative impacts include limited automation that had a path coefficient of -0.259 on low cost leadership, training-based empowerment that had a path coefficient of -0.190 on quality leadership, and flexible automation, the path coefficient on quality leadership being -0.269.

In the path diagram, the nine boxes representing the agility and non-agility enablers were not linked by directional arrows and path coefficients. The same applied to the four boxes symbolizing the four models of competitive objectives as well as the three boxes standing in for the three dimensions of business performance. This does not mean for instance that competitive objectives such as cost leadership and quality leadership were not related. For the agility enablers, intelligent automation and transparent customisation should of course exhibit a positive relationship. However, such relationships amongst the agility enablers, amidst the four competitive objectives, and within the business performance measures were not reported. This is because the research only aimed to identify agility enablers and provide the evidence that they impact on competitive and business objectives more than several other manufacturing competencies identified earlier, including flexible automation.

The preceding paragraphs explained how the terms and the associated path coefficients in the path diagram derived respectively from factor analysis and regression analysis, the results of which were summarised in Tables 4.19 and 4.20. The results confirm the superiority of each of the five agility enablers over and above the remaining nine models of competence building in manufacturing. However, in spite of the superiority of the five agility enablers, the path diagram in Figure 4.6 shows that their individual impacts were not widespread. For example and of course most importantly, agile supply chain has only one impact, which is 0.169 on low cost. Total empowerment and technology integration have the largest number of three effects each, out of which one each was indirect. The lean supply chain, which was not proposed as an agility enabler, had the largest number of four effects, one being indirect. Following next, the terms and relationships shown in the path diagram are explained and justified. This includes illustrative examples either composed by the researcher or drawn from the literature.

The path diagram in Figure 4.6 justifies the initial conceptual framework in Figure 3.1. The main objective of the conceptual framework was to show that agility enablers impact on change drivers, competitive objectives and business performance. It was in order to identify such agility enablers from several alternative approaches to competence building that factor analysis was conducted earlier in the study. Figure 4.6 reveals that the agility enablers that were shown in shaded boxes exercised a wide range of positive significant impacts on the dimensions of competitive objectives and business performance. These impacts include environmental performance, which derived from the box named change drivers in Figure 3.1. In contrast, the impacts of the three non-agility enablers, which were retained in the path diagram because they passed regression tests of significant relationship, were all negative. They are limited automation, training-based empowerment and flexible automation. The path analytic results therefore validate the role of the agility enablers as specified in Figure 3.1.

4.6.5 EXPLANATION AND JUSTIFICATION OF TERMS AND RELATIONSHIPS SHOWN IN THE PATH DIAGRAM

This section explains and justifies the terms and relationships shown in the path diagram of regression results. The discussion pivots on the agility enablers and includes illustrative examples either composed by the researcher or drawn from the literature.

Transparent customisation is one of the terms in the path diagram in Figure 4.6. It is one out of three models of mass customisation derived from factor analysis. The two other models were limited customisation and cosmetic customisation. These two models did not fit well with other variables and they were therefore excluded from the regression results in Table 4.20 and the path diagram in Figure 4.6.

The term transparent customisation was coined by Gilmore and Pine 11 (1997). It can be described as the practice whereby a company strives to convert a traditionally functional product into an innovative product by "adding a steady stream of newer innovations" and targeting them at specific markets and customers (Fisher, 1997). After a product has become significantly innovative, new targets of say primary or short-term, secondary or medium-term, and tertiary or long-term innovation may be set (Maskell, 2001).

In the automobile industry, a car such as Rover 100 will be a functional product (limited customisation) if its features are standardised for only the basic needs of a car user. In order to boost demand and profits, more advanced options such as Rover 200, Rover 300 and Rover 800 could be introduced and customised for specific niche markets such as sports. This exercise is different from unguarded variety such as where, considering the range of available options, "... the company was actually offering 20 million versions of the car" (Fisher, 1997). Century products, a leading manufacturer of children's car seats makes a good justification of innovative or transparent customisation. The company designed new seats and offered a wide range of options that were so innovative that they compelled a positive change in product safety standards (Fisher, 1997). Remmele Engineering, a precision engineering company in the US is also well reported as a success case in transparent customisation (Dove et. al., 1996; Harrison, 1997). Its mission was to offer leading and customised solutions that competitors would find difficult to match. Honda Motorcycle in Japan is another success case in transparent customisation. The company has developed a range of machines that customises performance through a credit-card sized electronic key (Maskell, 2001). The key contains information that programmes the performance of the machine through fuel injection, timing or ignition settings so that the rider could choose from fast, high performance, economy, town, or mountain driving.

Such innovations would delight customers and motivate collaborators whilst confusing competitors. If a product has significant technology input in terms of value-added to customers and it is delivered ahead of competitors, the manufacturer becomes a time-based technology leader. Accordingly, in Figure 4.6, transparent customisation has a path coefficient of 0.593 on time-based technology leadership, a competitive objective of being first to market with new product solutions that delight customers and are difficult to match by competitors. Subsequent to the impact of 0.593 on time-based technology leadership, transparent customisation exhibited a significant impact of 0.219 (0.593 x 0.369) on overall survival prospects. The latter is a summary scale for three dimensions of business performance namely sales profitability, market share and environmental performance.

Commodity or functional products such as oil, gas and processed food may be less amenable to significant amounts of transparent customisation. However, the foregoing results are indicative of the potential benefits of continuous innovation and incremental additions to product features. Such additions to product features are not necessarily complex but they should be customer-focused whilst also appearing as the first of their kind. In packaging, examples include tamper evident caps, class and economy packs, single-user packs and environment friendly innovations. Particularly in the food processing industry, every product now comes in a bewildering variety of sizes, packs, variations, diet, low sodium, decaffeinated, kid's size, and so forth (Maskell, 2001).

As a means of making a product more innovative, superior to competitors' offerings and boosting profits and market share, transparent customisation is therefore a direction rather than a one-off goal. Especially as UK manufacturers face increasing competition and market saturation caused by imports from Eastern Europe and South East Asia, transparent customisation via "*a steady stream of newer innovations*" is a means of making products smarter and warding off competition from low-wage countries (DTI, 1995; Fisher, 1997).

Intelligent automation is another term in the path diagram. It appears as an agility enabler, and it is one out of three contingency models that emerged from factor analysis of variables used to measure manufacturing automation. The two other models namely limited automation and flexible automation also appear in the path diagram. The three models of automation were explained earlier in sections 2.8 and 4.6.3. Intelligent automation is the application of intelligent machines and technologies, which can be programmed continuously as a means of enhancing transparent customisation and first to market with leading technology products. Versatile machines supported by significant amounts of computer power enable swift reconfiguration of plants and facilities with minimal downtime (Lee, 1997). The attendant operational benefits include experimental product design, prototyping and manufacture. These in turn lead to reduced product development cycle times and rapid switch over to new customer-led specifications that a plant may be confronted with.

Accordingly, intelligent automation has a path coefficient (impact) of 0.212 on time based technology leadership and an indirect impact of 0.078 (0.212 x 0.369) on overall survival prospects. In effect, a unit change in the use of intelligent machines potentially raises time-based technology leadership by 21.2 percentage points and overall survival prospects by 7.8 percentage points. These positive gains create challenges for limited automation where operations are largely manual and therefore potentially exposed to errors and restrictions caused by human fatigue and limits of human versatility and dexterity. The gains resulting from intelligent automation is superior to the relatively high degree of transient flexibility exhibited by flexible automation (Browne et. al., 1995).

In spite of the reported success of flexible automation (FMS), it is more suitable for relatively simple machining and assembly tasks especially in high volume repetitive batch processes (Edwards, 1996; Kusiak and He, 1997). In such situations, cost, level schedule and delivery reliability would tend to be more important than product customisation and leadership in new technology products. The flexibility offered by flexible automation therefore falls short of the responsiveness imposed on manufacturing by declining product life cycles that now make transparent customisation and time based technology leadership more crucial to overall survival prospects (Browne, 1995).

Browne et al (1995) had argued that:

"By the late seventies and eighties, the concept of FMS was widely publicised. The system that resulted serviced an environment where product life had fallen below manufacturing facilities life. It was becoming increasingly difficult to justify dedicated single-product automated manufacturing facilities. FMS exhibited a relatively high degree of transient flexibility compared to hard automation... This state of flexibility must not be confused with the emerging requirements imposed on manufacturing facilities by developments in product life cycles and customisation"

As explained in section 2.8, intelligent automation is not necessarily complex, expensive or inflexible. It only requires that manufacturing automation policies and programmes extend beyond functional and repetitive operations such as welding and painting, whilst accommodating high value-adding operations and processes. Especially in markets where products have become highly innovative and product life cycles have fallen below manufacturing facilities life, operations that are either significantly error-prone or value adding would benefit from intelligent automation. An example is the pro/Engineer

CAD/CAM system that speeds up the manufacture of prototypes and Pro-Engineering that links a generic set of tool paths to a generic family of products (Kohler, 1993).

In addition to speedy replication of custom design, intelligent automation is not necessarily expensive and limited to large-scale companies. However, to be cost-effective, the scale of production and / or value-added by the process to be automated should be sufficiently high (Maskell, 1994; Kirk and Tebaldi, 1997). The foregoing discussion suggests that intelligent automation harps more on leadership in new technology products. Therefore, in the path diagram, it had no significant impact on the two competitive objectives of low cost leadership and quality leadership (Edwards, 1996). However, as alternatives to intelligent automation, limited automation had a negative impact (-0.259) on low cost leadership whilst flexible automation also had a negative effect (-0.269) on quality leadership and an overall negative impact of -0.069 (-0.269 x 0.255) on the direction of change in market share. These negative impacts do not connote that flexible automation does not serve any useful purpose but they justify intelligent automation as more relevant to competitiveness. Perhaps, rising labour costs and some difficulty of attracting sufficient numbers of young people into manufacturing explain the negative impact of limited automation on low cost leadership. As well, advances in quality expectations beyond compliance with specifications explain the negative impact of flexible automation on quality leadership.

The manufacture of printed circuit boards (PCB) is a handy example of an operation that could be performed manually (limited automation), standardised (mass automation), flexible (flexible automation) or made adaptable (intelligent automation). The manual process would most likely involve a number of individual employees assembling single units of PCBs from start to finish. This manual process may be cheaper in the short run but it could suffer eventually from increases in labour cost as well as lower speed, errors and too little innovation caused perhaps by employee fatigue and limited dexterity. In order to widen the range of product options whilst also saving money from repetitive processes such as wiring, flexible automation (FMS) including the use of complete off-line retool kits and kit parts might be introduced. The potential flexibility and cost efficiency of flexible automation, which is however not apparent in the path diagram (Figure 4.6) are desirable, but they fall short of the technological content, choice and smartness required by modern products and hard to please customers.

The agile supply chain and the lean supply chain appear in the path diagram as two out of three models that emerged from factor analysis of supply chain networking. The third was the traditional supply chain, which did not relate significantly with other variables during regression analysis, and was consequently excluded from the path diagram. The traditional supply chain was used by large conglomerates in the 1970s as joint ventures, mergers or agencies to penetrate foreign markets (Badaracco, 1991; Russ and Camp, 1997; Prater, 2001; Hoek et. al., 2001; Maskell, 2001). It seems to have given way to the agile and the lean supply chains as a means of supporting the manufacturing function.

The agile supply chain is an opportunistic alliance of core competencies across several firms formed to take advantage of temporal change whilst providing first of its kind product solutions ahead of companies that preferred to go solo (Mason-Jones, 2000). Accordingly, the agile supply chain has a positive impact of 0.169 on low cost leadership. The range of impacts exhibited by the agile supply chain relative to the lean supply chain was narrower than expected. This is indicative of the developmental stage of the agile supply chain which would take some time to mature and the fact that the practices constituting the agile supply chain were yet to be adopted widely (Hoek et. al, 2001).

A notable example of the kind of co-operation that justifies the positive role of the agile supply chain in Figure 4.6 is the link forged between IBM, Motorola, and Apple Corporation to develop the new PowerPC chip to compete with the Intel Pentium (Maskell, 2001). Such links are facilitated by advanced communication and information technologies through which companies can share the same design and product data files whilst working interactively and simultaneously. The benefits include time compression as well as a wider access to global resource and knowledge bases, which enhance the ability to deliver leading edge technology solutions that delight customers and shatter competitors plans.

In contrast, the lean supply chain is a long-term contractual alliance often formed with suppliers and distributors to facilitate the efficiency, quality and reliability of deliveries of core inputs to the plant and final products to showrooms and distribution chains. Sometimes, it involves tutoring, sponsorship and part-ownership of suppliers and distributors (Womack et al, 1990; Badaracco, 1991; Browne et al, 1995). In order words, the lean supply chain focuses on the quality of supplies and the efficiency of physical distribution (Fisher, 1997).

In the path diagram, the lean supply chain has a range of positive impacts. These impacts are 0.203 and 0.236 on two competitive objectives namely quality leadership and flexibility leadership respectively. In addition, the lean supply chain has a direct effect of

0.215 on environmental performance and an additional indirect impact of 0.058 through quality leadership (0.203 x 0.287). Furthermore, through its direct impact on flexibility leadership, the lean supply chain has an indirect impact of 0.078 (0.236 x 0.331) on overall survival prospects. The wide range of significant impacts exhibited by the lean supply chain, especially the impact on environmental performance and the fact that the lean supply chain did not reveal any impact that negates those of the agility enablers explained its earlier adoption in this study as a sixth agility enabler. Moreover, it has been stressed earlier in section 2.12 that the lean and agile supply chains can complement one another within one company or even as a development strategy for a product. The lean supply chain can be deployed to enable a level schedule and an opportunity to drive down costs upstream whilst the agile supply chain can be applied as a means of ensuring an agile response to an unpredictable market downstream (Mason-Jones, 2000)

Supply chain initiatives by Campbell Soup (Fisher, 1997) justifies the positive role of the lean supply chain in Figure 4.6. Campbell developed a programme of just in time or continuous replenishment with the most progressive retailers. It established EDI links with the retailers through which inventory levels were monitored electronically, and production schedules and inventory levels were replenished daily. Significant improvements in inventory levels and delivery reliability were reported. As a means of improving the efficiency of physical distribution, Maskell (2001) also reported on an Australian company that experienced materials replenishment problems with principal suppliers. The company entered into a co-operative relationship with a transportation company. The drivers were trained to identify component parts that were in short supply, enter requirements message in the computer system and drive to the supplier for instant replenishment. This effort significantly reduced costs, eliminated the purchasing / order entry role within the customer and the supplier, and solved many of the part shortage problems.

The relative importance of the lean supply chain and the agile supply chain is significantly influenced by the nature of product markets and the level of market instability (Fisher, 1997; Mason-Jones, 2000). Fisher (1997) emphasised that for relatively stable markets and traditionally functional products, supply chains should focus more on the efficiency of physical distribution and thus be more lean than agile. However, in the light of the positive impacts of the lean and the agile supply chains, and increasing emphasis in the literature that these two forms of supply chains can be deployed jointly, companies could toe the line of British Telecom in joint deployment of supply chains (Robertson and Jones, 1999).

Technology integration is another core term used in the path diagram. It appeared from factor analysis of technology utilisation by companies and it was deciphered as an agility enabler in section 4.6.3. An alternative model of technology utilisation namely technology differentiation was also recognized. This model did not exhibit a strong relationship with any other variable during regression analysis and it was excluded from the path diagram.

It was argued earlier in section 2.9 that the choice between technology integration and technology differentiation arises from the way that manufacturing is being confronted with an assortment of new technologies for improving production efficiency. The technologies include MRP, JIT, TQM, OPT, EDI and electronic commerce. As in many areas of business, choosing the best operations and information technology requires making trade offs. Whereas MRP allows for an extraordinary degree of advance planning for inventory and production scheduling, it suffers from inflexibility and formality. Herein lies the benefit of JIT and TQM, which have a higher degree of flexibility, informality, cost efficiency and employee involvement but requires well-structured supply lines and co-operative workers. OPT focuses on clearing up bottlenecks in the manufacturing process but its exceeding focus on areas of constraints can adversely affect non-bottleneck areas.

To what extent and for how long could a company depend exclusively on a particular technology? Alternatively, to what degree could a company implement the ideas or principles contained in a range of technologies as an integrative package or as stand-alone packages? Technology integration as an agility enabler required that companies learn incrementally from newly emerging technologies rather than perceiving technologies as alternatives. Technology integration is important because individual technologies are incapable of solving all problems, and more so during periods of continuous change when new technologies proffer solutions to emerging problems. Accordingly, technology integration is a way of making sense and building a production operations foundation that will last (Aggarwal, 1985; Wallace, 1992; Tyre and Orlikowski, 1994; Gunneson, 1997). Using the concepts of range and reach of technology, Browne et. al. (1995) gives a good indication of the scope for innovative business improvement through technology integration. Nevertheless, choosing a system takes time, money and effort in terms of the initial investment, training, employee buy-in, implementation and assimilation.

In the light of the foregoing arguments supportive to integration, the path diagram shows that technology integration exerts a positive influence of 0.257 on environmental performance as well as a direct impact of 0.260 on overall survival prospects. In the path diagram, the impact of technology integration on overall survival prospects is the only direct impact of any model of competence building on a core measure of business performance that bypassed the four dimensions of competitive objectives. Nevertheless, technology integration had a negative impact on the competitive objective of flexibility leadership, which of course was the only negative impact exercised by any of the agility enablers. This negative impact is difficult to explain but it needs restating the argument in section 2.11 that flexibility is about the most difficult competitive objective. The path diagram also shows that besides the negative impact of technology integration and the positive impact of 0.236 exhibited by the lean supply chain, flexibility leadership was not influenced by any other agility enabler. Some other probable reasons behind the negative relationship between technology integration and flexibility leadership are as follows.

Companies adopting technology integration might be carried away and work as if technology is an end in itself rather than as a means to an end. Yusuf (1996) identified this problem as one of the causes of failed implementation of computerised planning systems such as MRP and MRPII in companies. In particular, new technologies affect the structure of jobs and work relationships whilst they also take time to be fully integrated into the production process. Employees may therefore be less inclined to adapt existing operational systems especially where new skills are required. This perhaps explains the argument that only employees can make a plant truly flexible (Upton, 1995; Pinochet et al, 1996).

Furthermore, in a study of technological adaptations, Tyre and Orlikowski (1994) found that subsequent to new competitive pressures, companies occasionally re-examine existing technologies and make important modifications. They argued that regular use of new technologies was not consistent with the mental and physical effort required in developing and implementing new ideas. Even then, beyond a few studies of integrated JIT/TQM and integrated MRP/JIT, there is little knowledge of best practice in technology integration (Ahmed et. al., 1996; Sriparavastu and Gupta, 1997).

Accordingly, frequent adaptation of work processes to embrace modules of new technologies will be a complex process involving money, time and new skills. Especially during this period of rapid technological change, training, adaptation, assimilation and consolidation are crucial challenges. These are in addition to compatibility problems and associated problems of robustness and accuracy amongst several modules of new technologies (Davenport, 1998). In all these however, technology integration will be easier to manage and be beneficial if it responds to abrupt pressures imposed by rapid technological change within a policy of timed and continuous process of modification and accommodation (Tyre and Orlikowski, 1994). Technology integration is not necessarily limited by company size. Technologies such as MRP, TQM, JIT and EDI may not be too expensive even as they seem to require user-discipline much more than money. Above all, Ahmed (1996) found that although small-scale companies had lesser access to new technology, this did not solely fix their competitiveness relative to large-scale companies.

Total employee empowerment is another core term used in the path diagram of regression results. The term emerged from factor analysis alongside two other models of employee empowerment namely limited empowerment and training-based empowerment. Limited empowerment was excluded from the path diagram because it had no significant relationship with any other variable.

Employee empowerment characterizes the new organisation system required in companies and it was discussed in the literature review as one out of five dimension of competence building from which agility enablers could be identified. The concept of employee empowerment in agile manufacturing (Hormozi, 2001) "*...can greatly reduce the levels of management, thus facilitating the decision-making process*". Employee empowerment was discussed in section 2.7 from three main dimensions of teaming, training and involvement. When employees are enriched mainly on training, empowerment is training-based as against total empowerment when there is equal emphasis on all the three dimensions.

Training alone is not sufficient to make employees deliver even as it implies access to appropriate knowledge, skills and tools. This explains why training-based empowerment had only one direct impact, which was negative (-0.190), on the competitive objective of quality leadership. This negative impact translated to a negative impact of -0.055 or five percent (-0.190 x 0.287) on environmental performance. These negative impacts were in contrast to two direct impacts and two indirect impacts of total empowerment in the path diagram. The direct impacts of total empowerment were 0.309 on quality leadership and 0.248 for sales profitability whilst the indirect effects were 0.070 for market share and 0.121 on overall survival prospects.

These results can be attributed to a more flexible and quicker response to fast moving market conditions achieved through increasing leverage of employees' intellectual power (Hormozi, 2001). Employee development and motivation should therefore be from all directions such as training, teaming and involvement, even as industry and product-specific requirements may determine the relative emphasis to be placed on the dimensions. For instance, it was reported that in Japanese companies (Browne et. al., 1995):

"Techniques based on project leadership, teamwork, good communications and simultaneous development/ engineering have had tremendous consequences in the automobile industry"

Small-scale companies such as the Chinese family-run businesses provide a good illustration of total empowerment, as trust, delegation and joint stakes amongst family members would tend to be unlimited. The Whirlpool Corporation has been reported as a good example of employee empowerment (Hormozi, 2001). Empowerment initiatives were pivoted around cross-functional teams of employees, who were used to identify an opportunity to leapfrog the competition by integrating all regional logistics activities. Empowerment should however extend beyond teaming, and accommodate the systematic acquisition of skills, rules, attitudes and a learning culture that result in improved performance (Pennathur et. al., 1999; Hormozi, 2001). Hence, Saturn Corporation, a US car manufacturer, requires its employees to take no less than 96 hours of training every year (Maskell, 2001). While training is voluntary, the company's bonus system has strong incentives for meeting the training target. Of course in the early years (Maskell, 2001):

"Training achievement was the only performance measure for plant people because it was clear that training was the principle key to quality, timeliness, low cost, team work, and the companies other strategies"

There remains yet eight terms in the path diagram. These eight terms are dependent variables. They are the four principal dimensions of competitive objectives namely cost leadership, quality leadership, flexibility leadership and time based technology leadership as well as four categories of business performance measures namely sales profitability, market share, environmental performance and overall survival prospects. These dependent variables do not require any more elaboration since they were discussed earlier in section 2.11. The competitive objectives reflect the degree of emphasis placed on low cost, quality, flexibility and speedy delivery of new technology solutions by companies. As well, sales profitability measures the direction of change in sales turnover and net profit whilst market share is an index of change in total market demand met by a company's product. Environmental performance was derived by summing up the scores by companies on the five environmental change drivers studied. The scores, which ranged from negative to positive, measured the extent to which companies have succeeded in converting the perturbing threats of the change drivers into positive gains.

In the path diagram, variables such as technology integration, the lean supply chain and quality leadership had positive impacts on environmental performance. This means in effect that through those variables, companies can become better positioned to meet the challenge of the change drivers. Better positioning arises through the range of positive impacts exercised by the agility enablers, which ultimately translates to a positive impact on "Overall survival prospects". The latter was derived from the results of factor analysis by summing up companies' standardised factor scores on sales profitability, market share, and the impact of change drivers as a measure of environmental performance. "Overall survival prospects" therefore provides a summary indicator of business performance that arises from the interplay of the agility enablers.

In the preceding paragraphs, the terms used in the path diagram and the relationships indicated by the path coefficients amongst the terms were explained and justified. The discussion included several illustrative examples either composed by the researcher or drawn from the literature. In spite of the significant relationships to the credit of each of the agility enablers, none of them is complete as a determinant of competitive objectives and business performance. Just as competitive objectives reinforce themselves when pursued with equal vigour Fliedner and Vokurka (1997; Ward et. al., 1998), the agility enablers are expected to interact positively and reinforce themselves. In effect, the agility enablers would impart widely on competitive objectives and business performance only if they are deployed jointly as a comprehensive package of agile change initiatives. The need arises therefore to test for the collective impacts of the agility enablers.

4.6.6. TEST FOR THE JOINT IMPACT OF AGILITY ENABLERS

This section tests for the collective impact of the agility enablers. This is with a view to reveal any differences in the level of adoption of the five agility enablers across sub-samples of companies and the extent to the degree of attainment of competitive objectives and business performance can be attributed to such differences.

Independent samples test and one-way analysis of variance were applied to explore differences in companies' scores on the dimensions of competition and business performance across the models of product customisation, supply chain networking, manufacturing automation, employee empowerment and technology utilisation. Although the results were excluded from this thesis for purposes of parsimony, the results confirmed the revelation in the path diagram that the agility enablers had isolated impacts.

In order to test the collective impact of the five agility enablers, two groups of low and high adopters of the five agility enablers were composed. Thereafter, tests of significant differences in mean scores on competitive objectives and business performance measures were conducted. Using the SPSS multiple selection command, 23 out of 91 companies (25 percent) were listed as qualified for the analysis because they had no missing data. The twenty-three companies were identified with a relatively higher degree of implementation of the five agility enablers. The 23 companies were classified as high adopters of the agility enablers whilst the other 68 companies were low adopters.

Table 4.22 presents the results of mean difference tests between two sub-samples of the companies studied, based on the level of adoption of the agile manufacturing enablers. The tests were conducted using seven competitive objectives and six business performance measures studied in the survey by questionnaire. Significant differences in mean scores are indicated in Table 4.22 by t-values greater than 2.00 and p-values less than 0.05. The results reveal that the high adopters of the agile manufacturing enablers outperformed the low adopters on several measures of business performance. However, only two competitive objectives differed significantly across the two groups. The high adopters outperformed the low adopters on leadership in new technology products whilst the low adopters outperformed the high adopters on volume flexibility. The results suggest that leadership in new technology products account for the differences in performance measures, which favoured the high adopters. The results also imply that leadership in new technology products and volume flexibility are non-complementary, and that companies implementing the agility enablers need to improve on volume flexibility.

Competitive objectives and business performance measures	*t*-Test of mean difference			
	Low adopters	High adopters	t-value	p-value
Volume flexibility	4.09	3.35	-2.486	0.015
Leadership in new technologies	3.25	4.00	2.813	0.006
Sales turnover	3.54	4.30	3.372	0.01
Net profit	3.31	4.04	3.072	0.003
Market share	3.41	3.74	2.048	0.046
Customer loyalty	3.46	3.87	2.212	0.029
Aggregate business performance	20.87	23.57	3.438	0.001
Low adopters- 68 companies (75%), High adopters- 23 companies (25%)				

Table 4.22 Differences between high and low adopters of agility enablers

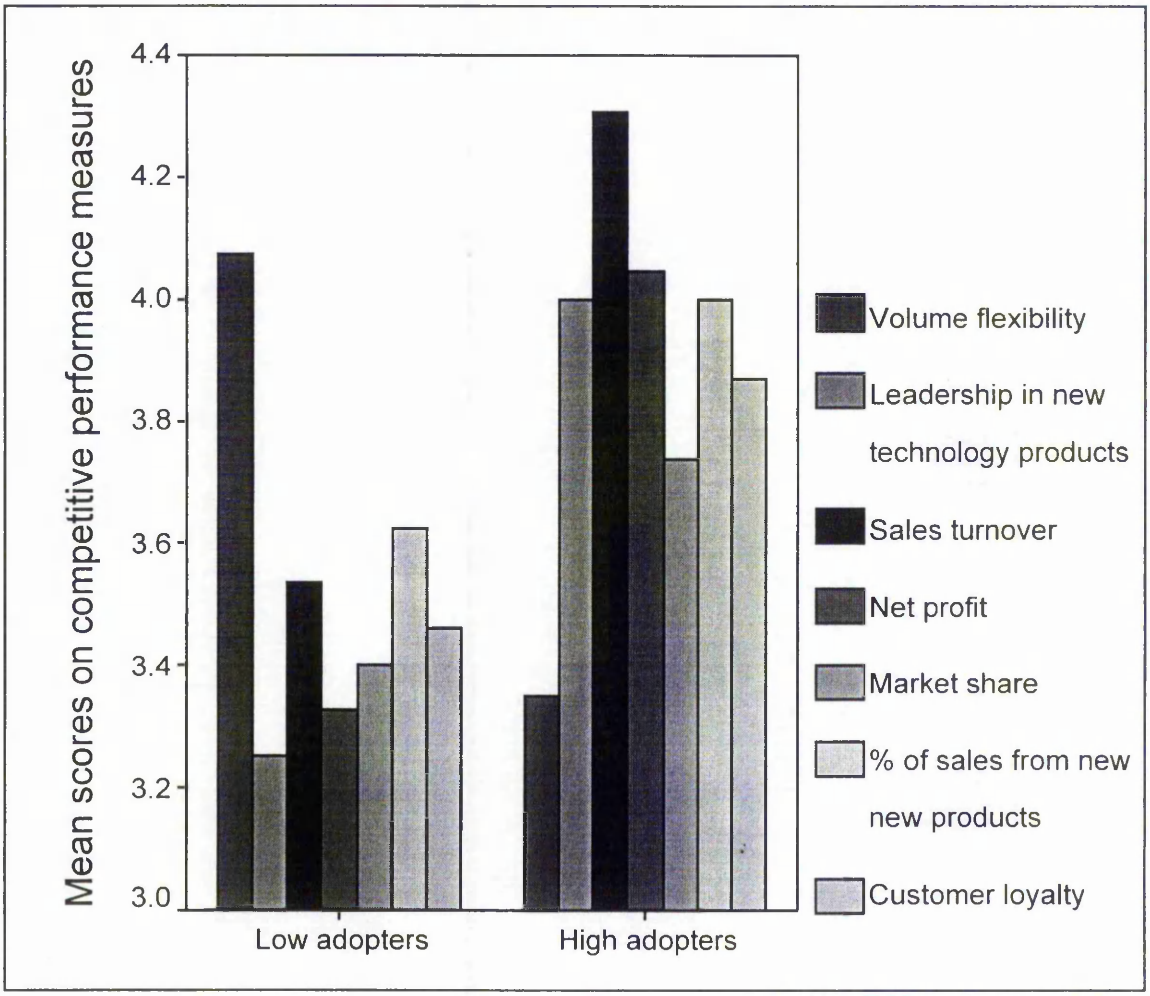


Figure 4.7 Clustered bar charts of scores by low and high adopters of agility enablers

Figure 4.7 presents clustered bar charts that enable the visualization of differences between companies classified as low and high adopters of agility enablers in Table 4.22. Two sets of clustered bars are shown, one each for the low and high adopters. Within each cluster of charts, the length of the bars represent the mean scores computed for the variables listed in Table 4.22. Except for volume flexibility, all the bar charts of the high adopters were longer than for the low adopters. This means in effect that the companies classified as high adopters of agility enablers outperformed the low adopters.

In order to provide more evidence in support of the agility enablers, the level of implementation of the five agility enablers between two groups of least and most successful plants were explored using independent samples test. It was expected that the most successful plants would return higher mean scores on the agility enablers as well as attainment of competitive objectives.

4.6.7. COMPETITIVE ENABLERS OF THE LEAST SUCCESSFUL AND THE MOST SUCCESSFUL PLANTS

This analysis aimed to reveal the extent to which the most successful plants implement the five agility enablers relative to the least successful plants. For this purpose, two extreme groups of least and most successful plants were constituted. It was expected that the most successful plants would return significantly higher mean scores on the five agility enablers. In contrast, the least successful plants were expected to return significantly higher mean scores on the remaining nine alternative models of manufacturing competencies.

In order to compose the least and most successful plants, companies' scores on all survey instruments that measured the two concepts of environmental and business performance were aggregated and an aggregate mean performance score was calculated. All plants scoring more than one-half standard deviation below the mean score were named as the least successful (LS) whilst all plants scoring more than one-half standard deviation above the mean score were grouped as the most successful (MS). The procedure identified thirty LS plants and thirty-five MS plants respectively. Thirty-five companies (38.5%) falling within less than one-half standard deviation below or above the mean were excluded. One standard deviation from the mean would have excluded over 50 percent of companies.

Table 4.23 presents the results of mean difference tests. The table reports F-test of variance, t-test and the confidence interval of mean difference for the fourteen models of manufacturing competencies and the four core dimensions of competitive objectives reported earlier in Table 4.19. Between the least and most successful plants, the mean scores of three out of the fourteen models of manufacturing competencies differed significantly in favour of the most successful plants. The three models are the agility enablers of transparent customisation, technology integration and intelligent automation. Their corresponding significance levels were emboldened in Table 4.23. In addition to the three agility enablers, the most successful plants also had a significantly higher mean score on adoption of the lean supply chain. The 95 percent confidence interval statistics also confirmed that the LS and the MS plants differed significantly. Table 4.23 shows that the lower and upper limits of the 95 percent confidence interval for transparent customisation, integrated technology, intelligent automation and the lean supply chain do not contain zero in-between.

	Test for Equality of Variances				Test for Equality of Means				
Models of manufacturing competencies	Least successful	Most successful	F	Sig.	t-Test	df	Sig.	95% Conf. Interval	
								Lower	Upper
Transparent customisation	-.340	.379	.011	.916	-2.94	58	**.005**	**-1.210**	**-.2296**
Cosmetic customisation	-.096	-.051	.085	.772	-.185	58	.854	-.5348	.4443
Limited customisation	-.021	-.077	.187	.667	.358	58	.722	-.4522	.6492
Integrated technologies	-.401	.273	2.89	.094	-2.86	65	**.006**	**-1.145**	**-.2034**
Modern technologies	-.179	-.001	.124	.726	-.687	65	.495	-.6960	.3398
Traditional technologies	.179	-.002	.210	.648	.779	65	.439	-.2845	.6483
Agile supply chains	.185	-.061	.043	.836	1.058	65	.294	-.2182	.7101
Traditional supply chains	-.157	.050	2.62	.111	-.807	65	.423	-.7216	.3063
Lean supply chains	-.453	.218	.188	.666	-2.83	65	**.006**	**-1.143**	**-.1976**
Intelligent automation	-.184	.394	23.67	.000	-2.173	64	**.033**	**-1.110**	**-.0467**
Flexible automation	-.151	.101	.840	.363	-1.02	64	.312	-.7457	.2420
Limited automation	.027	-.045	.002	.965	.306	64	.761	-.3968	.5401
Total empowerment	-.040	-.066	.080	.778	.100	61	.921	-.5139	.5677
Training empowerment	-.059	.226	3.12	.082	-1.17	61	.248	-.7766	.2046
Models of competition									
Low cost	-.025	.173	.694	.408	-.855	65	.396	-.6609	.2648
Quality	-.455	.358	4.97	.029	-3.45	65	**.001**	**-1.283**	**-.3416**
Time-based technology	-.560	.567	7.38	.008	-5.17	65	**.000**	**-1.563**	**-.6911**
Flexibility	-.268	.328	.376	.542	-2.67	65	**.009**	**-1.041**	**-.1510**

Table 4.23 Differences between the least successful and the most successful plants

Figure 4.8 presents clustered bar charts showing the relationship between adoption of alternative manufacturing competencies and attainment of competitive objectives across the least successful plants (LS) and the most successful (MS) plants. The first four bars for both groups of plants represent the standardised mean scores on four out of fourteen manufacturing competencies in Table 4.23 that varied significantly between the LS and the MS plants. The remaining four bars also represent the standardised mean scores on four competitive objectives that varied in Table 4.23 between the LS and the MS plants. In Figure 4.8, all the eight bars shown for the LS plants lie downwards of the zero dividing line, the standardised mean scores being negative. In contrast, the bars of the MS plants lie above the zero dividing line, the standardised mean scores being positive.

The bar charts in Figure 4.8 also reveal the models of manufacturing competencies and the dimensions of competitive objectives that were emphasised by the MS plants. The MS plants emphasised the manufacturing competencies described as agility enablers, that is, transparent customisation, integrated technologies, the lean supply chain and intelligent automation. Because of significant adoption of the agility enablers by the MS plants, their mean scores on four competitive objectives namely low cost, quality, time based technology and flexibility were positive and significantly higher. Figure 4.8 also reveals that the MS plants had the longest positive bar chart on time based technology whilst in contrast, the LS plants had the shortest negative bar chart on low cost. The results in Figure 4.8 showing that the MS plants had the longest positive bar chart on time based technology leadership validate those in Table 4.22 where high adopters of the agility enablers returned significantly higher mean scores on time based technology leadership and aggregate business performance.

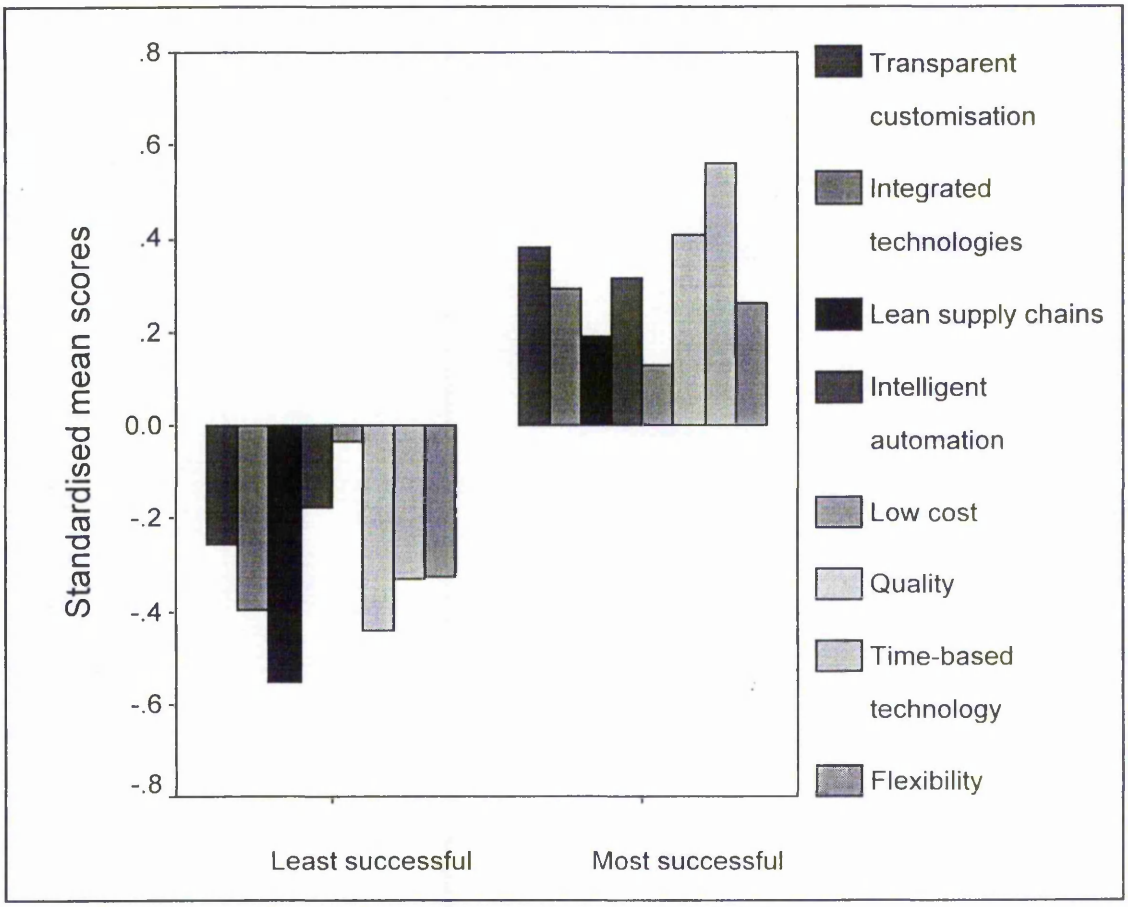


Figure 4.8 Clustered bar charts of mean scores of the least and most successful plants

4.6.8. TEST OF DEMOGRAPHIC INFLUENCES

If the emerging results of this study were to be widely applicable, they should not differ significantly across company size, product, market and other demographic classifications. In particular, the significant correlations amongst change drivers, competitive objectives and business performance measures should be devoid of demographic influences. In addition, differences in the adoption of agility enablers across demographic sub-samples based on company size, product or industrial classifications should not differ significantly from zero. Otherwise, the results of this study will have contextual limitations. Nevertheless, the results of the study are expected to be more relevant to companies competing in more markets characterised by rapid changes and less docile customers, where products are more innovative than functional.

DEMOGRAPHIC SUB SAMPLES (NUMBER OF COMPANIES)	CORRELATION COEFFICIENTS[3]		
	CD and AP (1)	CD and AA (2)	AA and AP (3)
Small scale companies (58)	0.368 (0.004)	0.257 (0.056)	-
Medium scale companies (26)	0.394 (0.063)	-	-
Large scale companies (25)	-	-	0.371 (0.081)
Perfect competitive[1] (40)	0.307 (0.054)	0.360 (0.026)	-
Oligopolistic competitive[2] (55)	0.428 (0.001)	-	0.247 (0.069)
Automobile companies (17)	0.602 (0.014)	0.429 (0.097)	-
Aircraft and shipping (8)	0.481 (0.051)	0.454 (0.067)	-
Industrial and agricultural equipment (26)	0.480 (0.015)	-	-
Electrical and electronic (15)	-	0.846 (0.001)	-
Personal and fashion products (10)	-	0.639 (0.047)	0.606 (0.064)
Food, chemical and pharmaceutical products (11)	-	0.535 (0.090)	-

[1] A concept used by Economists to describe markets dominated by several companies of relatively equal size

[2] A concept used by Economists to describe markets dominated by a few large companies

[3] CD (Change drivers); AA (Aggregate agility); AP (Aggregate business performance)

Table 4.24 Correlation results of demographic sub-sample tests

The first demographic test explored differences in the relationships established earlier in section 4.6.1 amongst aggregate change drivers (CD), aggregate agility (AA) and aggregate business performance (AP). Thirty-six correlation tests amongst CD, AA and AP were run for thirty-six demographic sub-samples of companies. The pattern of correlation did not differ significantly from the results reported in Table 4.8 for all companies studied. Table 4.24 reports sub-sample correlation coefficients that were significant at $p<0.10$. The results show that CD correlated widely with AA and AP. This means in effect that change drivers (CD) impact on business performance across a wide range of companies' sub-samples. As well, in tune with the earlier results in Table 4.8, AA and AP did not correlate widely in Table 4.24.

Further tests of demographic differences were conducted. The standardised mean scores on the agility enablers, the four categories of competitive objectives and three dimensions of business performance identified earlier through factor analysis were studied for differences across sub-samples of companies based on size, product groups and market types. In addition, the relationship between adoption of agility enablers and plant success was explored for several sub-samples of companies based on size, product group and market type. To this end, the t-test procedure was applied to test for differences across two market types while the ANOVA procedure was applied to test for differences across three sales turnover sizes and seven product groups, which were reported earlier in Table 4.7. The ANOVA procedure tests for differences in variance and mean scores between any one sub-sample and all other sub-samples combined. Finally, chi-square test was conducted to explore sub-sample differences in the relationship reported earlier between adoption of agility enablers and plant success.

FACTOR MODELS	Test for Equality of Variance		Test for Equality of Means		
	F	*p*	t	*Df*	*p*
AGILITY ENABLERS					
Transparent customisation	.681	.411	.317	87	.752
Integrated technologies	.163	.687	-.335	96	.738
Agile supply chains	.138	.711	-.287	96	.775
Lean supply chains	.219	.641	-1.714	96	.090
Intelligent automation	.002	.968	.322	94	.748
Total empowerment	.085	.771	-1.049	90	.297
COMPETITIVE OBJECTIVES					
Low cost	.287	.593	-1.554	95	.124
Quality	.319	.574	.035	95	.972
Speedy delivery of new technology	1.720	.193	-.647	95	.519
Flexibility	1.853	.177	-.497	95	.621
BUSINESS PERFORMANCE					
Market share	.019	.890	.816	92	.416
Environmental performance	1.117	.293	-1.255	92	.213
Sales profitability	.370	.544	-.508	92	.613
Survival prospects	.213	.646	-.817	91	.416

Table 4.25 T-test of differences across dominant market types

Tables 4.25 to 4.27 display the impacts of demographic influences on the mean scores and variances on agility enablers, competitive objectives and business performance. Table 4.25 presents the t-test results of mean differences between two market types identified in the study and classified earlier as perfect competitive and oligopolistic competitive. The F and t statistics were less than 2.0 while the probability levels were greater than 0.05. These values indicate that differences between the two groups are not statistically different from zero. Similar results were repeated in Tables 4.26 and 4.27. In both tables, the F-values were lower than 2.0 while the probability levels were greater than 0.05. The only exception was for technology integration in Table 4.26. Companies of larger size were better integrators of technology. However, agility enablers would impact significantly only when deployed jointly, and companies of smaller size would not lose competitiveness due solely to access to technology alone. Relatedly, Ahmed et al (1996) concluded that better access to technology by bigger companies did not create superior competitive advantage.

Finally, chi-square tests of the relationship between adoption of agility enablers and the degree of plant success were conducted first for all companies and for a wide range of demographic sub-samples. The results in Table 4.28 show a strong relationship between the level of adoption of agility enablers and the level of plant success. For all companies, a chi-square of 5.50 at p=0.019 was computed. Except for large-scale companies, all sub-sample chi-squares are significant at p<0.10. Chi-square test was not conducted for the seven product groups due to a statistical limitation of 50 valid cases in seven sub-samples.

FACTOR MODELS	Sum of Squares	df	F	Sig.
AGILITY ENABLERS				
Transparent customisation	.574	2	.283	.754
Technology integration	12.788	2	7.111	.001
Agile supply chains	4.044	2	2.062	.132
Intelligent automation	1.366	2	.679	.509
Total empowerment	1.351	2	.671	.513
COMPETITIVE OBJECTIVES				
Low cost	.425	2	.209	.812
Quality leadership	.414	2	.204	.816
Time based technology leadership	.879	2	.435	.648
Flexibility	2.910	2	1.468	.235
BUSINESS PERFORMANCE				
Market share	.566	2	.279	.757
Environmental performance	2.743	2	1.382	.256
Sales profitability	.650	2	.321	.726

Table 4.26 ANOVA tests of differences across sales turnover size

FACTOR MODELS	Sum of Squares	df	F	Sig.
AGILITY ENABLERS				
Transparent customisation	9.450	6	1.635	.146
Technology integration	8.296	6	1.414	.216
Agile supply chains	5.167	6	.854	.531
Lean supply chains	2.252	6	.362	.901
Intelligent automation	3.412	6	.554	.765
Total empowerment	2.013	6	.322	.924
DIMENSIONS OF COMPETITION				
Low cost leadership	4.887	6	.806	.568
Quality leadership	3.055	6	.495	.811
Time based technology leadership	1.545	6	.247	.960
Flexibility	2.377	6	.383	.889
DIMENSIONS OF BUSINESS PERFORMANCE				
Market share	3.382	6	.549	.770
Environmental performance	8.437	6	1.442	.206
Sales profitability	7.718	6	1.309	.260
Survival prospects	3.303	6	.536	.780

Table 4.27 ANOVA tests of differences across product groups

The preceding results reveal that pressures compelling agile manufacturing design as well as the impacts of the five agility enablers on competitive and business performance objectives are devoid of demographic limitations. In effect, agile manufacturing is widely applicable as a means of enhancing competitive advantage. Nevertheless, the results should be taken as indicative rather than prescriptive. In addition, the results should apply more to companies faced by a higher degree of market instability and product complexity. Following next, research hypotheses are discussed relative to the empirical results.

Number of Valid Cases	Chi-Square	Sig.
All companies (50)	5.500	.019
Small scale (24)	6.316	.012
Medium scale (15)	2.784	.095
Large scale (11)	.749	.387
Market type- perfect competitive[1] (15)	4.286	0.038
Market type- oligopolistic competitive[2] (27)	3.844	0.050
1. Several companies of relatively equal strength, product customisation is minimal 2. A few large companies dominate, product customization is significant		

Table 4.28 Chi-square test of agility enablers and plant success

4.7. RESEARCH HYPOTHESES VALIDATED

By way of discussion, this section attempts to validate the research hypotheses based on emerging empirical results. The hypotheses are discussed in turns as follows.

4.7.1. HYPOTHESIS 1

There is a strong relationship between change drivers, competitive objectives and business performance.

Statistical tests confirm speculations in the literature that unprecedented instability emanating from the external business environment compels agile manufacturing design as a means of enhancing business performance (Hill and Chambers, 1991; DTI, 1995; Sheridan, 1996; Bhattacharya, 1996). Such pressures constitute the driving forces for agile manufacturing as a means of defending business performance against the effects of market instability (Levary, 1992; Droge et al, 1994; Ling X, 2000; Sharifi and Zhang, 2001).

The results in Table 4.8 showed that change drivers and business performance had a correlation of 0.402 at $p<0.01$. In addition, change drivers and competitive objectives as a measure of agility had a correlation of 0.230 at $p<0.05$. Furthermore, competitive objectives (agility) and business performance had a modified correlation of 0.226 at $p=0.007$. The correlation of 0.402 at $p<0.01$ between change drivers and business performance measures the potential impact of the former on the latter. As market instability intensifies, this coefficient of 0.402 would tend towards 1.0 unless companies generate additional change proficiency and responsiveness through agile manufacturing.

Meanwhile, the significant correlation of 0.230 at $p<0.05$ between change drivers and competitive objectives (agility) is a measure of the extent to which current attainment of the latter attacks the perturbing influence of the former on business performance. Between the two correlations of 0.402 and 0.230, there is a shortfall of 0.172. This shortfall is a change proficiency gap, which necessitates agile manufacturing design as a means of coping with external competitive pressures.

Not only would higher attainment of competitive objectives (agility) attack the perturbing influence of the change drivers, it should also exert a defensive support for business performance. The significant correlation of 0.226 shown in Table 4.8 between competitive objectives as a measure of agility on one hand and business performance on the other hand is an index of the defensive power of the former on the latter. Between 0.402 and 0.226, there is also a shortfall of 0.176. This shortfall can be described as competitive attainment gap, which exposes business performance to the perturbing influence of environmental change drivers. This exposure can be eliminated through agile manufacturing design, using the agility enablers as building blocks for change initiatives.

The three correlations of 0.402, 0.230 and 0.226 support the hypothesis that there is a strong relationship between change drivers, attainment of competitive objectives and business performance. The attendant change proficiency requirement gap of 0.172 and the competitive attainment gap of 0.176 justify agile manufacturing design.

4.7.2. HYPOTHESIS 2

Companies that pay simultaneous attention to a wide range of manufacturing competitive objectives will outperform the competition.

Hypothesis 1 provided the evidence of a strong relationship between change drivers, attainment of competitive objectives as a measure of agility and business performance. It is therefore important to demonstrate its benefits based on the working definition of agility adopted in chapter 2 as relatively equal emphasis on competitive objectives.

Accordingly, Hypothesis 2 proposes that companies that pay simultaneous attention to a wide range of competitive objectives will outperform other companies. This hypothesis implies that relative attainment without trade-off rather than absolute attainment of specific dimensions of competition is important in agile manufacturing.

Fliedner and Vokurka (1997) had defined agile manufacturing as the ability to produce a broad range of low cost, high quality products with short lead times in varying lot sizes and built to individual customer specifications. The definition summed up a wide range of capabilities. Elimination of tradeoffs amongst such capabilities is a means of enhancing business performance (New, 1992; Silveira and Slack, 2001; Gordon and Sohal, 2001).

Table 4.9 provides the evidence that companies that pay simultaneous attention to a wide range of capabilities will outperform the competition. The evidence derives from the prior statistical test based on differences in the range of mean scores. Table 4.9 shows that companies returning a lower range of mean scores had significantly higher scores on all competitive objectives. This is because competitive objectives reinforce themselves when pursued with equal vigour. By extension, they generate positive spill over effects on core measures of business performance.

Chi-square test provided additional evidence. It revealed that the low range companies had fifteen positive significant correlations amongst individual change drivers, competitive objectives and business performance measures. In contrast, the high range companies had only one negative significant correlation of -0.564 at $p<0.05$ between low cost as a competitive objective and customer loyalty as a business performance measure.

The contrast tests results of one-way analysis of variance provided further evidence that simultaneous attention to competitive objectives lead to superior performance outcomes. The results reported in Table 4.22 and Figure 4.7 attributed outcomes in market share and overall business performance to higher adoption of agile manufacturing enablers. As well, the visual output of the corresponding contrasts tests, which is shown in Figure 4.5 visually confirms the competitive superiority of the agile manufacturing model amongst the three models of competition, which were reported earlier in Table 4.17. The agile model was unique for high and positive coefficients on all competitive objectives, and as competitive objectives reinforce themselves when pursued with equal vigour, the agile model returned superior business performance. To this extent, the hypothesis that companies paying simultaneous attention to a wide range of manufacturing capabilities will outperform the competition is valid.

Having provided the empirical evidence that agile manufacturing design is inevitable, the next hypothesis identified resource competencies as the enablers of agile manufacturing. Identification and justification of agility enablers was the main objective of the research.

4.7.3. HYPOTHESIS 3

Attainment of manufacturing competitive objectives and business performance is directly related to the level of adoption of agile manufacturing enablers.

As proposed, Hypothesis 3 attempted to identify agility enablers from a wide range of resource competencies in manufacturing. It also aims to provide the evidence that agility enablers identified lead to higher attainment of competition and business performance.

In chapter 2, the need for companies to identify and nurture appropriate competencies that enhance competitive advantage was stressed (Dove et al, 1996; Gardiner, 1996; Gagnon, 1999, Gunasekaran, 1998; Gunasekaran, 1999). Especially for companies competing in markets characterised by market instability and product complexity, such competencies should be kept in constant tune with changes in product, material and technological development (Hall, 1980; Levary, 1992; Hamel and Prahalad, 1994; Gagnon, 1999)

The five agility enablers are discussed in the order of transparent customisation, agile supply chains, technology integration, intelligent automation and employee empowerment.

Customer enrichment through mass customisation is the ultimate goal of agile manufacturing. However, customisation should be transparent by adding significant enhancements to current products without penalties in time, cost or quality. Otherwise, it is an exercise in variety, which adds more to cost than to revenues and restricts rather than enhance competitive advantage.

In an effort to consolidate and explore new markets, companies strive to customise and extend product options. To this end, practices differ across companies (Lampel and Mintzberg, 1996; Gilmore and Pine II, 1997). Seven such practices were investigated, four of which defined transparent customisation in Table 4.11. The four practices were unique technical functions, new technology to customers, dominant design customised at the point of sale and profit impact.

The regression results in Tables 4.20 and 4.21, and the path diagram in Figure 4.6 show that transparent customisation had a direct impact of 0.593 on time based technology leadership and an indirect impact of 0.22 on overall survival prospects. Table 4.23 also reveals that competence in transparent customisation accounts for the greatest difference between the least and the most successful plants. To this extent, transparent customisation should underpin the design of agile plants. More emphasis on transparent customisation is necessary as its impact was not widespread enough.

In order to widen the impact of transparent customisation the requirements of which are beyond single factory capabilities, agile supply chain networking is crucial (Browne et al, 1995; Dyer, 1998; Kasarda and Rondinelli, 1998; Soliman and Youssef, 2001).

Supply chain practices differ across companies (Kehoe and Boughton, 2001; Hoek et al, 2001; Soliman and Youssef, 2001). Eight dimensions of current practice were investigated, which give rise to three models (traditional, lean and agile) in Table 4.12. In the agile model characterised by computer-based data integration, interaction with competitors and knowledge sharing on design and manufacture, cluster analysis identified only about twenty percent of companies. Prior studies identified practices that distinguish agile supply chain even as they discovered that such practices were yet to be popular (Upton and McAfee, 1996; Lee and Lau, 1999; Hoek et al, 2001; Soliman and Youssef, 2001).

The regression results in Tables 4.20 and 4.21, and the path diagram in Figure 4.6 confirm that agile supply chains exerted a significant impact on cost leadership, even as the lean supply chain had a wider spread of significant impacts. Gordon and Sohal (2001) also found that variables that defined the agile supply chain were much poorer in adoption and impacts relative to the lean supply chain, which is the dominant form of current practice.

Figure 4.6 also shows that the lean supply chain impacts significantly on flexibility leadership as a dimension of competitive objectives whilst the agile supply chain has a strong impact on low cost leadership. The significant impact of the lean supply chain on flexibility leadership as revealed in this study should be a welcome development given that the literature strongly associates the lean supply chain with cost efficiency more than flexibility. The low cost advantage attributed to the lean supply chain in the literature did not show in the path diagram perhaps because the lean supply chain had become expensive. Stronger market power accumulated by component suppliers (Browne et. al., 1995; Lewis, 2000) and profit margins that accompany hierarchies of outsourcing contracts seem to hinder the low cost advantage of the lean supply chain. Such margins are potentially excluded from the agile supply chain, which is known more for collaborative rather than contractual deployment of manufacturing competencies. This explains the positive impact of the agile supply chain on low cost leadership in Figure 4.6.

The result in Figure 4.6 which show that the lean supply chain had a much wider impact on dimensions of competition and business performance than the agile supply chain should not be seen as the evidence that the former is superior to the latter. It would take some time before current investment and research efforts on the agile supply chains achieve tangible results. However, it is significant that the lean and agile supply chain models exhibited no negative interaction effects, and can therefore be deployed jointly. Such joint deployment could blend the low cost benefit of the agile supply chain with the flexibility of the lean supply chain whilst potentially extending the range of benefits to include time based technology leadership. The specific demands of an integrated lean and agile supply chain require further study as a means of smoothening the interfaces between lean and agile.

Besides supply chain networking, adoption of multiple technologies is another enabler of competitive advantage in markets characterised by market instability. In order words, the synthesis rather than piece-meal substitution of technology provides a means of building an operations management foundation that will last (Aggarwal, 1985; Zachary and Richman, 1993; Samitt and Barry, 1993; Gunneson, 1997). This is in addition to supply chain networking which recommends access to a wider range of potentially available information and communication technologies as a means of enhancing compatibility and robustness as valued data are dispersed over space and time. However, empirical studies of the benefits of adoption of multiple technologies beyond MRP, JIT and TQM are rare even as little is known about compatibility problems and best practice (Samitt and Barry, 1993; Flynn et al, 1995b; Hackman and Wageman, 1995, Sriparavastu and Gupta, 1997).

The path diagram in Figure 4.6 also shows that technology integration impacted positively on environmental performance and overall survival prospects, the path coefficients being 0.118 and 0.257 respectively. In contrast, technology integration had a negative effect on flexibility leadership, the path coefficient being -0.248. In spite of the negative impact on flexibility leadership, the total effect of technology integration on overall survival prospects was positive. Moreover, technology differentiation, which is the alternative to integration did not fit into the regression model and was excluded.

Technology integration is important in several respects. For example, the pull principles of just in time scheduling and inventory systems provide a means of reducing fluctuations associated with MRP and MRPII and keeping them in tune with rapidly changing customer requirements. In addition, the top-bottom leadership orientation inherent in TQM has made it unwieldy and irresponsive unless it is blended with JIT that harps only on value adding structures and activities (Sriparavastu and Gupta, 1997). By virtue of increasing importance of flexibility leadership and time based technology leadership as revealed in this study, advanced technologies such as CAD/CAM, CIM, CAPP and ERP have become crucial to speedy design and replication of innovative products (Gerard et. al., 1999).

In addition to operations technologies, EDI technologies, which initially cropped up in support of secure and evidential transfers of trading reports, cash and other assets and obligations also support extended logistics involved in integrated lean and agile supply chains. EDI technologies aid smaller volumes of repetitive and just in time operations through effective data transfers and routine monitoring of specified and delivered customer expectations. In addition to EDI technologies, client server networks support co-operation and real time sharing of ideas amongst spatially distributed functions, departments, teams and companies (Davenport, 1998; Bhatt, 200). This is important as market instability compels more delegation and integration so that plans and budgets are more responsive.

In addition to transparent customisation, agile supply chains and technology integration, intelligent automation is also crucial to agile manufacturing design. This is because it enhances dynamic configuration and operational flexibility necessary for coping with swift changes in product design and market requirements (Hatvany, 1985; Lee, 1998). Central to intelligent automation are networks of independent software-driven machines organised into cells and conveyors connecting small modules of synchronous and asynchronous operations (Lee, 1997; Kusiak and He, 1997; Bodine, 1998).

Table 4.13 reports six measures of manufacturing automation and three empirical models of automation, which were described as limited, flexible and intelligent. All the three models of automation were significant and retained within the regression model. The path diagram in Figure 4.6 shows that intelligent automation has positive impacts on competitive and business performance objectives as against negative impacts exercised by limited automation and flexible automation. The negative impact of limited automation on low cost leadership seems to emanate from operational inefficiency arising from companies' efforts to mass customise using machines originally designed for mass production. Likewise, the negative impact of flexible automation on quality leadership suggests that it may not deliver precision quality required by modern products/ customers.

In spite of the positive impacts of intelligent automation, the literature lends more support to flexible automation. Such absolute support excludes the needs of plants characterised by many materials in and many products out (Edwards, 1996; Bodine, 1998).

In order to widen the competitive impact of intelligent automation, employee empowerment through training, teaming and involvement is crucial. Although intelligent machines have tremendous capabilities for data storage, retrieval and manipulation, they lack world knowledge, intuition and power to prevent and recover self from failure (Pinochet et al, 1996; Upton and McAfee, 1996).

Table 4.14 reports five measures of employee empowerment from which three factor models of empowerment namely limited empowerment, training-based empowerment and total empowerment were derived. The path diagram in Figure 4.6 excludes limited empowerment because it did not relate to any other variable in the regression results. Training-based empowerment had a single relationship, which is negative on quality leadership with a path coefficient of –0.190. In contrast, total empowerment had a positive impact of 0.309 on quality leadership. In all, total empowerment had two direct and two indirect impacts all of which were positive on quality leadership, sales profitability, market share and overall survival prospects.

The factor coefficients in Table 4.14 reveal that significantly higher emphasis on training as against a blend of training and teaming distinguished training-based empowerment from total empowerment. Total empowerment of employees rather than empowerment by training or teaming alone, falls short of the needs of modern plants using intelligent machines for rapid replication of core modules of products (Upton, 1995; Upton and McAfee, 1996).

The preceding discussion shows that the five agility enablers interacted harmoniously without negative interaction effects and led to superior outcomes on core dimensions of competitive objectives and business performance. The same applies to the lean supply chain which was therefore included as a sixth agility enabler. More importantly, it is noteworthy that the agility enablers had only a few individual effects on competitive and business performance objectives whereas collectively, Tables 4.22 and 4.23 associate them with business success. Collective deployment of the five agility enablers alongside the lean supply chain is therefore crucial to agile manufacturing design.

In the light of significant effects attributed to the agility enablers, the question arises whether the adoption and impacts of agility enablers apply widely across demographic sub-samples of companies. This question leads to Hypothesis 4.

4.7.4. HYPOTHESIS 4

Demographic and industrial contingencies determine the need for agile manufacturing design and its potential impacts on competitive objectives and business performance.

Hypothesis 4 tested the extent to which the empirical results being discussed apply equally to all companies studied and by extension, to markets and industries. In this regard, the relationships established earlier amongst change drivers, competitive objectives and business performance were tested for validity across demographic sub-samples of companies. The results show that change drivers correlated widely and strongly with each of competitive objectives and business performance. In addition, statistical tests confirmed that attainment of agility enablers did not vary across demographic sub-samples of companies. Furthermore, the significant relationship between adoption of the agility enablers and plant success remained valid across size, product and market classifications.

Gap analysis of the tripartite relationship amongst agility enablers, competitive objectives and business performance confirmed that the change proficiency gap and the competitive attainment gap identified in hypothesis 1 remained valid across demographic sub samples. This suggests that pressures for agile manufacturing design tend to be universal. However, the size of the change proficiency gap, which derived from the coefficient between agility enablers and business performance varied across demographic sub-samples of companies. This implies that companies, product markets and industries required different degrees of agile intervention. In line with expectations in the literature, the study confirmed that aircraft and shipbuilding as well as automobile and automotive product groups required the highest degrees of agile intervention. This confirmation emanated from sub-sample relationship between change drivers and business performance, which computed the highest correlations of 0.624 at $p=0.010$ for aircraft and shipbuilding, and 0.602 at $p=0.014$ for automobile and automotive companies.

Significant change proficiency gap and competitive attainment gap across sub-groups confirm the weight of emphasis on market instability and recommend agile manufacturing design as a means of enhancing responsiveness. Just as the results confirmed that pressures compelling agile manufacturing tend to be significant, they also showed that the relationship between the level of adoption of agility enablers and attainment of competitive and business performance objectives did not vary significantly across demographic sub-groups of companies.

The preceding discussion of empirical results showed a significant relationship between the level of adoption of agility enablers and attainment of competitive and business performance objectives. Yet, there remains the unresolved problem of lower volume flexibility at higher levels of adoption of agility enablers. Section 4.8 explained probable causes of lower volume flexibility and proffers solutions for improving its attainment.

4.8. LOWER VOLUME FLEXIBILITY EXPLAINED

The preceding survey results suggest that the agility enablers had a negative collective impact on the competitive objective of volume flexibility. Table 4.22 shows that high adopters of the agility enablers returned significantly lower mean scores on volume flexibility. As well, Figure 4.6 reveals that one out of the five agility enablers had a negative impact on the flexibility leadership dimension of competitive objectives. The results in Table 4.16 show that flexibility leadership was defined exclusively by two competitive objectives namely volume flexibility and product customisation.

The results agreed with the discussion of the nature of volume flexibility in the literature review. Accordingly, volume flexibility potentially hinders the overriding objective of agile manufacturing design, which this study defines as simultaneous attainment of competitive objectives. This study further explored the nature of volume flexibility. The aim was to identify its true determinants and integrate them with the agility enablers.

As reported earlier in the literature review, research evidence shows that companies' operational competencies for attainment of volume flexibility were near zero (Hoek et. al., 2001). This is in spite of the report that CEOs of manufacturing companies had long identified a blend of elasticity (volume flexibility) and leadership in new technology products as their dream and assured path to future survival (DTI, 1995).

Although AMTs support leadership in new technology through time compression and improved design/manufacturing cycle times, the same cannot be said about endless adjustments in the levels of output (Vakharia and Kaku, 1993). Improved hardware designs such as quick release mechanisms, cartridge-tooling assemblies, CNC machines, simulation and animation software, and improved information processing facilitate attainment of leadership in new technology products. Nevertheless, they still have not made small and large batches equally economical and efficient (Vakharia and Kaku, 1993; Voss and Freeman, 1994; Hoek, 2001). The challenge lies in ability to extend the range of profitable volumes of output by minimising transition penalties in time, effort and cost. To this end, changeover time compression as well as routing flexibility in terms of the ease of substituting process options is crucial to higher volume flexibility (Gupta and Somers, 1992; Voss and Freeman, 1994; Marsh et al, 1997).

The literature review also reported some other factors that limit volume flexibility. They include lack of hierarchical specifications of the several dimensions of flexibility into cause and effect (Son and Park, 1987; Upton, 1994; Das, 1996) and casual references to volume flexibility in the discussion of flexibility in general. Yet, such references focused on seasonal demand fluctuations rather than random fluctuations in demand (Dixon, 1992; Upton, 1994; Sharifi and Zhang, 2001).

One other conceivable cause of lower volume flexibility arises from "market concentration" (Chen et al, 1992). Market concentration is a practice by which companies enter into high volume, long-term contracts of supply prior to commitment of resources to a customised or leading edge technology product. Accordingly, delivery quantities are paced over the contract period based on agreed call off quantities. Consequent to market concentration, contractual commitment to long-term high volume supplies of a leading technology product would require putting in place a high volume flow cell.

However, high volume flow cells would tend to discourage interest in small orders as well as investment in marginal capacity and parallel steps, which can be added to or stopped short at ease. In other words, high volume flow cells are characterised by limited investment in capacity flexibility, which ordinarily should more than pay for itself through enhanced operational and volume flexibility (Upton, 1994; DTI, 1995; Suri, 1998).

In order to improve upon volume flexibility irrespective of market concentration, this study proposes a fifth objective of "flexible volume/ high variety" as an addition to four widely discussed optional objectives in manufacturing system design (Slack et al., 1998: 119-125; Metaxiotiset al, 2001). The four objectives are high volume/ high variety, low volume/ high variety, low volume/ low variety, and high volume/ low variety. Figure 4.9 positions the four optional objectives relative to the fifth objective of "flexible volume/ high variety". The cells correspond to the four optional objectives and the four major manufacturing systems- mass, batch process, flow cells and job shops that emanate from them. The fifth cell named agile cells provides the means of enhancing volume flexibility, leadership in new technology products in parallel.

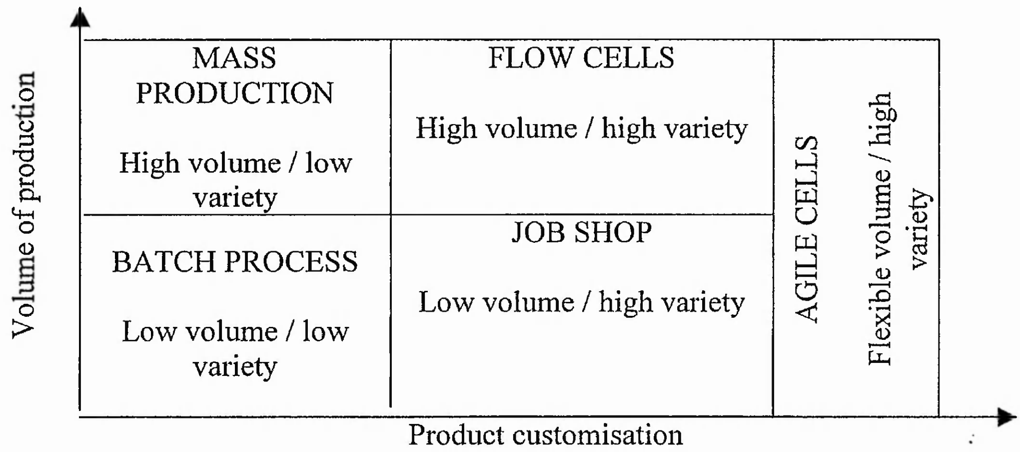


Figure 4.9. Five options in manufacturing system design.

In pursuit of the joint objective of "flexible volume/ high variety", several factories are transiting from batch to cellular manufacturing (Sheridan, 1998; Chambers and Nicholson, 2000). However, in the light of market concentration, such transitions result to flow cells (rather than agile cells), which support lead-time reduction and product customisation much more than volume flexibility (Vakharia and Kaku, 1993). Indeed economic and operational justifications for cellular design and flow cells in particular often exclude volume flexibility (Beach et al, 2000). Nevertheless, sporadic customer shifts and horrendous changes in order quantities warrant volume-flexible agile cells.

Agile cells can be distinguished by porous boundaries or the virtual character (Vakharia and Kaku, 1993; Kannan and Ghosh, 1996; Marsh et al, 1997). This is in terms of free inter-cell movement of WIP, skills, machines and other resources as a means of adjusting total and inter-cell capacity to variations in design and volume requirements (Vakharia and Kaku, 1993; Kannan and Ghosh, 1996; Marsh et al, 1997). Consequent to design and volume changes caused by market instability, agile cells are invaluable for balancing workloads and capacity utilisation, avoiding wasteful re-designs as well as simultaneous trading across mass and custom markets (Maruka and Halliday, 1993; Kannan and Ghosh, 1996; Marsh et al, 1997; Chambers and Nicholson, 2000; Beach et al, 2000).

The benefits of agile cells arise from "pooling synergy" amongst cells (Kannan and Ghosh, 1996). With pooling synergy, a cell to which a family of product modules has been assigned could tap excess capacities in other cells rather than being over-worked or constrained on a temporal opportunity. In addition, it is possible to continuously reassign workloads across cells and for cells to evolve and dissolve naturally in response to changes in product mix and volume requirements. Accordingly, agile cells have the potential to push volume flexibility to higher heights and therefore eliminate the trade-off identified earlier in section 4.6.5 between two competitive objectives of leadership in new technology products and volume flexibility.

Figure 4.10 is a modified form of the conceptual framework in Figure 3.3. It provides an if-then illustrative summary of the foregoing discussion of empirical results. The question posed by the first box in the model implies that agile manufacturing is indispensable based on the validity of hypothesis1. As indicated in Figure 4.10, significant impact of change drivers on business performance necessitates implementation of the agility enablers. Implementation of the agility enablers restricts volume flexibility but enhances leadership in new technology, with attendant overall positive gains in business performance. In order to raise volume flexibility and further improve on business performance, Figure 4.10 showed that the virtual cell is indispensable.

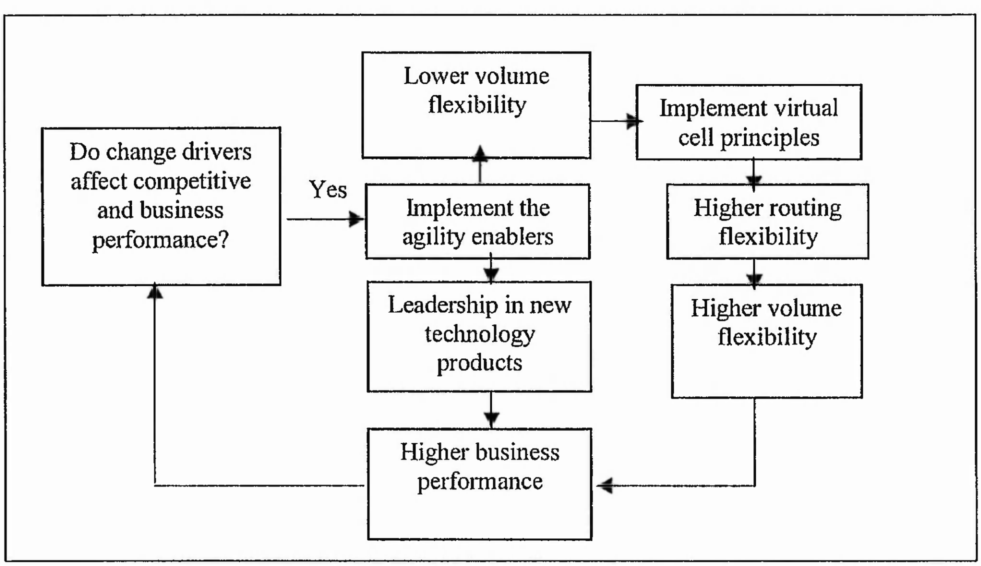


Figure 4.10 Modified conceptual framework for research

4.9. SUMMARY AND CONCLUSIONS

Five hypotheses were proposed with a view to test the need for agile manufacturing, identify its enabling competencies and test their impacts on competitive and business performance. The results that emerged from statistical tests of the five hypotheses validated the threats emanating from environmental change drivers. The results also provided support for the agility enablers in terms of their significantly higher impacts on competitive and business performance objectives.

Using correlation analysis, Hypothesis 1 confirmed that pressures compelling agile manufacturing were real. The confirmation emanated from the strength of impact exerted by environmental change drivers on business performance, which was far and above the neutralising impact of competitive objectives on the change drivers. A change proficiency gap was identified, which justifies agile manufacturing design as a means of mastering change, retaining relative competitive position and profiting amidst market instability (Bhattacharya, 1996; Richards, 1996, Sharifi and Zhang, 2001).

Having demonstrated the need for agile manufacturing, Hypothesis 2 provided a means of defining and measuring attainment of agility. Using an analysis of differences in the range of mean scores on seven competitive objectives, companies returning lower range of mean scores outperformed companies returning a higher range of mean scores. Hypothesis 2 therefore provided the evidence that relative attainment on an ever-increasing range of competitive objectives, rather than absolute attainment on some preferred dimensions leads to superior competitive and business performance outcomes. This is the theoretical position in the literature of agile manufacturing. In effect, low cost or any isolated pursuit of competitive objectives rather than equal emphasis on all bases of competition restricts competitiveness.

The empirical evidence emerging from this study confirms that pressures for agile manufacturing applies widely to companies and that adoption of agile manufacturing enablers is inevitable. Accordingly, the study identified from amongst the range of alternative models of competence building for competitive manufacturing, those models that were more close-knit to the principles of agile manufacturing. The models so identified were described as agile manufacturing enablers (agility enablers). The need for companies to identify appropriate and deployable resource competencies for enhancing competitive advantage has been stressed (Hamel and Prahalad, 1994; Henry, 1998;

Gunasekaran, 1998; Gagnon, 1999). All the models of manufacturing competencies identified by factor analysis results including the agility enablers were tested for impacts on core dimensions of competitive objectives and business performance that were identified through factor analysis. The results of regression, ANOVA and sub-samples mean difference tests confirmed that the five agility enablers individually and collectively led to superior outcomes in competitive advantage. This is the sense in which this research proposed the agility enablers as the building blocks for agile manufacturing design.

The results of the study were tested for demographic differences based on size, product group and market characteristics but none was significant. The only exception was that a significantly higher percentage of large-scale companies were technology integrators, perhaps because they had greater financial power to purchase, learn and assimilate a wider range of operations and information technologies. However, since the agility enablers had little or no individual but collective impacts, greater access to technology by large-scale companies would not alone lead to superior performance outcomes. Moreover, Ahmed et al (1996) associated a similar benefit to large-scale companies, which however did not lead to superior performance outcomes.

Two surprising results of the study are important in several respects. First, lean supply chain matches the five agility enablers in terms of impact on dimensions of competition and business performance. It therefore qualifies for inclusion as the sixth agility enabler. Indeed, the most successful plants applied it much more than the agile supply chain, the operational mechanics of which is still being nurtured and researched. In effect, the lean and agile supply chains are compatible and could indeed be deployed jointly. This view is supported by Fisher (1997) and Naylor (1999). Fisher opined that the lean supply chain could be deployed to improve the efficiency of physical distribution of traditionally functional products whilst the agile supply chain ensures responsiveness in the delivery of innovative products. Naylor also opined that:

"... Combination of the lean and agile paradigms within a total supply chain strategy ... so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream ..."

The second surprising result is that volume flexibility was not positively influenced by the agility enablers. An aggregate measure of agility did not correlate significantly with an aggregate measure of business performance until volume flexibility was isolated from the six competitive objectives that were summed up to derive aggregate agility. In addition, high adopters of agility enablers returned significantly lower scores on volume flexibility. Furthermore, only one out of the five agility enablers, that is, technology integration had a significant impact on volume flexibility. However, the impact was negative with a path coefficient of 0.248 in Figure 4.6.

To this extent, volume flexibility, the ability to adjust capacity to demand fluctuations without adding to the unit cost of manufacture, is a barrier to agile manufacturing. Therefore, empirical studies of the determinants of volume flexibility are crucial (Hill and Chambers, 1991; Sheridan, 1998; Sharifi and Zhang, 2001). Sheridan (1998) argued that:

"Volume flexibility demands more flexible and less bureaucratic organisations, alongside cross-functional teams, closer links with customers and suppliers, and more intelligent use of information technology".

The study traced lower volume flexibility to the transition by many discreet product factories from batch processing to cellular processing as a means of accommodating reduced lot sizes and ensuring smooth flow of assembly operations [Sheridan, 1998]. However, such transitions were more preoccupied with cost and customisation rather than volume flexibility (Wemmerlov and Hyer, 1989; Chambers and Nicholson, 2000)

In order to enhance volume flexibility so that small and large batches become equally economical, routing and operational flexibility within and across cells in terms of the range and ease of substituting processing options and resource capabilities are most important (Gupta, 1992; Vakharia and Kaku, 1993; Marsh et. al., 1997). This is quite unlike stable volume flow cells characterised by resource dedication, which restricts responsiveness to longer-term changes in demand, especially at higher levels of capacity utilisation (Vakharia and Kaku, 1993; Chambers and Nicholson, 2000). In the circumstance, current transitions towards cellular design should embrace the principles of virtual cellular manufacturing (Kannan and Ghosh, 1996). If agile virtual cells operate alongside integrated lean/agile supply chains and within the context of the six agility enablers, it should be possible to advance simultaneously on competitive objectives without trade off.

The empirical findings emanating from the survey by questionnaire provided direction for in-depth case studies of four companies. More quantitative and qualitative information were sought on the exact nature of change drivers, current and future competitive objectives, business performance and operational enablers of volume flexibility. The results emanating from case studies were tested for harmony with the survey results. In addition, operational determinants of volume flexibility were identified and tested for impacts on competitive and business performance objectives based on the fifth hypothesis.

CHAPTER FIVE

CASE STUDIES

This chapter reports the detail of industrial case studies, by which data was collected on a large number of variables from four plants. The studies were conducted to explore explanatory data and secondary evidence in support of the survey results in chapter 4. The case studies also aimed to generate data for testing the fifth research hypothesis on the determinants of volume flexibility and their impacts on competitive and business performance objectives. The data from case studies confirmed the threats of change drivers on business performance as a driver of agile manufacturing. In addition, case study data justified a positive relationship between the level of implementation of agility enablers and attainment of competitive and business objectives. Furthermore, the data from case studies was used to investigate Hypothesis 5, which states that virtual cells enhance operational flexibility, which in turn determines attainment of volume flexibility as a competitive objective. The hypothesis was proposed to identify the operational boosters for volume flexibility that could be deployed alongside the agility enablers as a means of achieving simultaneous attainment of competitive objectives.

The conduct of case studies as a follow up to industrial surveys has become popular. It enables plurality of methods and multiplicity of evidence, whether the purpose of research is to inform practice or further theoretical knowledge or both (Gummesson, 1991: 135-174). The data for such studies often derive from a microscopic expansion of survey instruments, and their administration to a fewer number of companies, usually between four and ten (Eisenhardt, 1989; Yin, 1994; Filippini, 1997). Through case studies, complementary data are generated for rigorous analysis of results and resolution of research dilemmas such as lower volume flexibility amongst higher adopters of agility enablers. In addition, contradictory evidence and new hypotheses could emerge from contextual differences. For every emerging result, the question arises whether it is applicable to a particular plant, and if not, why? (Collins and Cordon, 1997)

Case studies also enable researchers to negotiate a strong relationship and access as a means of seeing and hearing by themselves at the plant and digging into more quantitative and qualitative inputs that aid knowledge of reasoning behind survey results. This is crucial as senior executives of companies receive loads of questionnaires the answers to which might be exaggerated and superficial (Collins and Cordon, 1997; Gill and Johnson, 1997). For this reason, this study followed the formal processes often adopted by researchers as reported in section 4.1.

The main tools used for data collection were a quantitative questionnaire and a nine-item qualitative questionnaire addressed to the head of manufacturing. In addition, a six-item qualitative questionnaire was addressed to between two and three departmental heads. The main tools used for data collection derived from a literature-driven microscopic extension of questions asked in the earlier survey by questionnaire. Specifically, in-depth data was collected on supply chain practices, manufacturing technology, manufacturing automation, operational capabilities for flexibility, employee empowerment, competitive objectives, change drivers and business performance. Relationships amongst these concepts were studied as a means of validating the four hypotheses studied earlier.

Chapter 5 is organised as follows. Section 5.1 reports on sample selection and access. The subsequent sub-sections report on data collection and methods of analysis, case-by-case summary reports, cross-case analysis and summary and conclusion.

5.1. SAMPLE SELECTION AND ACCESS

Four companies were studied, as multiple case studies are preferable to single studies. For most case studies, between four and ten are sufficient for incremental learning within the limits of time and money (Eisenhardt, 1989; Yin, 1994). The companies were selected based on unifying rather than contrasting characteristics [Pettigrew, 1990]. Accordingly, the four companies were selected from the 23 high adopters of agility enablers identified in Table 4.22. However, although empirical results in Chapter 4 identified a significant relationship between adoption of agility enablers and plant success (Chi-square of 5.50 at $p=0.019$), three of the companies selected for the case studies were identified as low performers based on the survey data.

Company selection also considered voluntary consent to participate. This was based on a choice of “Yes” or “If” or “No” to a question in the survey by questionnaire, which asked companies to indicate interest in the second stage of the research. Twelve out of twenty-three high adopters of agility enablers returned “Yes” or "If" whilst eleven companies returned "No". Two other bases of selection were spread of companies across demographic groups, and peculiar interest shown by CEOs who personally completed the questionnaire.

Seven companies met all the criteria specified above and they were approached for participation. Most of the companies excused themselves due to pressure of time or policy of non-participation beyond cursory surveys. More pressures were put on the companies with direct inputs from the Directors of Study. Subsequently, five companies consented.

Initial contacts were made via a letter addressed to CEOs. The letter explained the purpose of study, provided assurances of minimal demands, sought an appointed plant visit, and promised a feedback on results. For purposes of further contacts, participating companies were asked to appoint a senior member in manufacturing as Research co-ordinator. Case study materials were thereafter mailed to the appointed research co-ordinators.

The materials were attended to and returned to the researcher ahead of appointed plant visits (Collins and Cordon, 1997). Thereafter, the four plants under study were visited. Activities during the visits started with semi-structured interviews, which were followed up by a guided walk through the plants. The investigative team made several observations and noted vital information. Available published materials and reports were also collected. In two of the four companies, interviews were held with the CEOs whilst in the two other companies, the interviews involved two senior manufacturing managers. The interviews focused on issues arising from prior responses to the quantitative and qualitative questionnaires. The responses were studied by the researcher subsequent to which some follow up questions were pencilled down ahead of plant visits.

5.2. METHODS OF DATA COLLECTION AND ANALYSIS

This section provides details of the methods of data collection and analysis. Five methods of data collection were used. They are a quantitative questionnaire, two qualitative questionnaires, a semi-structured interview, plant walk through observations and scrutiny of published materials such as newsletters, annual reports and bulletins. Quantitative and qualitative questionnaires were used jointly due to the exploratory nature of the study. Verbal responses alone can be inadequate for effective exploration of relationships amongst concepts such as transparent customisation and business performance. A case study can combine quantitative and qualitative methods so that inferences are based on correspondence between quantitative and qualitative data [Eisenhardt, 1989; Yusuf, 1996].

The quantitative questionnaire was completed independently by two senior managers in the manufacturing function of each company. The questionnaire was structured into eight sections made up of one hundred and fifty-eight questions in all. They were objective questions, which were ranked on five or seven-item Likert Scales. The sections asked questions on environmental change drivers, competitive objectives, business performance, manufacturing automation, supply chain practices, manufacturing technology, manufacturing flexibility, and employee empowerment.

On the other hand, the qualitative questionnaires consisted of a nine-item questionnaire attended to by the Head of Manufacturing, and a six-item questionnaire completed by two other departmental heads that had the most significant relationship with manufacturing. The nine-item questionnaire consisted of nine open-ended questions. The questions asked include initiatives towards making small and large volumes equally profitable, and supply chain improvement initiatives. The six open-ended questions investigated emerging challenges and changes compelled in operational processes as manufacturing engages in speedy response to changing market and customer requirements. Details of the quantitative questionnaire and the two qualitative questions are available in Appendix 2.

The plant visits involved holding semi-structured interviews with the CEO or Head of Manufacturing, as well as a comprehensive walk through of two plants. The visits enabled access to published materials such as newsletters, manuals and reports. The Director of Studies took part in the interviews, the proceedings of which were tape-recorded.

The responses to the one hundred and fifty-eight questions in the quantitative questionnaire were scrutinised for common threads, which were aggregated into common themes. Relationships amongst emerging common themes were studied. Following next, for each of the one hundred and fifty eight questions, the responses of the four companies were studied for commonality. As the purpose of this study is theory building on the competitive impact of agile manufacturing enablers of competitive advantage, data analysis searched for unifying rather than contrasting characteristics (Pettigrew, 1990).

Measurement scales for which unique clusters of at least two companies were not identified on either the low end or the high end of the Likert Scale were eliminated. This was done in order to reduce the number of scales to a manageable few that could provide a handy basis for making useful inferences and conclusions. Accordingly, the scales on which companies clustered together or were polarised into two groups were retained and used to study similarities and differences. The scales retained were studied for common threads. Emerging themes were interpreted relative to the concepts under study and explored for significant relationships (Collins and Cordon, 1997).

The responses to qualitative questionnaires were also studied independent of the quantitative questionnaire. The content of qualitative responses and tape-recorded transcripts of interviews were analysed and significant quotations were lifted and documented (Yin, 1994). Independent analysis of quantitative and qualitative data was followed by a search for correspondence (Eisenhardt, 1989; Collins and Cordon, 1997).

Thereafter, case-by-case summary reports were composed. The companies were labelled A, B, C and D in order to hide their identities. The summary reports were written in six sub-sections. The summary reports were followed by a discussion of common threads, which were themed and interpreted relative to the concepts being investigated (Figure 3.1). Case study reports often use one of three methods. They are individual case summaries followed by a discussion of common threads, an account structured around the main themes investigated, and a thematic presentation of the main themes identified using a case to illustrate each theme (Yin, 1994; Collins and Cordon, 1997).

Following next are summary reports on the companies studied. The reports are in six sub-sections namely introduction, competitive situation, adoption of agility enablers, operational flexibility, future plans and a summary.

5.3. SUMMARY REPORTS- COMPANY A

5.3.1 INTRODUCTION

Company A was founded in 1961 as an edible salt packaging business. It has extended to a range of edible and non-edible products including salt in granular and tablet form, dishwater liquid, water softener, toiletries, soap flakes and a range of cleaning applications. Twenty-five percent of current business is in packaging salt for dishwater, and the company claimed to be about first in this. The company had three factories out of which one was visited. The site visited had sales turnover of over £11 million and 130 workers.

5.3.2. COMPETITIVE SITUATION

Company A had a high reputation built on quality, service and new packaging solutions. To this end, the plant ran a laboratory used for analytical work on products. In addition, the company maintained a fleet of vehicles used to distribute directly to warehouses of large retain chains so that scheduled delivery dates were realised. Company A competed in both mass and custom markets. It delivered after-sales support and superior quality conformance, whilst also responding swiftly to higher volume requirements during extreme and prolonged icing. The company was committed to improving on a wider range of competitive objectives; the most important being new customised solutions. Accordingly, investment in the latest flexible packing technologies was significant. However, machine set up costs were high and this restricted interest in low volume orders.

Company A faced a tremendous amount of market instability. Its operations were being threatened by foreign competition, European Union directives, high value of the pound, sudden customer shifts and demand fluctuations caused by extended periods of extreme temperatures. However, the company was benefiting from environment concerns, increasing demand for customised private labels as well as customers' emphasis on innovative packaging such as tamper-evident caps. These are in addition to advances in information technology and speedy introduction of new products. Overall, pressures exerted by environmental change drivers have caused a modest decline in market share and net profit, even as sales turnover and repeat orders have grown marginally due to commitment to expansion as well as product and process innovation.

5.3.3. ADOPTION OF AGILITY ENABLERS

The plant consisted of simple machines, which required low labour skills. The machines were arranged sequentially as workstations integrated into flow lines. On these lines, different required quantities of materials were mixed and formed into a few standard and various customised products. In order to enhance efficiency of customised private labels, packaging operations were highly automated and flexible. Nevertheless, equipment changeover times and costs were relatively high, and in effect, low volume production of customised labels was relatively expensive. The situation was made worse by stringent quality control processes of visualisation, inspection and documentation. However, in order to balance workload and fulfil momentary orders, employees were often moved across product lines, several times in the course of a day.

Company A scored poorly on technology utilisation. Manufacturing technologies such as MRP, MRPII, ERP, TQM and JIT were not elaborately applied but the CEO claimed that the principles underlying them were understood and applied at management meetings.

The CEO argued thus:

"There is nothing really high tech in all that we do…."
"The packaging is highly automated and flexible."
"We use numerical control and are equally as automated as our competitors."

Relative to manufacturing technologies, Company A fared better on IT applications. The company had its own web site. It also had the facilities to monitor and replenish real time, the minimum stock holdings of large retail customers. On responsiveness, the CEO opined that besides keeping more stocks and a fleet of delivery vehicles:

"The computer is getting us far better control of the stocks…."
"We carry a little bit more stock, and pressurise suppliers to reduce lead times."
"We run overlapping shifts, vary the number of shifts and indeed move people around endlessly over twelve hours per day whenever the need arises."

Company A selects suppliers through open competitive tendering. The practice was underpinned by "*ability to supply specifications rather than cost…and we ensure compliance.*" In order to reduce lead times, suppliers were motivated through a performance-based retention clause. Furthermore, plans were underway to reduce the number of suppliers to between five and fifteen. On relationship with competitors, company B claimed to know all its competitors but that direct interaction was limited to inter-trading in small volumes with two major competitors. However, the company had a more advanced relationship with major customers. Such relationship fell short of any significant amount of electronic or Internet-based data integration, even as the company owned electronic communication tools and a web page. The nature of customer interaction manifests in four statements made by the CEO.

"We always try to improve on our relationship with the big customers. However, in the last three to four years, it is not as good as it used to be. There has been less personal contact, and much business is done on the phone."

"However, a few of the high volume customers send in people to certify quality standards in the plant, and they ask for some required changes."

"We look at valued customers' databases to monitor stock levels and plan production, based on the number of days or weeks that a replacement delivery is necessary."

"One valued high volume customer often makes us attend quality requirement meetings alongside four of our major competitors."

Supply chain practices in Company A were characterised by punitive rationalisation, single instance commercial contracts of supply and limited collaboration with competitors. Such practices fell short of the requirements of agile supply chains as discussed in Chapter 2.

Employee empowerment was limited in Company A even though case study data showed that workers were satisfied with pay, on the job training and career flexibility. Anybody could be trained for any new opportunities depending on their potentials and career preferences. However, a significant presence of top management control of routine operational processes and procedures was evident. For example, telephone calls to the CEO during the interview revealed that the CEO was asking customers to wait, an indication of limited delegation of routine decisions and actions. The CEO concurred that:

"Top managers are responsible for everything...."
"There is less flexibility at the floor level because operations take specific specifications."

5.3.4. OPERATIONAL FLEXIBILITY

The preceding discussion shows that machine set up costs and times were high and that daily frequent movement of employees across lines was the major means of responding to momentary orders. In effect, although employees were freely mobile across lines, workloads were not freely transferable due to full dedication of machines and equipment. Accordingly, the plant was deficient in alternative operations routes and sequences as a means of enhancing operational and volume flexibility. However, the company aspired for easier adjustment of production volumes to turbulent customer shifts even though it did not realise that ability to vary operations routes and sequences was crucial in that respect.

5.3.5. FUTURE PLANS

Company A plans to advance from cosmetic customisation to transparent customisation as a means of switching buyers' attention from marginally cheaper local and imported alternatives. The plans were underpinned by speedy delivery of leading edge product features such as smarter packages, tamper evident caps, simple open and close caps, comfortable handling for different consumers, and more intense customisation for large retail chains. Such innovations would target family tables and offer comfort to workers who use most of the washing/cleaning applications. Such product initiatives would be driven by customer preferences and margin considerations. To that end, the company planned to contract product design contractors, invest in flexible packaging technologies, improve on parallel product lines and replace mature products. In support of transparent customisation, Company A also planned to improve machine change over costs and capacity flexibility so that small orders could be profitable. In the words of the CEO:

"We *plan to engage* in *continuous evaluation of what we do and what the market needs.... "*

"Innovation will be market-led, ...but we intend to lead not necessary follow. "

The foregoing discussion reveals that agility enablers such as transparent customisation, technology integration, agile supply chains, intelligent automation and total employee empowerment were not significantly adopted. However, the afore-mentioned plans suggest that future change initiatives would be more positive towards the agility enablers.

5.3.6. SUMMARY

The preceding discussion provides the pointer that Company A faced a significant amount of market instability, which ought to make the agility enablers indispensable. Specifically, manufacturing automation was flexible rather than intelligent just as supply chain practices were more lean than agile. Likewise, employee empowerment and technology utilisation were limited rather than total and integrative. Furthermore, enhancements to product features focused on size and shape (cosmetic customisation) rather than technical functions (transparent customisation). Above all, product lines lacked the virtual character of porous boundaries. This is in terms of unhindered mobility of machines, manpower and workloads across dedicated lines as a means of flexing capacity and mastering horrendous demand.

In the light of limited adoption of agility enablers including the virtual cell concept, over the last five years, the company has not delivered significant positive changes on several competitive objectives and business performance measures.

5.4. SUMMARY REPORTS- COMPANY B

5.4.1. INTRODUCTION

Company B was a leading manufacturer of refrigerated cooling systems for vegetable crops storage. Its products were designed for lengthy box and bulk storage of potatoes, onions and vegetables as a means of keeping quality close to harvest condition. The company operated from two sites. The site studied had an annual turnover of over 2.5 million pounds and seventeen permanent employees most of whom are engineers and technicians. Recently, the company won two top awards for innovation.

5.4.2. COMPETITIVE SITUATION

The company competed against about half a dozen other manufacturers, but the market was most unstable. The CEO employed the "Cobweb Theorem" to explain the precise nature of instability. From year to year, farmers anticipated that preceding years' high or low prices would prevail and they rushed en-mass into or out of planting. Consequently, either too much or too little was always available for storage. Indeed, turnover in 2000 was about half the 1999 figures, but by May 2001, it had overshot year 2000 figures. In the face of this random fluctuation, the company has learnt never to be carried away by its booms.

"*We plan our house according to the lower end of anticipated sales turnover.*"

Besides the problem of farmers' speculative behaviour, high value of the pound constituted a major threat. Accordingly, over the years, sales turnover had reduced by 60 percent as foreign competitors harvested from a 20 percent price advantage even as export markets penetrated in the late 1980s had become inoperable. Nevertheless, the company reaped from environmental concerns and food education which made quality storage essential.

For enhanced value-added, assembly and installation at customer-sites was being replaced by complete in-plant fabrication, assembly and testing of products in different capacities and in own registered trade labels. These changes impacted positively on reliability and flexibility. Consequently, value-added to throughput, repeat orders, sales turnover, net profit and return to shareholders had increased significantly in the last five years.

5.4.3 ADOPTION OF AGILITY ENABLERS

Except for a semi-automatic band saw that was bought recently, machines were small-scale and general-purpose. They were arranged sequentially and used by specialist technicians to fabricate panels and assemble numerous small components. Separate but interdependent workbenches existed for cutting, shaping, filing, painting, imprinting, wiring, assembly and testing, each of which was operated by highly skilled engineers and technicians.

The company applied the principles of total quality management, continuous improvement and just in time to purchasing, scheduling and job execution. However, there was little use of tools such as MRP, MRPII, ERP and CAD/CAM systems. In order to enhance the efficiency of stocks and parts costing and control as well as job tracking and scheduling, a proprietary production management system, Job Boss, was purchased in early 2000. Although, the system was yet to impact significantly on operations, the company realised that such technologies were crucial to its growth efforts.

In consonance with TQM, JIT and continuous improvement principles, the company relied on team spirit amongst employees as a means of getting things done. Accordingly, it scored highly on scales measuring power of team members relative to team leaders, on the job training, free flow of knowledge amongst workers, individual responsibility for job completion and quality, implementation of suggestions and responsibility-based wages.

In addition, a weekly production control meeting specified the rolling production sequence over the next 2-3 weeks, based on site conditions, timetables and schedules already agreed with customers. The meeting was the strongest tool for co-ordination and communication on new and on-going contracts, progress and feedback. The Production Director argued:

"The process aims to maximise production capacity by manufacturing and despatching product at the most appropriate time both to meet our demands for maximum efficient production and the customers requirement of delivery as the site preparation is completed."

Most permanent employees were engineers and technicians with a diversified skill base. Hence, modest emphasis was placed on free flow of knowledge, individual responsibility for tools, methods and quality, implementation of suggestions, on the job training and responsibility-based compensation. However, social relations amongst employees and the proportion of working hours allocated to training were rather low. Employees' skills and co-operation accounted for flexibility in design, fabrication and assembly operations.

Company B nurtured customer and supplier confidence and rapport through several means such as e-mails, quarterly newsletter and web site Internet access. These were in addition to some advertising and editorials in specialist media and exhibition in national and international events. The company opined however that reaching out to suppliers and sales agents was much easier than reaching out to end users and customers.

As a means of strengthening supplier confidence, suppliers numbers were being rationalised. This is with a view to build a stronger relationship with a few as a means of shortening lead-times and improving delivery reliability and certainty. The company had no significant interaction with competitors but a few of the less prominent competitors were customers.

Company B was committed to leadership in the manufacture of fully packaged air-conditioning and energy-saving systems for crops storage. In this direction, emphasis was shifting from customer site to fully in-plant fabrication and assembly. This change aimed to maximise equipment and specialist skill utilisation, rather than holing up engineers and technicians in several project sites. Likewise, the company had started using and customising its own component labels as a means of enhancing value-added. Furthermore, stock control, parts costing, production planning, despatching and invoicing were being re-organised in support of the shift from a project-based system to a batch processing system.

Automation was minimal in Company B because operations were in small batches. However, the processes of metal cutting, painting and wiring were to be automated. According to the CEO, automation would evolve in the light of new emphasis on fully packaged factory built systems combining refrigerated cooling with ambient ventilation and air mixing. The overriding determinant of the level of automation will be:

"... T*ime saving and payback in relation to volume and employees' costs*."

5.4.4. OPERATIONAL FLEXIBILITY

Operations were project-based and in small batches. Therefore, automated technologies such as CNC machines, automated guided vehicles, automated storage and retrieval systems and automated quality control were not used. In addition, once skills were assigned to ongoing projects, they could not be recalled or reassigned as operations were conducted in the customers' sites. As machines and skills were always holed up at individual project sites, the virtual character of porous boundaries amongst lines, cells and projects as a determinant of operational flexibility was almost non-existent. Consequently, responsiveness to sporadic changes in demand and the ability to manufacture small and large volumes were limited.

However, the introduction of batch processing alongside project-based processing had created a pooling synergy across machines and manpower, the attendant benefit of which was significant ability to manufacture standardised and customised product models in parallel. This ability would be further enhanced when the repetitive processes of cutting, painting and wiring become automated.

5.4.5. FUTURE PLANS

On future plans, the verdicts were "*business as usual*" and "*there is no great master plan.*" Nevertheless, the CEO also stated that over the next five years, innovation will be underpinned by "*improved facilities for accurate production planning as well as time saving and payback in relation to volume and employees costs.*"

In addition, current changes towards fully in-built production of standardised and customised product solutions would continue. In support of this programme, customer and supplier confidence and involvement will be nurtured as a means of improving on product development and production cycle times.

5.4.6. SUMMARY

The foregoing discussion reveals that Company B competes in a market characterised by oscillation in customer demand. Surprisingly, the agility enablers were not significantly adopted. However, change initiatives towards the agility enablers were underway. Such initiatives included the change from project to batch processing as a way of creating pooling synergy amongst resources that were hitherto holed up on individual project sites.

In addition, supplier numbers were being rationalised prior to development of collaborative rather than commercial ties in support of the goal of leadership in the manufacture of fully packaged air-conditioning and energy-saving technologies for crops storage. In support of these goals, automation and further employee empowerment were being initiated

The changes being implemented especially in the area of energy-saving technologies for crops storage were in consonance with leadership in new technology products as a means of advancing competitive objectives and business performance. Accordingly, the company advanced simultaneously on a range of competitive objectives such as speed, leadership in new technology and superior quality of design. The attendant result had been positive changes in business performance measures such as sales turnover, net profit, customer loyalty, value-added to throughput and returns to owners.

5.5. SUMMARY REPORTS- COMPANY C

5.5.1. INTRODUCTION

Company C was a chemical and pharmaceutical products' manufacturer. It was part of a global conglomerate trading in more than 130 countries, with staff strength of over 57, 000 and sales turnover above £13 billion. The site visited had an average annual sales turnover of about 320 million pounds and a workforce of 550. The plant made fifteen basic products mainly tablets, reconstituted granules, capsules and chemicals in about fifty different formulations. Seventy five percent of turnover was export.

5.5.2. COMPETITIVE SITUATION

Company C competed in an intensely competitive and unstable market. Although, it benefited from advances in manufacturing technology as well as speedy introduction and customisation of products, competition from foreign products, high value of the pound, sudden customer shifts and strict institutional regulations constitute major threats. The threats were strongest after sudden launching of new and perhaps cheaper health solutions with fewer side effects. Indeed, the company's share in some market niches often oscillated between ten and ninety percent. However, the principal informant opined that:

"Fortunately, on average, we have been on the winning side rather than the losing side"

Other causes of market instability included medical discoveries and changes in regulatory requirements. For these reasons, about two years ago, a life-saving capsule had to be withdrawn and more batches of an alternative liquid formulation were introduced to service the capsule market. Yet, the requirements of specific markets, Good Manufacturing Practice, Good Laboratory Practice (GMP/GLP), and regulatory authorities such as the Medical Control Agency had to be met. A principal informant who was involved in the "capsule crisis" remarked that due mainly to capacity inflexibility, it was a tough time and that several lessons were learnt.

"Lessons learnt include the need for more extensive physical characterisation work on drug molecules during early development, appointment of "product champions" in the Technical Support Department, and a flexible manufacturing chain, which can increase production at a moment's notice."

In response to competitive pressures, quality conformance and service were deemed as "given" and "non-negotiable", just as price, speedy delivery and product innovation were crucial. However, swift response to large order volumes during epidemics and prompt compliance with scientific breakthroughs and regulatory controls created the greatest challenges. Recent innovations included detailed user-information and single dose blister packs, such that an initial dose could be dispensed at the point of prescription whilst mid-day doses could be pocketed to work. In addition, just in time had been introduced as a means of keeping in constant tune with emerging regulatory, competitive and scientific pressures. Accordingly, logos, labels, colours and inactive material ingredients of expected major customers were kept as customised stocks. Because of several innovations aimed at enhancing speedy response, sales, net profit, market share, value-added to throughput, asset utilisation and expansion prospects had increased over the last five years

5.5.3. ADOPTION OF AGILITY ENABLERS

The factory consisted of several product line families dedicated to a family of related tablets and reconstituted granules. The lines operated as standalone workstations integrated into flow lines. The lines were made up of several independent machines connected by flow pipes for moving in-process materials. The range of skills required within each line was high even as the proportion of output fully processed on a line was significantly low.

The tablet lines were connected by flow pipes, which terminated on the tablet compression machine where tablets were collected manually and delivered to the coating section, and thereafter to the packaging section.

Manufacturing automation was significant. It was characterised by the use of computer-integrated CNC machines, computer-aided process planning and automated quality control.

Some other features of the manufacturing system were:

a. A quality control department vested with overall responsibility for quality.
b. A complex system of Finishing Work Order Documentation Records. Indeed, "up to eleven hundred signatures were inputted for a line cycle." The records enhanced forward and backward tracking of lots for quality assurance.
c. Release of products was contingent on certification by qualified personnel after the quality department had verified all documentation records.
d. The use of key-on, key-off computerised control panels to monitor quality and safety. In the tablet compression and punching processes, the system reported tablet force information every two hours.
e. The use of a camera system in the packaging lines, which detected and rejected blisters and other packages containing missing and under-counted tablets.
f. Examination of in process tablet samples every fifteen minutes.

The list above shows that quality verification processes were significantly automated with a view to lower cost and boost high volume patronage. In addition, packaging was fully automated with a view to enhance operational flexibility. The packaging system could be pre-set and gauged to work on a wide range of sizes of blisters, sachets, tins and cans.

The company also placed tremendous emphasis on demand planning and control, which it emphasised in several ways including the following.

a. Firm forecasts three months ahead of scheduling production.
b. Dedicated staffs in charge of demand management for specific products.

c. Formal arrangement for forecast demand. The SAS BPCS software was bought in 1992, but it was still being modified to comply with regulatory requirements.
d. The use of a computerised Conformance Measures Status Chart. The chart measured data accuracy, quality of planning and quality of execution for twenty-two items including inventory, bill of material, forecasts, routing, lead-times and purchases.
e. A modest amount of contingency stocks in anticipation of winter disasters.
f. A large stock of materials, mainly cartons and papers pre-printed in different logos, colours and languages of major customers worldwide.

Towards operational flexibility, employees were considered as the most crucial asset. Plant operators and technicians were trained in multiple skills, motivated for teamwork and empowered to handle several support jobs that had been transferred to the lines. Worker empowerment was also manifest in employee suggestion schemes, reward for successful project completion, performance-based pay, ownership through shareholding, and career stability. Nevertheless, a destructive distinction existed between "direct" and "indirect" workers, which potentially threatened team spirit. A principal informant and Manufacturing Engineering Manager made a casual reference to this threat, which he dismissed as an "emerging problem" for the accountant to solve. However, he queried:

"Who is direct and indirect? Everybody has become an indirect employee because plant operators themselves only feed and take from machines."

Supply chain practices as a means of enhancing attainment of competitive objectives were characterised by electronic enquiries, open competitive tendering, long-term contracts, long delivery lead times and limited collaboration in design and manufacture. However, in order to facilitate the development of collaborative ties, approved supplier status had been introduced as a means of rationalising supplier numbers based on several criteria such as volume, cost, lead-time and dependability. Company C had no special relationship with customers. However, a few highly valued customers including foreign governments and pharmaceutical companies in the UK were often pressurised to be pro-active in their order requirements. However, there was a wide range of customer-focused initiatives, which manifested in the following extracts from interview transcripts.

a. "Creation of a new Healthcare Development Team"
b. "Establishment of a new Communication department, which is to ensure that the company is more closely aligned with the changing NHS".

c. *"Creation of two specialist business units for dedicated sales and marketing in new franchises".*
d. *Appointment of an administrator to manage demand for named patent supplies of a recently launched new chemical entity in the field of HIV.*

Company C's competitors consisted of other factories within the global conglomerate as well as foreign plants mainly in France and Italy. Direct relationship with either category of competitors was limited, except that one subsidiary of the global conglomerate, which markets pharmaceuticals in the UK, was a major customer. An informant argued that:

"We do occasionally share information but there is mutual suspicion and supplier missing information... However, global initiative to reduce cost is forcing some co-operation with some other laboratories in the purchase of materials."

The company under study was committed to introducing advanced formulations ahead of competitors and protecting them with patents. In order to earn prolonged patents, new product features were paced and introduced. In addition, packages and blisters were customised for patient-convenience rather than for attraction or buyers' purchasing power.

The company also tendered some generic and cheaper formulations for lower income customers worldwide. However, profit margins were lowered in such markets rather than bartering quality for lower prices.

5.5.4. OPERATIONAL FLEXIBILITY

In addition to rapid introduction of advanced formulations ahead of competitors, there was significant emphasis on routing, operational and capacity flexibility within the limits of regulatory controls such as total batch segregation. Innovations in this regard included introduction of more parallel lines, contingency stocks, global initiatives with competitors in the purchase of materials, expansion of sales force, and inter-line movement of employees. Indeed, full-scale re-partitioning and relocation of machines with a view to enhance inter-line capacity flexibility as a determinant of timely response to momentary fluctuations in order volumes were on going at the time of this study.

In addition, several processes such as granulation, drying, blending, compression and coating were run in small lots, with varying degrees of machine duplication. This was in order to enable process flexibility, which was considered crucial to effective operations.

Nevertheless, potentials in this regard were restricted by the regulatory requirement of total batch segregation, which prohibited mixed lots and inter-line movement of machines and in-process materials. In addition, flexibility was limited by extreme variances in operations cycle times from twenty-four hours to fifteen minutes.

In order to garner speed and operational flexibility, complete off-line retooling kits had been introduced, with the attendant benefits of reduced machine set up times as well as enhanced ability to manufacture small batches of related custom orders in parallel and profitably. According to a principal informant:

"We use job sequencing to minimise machine changeovers, ... and complete changeovers, which took between twenty- four to thirty hours have been replaced by complete off-line re-tooling sets."

Moreover, a fully automated packaging system had been installed to further enhance flexibility. The system could be pre-set and gauged to work on a wide range of sizes of blisters, sachets, tins and cans. It had the ability to count and position tablets into blisters and tins, place tablets into cartons, seal and imprint. Furthermore, a three-tier system of writing and approving packaging specifications had been introduced to facilitate and speed up the packaging process. Packaging information given to suppliers consisted of baseline general requirements, a carton specification, and a text specification of exact market requirements. The tiered system eliminated repetitive information, quickened instigation of changing information, and enhanced tracking of a large inventory of packaging materials.

5.5.5. FUTURE PLANS

The company aspired to become more responsive and win more orders in the next few years. However, it had no master plan except significant emphasis on:

"Robustness and reliability of planning and delivery systems... and stable forecasts"

In addition, plans were underway to conduct financial and technical feasibility tests of some currently unavailable technologies, which were considered invaluable in optimising existing processes and creating patent advantage. Such technologies included tablet simulators, pilot-manufacturing equipment, and on-line analytic equipment capable of measuring the physical nature of material, predict manufacturability and cut down on processing times. Some other technologies to be introduced include tools and methods for containment of very potent products. This was in order to protect operators, maintain batch integrity, and minimise the needs for disposal and decontamination following manufacture.

Furthermore, the company planned to involve and commit suppliers, customers, competitors and regulatory authorities to long-term collaboration. The goal was to reduce lead times and material stocks, improve real time response to enquiries and emergencies, and share emerging knowledge on medical and pharmaceutical science and practice.

Above all, there were plans to improve understanding between technical staff and manufacturing staff as a means of enhancing team spirit and cross-functional integration. To this end, "Away days" for engineering and manufacturing staff had been introduced and would be extended to other departments if successful. A Principal informant explained a recent problem caused by limited integration amongst functional departments.

"One of the company's products faced manufacturing/ regulatory obstacles, which resulted in all patients being switched to a less patient friendly formulation... and refocusing sales force effort from developing new patient initiatives to managing patient retention initiatives."

The plans specified in the preceding paragraphs centred on the use of advanced technologies, supply chain re-design and cross-functional integration as a means of realising leading-edge product solutions for niche and mass markets.

5.5.6. SUMARY

The preceding discussion revealed that Company C competed in a market characterised by intense competition and instability. In the circumstance, significant investment went into speedy development of leading products, which were protected with patents. In addition, a high level of operational flexibility was achieved through machine duplication, flexible packaging, mixed lots and some inter-line movement of machines and in-process materials.

In addition, a significant level of automation was discernible. Although automation was more flexible than intelligent, equipment set up time and cost which was the bane of flexible automation had been reduced appreciably due to the use of off-line retooling kits. Nevertheless, plans for more automated technologies supportive to leading products and patent advantage were underway. Such technologies include tablet simulators, pilot-manufacturing equipment and on-line analytic equipment capable of measuring the physical nature of material, predict manufacturability and cut down on processing times.

Furthermore, considerable attention had been paid to cross-functional integration and supply chain re-engineering. Such efforts included reward for successful project completion, performance-based pay, ownership through shareholding, and establishment of a new communication department to ensure that the company was more closely aligned with the changing needs of customers.

Several of the changes being introduced such as co-operation with competitors in sourcing cheaper inputs, investment in new technologies for containment of very potent materials as well as inter-line flexibility match up with some of the agility enablers. Subsequent to the adoption of practices that strongly match up with the agility enablers, company C delivered on several competitive objectives such as leadership in new technology, swift response to changes in demand, product customisation, and quality conformance. Consequently, over the last five years, business performance measures such as value-added to throughput, fixed asset utilisation, process and product innovation, and growth and expansion prospects changed positively.

5.6. SUMMARY REPORTS- COMPANY D

5.6.1. INTRODUCTION

Company D manufactured specialist medical utilities such as electro-surgical equipment, operating tables, autoclaves and pumps. The products were in over 180 models, all manufactured to stock. Operations were in low volumes and consisted of manual assembly of hundreds of components into life equipment used by hospitals and surgical laboratories. The leading model was launched in 1991 and it currently accounted for ten percent of sales. Annual sales turnover was about £18 million pounds whilst employee strength was 230. Major customers were NHS Trusts and independent distributors around the world.

5.6.2. COMPETITIVE SITUATION

The market is intensely competitive and inherently unstable. However, the company benefited significantly from rapid changes in manufacturing and information technologies.

On the other hand, unanticipated breakthroughs in medical and surgical science, competition from foreign products, rising value of the pound, sudden customer shifts, and oscillations in medical equipment budgets threaten stability and survival. Three principal informants revealed vividly the exact picture of product and market instability as follows:

"Our products are complex and not easy to quickly speed up the supply chain... Sales forecasting is an art in the turbulent medical capital equipment market."

"Demand pattern is horrendous, and consists of unpredictable peaks. Last year, it was near nothing. Crisis and government policies determine funds allocation.... It is not a commodity market as such."

"Our major competitors started to attack our domestic market... and some were successful. Our market share fell from over 70 percent as it had been for more than half a century to about 30 percent today."

In response to intense competitive pressures and market instability, the company had extended the product range with more advanced products whilst offering better after sales service and superior design quality. However, several operational and new product initiatives suffered and failed because of limited integration across functions and work processes. Consequently, attainment of competitive objectives such as leadership in new technology, swift response to demand surges, speed and product customisation were rather low. In return, over the last five years, there had been a pointed decrease in business performance measures even though growth and expansion prospects were high.

5.6.3. ADOPTION OF AGILITY ENABLERS

The factory was organised as mini-factories in which about 8,000 bought-in active parts and components were independently assembled and tested. The operating tables unit was run as a job shop. Typically, each item of equipment was fully assembled by a single operator working on a single bench. The process took about forty hours per item. The units of equipment were thereafter moved for testing, which also took about thirteen hours. The electro-surgical assembly unit was in contrast run as a low volume batch process, with operations terminating in an off-line assembly and testing unit.

In addition to its assembly operations, Company D repaired and serviced products already sold to customers. Each product line had a separate service unit for this purpose. The company recognised that the present product-focused arrangement restricted optimal resource utilisation, pooling synergy and operational flexibility. Accordingly, the virtual cell concept of porous boundaries across product lines as a way of flexing capacity and mastering horrendous changes in demand was absent. However, in order to enable resource sharing and cross-functional integration as a means of enhancing competitive performance, operations were being redesigned as process-oriented cells headed by team leaders.

Besides the absence of porous boundaries between product lines, operations were largely manual and devoid of any significant level or type of automation. According to a principal informant, automation was minimal because:

"The products are complex and cannot easily be automated to a high degree"

The aforementioned extract revealed that automation was understood in terms of repetitive automation of simple and routine processes, rather than flexible or intelligent automation of complex processes. However, the low volume of production also explained limited automation. Further questioning revealed that certain processes would be automated appreciably after current efforts to simplify product design and assembly through "kit component parts" have yielded significant results. In addition, automated storage and picking systems were to be introduced in order to reduce space limitations. Furthermore, in-house automated production of printed circuit boards (PCB) was being evaluated for cost effective in-house manufacture as an alternative to outsourcing. If eventually implemented, in-house manufacture of PCB and a few critical component parts would enhance value-added to throughput.

The company scored highly on empowerment, as employees were highly educated and skilled. However, employees' potentials were restricted by limited team disposition, which was caused by a compartmentalised structure, within which several round pegs occupied square holes. For instance, an accountant headed manufacturing until recently. In addition, material stores were decentralised on product basis, poorly organised and documented whilst overall authority for stores rested in the head of personnel. The interviews revealed mutual suspicion, lack of trust, limited functional integration and a culture of "we" and "them". The "we" and "them" culture showed in some responses by a key marketing staff.

"...This forces us to give them a clearer and more accurate picture of what is wanted and to justify our demands. They in turn have to show that their design meets our specification every step of the way."

In addition to absence of porous boundaries, limited automation and limited internal integration, supply chain practices with suppliers, customers and competitors were miserable. The company had about seven major competitors in the UK and several others in Europe but there was no direct relationship in any form. The same applied to major customers who were independent distributors around the world and NHS Trusts in the UK, the latter being the single most valued customer. However, a three to four months' theatre demonstration of new products ahead of launching as well as visits to theatre by engineers to observe the workings and functioning of new equipment were often undertaken. A close relationship with the NHS was considered invaluable but in its absence, NHS databases were remotely accessed to monitor contracts available as well as quality and bidding specifications. On the NHS as the most valued customer, a principal informant stated that:

"Considering the changes made by government policy, we have seen more bureaucracy and a loss of personal relationships."

Operations were also devoid of any significant relationship with suppliers. This was in the light of a total supplier base of about seven hundred out of which between thirty and forty were major suppliers. However, ongoing programmes aimed at refocusing on a few number of new products, rationalisation and simplification of components through kit parts, and lead-time reduction were compelling a review of supplier relationships. Accordingly, supplier numbers were being rationalised and new agreements entered into, in line with new product development initiatives. Furthermore, a Direct Alliance Scheme under which quality assurance personnel will visit and monitor implementation of specifications in major supplier companies was being planned.

The following extracts from the responses of a principal informant revealed the need for new supply chain initiatives as a means of improving design quality and lead times.

"Recently, two major projects ran out of control partly due to software design problems with sub-contractors."

"Suppliers ask for long lead times and rarely comply with agreed dates"

"Volatility in the supply of off the shelf items, typically electronic components now requires continual monitoring and a willingness to make strategic purchasing decisions at short notice and beyond normal stock cover levels."

The principal informant also added that:

"Emphasis on a better quality of suppliers limits options and leads to a greater concentration on Grade1 core suppliers who in turn now demand better and closer support."

The preceding extracts provided the evidence that stronger ties with suppliers were desirable but the demand by Grade 1 core suppliers for better and closer support needed to be understood within the context of its potential benefits for all stakeholders. If properly managed, the demand could lead to closer collaboration up and down the supply chain.

5.6.4. OPERATIONAL FLEXIBILITY

In the preceding section, it was reported that two major product lines that accounted for a significant proportion of sales turnover were run independent of one another. One was run as a job shop whilst the other operated as a low volume batch process. Each of the product lines had its own stocks and inventory reporting system. This is in addition to independent service and repair units for products already sold out to customers.

Workstations were run as standalone units with tools and fixtures completely dedicated. There were no movement of workers or work in progress across product lines even as within the product lines, no pivotal machines or operations processes were duplicated. As a result, opportunities for resource sharing and pooling synergy as a means of enhancing operational flexibility, which is indispensable in flexing inter-line capacity and mastering momentary changes in order size requirements were absent.

In the light of limited internal integration and resource sharing across units and product lines, attainment of competitive objectives such as product customisation, volume flexibility and leadership in new technology products was low. Consequently, in the last five years, there had been a negative change in performance measures including sales turnover, net profit, market share, customer loyalty, fixed asset utilisation and performance against competitors. However, sharp increases in growth and expansion prospects were manifest, but their sustainability would depend on the success of new product initiatives.

5.6.5. FUTURE PLANS

The company aimed to become more responsive and customer driven in order to win more orders and survive the next few years. To this end, change initiatives include development of a new generation of leading technology products, supply chain networking, a change from product-based to process-based assembly system, automated PCB manufacturing and cross-functional integration. According to the principal informant, the change initiatives were being packaged as a "clean slate approach" and the overriding aim was to:

"Get the product right."
"Introduce a new generation of products."

The following extracts from the responses of three different informants also lend credence to "a fresh start" or "a clean slate approach."

"A crash programme of new product development is crucial to the company's survival."

"Future product development efforts will be customer-led and continuous research into our customers' changing requirements will be emphasised to enable us to keep our product range up to date."

"Having completed the current catch up programme, we will pursue a rolling programme of innovation to put us in the lead."

"In addition, we will seek more first hand experience of major European markets... This is where our major competition and future innovation will originate, not just for Europe but for the rest of the world."

Some elements of the rolling programme of innovation as expatiated in the transcripts of qualitative questionnaires and interview responses include the following.

a. *Purchase of low cost prototyping, self-documenting and explicit hardware/ software product development process tools.*

b. *Rationalisation of 80 percent of products within three years as part of a focused strategy for new product development underpinned by better marketing information.*

c. *Better configuration for all products through a change to modular kit parts, with a view to simplify products, assembly, testing, and disassembly for service.*

d. *Better knowledge-capture and improved access to design intent and design history.*

e. *A re-organisation underpinned by job specialisation.*

f. *Greater use of IT including greater Internet and Intranet capabilities in order to drive requirements processes in internal and external operations.*

g. *Automation of testing operations, which at present takes up to thirteen hours.*

The motivation and commitment of senior managers to the plans were overt and manifest:

"An e-mail system of trench warfare has been replaced by team work."
"We now talk to each other."
"Changes in the marketing and product design teams have led to a new spirit of communication and co-operation which is generating some exciting new products which, I am convinced, will enable us to win back market share."

5.6.6. SUMMARY

The foregoing report revealed that Company D competed in an unstable market where change drivers such as competition from foreign products, high value of the pound, new products and sudden customer shifts took pre-eminence. However, there was the evidence that innovative changes were not devised timely enough, which accounted for a pointed decrease in attainment of competitive objectives and business performance measures.

However, new change initiatives were being commissioned towards the development of a new generation of leading technology products. The change initiatives included job professionalisation, internal integration, process-based manufacturing, collaboration with Grade 1 suppliers, and more use of Internet and intranet technologies. The proposed changes match up to the agility enablers discussed and identified in sections 2.4 and 4.6.3. If implemented, they have the potential to reverse the company's dwindling fortunes.

The foregoing sections 5.3.1 to 5.6.6 offered a case-by-case summary report on the four companies studied. The reports were based on data extracted from quantitative and qualitative questionnaires completed by informants as well as follow up interviews held with them by the researcher. The reports provided the evidence that change drivers impacted on competitive and business performance objectives. The overall impact of the change drivers however depended on the degree to which the operational characteristics of manufacturing systems tallied with the agility enablers identified in sections 2.4 and 4.6.3.

Two companies, B and C returned an overall positive change in business performance in the last five years. The two companies were unified by new product initiatives, competition in both mass and custom markets, and a significant level of operational and volume flexibility underpinned by resource sharing and pooling synergy across product lines and work units. This is in addition to a high level of employee empowerment, reliance on peer consensus rather than formal authority, internal integration and networking with customers, suppliers and competitors. Accordingly, Companies B and C were high performers.

In contrast, Companies A and D were unified by limited product initiatives, inability to compete in both mass and custom markets, and inadequate operational and volume flexibility, which inhibited resource sharing and pooling synergy across product lines. In addition, employee empowerment was limited especially in Company A, where it was characterised by significant use of superior authority rather than peer consensus. Furthermore, internal and supply chain integration was almost inexistent in Company D. Accordingly, Companies A and D were low performers. However, change initiatives similar to those of the high performers were already being conceived.

The change initiatives already implemented by the high performers and those being newly conjured up by the low performers reckoned with agile manufacturing enablers of competitive advantage as identified in chapters 2 and 4. The next section reports common threads amongst the companies. They were identified and used to test research hypotheses.

5.7. COMMON THREADS ACROSS COMPANIES

This section identifies and discusses common themes across the four companies studied. The themes identified relate to the concepts of change drivers, agility enablers, competitive objectives, volume flexibility, and business performance. Significant relationships amongst the themes were used to test the validity of research hypotheses.

5.7.1. CHANGE DRIVERS COMPEL AGILE MANUFACTURING

Eleven change drivers were studied for their impacts on manufacturing operations. Eight of the change drivers provided a handy starting point for making inferences because each of them clustered the four companies into two extreme positions namely most harmful and most helpful. A change driver is most harmful if its impact is negative. In contrast, a change driver is helpful if its perturbing influence had been mastered and made positive.

Four of the eight change drivers were identified as most harmful. They were competition from foreign products, high value of the pound, unanticipated customer shifts and EU directives. The other four change drivers were identified as most helpful. They were advances in IT, advances in manufacturing technology, speedy introduction of new products and the intensity of product customisation.

The following extracts from qualitative responses confirmed that manufacturing operations and performance outcomes were significantly affected by the change drivers.

"The market is turbulent and comprises about half a dozen important players." "The Cobweb Theorem best explains the impact of farmers' speculative behaviour on our operations ..." "We plan our house according to the lower end of anticipated sales turnover." "Over the next five years, improved facility to plan production accurately will be the key to winning orders and maintaining market share in an increasingly competitive environment." [Company B]

"The market is intensely competitive and turbulent..." "Robustness and reliability of planning and delivery systems... and stable forecasts." "Fortunately, on the average, we have been on the winning side rather than the losing side." [Company C]

... *"Sales forecasting is an art in the turbulent medical capital equipment market." "Demand pattern is horrendous, and consists of unpredictable peaks. Last year, it was near nothing..." "Our major competitors started to attack our domestic market... Our market share fell from over 70 percent as it had been for more than half a century to about 30 percent today."* [Company D]

Two important inferences emanate from the data above. First, it is tenable that the benefits attributed to advances in information and manufacturing technologies accrued through time compression and enhanced mass customisation. However, in as much as the plants reported that competition from foreign products remained most harmful whilst increasing emphasis on mass customisation was most helpful, it is arguable that mass customisation was cosmetic rather than transparent. This means that products were not significantly customised based on unique technical functionality as different from cosmetic or aesthetics, visual appeal, packaging and appearance. Accordingly, the plants studied were yet to maximise the potentials of advanced technology as a means of delivering smarter and transparently customised products by which they could ward off foreign competition irrespective of the high value of the pound. This scenario however applied less to Companies B and C who were high performers. To them, increasing emphasis on product customisation was most helpful whilst competition from foreign products was not significantly harmful. This suggests that Companies B and C were more successful because they were better users of advanced technologies as a means of realising smarter and transparently customised products and warding off foreign competition.

The second inference is that change drivers such as sudden customer shifts remained highly destructive due to inadequate resource sharing and pooling synergy across product lines and cells as a means of enhancing operational and capacity flexibility. Therefore, in the light of the trade-off identified earlier in chapter 4 between leadership in new technology and volume flexibility, it is conceivable that enhanced competitiveness of UK companies is contingent on the ability to master sporadic changes in demand. It is also remarkable that as a means of enhancing operational and capacity flexibility, Companies B and C who were high performers had a higher level of resource sharing and pooling synergy across product lines. The two companies therefore had a greater ability to re-route operations, balance workload across lines, manufacture standard and customised products in parallel, and respond swiftly to surges in demand without significant cost penalties.

In the light of the foregoing, it can be stated that Companies B and C were high performers because they were more conscious of the harmful impacts of the change drivers and had put in place a manufacturing system that mimic the agility enablers. In essence, Hypothesis 1, which argued that the impact of change drivers on business performance objectives justified agile manufacturing design, is valid. In addition, the proposition in Hypothesis 5 that virtual cells enhance operational flexibility, which in turn determines attainment of volume flexibility as a competitive objective, is valid. This is a sequel to a higher level of resource sharing and pooling synergy across lines and cells in Companies B and C, which accounted for greater ability to re-route operations at minimal cost, balance workloads across lines and respond swiftly to surges in demand.

5.7.2. RELATIONSHIP BETWEEN AGILITY AND PERFORMANCE

This study defined agility earlier in chapter 2 as simultaneous attainment of a wide range of competitive objectives. It was in order to test the relationship between agility as defined above and business performance that Hypothesis 2 was proposed. Although some results in chapter 4 already validated Hypothesis 2, the case studies also set to retest the validity of the relationship between agility and business performance.

The case studies collected data on companies' current attainments and future aspirations on twenty competitive objectives. Fourteen out of the twenty competitive objectives provided a functional basis for making inferences because of similarities in the responses by companies. The companies indicated that the levels of current attainment of five out of the fourteen competitive objectives were high whilst, in contrast, future aspirations for all the fourteen competitive objectives were high.

Out of the five competitive objectives over which companies returned high scores on current attainment, Companies B and C were identified with between three and four while in contrast, Companies A and D were identified with only two. A wider range of high scores on current attainment of competitive objectives by Companies B and C means that they delivered simultaneously on a wider range of competitive objectives than Companies A and D. Accordingly, Companies B and C were high performers. In order to advance business performance even further, more agility in terms of simultaneous attainment of competitive objectives is desirable.

Even as companies aspired for simultaneous attainment of competitive objectives, case study data showed that volume flexibility was least recognised and pursued as a competitive objective. Attainment of volume flexibility was measure by four scales in the case studies. The four scales were stable unit cost for all batch sizes, competition in mass and custom markets, ability to supply any quantities of orders and swift response to demand fluctuations. Companies' current attainments and future aspirations on three out of the four scales were not significantly high. This finding is important in the light of the position taken in chapter 2 that volume flexibility is invaluable in decoupling cost and lot sizes so that small and large volumes are equally competitive and profitable.

The following sections 5.7.3 to 5.7.7 report the basic features of manufacturing systems of the companies studied. This is as a means of enhancing simultaneous attainment of competitive objectives including volume flexibility, product customisation and leadership in new technology. The aim is to identify elements of the agility enablers contained in the four manufacturing systems studied and explore what differences they make towards attainment of competitive and business performance objectives. The report also investigates the hypothesis that virtual cells influence operational and volume flexibility.

5.7.3. ADOPTION AND IMPACT OF AGILITY ENABLERS

The quantitative questionnaire employed 101 scales to study the basic features of manufacturing systems. Appendix 2 reports the scales in four sections namely system design, supply chains, manufacturing technology and organisational empowerment. The quantitative scales were invaluable in exploring system characteristics far and beyond the reach of verbal responses, in-plant observations and historical records.

Out of the 101 scales, 48 were used in the analysis. This is because the pattern of responses to them revealed significant similarities and differences amongst scales as well as companies. Related scales having a distinct cluster of at least two companies either on the high or low end of ranked scores were recognized and used as templates to identify manufacturing system characteristics relative to the agility enablers. The process revealed that automation was more flexible than intelligent and that employee empowerment was limited rather than total. As well, product lines and cells were more dedicated than virtual, a few technologies were used instead of many, and supply chains were leaner than agile.

The basic features identified fell short of the agility enablers but some exceptions were noted for Companies B and C, which perhaps explained their superior attainment of competitive and business performance objectives. The following sections discuss the manufacturing system of the four companies studied relative to the agility enablers as determinants of competitive advantage.

5.7.4. AUTOMATION AND TECHNOLOGY

The data from case studies revealed the prevalence of flexible automation as against intelligent automation. Automation was not intelligent because companies did not significantly apply intelligent machines with considerable amount of computing power. Albeit, high scores by companies on machine and equipment changeovers as well as standalone workstations operating independently meant that mass automation was out.

Just as automation fell short of the agile manufacturing prerequisite of intelligent automation, technology utilisation fell short of the requirement that companies embrace a wide range of information and manufacturing technologies. Most popular amongst the companies were technologies such as JIT, TQM and continuous improvement. In contrast, technologies such as CNC, CAD, CAM, AGVs, ASRS and robots were not prominent.

The following extracts confirm the nature of automation and technology in the companies.

"There is nothing really high tech in all that we do…." [Company A]

"… There is no elaborate use of high technology machines… design, fabrication and assembly flexibility derives from employees' skills and co-operation
"We only produce small batches, so benefits (of automation) are limited."
"Time saving and payback in relation to volume and employees' costs." [Company B]

"We use job sequencing in order to minimise machine changeovers, … and complete changeovers, which took between twenty- four to thirty hours have been replaced by complete off-line re-tooling sets." [Company C]

"Recently, two major projects ran out of control partly due to software design problems"
"Products are complex and cannot easily be automated to a high degree" [Company D]

The extracts also differentiated Companies A and C from Companies B and D. Packaging was fully automated and flexible in Companies A and C whilst Companies B and D opined that the level and nature of operations did not recommend significant automation. Company C was further distinguished by the use of computer integrated CNC machines, computer-aided process planning and automated process control of quality, TQM, JIT and continuous improvement. The use of more technologies and a higher degree of automation by Company C accounted for simultaneous attainment of competitive and business performance objectives. Company C outperformed the other companies on superior quality of design, higher quality conformance, leadership in new technology, swift response to demand changes, and product customisation. Accordingly, over the last five years, Company C did not experience negative change in all measures of business performance studied. Instead, it was distinguished by a sharp increase in value-added to throughput, fixed asset utilisation, product/ process innovation, and growth/ expansion prospects.

In order to further advance business performance, Company C was set to introduce new technologies such as tablet simulators, pilot-manufacturing equipment, and on-line analytic equipment as a means of cutting down on processing times, predicting manufacturability and creating patent advantage. The lower volume of operations in the other companies perhaps restricted the degree of freedom in applying automation and technology. However, enhanced access to automated technologies by large-scale companies does not solely determine attainment of competitive and business performance objectives (Ahmed, 1996).

5.7.5. EMPLOYEE EMPOWERMENT

Twenty-five scales were used to gather quantitative data on the degree of employee empowerment in the companies studied. Eleven of the scales were retained for further analysis because the pattern of responses provided a valuable basis for drawing conclusions. The responses revealed that limited empowerment was prevalent as different from team-based empowerment, training-based empowerment and total empowerment.

The companies emphasised professional skills, on the job training and safeguards against exposures and accidents. The prominence of professional skills is logical given the advantage of a world-class education industry in the UK and the need to use novel skills and craftsmanship to make products smarter and ward off competition. Professionals were therefore taken through continuous programmes of on the job training.

Nonetheless, the importance attached to peer consensus relative to superior authority, team based structures, free flow of knowledge and operators' influences over routine decisions was insignificant. In addition, the powers of team members relative to team leaders and the proportion of working hours allocated to training were rather low.

In the circumstance, operational efficiency and flexibility suffered due to limited initiatives from frontline workers, absence of peer consensus as a tool for mobilisation, co-operation and commitment were limited.

The following qualitative data further revealed the nature of employee empowerment.

"We ... indeed move people around endlessly over twelve hours per day..."
"There is less flexibility at the floor level because operations take specific specifications."
"Top managers are responsible for everything...." [Company A]

"A weekly production control meeting specified the rolling production sequence..."
"Employees' skills and co-operation accounted for flexibility..." [Company B]

"Up to eleven hundred signatures were inputted for a line cycle."
"Who is direct and indirect? Everybody has become an indirect employee."
"Away days for engineering and manufacturing staff had been introduced and would..."
"Appointment of product champions in the technical support department" [Company C]

"... We give them a clearer and more accurate picture of what is wanted..."
"They in turn have to show that their design meets our specification every step of the way."
"An e-mail system of trench warfare..." [Company D]

In Company A, employees were moved around endlessly even as operations processes were standardised and top managers were responsible for everything. In Company B, top management was less visible and a weekly production meeting was pivotal. In Company C as well, several signatures were imputed into a line cycle as a means of tracking decisions and action taken in a plant where employees appeared to be polarised into direct and indirect. Finally, "we and them" and trench warfare were evident between marketing and manufacturing in Company D.

Significant emphasis placed on training whilst centralising authority at the top suggests that training emphasised mastery of standard processes from which employees must not deviate. As well, limited emphasis on teaming can derive from the British culture of individualism, personal freedom and limited interest in the affairs of third parties. As well, compliance with legislations, damage to machines and compensation claims explain the emphasis placed on safeguards against exposures and accidents by companies.

However, Company B was noted for high power of team members relative to team leaders even as the culture of individualism, personal freedom and limited interest in third party affairs suggests otherwise. This distinction contributed to the success of Company B who over the last five years had witnessed sharp increases in sales turnover, net profit, customer loyalty, value-added to throughput and returns to the owners of the business.

In the light of these results, more empowerment is desirable as a means of dignifying and tooling frontline employees to face the challenge of unprecedented market instability.

5.7.6. SUPPLY CHAIN PRACTICES

Supply chain practices were measured on twenty-six scales, fourteen of which provided a rational basis for reaching conclusions. Two dimensions of supply chain practices were identified from the quantitative data. The first dimension consisted of practices that were significantly emphasised by the companies studied. They were suppliers' involvement in continuous improvement, suppliers' involvement in new product introduction, long-term contractual relationships with suppliers, lead-time compression and JIT deliveries. This set of practices mimic those that defined the lean supply chain in Sections 2.6.1 and 4.6.2.

The second dimension of supply chain involves practices that received little attention from the companies studied. They were investment in supplier companies, joint bidding for contracts, subcontracting to competitors, sharing of plant facilities, risk sharing with suppliers and customers, supply chain information networking and knowledge sharing with competitors on design and manufacture. These less than prominent practices were interpreted as agile supply chains in Sections 2.6.1 and 4.6.2. In essence, supply chain practices were leaner than agile.

The following qualitative responses also revealed the nature of supply chain practices.

"*We look at valued customers' databases to monitor stock levels and plan production...*"
"*One valued high volume customer often makes us to attend quality requirement meetings alongside four of our major competitors.*"
"*However, a few of the high volume customers send in people to certify quality standards in the plant, and they ask for some required changes.*" [Company A]

"*...We promote the product range and ...encourage customer response either on a direct link from the web site or through our alternative e-mail addresses.*"
"*E-mails are used to communicate with sales agents but so far the end user/ customer has been slow to adopt this new technology*"

"...But a few of the less prominent competitors are customers." [Company B]

"... Global initiative to reduce cost is forcing some co-operation with some other laboratories in the purchase of materials."
"Establishment of a new Communication department, which is to ensure that the company is more closely aligned with the changing NHS."
"Creation of two specialist business units for dedicated sales and marketing in new franchise areas." [Company C]

"We try to access NHS databases to monitor ..."
"Volatility in supply of off the shelf items, typically electronic components now requires continual monitoring and a willingness to make strategic purchasing decisions at short notice and beyond normal stock cover levels."
"Emphasis on a better quality of suppliers limits options and leads to a greater concentration on Grade 1 core suppliers who in turn now demand better and closer support." [Company D]

The quantitative and qualitative data tallied in several respects but a distinction was apparent between Companies B and C as high performers on one hand and Companies A and D as low performers on the other hand. The companies promoted their product range and encouraged customer feedback through printed, electronic, web, and dedicated sales media. In particular, EDI applications were used for remote access to databases. However, interaction with competitors did not advance beyond quality specification meetings called by a few valued customers as well as trading in small volumes with a few competitors.

Supply chain networking were therefore characterised by remote assess to databases and long-term contractual obligations rather than temporal and opportunistic collaboration. Consequently, Supply chain practices were short of a flexible manufacturing chain, which can increase production on a line at a moment's notice without jeopardising commitments or schedules already agreed in other lines. Supply chain practices were also diminutive of a responsive virtual chain that can mobilise global resources real time for transparent customisation of leading edge technology products.

Supply chain practices prevalent in the companies would at best support level schedules. This however was a problem as lead times and quality assurance problems were apparent in the face of punitive rationalisation and open competitive tendering.

"Suppliers are selected through open competitive tendering, based on ability to supply specifications rather than cost...and we ensure compliance."

"In order to ensure closer relationship and involvement, plans are underway to reduce suppliers to between five and fifteen" [Company A]

"E-mails are used to communicate... but so far the end user/ customer has been slow to adopt this new technology" [Company B]

"... But there is mutual suspicion and supplier missing information..."

"Lessons learnt include the need for ... a flexible manufacturing chain, which can increase production at a moment's notice, without jeopardising..." [Company C]

"Our products are complex and not easy to quickly speed up the supply chain...

"Recently, two major projects ran out of control... due to problems with sub-contractors."

"... We have seen more bureaucracy and a loss of personal relationships."

"Supply problems with long lead times" [Company D]

The data above imply that supplier relations were adversarial and typified by mutual suspicion, painful rationalisation, contractual rather than collaborative deals, margin squeezing and long lead times. As dealings were contractual than collaborative, and perhaps leaner than agile, several non-value adding margins would have been built into hierarchies of contracts of supplies and shifted forward to the customer.

In contrast, an agile chain would be relatively devoid of intermediate margins as the emphasis is on collaboration rather than contracts. This perhaps explains the significance of agile supply chain on the competitive objective of low cost in Figure 4.6. Accordingly, because supply chain practices in most of the case study companies lacked the element of agility to some extent, the companies failed to deliver on the most basic competitive objective of low cost. By extension, only one company delivered on cost-related business performance measures of sales turnover and net profit. As well, Companies A and D had a distinct minus on supply chain practices and they were low performers. They did not witness a sharp increase on any business performance measure.

Companies B and C who were high performers were again singled out for having a blend of lean and agile supply chain practices (Appendix 3). First, Company C was most outstanding on scales that defined the lean supply chain. In addition, Company C was least prominent amongst companies crowded together on the low end of scales that defined the agile supply chain. Third, Company C was solely distinguished by high scores on collaborative design and manufacture. Fourth, the qualitative responses showed that Company C strived for a flexible manufacturing chain that could increase production at a moment's notice without jeopardising other supply commitments. This explains co-operative efforts with some other laboratories towards reducing the cost of material, creation of a new communication department to align the company with customers changing needs and formation of dedicated sales units in new franchise areas.

Company B was remarkable for insignificant emphasis on long-term contractual obligations. This suggests that supplier relations were more opportunistic and flexible. In addition, Company B harped on just in time supplies and lead-time compression. Accordingly, Companies B and C delivered on a wider range of competitive objectives including quality, product customisation and volume flexibility. By extension, over the last five years, Companies B and C were distinguished by sharp increases on a wide range of financial and non-financial measures of business performance.

Superior competitive and business performance outcomes attributed to Companies B and C clearly emanated from positive efforts in blending lean and agile supply chain practices. The lean and agile supply chains were independently justified in the empirical results summarised in Figure 4.7. In addition, a fair blend of the lean and agile supply chains partly accounted for the success of Companies B and C. To this extent, the lean and agile models of supply chains are both valid as agility enablers. Also valid is their joint deployment as building blocks for agile manufacturing (Mason-Jones et al, 2000).

5.7.7. FACILITIES DESIGN AND VOLUME FLEXIBILITY

This section investigates the layout of manufacturing facilities with a view to identify elements of the virtual cell requirement as a determinant of attainment of operational and volume flexibility. In chapters 2 and 3, it was proposed that cells should be virtual in terms of porous boundaries as a means of boosting volume flexibility as a competitive objective.

In order to study the extent to which cells were dedicated or virtual, a product line was equated with a part-processing cell. This is because the companies studied were involved in assembly and substance forming operations rather than parts processing. Accordingly, a line dedicated to the manufacture of a liquid pharmaceutical was equated to a cell dedicated to the manufacture of a piece-part such as automobile oil filter. Product lines and cells were therefore used interchangeably in this study.

The quantitative questionnaires used thirty scales to capture data on the type and layout of facilities and the structure of jobs. The quantitative responses revealed that facilities were structured into lines or cells dedicated to product families. The lines consisted of a range of simple machines and human skills that were sequentially arranged and integrated into flow lines for repetitive batch processing. Each line was completely dedicated and lacking in free movement of machines and human skills across product lines or cells. Not only this, machines were specialised, machines were not duplicated and movement of work in progress across dedicated lines and cells were insignificant. These features imply that manufacturing operations lacked porous boundaries or the virtual character of product lines and cells as a means of enhancing operational and volume flexibility.

Dedicated cells are useful in themselves as they are compatible with division of labour and specialisation. Responsibilities, accounts and commitments are easier to track and value. More importantly, they support modular product design and mass customisation. If dedicated stand-alone operations were integrated into flow lines as some of the companies did, they enhance efficiency in repetitive operations such as packaging especially if volumes justify a significant degree of automation. These benefits were worthwhile but they can be reconciled and made consistent with the virtual character of porous boundaries across lines and cells as a means of accomplishing operational and volume flexibility.

Extracts from qualitative interviews also revealed the degree of porosity across product lines and cells as a means of boosting operational and volume flexibility.

"There is less flexibility at the floor level because operations take specific specifications."
"We ... indeed move people around endlessly... whenever the need arises." [Company A]

"... Operations are guided by a weekly production control meeting, ...to agree the rolling production sequence.... and timetables ...helps avoid giving production priority to an item which is not yet required...
"The process aims to maximise production capacity by manufacturing and despatching product at the most appropriate time..." [Company B]

"Process flexibility is restricted by a statutory requirement of total batch segregation by the Medicines Control Authority, which inhibits mixed lots and inter-line movement of machines and in-process materials."

" ... Wide variances in operations cycle times... limits flexibility."

"In addressing the restrictions, several processes ...are run in small lots, with varying degrees of machine duplication.

"... Flexibility has improved through reduction of machine set up times."

"We use job sequencing is order to minimise machine changeovers, ... and complete changeovers, ... have been replaced by complete off-line re-tooling sets."

"More formal arrangement for forecast demand."

"...A flexible manufacturing chain, which can increase production at a moment's notice, without jeopardising other supply commitments..." [Company C]

"Greater use of information technology, including greater Internet and Intranet capabilities to drive the requirements process in internal and external operations."

"Better configuration for all products through a change to modular kit parts..."

"Internal re-organisation aimed at job specialisation." [Company D]

The preceding qualitative information revealed that companies desired porous boundaries across cells as a means of accommodating horrendous changes in order size requirements. To this end, some companies strived to compress equipment change over time as a means of making small and large orders equally profitable. Several other solutions devised by companies included better product configuration, more formal arrangement for forecast demand, a flexible manufacturing chain, job sequencing, machine duplication, and a centralised weekly meeting that rolled and prioritised production sequences.

In the quantitative responses, Company B was unique for limited dedication of tools and fixtures into product families. In the quantitative responses as well, company B was marked for significant empowerment of team members (see Section 5.7.5) and the use of a weekly production meeting as the main tool for prioritising schedules based on new commitments. In addition, Company B was unique for a much lower proportion of output fully processed within a single line. Furthermore, planning and forecasting was significantly emphasised. In effect, Company B fairly met the agile requirement of porous boundaries across lines as a means of enhancing operational and volume flexibility.

Company C was also identified in both the quantitative and qualitative responses for a greater amount of the virtual character. First, it was easier to adjust inter-line capacity to order size fluctuations because supplier relations were more opportunistic and collaborative rather than long-term and contractual (see Section 5.7.6). In addition, Company C was singled out alongside Company B for a much lower proportion of output fully processed within a single line. The extracts from qualitative data listed in the preceding paragraphs also revealed several steps taken towards meeting the requirement of porous boundaries. They include machine duplication, a flexible manufacturing chain, more formal arrangement for forecast demand, and small lot operations.

In effect, Company C who was also a high performer significantly met the agile prerequisite of porous boundaries across lines as a means of enhancing operational and volume flexibility. Superior competencies in the virtual character of product lines and cells explained superior attainment of competitive and business performance objectives by Companies B and C. In particular, they explain why Company C excelled simultaneously on higher order competitive objectives of leadership in new technology, swift response to surges in demand (volume flexibility), and product customisation. To this extent, it is plausible that because of superior competencies in the virtual character of product lines, the trade-off between leadership in new technology and volume flexibility, which was identified earlier in Chapter 4 did not apply to Company C.

Companies A and D also recognised the need for porous boundaries as a means of boosting attainment of operational and volume flexibility. To this end, Company A moved employees endlessly as required and just anyone could be trained and assigned to any momentary opportunities. However, little was achieved in the light of limited delegation of authority to frontline employees and the straightjacket structure of floor level operations. For Company D, there was a complete breakdown of internal structures for functional and process integration and communication. Trench warfare amongst design, manufacturing and marketing was apparent whilst round pegs occupied square holes. In the circumstance, Company D lacked the initiative, trust, confidence and teaming disposition required for coping with momentary changes in design specifications and order size requirements. Consequently, over the last five years, attainment of competitive objectives was limited to quality whilst a sharp decrease in a range of business performance measures was apparent. Nevertheless, Company D was set to reverse its declining fortunes through greater use of IT capabilities to drive the requirements process in internal and external operations, better product configurations via modular kit parts and internal re-organisation of job structures.

The preceding results show that virtual cells are imperative to agile manufacturing design. This is as a means of boosting operational and volume flexibility in companies faced by intense competition and unprecedented instability. To this end, the virtual character of cells with porous boundaries is indispensable as a means of creating pooling synergy and flexing inter-line capacity. Superior competencies in the virtual character significantly explained the competitive and business success of Companies B and C relative to A and D.

In addition to the requirement of porous boundaries across product lines, several other operational determinants of volume flexibility were identified and a distinction between Companies B and C on one hand and Companies A and D on the other hand was apparent. Companies B and C had greater competencies on flexible operations routes and sequences and re-routing of production at minimal cost to bypass a loaded or failing machine. These were in addition to simultaneous manufacture of basic and customised models, efficient manufacture of small volumes and swift response to changes in product mix and volumes.

In addition to the virtual cell, some other positive and negative factors affecting operational flexibility as a determinant of volume flexibility were identified from qualitative data.

"There is less flexibility at the floor level because operations take specific specifications."
"We ... vary the number of shifts and indeed move people around endlessly...."
"We carry a little bit more stock, and pressurise suppliers to reduce lead times."
"Top managers are responsible for everything...." [Company A]

"We plan our house according to the lower end of anticipated sales turnover."
"...Purchase of additional facilities for fully factory-built storage systems in parallel with customer-site assembly of units."
"Most permanent employees are engineers and technicians with a diversified skill base."
"JIT principles applied widely in purchasing and job scheduling." [Company B].

"... Complete changeovers ... replaced by complete off-line re-tooling sets."
"More formal arrangement for forecast demand."
"Some reasonable amount of inventory...."
"A new Communication department, ... and two specialist business units for dedicated sales and marketing ... to ensure ... more closely aligned with changing needs...."
"...A flexible manufacturing chain, which can increase production at a moment's notice, without jeopardising other supply commitments."

"Process flexibility is restricted by a statutory requirement of total batch segregation..."

"... Wide variances in operations cycle times ... limits flexibility."

"...Small lots, with varying degrees of machine duplication."

"...Reduction of machine set up times". [Company C]

"Internal re-organisation aimed at job specialisation"

"Greater use of information technology, including greater Internet and intranet ..."

"We try to access databases to monitor contracts available, bidders and ...specifications."

"Strategic purchasing decisions at short notice and beyond normal stock cover levels."

"A change to modular kit parts...." [Company D]

The following themes supportive to operational flexibility were identified from the preceding extracts.

- Contingency inventories [Companies A, B, C and D]
- Customer site and in-plant assembly in parallel [Company B]
- JIT purchasing and scheduling [Companies B and C]
- Demand planning and forecasting [Companies B and C]
- Complete off-line retooling [Company C]
- Flexible supply chain [Company C]
- Dedicated communication and marketing [Company C]
- Modular Kit parts [Company D]
- Strategic purchasing [Company D]

The foregoing list of common themes reveals significant emphasis on contingency inventories. The list also reveals that Companies B and C (high performers) were more prominent than Companies A and D (low performers). In particular, Company C emphasised a flexible chain that could increase production at a moment's notice without jeopardising other supply commitments.

Accordingly, Companies B and C were more committed to operational flexibility whilst they also complied more remarkably with the virtual cell requirement of porous boundaries across product lines and emphasised a flexible manufacturing chain. The attendant result was higher attainment of a much wider range of competitive and business performance objectives. In particular, Company C was singled out for higher and simultaneous attainment of product customisation, leadership in new technology products and volume flexibility. To this extent, it had mastered the trade-off identified earlier in Section 4.6.5 between leadership in new technology and volume flexibility.

In the light of the fore-going discussion of results, the fifth hypothesis that virtual cells enhance operational flexibility, which in turn determines attainment of volume flexibility as a competitive objective is justified. The virtual cell is thus valid as an agility enabler.

5.7.8. TEST OF DEMOGRAPHIC IMPACTS

This section tests whether contextual factors such as size, market or industry groupings affect the empirical results of the research. A simple test of demographic relationship between Companies B and C relative to Companies A and D was conducted. The test was based on a simple assumption. Demographic influences will be assumed away if the evidence existed that the high performers (Companies B and C) had a weaker demographic relationship amongst themselves in contrast to a stronger demographic association with the low performers (Companies A and D).

The evidence proposed in the previous paragraph was positive and revealing. As unrelated as they were in the empirical results, Companies A and B were small-scale companies with annual sales turnover lower five million pounds. In contrast, Companies D and C were medium to large-scale with sales turnover figures of 18 million pounds and 320 million pounds respectively. As well, although Companies A and C as well as B and D were polarised in the empirical results, operations in Companies A and C were run as flow batch process whilst they were more project-based in Companies B and D.

In addition, whereas Companies A and C were poles apart in the adoption of agility enablers and attainment of competitive and business performance objectives, they were both in the food and pharmaceutical product group (see Table 4.7). As well, although Companies A and D were both identified as low adopters of agility enablers the attendant consequence being lower competitive and business success, the companies were in two different product groups. Company A manufactured foods whilst Company D manufactured equipment. Likewise, whereas Companies B and C were high adopters of agility enablers and high performers, they also were in two different product groups. Company B was in electronic storage systems whilst C was in medical pharmaceuticals.

The foregoing results show that high adopters of agility enablers and high performers (B and C) had weak demographic relationships in contrast to strong demographic affiliation with low adopters of agility enablers and low performers (A and D). To this extent, the fourth hypothesis is not valid. The hypothesis states that demographic and industrial contingencies determine the need for agile manufacturing design and its potential impacts on competitive objectives and business performance. The findings of the study are therefore widely applicable to industries.

More importantly, the four companies accepted the reality of market pressures and were committed to responsive structures and systems. A study of future aspirations showed significant interest on simultaneous attainment of competitive objectives including leadership in new technology and volume flexibility. In essence, the companies aspired to eliminate the trade-off between leadership in new technology and volume flexibility.

Further evidence in support of plans and aspirations consistent with agile manufacturing were equally manifest in the following extracts from interview responses.

"... *Continuous evaluation of what we do and what the market needs....* "
" *Innovation will be market-led, ...but we intend to lead ...* " [Company A]

" ... *Plans to lead in large-scale fully packaged air-conditioning and energy-saving technologies, ... based on emerging demands from end customers* [Company B].

" ... *Advanced formulations ahead ... and protecting them with patents* " [Company C]

"Get the product right."
"Introduce a new generation of products."
"Product development efforts will be customer-led and continuous research into our customers' changing requirements ... [Company D]

Planned operational changes supportive to higher adoption of the agility enablers as a means of enhancing competitive advantage were also equally noticeable.

"The company plans to contract product design contractors"
"Further invest in emerging flexible packaging technologies... "
"Improve on parallel product lines... "

"...Replace products already in mature markets." [Company A]

"...Improved facility to plan production accurately will be the key... to winning ..."
"Fully utilise manufacturing software systems, to reorganise and streamline..."
"Automation based on time saving and payback relative to volume and employees' costs"
"Supply chain reforms to increase value added... reducing lead-times..." [Company B].

"Robustness and reliability of planning and delivery systems... and stable forecasts"
"Financial and technical feasibility tests of some currently unavailable technologies..."
"On-line analytic equipment...predict manufacturability and cut down processing times."
"Flexibility within limits of regulatory controls such as total batch segregation."
"Long-term collaboration aimed at reducing lead times and large stock...." [Company C]

"A clean slate approach ..."
"A catch up programme, [then] *...a rolling programme of innovation to put us in the lead."*
Better configuration... modular kit parts, with a view to simplify products."
"Internal re-organisation ..."
"A new spirit of communication and co-operation" [Company D]

The responses indicated that manufacturing automation and technology utilisation remained crucial as a means of making products smarter, widening the product range and wading off foreign competition. This is in addition to collaborative supply chains as a means of increasing value-added to throughput whilst cutting down on lead times.

5.8. SUMMARY

This chapter reports details of four industrial case studies, which were conducted to test contextual validity of the survey results in Chapter 4 and investigate the surprise finding that attainment of volume flexibility was lower amongst high adopters of agility enablers. The study collected more in-depth data in four companies, using quantitative and qualitative methods. The data collected were used to further explore the nature and relationship amongst change drivers, agility enablers and competitive objectives.

Chapter 5 reported methods of sample selection and access to companies, methods of data collection and analysis and case-by-case summary reports. They were followed by a discussion of common threads amongst companies as a basis for testing the five hypotheses proposed earlier in the study.

The case study results agreed with the earlier findings of the survey by questionnaire in Chapter 4. It was apparent that change drivers impact on companies' operations, the most significant dimensions being high value of the pound, sudden customer shifts, horrendous patterns of demand, competition from foreign products and EU directives.

Further results showed that agility in terms of simultaneous attainment of competitive objectives was rather low even as future aspirations were significantly high. Significant relationships were identified between attainment of competitive objectives and adoption of agility enablers. The discussion of common themes across companies revealed that on the five dimensions of competence building discussed earlier in Chapter 2, contingency models prevalent in the four case study companies generally fell short of the agility enablers. Manufacturing automation was more flexible that intelligent, employee empowerment was limited rather than total, and technologies were differentiated rather than integrated. In addition, mass customisation was more cosmetic than transparent, supply chains were leaner than agile, and product lines were more dedicated than virtual.

However, two of the four companies studied were more positive towards the agility enablers. Business practices, operations processes and facilities design contained a far wider range of elements of intelligent automation, employee empowerment, agile supply chains, transparent customisation, technology integration and virtual cells. The two companies delivered widely on competitive objectives. Consequently, over the last five years, sharp increases in business performance measures were documented. In contrast, the two other companies were identified as less positive towards the agility enablers. They did not deliver widely on competitive objectives and over the last five years, sharp decreases in business performance measures were documented.

In addition, hypothesis 5 which emerged from Chapter 4 as a research dilemma was investigated. The hypothesis states that virtual cells enhance operational flexibility, which in turn determines attainment of volume flexibility as a competitive objective. It was proposed to study determinants of volume flexibility, which was not strongly influenced by the agility enablers identified earlier in Chapter 4. The results showed that porous boundaries across product lines, in terms of inter-line movement of work in process, skills and machines enhanced operational flexibility as a determinant of volume flexibility. The evidence was marshalled that the two high performing companies complied more significantly with the virtual cell requirement of porous boundaries.

Finally, case study results were tested for demographic impacts but none was identified. The two high performing companies on one hand and the two low performing companies on the other hand lacked significant demographic relationships. In contrast, each of the high performing companies had considerable demographic similarities with either of the low performing companies. Consequently, the position was taken that the results of the study were significant and widely applicable.

In the light of the results showing that market instability and the competitive impacts of agility enablers were real and devoid of demographic boundaries, adoption and deployment of agility enablers become indispensable as a means of winning orders, market share and profits as market instability intensified. In this regard, a test of future aspirations and change initiatives were positive towards agile manufacturing principles and its enabling competencies as identified in this study. The low adopters of agility enablers who were also low performers planned a fresh start driven by new product initiatives and internal reorganisation aimed at enhancing value-added and shortening lead times. In contrast, the high adopters of agility enablers who were identified as high performers were also embarking on new initiatives such as a flexible manufacturing chain, market-led innovation and more use of manufacturing and information technologies.

CHAPTER SIX

SUMMARY AND CONCLUSION

This chapter presents a summary and conclusions of the research. It restates the research objectives, research methodology and major tasks undertaken. In addition, by way of conclusion, research hypotheses and the grounds for their validation and acceptance were reiterated. The chapter also outlines the contributions and critique of the research as well as suggestions for further research.

6.1. SUMMARY

This research aimed to identify and justify agile manufacturing enablers of competitive advantage. To this end, five dimensions of competence building that were most frequently mentioned in the literature of competitive manufacturing in general, as a means of enhancing competitive objectives, business performance and long-term survival were discussed. The five dimensions were mass customisation, supply chain networking, manufacturing automation, employee empowerment and technology utilisation. For each of the five dimensions, the discussion revealed three contingency options, out of which one was marked out for resemblance with the methods suggested in the literature of agile manufacturing. Such contingency options were labelled as agility enablers, and they were proposed in the study as the building blocks for agile manufacturing design.

In order to test the superiority of the agility enablers relative to other contingency models of competence building, a survey by questionnaire was undertaken, followed by four industrial case studies as a means of collecting more explanatory data and testing the validity of empirical results in different contexts. The survey by questionnaire and the case studies collected data from companies on their competitive situation, the resource capabilities and methods used to create competitive advantage, attainment of competitive and the direction of change in business performance measures. The evidence was marshalled that the agility enablers had a superior impact on competitive objectives and business performance over and above the other models of competence building.

The study also investigated the impact of environmental change drivers on business performance. The results showed that environmental change drivers impact significantly on business performance and that higher attainment of competitive objectives is crucial in order to attack the change drivers and boost business performance. It was argued that herein lays the essence of the agility enablers as a means enhancing competitive advantage.

The study commenced with a report on the main activities of the study. The main activities included a literature review, the development of a conceptual framework, a survey by questionnaire, and four case studies. In the introductory chapter, research objectives, research questions and research hypotheses were stated whilst methods of investigation, including quantitative and qualitative methods, were described and justified.

Chapter 2 reported the findings of a review of the literature on agile manufacturing and related topics. The chapter gave a chronological account of manufacturing systems, which have emerged in rapid succession to address different levels of market instability and product complexity. A clear distinction between lean production and agile manufacturing was made whilst employing recent threats to the former to justify the latter. However, the acclaimed success of lean production was recognised as well as contextual differences in the application of lean and agile methods.

It was argued that lean production was underpinned by a sense of managing through and the need to maintain a level schedule whilst agile manufacturing harped on structures for real time mobilisation of global resource capabilities to tap temporal opportunities. The point was made that a sense of managing through, via internal process-based programmes such as continuous improvement and just in time, would not guarantee competitive advantage, given the fast pace of change in the business environment. Accordingly, rather than focusing exclusively on internal process improvement initiatives, companies were asked to emphasise responsive adaptation and seek competitive advantage from outside. To this end, the agility enablers were proposed as a means of advancing simultaneous on a wider range of competitive objectives.

The literature review also discussed and identified the dimensions of change initiatives towards agile manufacturing. The dimensions were used as a template to recognise agility enablers from a range of contingency options identified in a discussion of competence building for competitive manufacture. The contingency options identified were limited customisation, cosmetic customisation, transparent customisation, traditional supply chains, lean supply chains and agile supply chains. These are in addition to technology differentiation, technology integration, mass automation, flexible automation, intelligent automation, training based empowerment, team-based empowerment and total empowerment of employees. From these contingency options, transparent customisation, agile supply chain, intelligent automation, total employee empowerment and technology integration were deciphered as agility enablers.

The literature review also provided a critique of agile manufacturing and the agility enablers. This critique centred more on the pattern of discussion in the literature. It was opined that the literature discusses agile manufacturing as a clean break from several existing methods and techniques, without empirical justification of a coherent set of agile methods and technique. In addition, remarkable attention focuses on supply chain networking as if internal factors such as process improvement were no longer important. It was argued that for these reasons, agile manufacturing had not significantly penetrated mainstream engineering and management literature as well as the collective consciousness of European practitioners. The agility enablers identified by the study were also criticised. This is in terms of problems of definition, prior empirical validation and implementation.

Finally, the literature review studied the nature of competitive objectives and business performance. It was argued that companies should not focus exceedingly on low cost and quality objectives but that they should also emphasise higher order objectives such as product customisation, volume flexibility and leadership in new technology. The evidence was tendered that volume flexibility was the most difficult to attain competitive objective and that it demands precise targeting by the agility enablers. The nature of business performance objectives was also discussed. The need for a balanced scorecard of performance measures in the process of accessing the impact of change drivers relative to the gains derivable from the agility enablers was stressed. The conclusion was reached that adoption of the agility enablers would enhance simultaneous attainment of competitive objectives, which in turn would neutralise the perturbing influence of the change drivers whilst also boosting business performance outcomes.

In chapter 3, the ideas emanating from the literature review were summarised in a conceptual framework. It consists of four concepts namely change drivers, agility enablers, competitive objectives and business performance. The framework was employed as a theory of method to focus the study. The conceptual framework argued that change drivers impact negatively on business performance and that higher attainment of competitive objectives, which is made possible through significant adoption of the agility enablers, is mandatory. In support of this mainstream argument, five research hypotheses were proposed to test the validity of relationships specified in the conceptual framework.

Chapter 4 reports the methods and findings of an industrial survey by questionnaire. The survey was administered to 600 companies, which were selected randomly from a wide range of industries. One hundred and ten companies provided useful data, the analysis and results of which were used as basis for making inferences and for reaching conclusions. The methods of data analysis such as correlation, factor analysis, regression analysis and sub-samples mean difference tests were reported. The problems encountered in the use of factor analysis were discussed prior to its use. The survey results validated the central argument in the conceptual framework and consequently the research hypotheses. The study provided the evidence that a significant relationship existed between change drivers and business performance, and that this relationship recommends agile manufacturing design as a means of enhancing competitive advantage.

Having demonstrated the need for agile manufacturing, the study identified agility enablers as deployable tools and methods for agile manufacturing design. Data was collected on five dimensions of competence building, change drivers, attainment of competitive objectives and business performance. The data were presented for factor analysis. Fourteen empirical models of competence building were derived out of which six models were interpreted as agility enablers. All the fourteen models of competence building were presented for regression tests of significant relationship with core dimensions of competitive objectives and business performance. The results revealed that individually, the agile enablers had superior impacts on principal dimensions of competitive objectives and business performance. Further tests of sub-sample differences showed that high adopters of the agility enablers had a significant positive change in market share growth. In addition, it was revealed that the most successful plants emphasised the agility enablers whilst the least successful plants applied the non-agility enablers. Tests of demographic effects on the results were conducted, but none was significant. The results of the study were deemed to apply widely to companies. However, the relevance of the results will be determined by the degree of market instability and product complexity confronting different industries.

In order to gather more explanatory data to explain empirical relationships whilst also testing the validity of the survey results in different settings, four in-depth case studies were conducted. The variables studied in the survey by questionnaire were extended into more minute details, with a focus on operational determinants of volume flexibility, which was not significantly influenced by the five agility enablers. Accordingly, a fifth hypothesis was proposed as a means of exploring the determinants of volume flexibility. Data was collected using quantitative and qualitative methods. The case study findings validated the survey results and justified the virtual cell as a determinant of operational flexibility, which in turn determines attainment of volume flexibility. The "virtual cell" as used in the study concept, refers to product lines and cells that have porous boundaries across which resources and work in progress could move without hindrance, in response to variations in workloads. The virtual cell was proposed as the seventh agility enabler.

6.2. VALIDATION OF RESEARCH HYPOTHESES

Research hypotheses were tested for validity based on data from industrial survey and case studies. The hypotheses and bases for validating them are as follows.

Hypothesis 1

There is a strong relationship between change drivers, competitive objectives and business performance.

Speculation is rife that change drivers threaten business performance, and that agile manufacturing design is indispensable as a means of limiting the threats and profiting from them. Therefore, the need to evaluate the magnitude of the threat from change drivers as a determinant of the need for agile manufacturing gave rise to hypothesis 1.

Hypothesis 1 was tested and supported based on tests for correlation amongst the concepts of change drivers, agility (total attainment of competitive objectives) and business performance. The scores by companies on the scales employed to capture data on each of the three concepts were aggregated into summary scores and tested for correlation. The correlation coefficients indicated the strength of relationship amongst the three concepts. The results showed that the relationship between change drivers and business performance was stronger than the relationship between agility (attainment of competitive objectives) and change drivers, and between agility and business performance. On this basis, a change proficiency gap was identified as a justification for agile manufacturing. The case studies supported the survey findings. The plants studied agreed that their businesses were under serious threat from market instability caused by horrendous demand, sudden customer shifts, competition from foreign products, high value of the pound and EU directives.

Hypothesis 2

Companies that pay simultaneous attention to a wide range of manufacturing competitive objectives will outperform the competition.

Having used hypothesis 1 to justify the need for agile manufacturing design, Hypothesis 2 establish a barometer for measuring the impact of agile change initiatives. The hypothesis provided the evidence that relatively equal attention to a wide range of competitive objectives enhances business performance more than focusing predominantly on a narrow range of competitive objectives.

The evidence was based on a simple measure described as the range of mean scores on competitive objectives. Based on the range of mean scores on seven competitive objectives, companies were classified into two groups. Those paying relatively equal attention to competitive objectives were coded as low range companies whilst companies that emphasised only a few competitive objectives were named as high range companies. For this test, high scores on a few objectives were inferior to fairly equal scores.

A test of mean difference (*t*-test) showed that the low fange group has significantly higher attainments of competitive objectives and business performance measures. This result was explained in terms of competitive objectives reinforcing themselves when pursued with equal vigour. This evidence also showed in case studies results. Two companies having the widest range of high scores on competitive objectives returned sharp increases in business performance measures over the last five years.

Hypothesis 3

Attainment of manufacturing competitive objectives and business performance is directly related to the level of adoption of agile manufacturing enablers.

Hypothesis 3 was largely the main concern of the research. The hypothesis had two major tasks. The first was to empirically identify agile manufacturing enablers from several other alternative methods deployed by companies as enablers of competitive advantage. The test task was to provide the empirical evidence that the agility enablers individually and collectively wield a positive significant impact on competitive and business objectives.

Agility enablers were identified by applying factor and cluster analyses to data collected from companies on five dimensions of competitive manufacturing. Fourteen empirical methods of enhancing competitive advantage were identified five of which were interpreted as agility enablers. Regression analysis was employed to test the individual impacts of the fourteen empirical methods. The results revealed that the five agility enablers had significant impacts on competitive and business objectives. The impacts of eight other empirical methods were either insignificant or negative.

In order to test for the collective impact of agility enablers, two groups of low and high adopters were composed and a test of mean difference in attainment of competitive and business performance objectives was conducted. The results favoured the high adopters. Secondly, a test for differences in methods implemented as enablers of competitive advantage by two groups of least successful and most successful plants was conducted. The results strongly associated the most successful plants with the agility enablers.

The preceding results were validated by the findings of case studies. Two groups of high and low performing companies were identified. The high performing companies had a wide range of elements related to the agility enablers. Based on the foregoing results, the conclusion was reached that the agility enablers identified were invaluable as enablers of competitive advantage especially in markets characterised by market instability. In addition to the agility enablers, the lean supply chain impacted on several dimensions of competitive and business performance objectives. At the same time, it interacted with the five agility enablers harmoniously without non-compensating impacts on competitive and business performance objectives. The lean supply chain was therefore adopted as an additional agility enabler. Some of its underlying principles such as supplier coaching for cost and quality enhancements can therefore be integrated into those of the agile supply chain (Mason Jones et. al., 2000; Lewis, 2000; Hoek et. al., 2001).

Hypothesis 4

Demographic and industrial contingencies determine the need for agile manufacturing design and its potential impacts on competitive objectives and business performance.

Hypothesis 4 tested the extent to which the results of the study apply widely to companies without demographic limitations based on size, industrial, market or manufacturing process characteristics. The hypothesis had two main tasks. The first was to test whether the pattern of correlation amongst the concepts of agility drivers, agility and business performance in Hypothesis 1 held for different sub-samples of the companies studied. Sub-sample correlation tests amongst the concepts of agility drivers, agility and business performance revealed a pattern similar to those obtained earlier in Hypothesis 1 for all companies.

The second task was to test whether the agility enablers were relatively relevant to sub-samples of companies as a means of enhancing competitive advantage. Mean difference tests revealed that mean scores by companies on the agility enablers, dimensions of competition and business performance did not vary significantly across demographic sub-samples based on size, product and market types.

The case studies provided the evidence that was more appealing. The case study results polarised the four companies into two groups. The first group consisted of two companies who were identified as high performers. Their manufacturing system including facilities design, technology and automation, employee empowerment accommodated a significantly wider range of elements of the agility enablers. They were therefore more agile as they delivered simultaneously on a much wider range of competitive objectives, which explained their business success. The second group was also made up of two companies who were recognized as low performers. They in contrast contained a significantly fewer range of element of the agility enablers. They were therefore less agile as they delivered narrowly on competitive objectives, which explained their business failure.

However, the two high performers had dissimilar demographic relationships with themselves whilst they exhibited strong demographic similarities with the low performers. As well, the two low performers had disparate demographic affiliation whilst they exhibited strong demographic connection with the low performers To this extent, the conclusion was reached that the results of the research were devoid of demographic boundaries based on size, process, market or industry types. In essence, the impact of change drivers on business performance as a determinant of the need for agile manufacturing was equally significant across demographic frontiers. The same applied to the impacts of agility enablers on competitive objectives and business performance.

Hypothesis 5

Virtual cells enhance operational flexibility, which in turn determine attainment of volume flexibility as a competitive objective.

Hypothesis 5 was proposed to address a research dilemma pertaining to unexpected behaviour and limited impact of the agility enablers on the competitive objective of volume flexibility. For instance, an aggregate measure of agility did not correlate with an aggregate measure of business performance until volume flexibility was excluded from the seven variables whose scores were summed up to derive aggregate agility. Likewise, high adopters of agility enablers did not deliver on volume flexibility. Nevertheless, the strange behaviour of volume flexibility was anticipated and discussed in Section 2.11. In addition, possible solutions for improving on it as a potential conundrum in realising the agile manufacturing goal of simultaneous attainment of competitive objectives were discussed in Section 4.8. It was stressed that in the light of speedy proliferation and customisation of products, volume flexibility remained important as a means of decoupling cost and lot size so that small and large volumes could be manufactured efficiently and profitably.

The study proposed operational flexibility as a determinant of volume flexibility and that the former depends largely on the extent to which resources are mobile across dedicated product lines and cells. Mobility is in terms of seamless flow of machines, skills and work in progress across process boundaries as a means of creating pooling synergy and flexing capacity to focus on the batches of products with which a plant is confronted momentarily.

Hypothesis 5 was tested using data from case studies. Two companies already identified as high adopters of agility enablers and high performers met the requirements of porous boundaries across product lines, the attendant benefit of which was significantly higher attainment of operational and volume flexibility. Not only this, the two companies delivered simultaneously on a wider range of competitive objectives whilst one of the companies effectively eliminated the trade-off identified in Chapter 4 between volume flexibility and leadership in new technology. Accordingly, over the last five years, the two companies returned sharp increases in financial and non-financial measures of business performance. Accordingly, a concept known as virtual cell was identified as an additional agility enabler. It was considered crucial to agile manufacturing design as a means of improving operational flexibility through virtual mobility of resources across product lines.

In effect, the five research hypotheses proposed in chapter 3 were validated. The next section provides a summary of research contributions.

6.3. RESEARCH CONTRIBUTIONS

The results of the study make important contributions to knowledge. Three of the contributions derive from three central objectives of the study. They were (a) assess the need for agile manufacturing, (b) demonstrate that agility as an approach to the design and management of the manufacturing function leads to higher business performance, and (c) identify / justify agility enablers that could be deployed for enhancement of competitive advantage especially in markets characterised by rapid changes. The other three results are incidental but they also make important contributions in terms of their implications for practice and research. The important contributions are presented as follows.

A method was devised for assessing the need for agile manufacturing in companies and industries. Speculations is rife in the literature of agile manufacturing that market instability has become unprecedented and that agile manufacturing provides a means of mastering the perturbing influence of the change drivers. It is important therefore to validate this speculation before embarking on change initiatives underpinned by the principles of agile manufacturing. What is required is a test of the relationship between change drivers, agility (attainment of competitive objectives) and business performance.

To this end, the study computed two indices namely change proficiency requirement index and competitive attainment index. The former computed the magnitude of relationship between change drivers and business performance whilst the latter estimates the strength of relationship between change drivers and competitive objectives. The change proficiency requirement index was greater than the competitive attainment index and a gap was therefore identified between the degree of impact of change drivers and the counteracting influence of competitive objectives. The difference between the two indices namely change proficiency requirement index and competitive attainment index is a change proficiency requirement gap. This gap is a shortfall in attainment of competitive objectives as a means of attacking the perturbing influencing of change drivers whilst also defending business performance measures. Companies can therefore estimate their change proficiency requirement gap and devise initiatives for narrowing it down. Such initiatives include the agility enablers. Accordingly, Mason-Jones et. al. (2000) argued that:

"Those companies who design business strategies that acknowledge the presence of uncertainty and provide mechanisms for pro-actively tackling it are rewarded by an opportunity to enable best practice ahead of competitors..."

Sub sample mean difference tests showed that the size of the change proficiency requirement gap differed across product groups but was highest for companies in the shipping and aviation product group followed by companies in the automobile and automotive product group. The two sectors fall within Fisher's (1997) category of innovative product markets that require a higher degree of responsiveness. A lower change proficiency requirement gap would imply that products are more functional than innovative, and change initiatives may be less agile.

The second major contribution is the confirmation that agile manufacturing leads to a higher level of business performance. The evidence derived from a significant correlation identified between agility (total attainment of competitive objectives) and business performance. A second test of the relationship between agility and business performance was also conducted using a derivative variable defined in the study as the range (difference between two extreme scores) of mean scores on competitive objectives. Companies who paid relatively equal attention to a wider range of competitive objectives would have a lower range of mean scores. A sub-sample of companies who delivered on a wider range of competitive objectives had a lower range of mean scores, and they were identified as high performers. In effect, a significant relationship exists between agility, which was defined earlier in this study as the ability to deliver simultaneously on a wider range of competitive objectives, and the level of business performance. Therefore, higher scores and a lower range of mean scores on a wide range of competitive objectives are achievable through agile manufacturing as a means of boosting business performance (Fliedner and Vokurka, 1997; Silveira and Slack, 2001; Gordon and Sohal, 2001).

The third major objective was to identify agility enablers from several methods of manufacturing competence building and provide the evidence that the agility enablers so identified lead to higher attainment of competitive objectives and business performance. This objective was achieved and its significance arises from the dearth of empirical work on enabling competencies for agile manufacturing.

To this end, companies practices on five dimensions of competence building were measured on multiple scales and presented for factor analysis. Fourteen empirical models of competence building were identified out of which five were justified as agility enablers based on their correspondence with change initiatives suggested in the literature of agile manufacturing. Statistical tests using regression analysis, path analysis and sub-sample tests of mean difference revealed that the agility enablers had positive significant impacts on competitive objectives and business performance measures. The five agility enablers are transparent customisation, agile supply chain, intelligent automation, technology integration and employee empowerment.

In addition to the five agility enablers, the lean supply chain was justified as a sixth agility enabler. This was by virtue of its positive significant impacts on competitive and business objectives, as well as complete absence of negative interaction effect between the lean supply chain and the five agility enablers listed above. The lean supply chain had a wider range of significant impacts on competitive objectives and business performance. This evidence does not mean that the lean supply chain is superior to the agile supply chain but that each one of them is effective. Accordingly, any of the two could be deployed according to the nature of product markets- whether functional or innovative or in support of differences in schedule requirements upstream and downstream (Fisher, 1997; Mason Jones, 2000). Since the lean supply chain and the agile supply chain interacted positively, their integration into the leagile supply chain is justified as being currently debated in the literature (Naylor et. al., 1999; Mason-Jones et. al., 2000; Hoek et. al., 2000). A wider range of impacts exercised by the lean supply chain can also be seen in the light of agile supply chain infrastructures, which are being nurtured and will take some time to permeate practice and bear fruits (Lewis, 2000; Hoek et. al., 2001; Christopher and Towill, 2001).

Besides the lean supply chain, the virtual cell was also identified and justified as an agility enabler. The virtual cell is underpinned by resource sharing and pooling synergy across dedicated product lines and cells. The potentials of the virtual cell as a means of boosting volume flexibility so that small and large volumes become equally profitable, was demonstrated. The virtual cell facilitates overall productivity and responsiveness. This is achieved by focusing attention on just in time mobility of resources as well as workload and capacity flexibility across product lines in response to momentary changes in product mix and volumes (Vakharia and Kaku, 1993; Marsh, 1997).

The seven agility enablers were justified as building blocks for change initiatives towards agile manufacturing design. The agility enablers were compatible, consistent and robust in terms of significant individual and collective impacts exercised on competitive and business performance objectives, which were devoid of negative interaction effects. What remained was how to synthesise the agility enablers in practice.

Especially for companies competing in markets characterised by rapid changes, the challenge of agile manufacturing design is to:

"... Identify correctly the distinctive capabilities that a firm can exploit for competitive advantage and then to put in place the right mix...that must lead to higher levels of performance alongside certain competitive dimensions..." (Fawcett and Myers, 2001:66).

Accordingly, although companies were yet to be fully agile in terms of significant implementation of the agility enablers, Kasarda and Rondinelli (1998) reported General Motors as a success story in the deployment of agile change initiatives.

"General Motors' Lordstown plant, which completed the shift to agile manufacturing in 1993, reduced its lead times by 38 percent, its inventories by 48 percent, and its production floor space by 27 percent"

The need to identify and justify deployable tools for agile manufacturing had been stressed and theorised upon in several works (Sheridan, 1996, Sheridan, 1998; Singletary, 1998; Gunasekaran, 1998; Gunasekaran, 1999, Sharifi and Zhang, 2001). However, no concrete efforts had been taken perhaps due to risk aversion by researchers in the light of the evolving nature of agile manufacturing. To the knowledge of this study, researchers were yet to empirically identify and justify an integrative set of deployable tools for agile manufacturing. In this regard, this research is a novel and leading contribution.

In the light of the aforementioned significant contributions, this research has the potential to provoke similar works on deployable tools and methods. The attendant benefits include reduction of risk aversion in empirical studies of agile manufacturing and better understanding of the "what, how and when" of agile manufacturing. Consequently, the focus would extend beyond discussion of ideas of a general nature and accommodate empirical research on tools and methods, and the evidence that agile manufacturing is superior to alternative operations models such as mass production and lean production. Furthermore, in the light of limited understanding and appreciation of agile manufacturing by practitioners, the time was ripe for empirical work that could demonstrate the splendour of agile manufacturing to industry. Several practitioners and some academicians that the researcher associated with during the course of study wondered what agile manufacturing offered and how it differed from lean production.

With the results of the study and papers already published from it (Appendix 4), doubts and queries on how agile manufacturing differs from lean production may be relevant no longer. The literature review discussed the limitations of lean production and the drivers of agile manufacturing even though several findings of the study support integration of some principles of lean production and its enabling techniques into agile manufacturing. In particular, notwithstanding the levels of cost efficiency associated with lean production, some degree of implementation of the agility enablers is desirable for enhancing responsiveness even for traditionally functional products. This is in order to boost competitive advantage as market stability intensified.

Three other incidental findings of the study are significant. First, the case studies revealed that companies focused more on assembly operations than component manufacture. This is a potential threat to market power as a determinant of competitive advantage, which companies need to accumulate through enhanced value-added to current customers and products (Lewis, 2000). As products become more complex with their secrets and values hidden in modular kit parts, assembly operations would add less value and lose control of the supply chain to component manufacturers (Browne et. al., 1995). In this regard, increasing focus on assembly rather than component manufacture as identified in this study would not augur well for long-term competitiveness of UK manufacturers.

Second, the study showed that supplier relationship remained largely adversarial and arms length in several companies rather than being collaborative and supportive to speedy and transparent customisation of leading technology products. Therefore, lead-time problems persisted and the tendency to hold more stocks was apparent. Adversarial supply chain relations fall short of the agile supply chain in which original equipment manufacturers, suppliers and customers alike operate as seamless chains of resource coalitions. In addition, adversarial supply chain relations could defeat the assured path to future survival, which CEOs of UK manufacturing companies had professed as a mixture of leadership in new technology products and volume flexibility (DTI, 1995). Attainment of these two competitive objectives would demand more collaboration and leverage of global competencies amongst OEMs and suppliers at plant, industry, national and global levels.

In spite of the assured path for future survival that was professed by CEOs of UK manufacturing companies (DTI, 1995), a trade-off between leadership in new technology and volume flexibility was identified as the third incidental finding of the research. This trade-off was explained in terms of increasing practice of market concentration. Under this practice, ahead of the introduction of a leading technology product, a company commits customers and suppliers to large volume contracts of supply, which are called off in small quantities over time. The argument was tendered that market concentration results to manufacturing system design characterised by high volume flow cells, which in turn restricts volume and capacity flexibility. However, with the virtual cell as an essential element of agile manufacturing design, resource mobility and the attendant ease of responding to sudden changes in product volume and mix is enhanced.

It is also noteworthy that the results of this research potentially shift the focus of debate on trade-offs amongst competitive objectives from cost and quality to two more advanced objectives namely leadership in new technology and volume flexibility. Although agile manufacturing seeks simultaneous attainment of competitive objectives, it might be difficult to eliminate all competitive trade-offs (New, 1992; Fisher, 1997; Ward, 1998). However, the results of this study show that dynamic shifts in the locus of the trade-off is crucial so that they involve competitive objectives that are crucial to order winning and market qualification (Ward, 1998; Silveira and Slack, 2001). Cumulative attainment of the two objectives of leadership in new technology products and volume flexibility is crucial to competitive advantage in unstable markets. The extent to which a company advances on them in parallel therefore provides a useful basis for evaluating the impact of change initiatives towards agile manufacturing design.

In spite of the significant contributions chronicled above, the study was far less than a perfect effort and hence, a critique follows next.

6.4. A CRITIQUE OF METHODOLOGY AND RESULTS

This section presents a critique of the methodology and results of the study. It is an assessment of the extent to which research aims were achieved and an acknowledgement of limitations inherent in research methodology and the emerging empirical results.

The goal of identifying and justifying agility enablers was achieved and the study therefore cleared the way for further empirical studies on tools and methods for agile manufacturing. However, the study was rather extensive and perhaps much larger than what should normally constitute a single study for the award of PhD. The researcher was nevertheless committed to visualising a more complete picture of change initiatives that could be deployed as building blocks for agile manufacturing.

In this regard, one major limitation of the results of the study was that due to the dearth of prior empirical research on agile manufacturing, it did not significantly build upon or depart from any prior theory driven empirical work. The study was driven by a conceptual framework made up of four concepts. The framework lacks prior empirical validation whilst the concepts that populated it were yet to have widely acceptable definitions. However, the limitations caused by absence of widely accepted definitions and empirical validation should be understood within the context of the foundation stage that agile manufacturing is in. Such limitations (Sarkis, 2001):

"Should not serve as a barrier for advancement from a practical dimension. Agility is an emerging theory on strategic change...the lack of definition/ theory should not be a hindrance in making advances... "

Accordingly, the study was a search for clues on the relevance of agile manufacturing to UK industrial sectors (Harrison, 1997). As a search for clues, the results should be seen as incomplete and indicative rather than prescriptive. More so, several terms used in the study required more study in order to further reveal their nature and relationships.

Although the research methodology was justified in section 4.1 whilst several tests of validity and reliability were conducted in Section 4.3, the study had some shortcomings in design, methodology and results. The general limitations of surveys by questionnaire including the prevalence of close-ended questions, validity of relative scales relative to absolute scales as well as parametric analysis of ordinal data were recognised in section 4.1 (Ward et. al., 1998; Gordon and Sohal, 2001:238). In addition, the following circumstantial inadequacies expose the results to several errors including measurement and sampling.

Measurement error refers to how well the conceptual framework in Figure 3.1 addressed all relevant issues and the extent to which research instruments emanating from the framework captured appropriate data. Although the conceptual framework was justified, it emerged from the researcher's interpretation of the literature, which was subsequently applied wholesale as a theory of method (Pettigrew, 1990). The researcher's degree of freedom in moving from theory to conceptual, data and result appeared rather too large. This limitation should however be seen in the light of the emerging nature of agile manufacturing and the attendant paucity of applicable frameworks and relationships. Nevertheless, in order to minimise the incidence of measurement error, concepts were measured by multi-item variables, field-based pre-testing of variables was performed whilst content validity, construct validity and data reliability tests were also conducted.

Statistical error was also likely in the use of factor analysis. The clusters of variables used to capture data on the five dimensions of competence building studied as a means of identifying agility enablers were heterogeneous for a single factor analysis. Yet, data and sample screening was not contemplated as they could suppress useful data on the basis of which the agility enablers could be teased out from several other models of competence building in manufacturing. In this study therefore, relationships amongst the agility enablers were not studied elaborately. The focus was on the individual and collective impact of the agility enablers on competitive objectives and business performance measures relative to the impact of alternative models of competence building.

Sampling error also potentially arises from the absence of a systematic definition and justification of the sample frame even though the companies studied were selected randomly from a public database. More importantly, the response rate of 18.16 percent was rather low even as only a handful of one hundred and ten companies were studied. However, non-response bias was found not to be significant. In order to triangulate the research results and reduce the danger of basing conclusions on aggregate data alone, four case studies were conducted but the depth of the studies were constrained by funds and limited time allowed by the companies.

By extension, industrial input to the study was lesser than planned. For the industrial survey, it was estimated that the 110 companies spent ten minutes to respond to the questionnaire. This implied a total of 1,110 minutes, which was less than 20 hours. The quantitative questionnaires for the case studies was expected to take a total of four hours from the four companies studied whilst plants visits lasted only one day per company. The field results could therefore not be stronger than the little that the researcher heard, saw and felt. Perhaps a longitudinal study of change initiatives over a period of three to four years would have been more useful but more time and money would have been required.

The utility of the results of the study is limited by the foregoing discussion of potential sources of errors. However, the empirical relationships identified are useful and indicative of appropriate change initiatives required for survival in increasingly competitive and unstable markets. Nevertheless, it is important to mention that validity of the results is also limited by an elapsed time gap of three years whilst the study lasted even though new developments in industry could only have strengthened rather than weakened the results.

In spite of the foregoing critique of the study, its results and conclusions as enumerated earlier in section 6.3 make significant contributions to knowledge and they would provoke further empirical research in agile manufacturing. In order words, a shift of emphasis from ideas of a general nature to theory driven empirical studies is possible. Having explored and identified the building blocks for agile manufacturing from a range of contingency options in manufacturing competence building, further research should be more focused.

6.5. SUGGESTIONS FOR FURTHER RESEARCH

Therefore, further research is required that will investigate detailed dimensions of each of the agility enablers. Such studies will sharpen and develop the agility enablers into if-then alternatives based on the degree of change proficiency required in different industrial sectors as a determinant of the appropriate doses of agility enablers to be packaged and deployed for enhancement of competitive advantage. Thereafter, comparative studies of relative competitive advantage accruable from the tools and methods of mass production, lean production, mass customisation, time-based competition and agile manufacturing would follow. Such studies aiming to demonstrate the exquisiteness of agile manufacturing can de-emphasise the clean slate approach which populated the literature but instead identify positive change initiatives from current practices in companies. This will make the relevance of agile manufacturing more comprehensible as a concept and as a practical approach to better management and engineering of the manufacturing function.

Still on suggestions for further research, some findings of this research, which were already published (see Appendix 4) but could not be reported in this final thesis, are noteworthy. They revealed negative interaction effects amongst teaming and training (two principal dimensions of total employee empowerment identified in this study) and intelligent automation. Yet, total empowerment of employees and intelligent automation were two of the seven agility enablers identified even as the literature of agile manufacturing focuses more significantly on employee empowerment and intelligent automation. Accordingly, further studies were required that investigate linkages between teaming and training in relation to the type and level of manufacturing automation.

The questions to be asked by such studies would include:

a. What training and teaming practices are prevalent in UK manufacturing companies?
b. What teaming and training practices are compatible with intelligent automation?
c. Are knowledge workers favourably disposed to team practices?

d. Does non-compensating effects between training and teaming restrict competition?

The primary objective will be to make known what elements of teaming, training and intelligent automation are appropriate for plants competing in highly competitive and unstable markets. Such studies would demands plurality of methods involving:

a. A review of the literature of agile manufacturing with a focus on appropriate teaming, training and automation required for boosting competitive advantage.
b. Industrial surveys by questionnaire involving several companies spread across industry.
c. Industrial case studies using an admixture of methods- quantitative and qualitative, retrospective and longitudinal, structured and unstructured interviews administered to multiple audiences, direct observations and archival/ published materials.

The following results from such studies are conceivable:

a. It is likely that Japanese teaming practices as described in the literature of lean production are inappropriate for intelligent automated plants.
b. It is possible that team practices as reported in Japanese plants are incompatible with the British culture of personal pride, freedom and limited interest in third party affairs.
c. A distinction might emerge between specialist and multi-skill training of workers relative to the needs of FMS and IMS.
d. Attainment of competitive advantage should be higher in companies that have mastered negative interaction between teaming and training.

Such further studies will be significant in several respects.

a. They will make novel contributions in the study of organisational innovation, studied from the perspective of employee empowerment through training and teaming, rather than organisational characteristics such as degrees of centralisation and formalisation.
b. Although the literature is rich in studies of employee empowerment, empirical studies of employee empowerment consistent with the needs of IMS engaging in transparent customisation as a means of enhancing survival amidst market instability are rare.
c. Such studies will also reveal the potential importance of integrative studies, especially from the point of view of competition based on resource competencies.

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APPENDIX 1

SURVEY BY QUESTIONNAIRE MATERIALS

COVERING LETTER

Dear Sir,

RESEARCH QUESTIONNAIRE ON AGILE MANUFACTURING

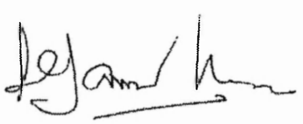
A research project has been commissioned within our department to investigate the adoption and implementation of agile manufacturing principles and develop frameworks for enhanced manufacturing systems.

We would very much appreciate your contribution by completing the enclosed questionnaire. It would be most helpful if you could be as accurate as possible and return your responses within two weeks, using the envelope enclosed.

Most of the questions only require a tick (✓) and this should not take more than five to ten minutes of your valuable time. There are no right or wrong answers as such.

Thanking you so much for your time and support. A summary of the findings of the research can be made available to your company.

Yours sincerely,



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AGILE MANUFACTURING ENTERPRISE STUDY QUESTIONNAIRE

Module 1 General Company Information

1. Name of company ....

2. Name of the respondent (optional) ....

3. Designation (position) of the respondent ....

4. What is the average **annual sales turnover** of your company? Please tick (✓)

   (a) £0 million- £10million. (b) £11million- £30 million. (c) £31million-£50million

   (d) £51million- £100 million. (e) £101 million- £300 million. (f) Above £300million

5. What is the total number of employees in your company? Please tick (✓)

   (a) 1- 50 (b) 51-100 (c) 101-200 (d) 201-300 (e) 301-500 (f) Above 500

6. What is the proportion of employees engaged in design, engineering and manufacturing operations? Please tick (✓)

   (a) Under 30 % (b) 31-50% (c) 51-70% (d) 71-80 % (e) Over 80 %

7. Which of the following (a-f) best describes the pattern of competition in your industry? Please tick (✓).

a. The industry is made up of several companies of relatively equal size.
b. Two large companies dominate the industry
c. Some few large companies dominate the industry
d. The industry is made up of one major company, and several other companies of relatively small size.
e. Any other pattern (please specify) ....

8 What is your company's major line of products? Please tick (✓) <u>only one</u>

Classification of lines of products	Tick (✓)
Automobile and automotive assembly, parts, components, accessories, etc	
Computer, office and communication equipment, components, accessories, etc	
Personal and fashion products like textiles, shoes, bags, soaps, ceramics, etc.	
Electrical and electronics equipment, components and allied products	
Food, drink, chemical, and pharmaceutical products	
Industrial, hospital and agricultural equipment, machines and components	
Aircraft and ship-building assembly, components, accessories, etc	
Any other classification (please specify)..........	

Module 2 Product customisation

9. Please tick (✓) to indicate the relevance of the following bases of differentiating to your company.
   (5) = Very high; (4) = High; (3) = Modest; (2) = Low; (1) = Lowest

Bases of product customisation	(5)	(4)	(3)	(2)	(1)
Unique technical functions					
Packaging and appearance of products					
Customers' ability to pay					
Unique specification of different customers					
Dominant design customised at the point of sale					
Making new technologies available to customers					
Impact on profit					
Any others (please specify)					

Module 3 Magnitude of organisational attention compelled by environmental change drivers

Please indicate by a tick (✓), the magnitude of attention compelled by the following environmental change drivers that impact on business performance.

	Environmental Change drivers	Positive impact	Neutral impact	Negative impact
10.	Advances in manufacturing technologies			
11.	Advances in information technology			
12.	Fast pace of introducing new products			
13.	Increasing emphasis on "made to order" products			
14.	Increase in the intensity of global competition			

Module 4 Direction of change in the performance of your company

Please tick (✓), the direction of change in the following measures of performance in your company in the last three years.

	Business performance measures	Sharp increase	Modest increase	Static	Modest decrease	Sharp decrease
15.	Sales turnover					
16.	Net profit					
17.	Market share					
18.	% of sales revenue from products not more than three years old					
19.	Customer loyalty based on repeat orders					
20.	Performance relative to competitors					

Module 5 Techniques of improving manufacturing operations

Please indicate by a tick (✓) if any of the following techniques that have been used by your company

	Techniques of manufacturing management	Used in the past (✓)	Used presently (✓)
21.	Computerised planning systems- MRP, MRPII or ERP		
22.	Just In Time (JIT) techniques,		
23.	Total Quality Management (TQM)		
24.	Computer Integrated Manufacturing (CIM)		
25.	Business Process Reengineering (BPR)		
26.	Concurrent engineering.		
27.	Co-operative manufacturing		

Module 6 Computer and Information technologies

Please tick (✓) any of the following information technologies that are in **current use** by your company

	Categories of technologies	Tick (✓)
28.	Electronic Data Interchange (EDI)	
29.	Client-server and network technologies	
30.	Computer systems linked to the internet/ intranet	
31.	Computer Aided Process Planning (CAPP)	
32.	Computer Aided Design and manufacture (CAD/CAM)	

Module 7 Characteristics of manufacturing and assembly systems

On a scale of 1-5, please indicate by a tick (✓), the relevance of the following to your company.
(5) = Very high; (4) = High; (3) = Modest; (2) = Low; (1) = Lowest

	Characteristics of Manufacturing systems	(5)	(4)	(3)	(2)	(1)
33.	Cellular arrangement of machines					
34.	Job or project based manufacturing					
35.	Range of automated processes					
36.	Plant mobility- auto guided vehicles and robots					
37.	Intelligent machines that tend to sense, think and see					
38.	Machine flexibility (time and cost of machine change-over and suitability for different operations)					

Module 8 Management of people

Please indicate by a tick (✓) the **emphasis** that your company places on the following practices.

		Very low	Low	Modest	High	V. high
39.	Employee autonomy over routine operations					
40.	Team spirit among workers and departments					
41.	Employees' commitment to work and comp.					
42.	Employees' involvement in decision making					
43.	Skills development and training					

Module 9 Competitive priorities of manufacturing

On a scale of 1-5, please indicate (✓) your company's attainment of the following competitive objectives.
(5) = Very high; (4) = High; (3) = Modest; (2) = Low; (1) = Lowest

	Competitive priorities of manufacturing	(5)	(4)	(3)	(2)	(1)
44.	Product customisation (Variety of product options)					
45.	Volume flexibility (ability to deliver any quantity)					
46.	Low cost					
47.	Leadership in new technology products					
48.	Speedy deliveries					
49.	Product quality					
50.	Dependability (order fulfilment)					

Module 9 Role and importance of alliances

Please indicate by a tick (✓), your company' use of the following supply chain practices.
(5) = Very high; (4) = High (3) = Modest (2) = Low (1) = Very low

	Partnerships and alliances	(5)	(4)	(3)	(2)	(1)
51.	Interaction with competitors					
52.	Customer involvement					
53.	Supplier integration					
54.	Exchange of core competencies					
55.	Alliances motivated by difficult operating conditions					
56.	Collaboration with complementary equals					
57.	Computer-based data exchange with other companies					
58.	Knowledge sharing on design and manufacture					

Module 10 Emerging core capabilities for better performance

59. Please indicate by a tick (✓), your comment on the view that companies need to focus on knowledge management, concurrent operations, adaptable manufacturing processes, and virtual alliances, in order to enhance performance
    a) Strongly agree. b) Slightly agree. c) Neutral. d) Slightly disagree. e) Strongly disagree.

59. Please indicate on a scale of 1-5 the extent to which the following core competencies for effective and responsive manufacturing are relevant to your company's performance.
    (5) = Very high; (4) = High; (3) = Modest; (2) = Low; (1) = Lowest

EMERGING CORE COMPETENCIES IN MANUFACTURING	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Employees' knowledge and skills					
Concurrent or simultaneous conduct of operations					
Effective adaptation of manufacturing facilities and systems					
Networking for exchange of knowledge on design and manufacture.					
Any other capability (please specify)...................					

60. Would your company like to participate in the second stage of this research, which is an industrial case studies involving four companies?

    a) Yes. a) No. c) If only we know the commitments.

THE END - THANK YOU

APPENDIX 2

CASE STUDY INVESTIGATION MATERIALS

1. INITIAL CONTACT LETTER

Dear Sir,

INVITATION TO SECOND STAGE OF RESEARCH

We are writing to invite your company to the final stage of our research on agile manufacturing. The information we gathered earlier by means of the survey questionnaire completed and returned by ...., was most useful and we are really grateful. This second and final stage involves in-depth investigation of the survey results.

The survey results identified two groups of companies in the UK. One group was superior in new technology leadership whilst the second was exceptional in volume flexibility. Between these two groups, seven measures of performance varied significantly. We like to investigate how companies can acquire competence in both capabilities. For this purpose, your company is one of the six identified as most suitable, out of 109 companies surveyed.

The study involves completion of a questionnaire by ten staff members, short interviews with five managers, analysis of published documents as manuals and policy statements, and a guided factory tour. The study will inquire about:

Competitive priorities and improvement initiatives;
Type of technology and work organisation; and
Future plans to improve competitive capabilities.

We assure that the study will not disrupt any plant operation or seek confidential data. In addition, your identity and data will be confidential.

It will be most useful if you could appoint a Research co-ordinator from the manufacturing department, as the chief informant and contact person. Please, kindly send his contact details using the form and envelope affixed.

We appreciate your tight schedules but your support is necessary for us to complete the study. In case you have any queries, please feel free to call us.

Yours sincerely
Ezekiel Adeleye [KELLY]
Research student
Tel. 0115 848 4738

2. CASE STUDY REMINDER LETTER

Dear Sir,

Re: INVITATION TO SECOND STAGE OF RESEARCH

We are writing to remind you about a letter inviting your company to the final stage of our agile manufacturing research.

This final stage involves further study of the survey results in only four companies that were identified as most suitable.

In case you have any concerns over the amount of involvement, the following list shows all that the study involves.

1. The study questionnaires will be mailed to you.
2. When they have been filled in, you would mail them to us, alongside any business, or policy documents that you might wish to share with us.
3. We would thereafter apply for a two-hour visit to your factory. The purpose is to observe and hold an interview with Head of Manufacturing.

We would be very much happy to receive your consent via the attached form.

Yours sincerely,

Ezekiel Adeleye [KELLY]

3. COVER LETTER TO CASE STUDY MATERIALS

Dear Sir,

STUDY MATERIALS FOR FINAL STAGE OF RESEARCH

We are very much grateful for your company's consent to participate in our four-company study. As it was explained earlier, the purpose of the study is to identify common themes to explain some relationships identified in a wider study in which your company participated.

The materials for the studies are enclosed. The variables are several, due to the need to map them into explanatory themes. The value of the study as a contribution to knowledge and practice depends largely on your modest efforts.

The study materials are enclosed. They are arranged in three parts as follows.

1. Manufacturing system questionnaire to be completed independently by between three and five manufacturing managers and/or supervisors.
2. Six open-ended questions for Heads of Department or their assistants.
3. Nine open-ended questions for The Head of Manufacturing or his assistant.

It will be most appreciated if you could send to us, together with the completed questionnaires, any documents or manuals through which we can read and gain better knowledge of your history, ownership, and operational processes.

We are most grateful for your interest and time in spite of your tight schedules.

Yours sincerely,

Ezekiel Adeleye [KELLY]
PhD Researcher

MANUFACTURING SYSTEM QUESTIONNAIRE

TO BE COMPLETED BY A CAREER WORKER IN MANUFACTURING

Please indicate by a dot (•) on a scale from 1 (low) to 7 (high):

A. Your company's current attainment on the following capabilities.

B. Your company's perceived future aspiration on each capability

CAPABILITIES		A. Current attainment							B. Future Aspiration						
		Low		Modest				High	Low		Modest				High
		1.	2.	3.	4.	5.	6.	7.	1.	2.	3.	4.	5.	6.	7.
1.	Lower production costs														
2.	Wider range of models & brands														
3.	Models for all income groups														
4.	First to market with new products														
5.	Leading technology products														
6.	Stable unit cost for all batch sizes														
7.	Sell in mass and custom markets														
8.	Supply any order quantity														
9.	Better after sales support														
10.	Greater on-time deliveries														
11.	Lower delivery lead time														
12.	Superior quality of design														
13.	Higher quality conformance														
14.	Swift response to demand surges														
15.	Lower rework and warranty costs														
16.	Modular/ upgradable products														
17.	Lower production cycle times														
18.	Lower product failure rates														
19.	Manufacture to order														
20.	More multifunctional products														

CHANGE DRIVERS

Please indicate by a dot (•) on a scale from 1 (low) to 7 (high), the impact of the following change drivers on your company's overall performance.

CHANGE DRIVERS		Impacts on overall company performance						
		Harmful			Neutral			Helpful
		←						→
		1.	2.	3.	4.	5.	6.	7.
1.	Competition from foreign products							
2.	High value of the pound sterling							
3.	Formation of manufacturing alliances							
4.	Developments in manufacturing technology							
5.	Developments in information technology							
6.	Fast pace of new product introduction							
7.	Emphasis on custom production							
8.	Growing concern for the environment							
9.	Decline in the life cycle of products							
10.	Customer shifts							
11.	European Union directives							

DIRECTION OF CHANGE IN PERFORMANCE

Please indicate by a dot (•), the direction of change in the following company performance measures over the last five years

CHANGE IN PERFORMANCE MEASURES IN THE LAST THREE YEARS		Sharp decreas e		Modest decreas e	Modest increas e		Sharp increas e	
		1.	2.	3.	4.	5.	6.	7.
1.	Sales turnover							
2.	Profit after tax							
3.	Market share							
4.	% of sales from new products/ models							
5.	Customer loyalty (repeat orders)							
6.	Value-added to throughput							
7.	Utilisation of fixed assets e.g. machines							
8.	Returns accruing to owners of the company							
9.	Process and product innovation							
10.	Employees career prospects and goodwill							
11.	Company's growth and expansion prospects							
12.	Support to community and/or environment							
13.	Overall performance relative to competitors							

4. QUESTIONNAIRE ON SYSTEM DESIGN

Please indicate by a dot (•) in the most appropriate box, the extent to which each of the following factory-design characteristics applies to your company.

SYSTEM DESIGN VARIABLES		Very Low ←		Modest			Very High →	
		1.	2.	3.	4.	5.	6.	7.
1.	Simple machines with low skill requirements							
2.	Complex machines with high training needs							
3.	Small scale general-purpose machines							
4.	Small scale specialised machines							
5.	Specialised large capacity machines							
6.	Machine flexibility for wide range of operations							
7.	Tools and fixtures dedicated to product families							
8.	Easy machine and equipment changeovers							
9.	State of the art manufacturing facilities							
10.	Quick fault reporting and correction system							
11.	Long term product and process innovation							
12.	Capacity Flexibility for changes in demand							
13.	Sequential arrangement of machines							
14.	Cellular layout based on part families							
15.	Movement of WIP across cells							
16.	Movement of skills across cells							
17.	Range of tasks done by workers within each cell							
18.	Use of master production schedules							
19.	Just in time scheduling of orders							
20.	Process redesign costs of new products							
21.	Capacity adjustment costs of change in demand							
22.	Average utilisation rates of machines							
23.	Duplication of machines within cells							
24.	% of total output fully processed in cells							
25.	Total number of cells in the factory							
26.	Average number of parts processed in each cell							
27.	Average number of end-products fully manufactured in each cell							
28.	Range of human skills required per cell							
29.	Diversity of skills required per cell							
30.	Balanced workload across the cells							

5. SUPPLY CHAIN QUESTIONNAIRE

Please indicate by a dot (•) in the most appropriate box, the extent to which each of the following relationships apply to your company.

SUPPLY CHAIN		Very Low			Modest			Very High
		1.	2.	3.	4.	5.	6.	7.
1.	Long term contracts with suppliers							
2.	Open competitive tendering for supplies							
3.	Materials delivered just in time to the plant							
4.	Electronic links for paperless transactions							
5.	Suppliers' role in continuous improvement							
6.	Suppliers' role in new product introduction							
7.	Suppliers act in partnership and share risks							
8.	Suppliers' commitment to contract terms							
9.	Automatic reordering systems with suppliers							
10.	Automatic reordering systems with customers							
11.	Investment in supplier companies							
12.	Programmes in aid of major suppliers							
13.	Regular review of contracts terms							
14.	Suppliers guarantee for quality of inputs.							
15.	Guaranteed supply of arbitrary order quantities							
16.	Suppliers' lead times							
17.	Joint bidding for contracts with competitors							
18.	Collaborative product design with competitors.							
19.	Sub-contracting with competitors							
20.	Sharing of plant facilities with competitors							
21.	Collaborative product design with customers							
22.	Risk sharing by suppliers and customers							
23.	Supplier participation in problem solving							
24.	Customer participation in product design							
25.	Computer-aided information sharing with competitors							
26.	Computer based knowledge sharing with competitors							

6. MANUFACTURING TECHNOLOGY

Please indicate by a dot (•) in the most appropriate box, the level of your company's adoption of each of the following technologies and methods.

	MANUFACTURING TECHNOLOGIES	Low, not important		Medium		High, critically important		
		1.	2.	3.	4.	5.	6.	7.
1.	Just in time purchasing and job scheduling							
2.	Continuous process improvement teams							
3.	Company-wide total quality management.							
4.	Preventive maintenance on key machines							
5.	Large capacity specialised machines							
6.	Standalone CNC machines							
7.	Computer integrated CNC machines							
8.	Integrated CAD/CAM systems							
9.	Materials moved by automated vehicles							
10.	Automated storage and retrieval systems							
11.	Automated assembly of end products							
12.	Mobile and intelligent robots							
13.	Use of robots in repetitive tasks like painting							
14.	Automated process control of quality							
15.	Material Requirements planning (MRP) systems							
16.	Manufacturing resource planning (MRPII)							
17.	Enterprise resource planning systems (ERP)							
18.	Computer-aided process planning							
19.	Standalone workstations performing a number of operations simultaneously							
20.	Machines and workstations integrated into a single flow or assembly line							

7. FLEXIBILITY QUESTIONNAIRE

Please indicate by a dot (•), your company's current capabilities and future aspirations on the following measures of operational flexibility.

MEASURES OF OPERATIONAL FLEXIBILITY		Current capabilities					Future aspirations				
		Low ◄				High ►	Low ◄				High ►
		1.	2.	3.	4.	5.	1.	2.	3.	4.	5.
1.	Easy adjustment of machines to manufacture a wide range of end-products										
2.	Ability to manufacture standardised and customised product models in parallel										
3.	Ease of manufacturing new products without additional investment in equipment										
4.	Alternative operations routes and sequences										
5.	Ease of re-routing production at minimal cost in order to balance workload										
6.	Ease of re-routing production at minimal cost when a machine fails.										
7.	Ease of adjusting volume of production to random fluctuations in customer demand										
8.	Ease of adjusting volume of production to turbulent customer shifts										
9.	Manufacture of different batch sizes at same unit cost										
10.	Workers' s adaptability to different tasks										
11.	Adjustability of number of employees										

8. EMPLOYEE EMPOWERMENT QUESTIONNAIRE

Please indicate by a dot (•) in the most appropriate box, the level of your company's attainment of each of the following organisational variables.

ORGANISATION EMPOWERMENT		Very Low ←			Modest			→ Very High
		1	2	3	4	5	6	7
1.	Responsibilities vested in interdisciplinary teams in relation to functional departments.							
2.	Management by peer consensus as against superior authority							
3.	Harmony among functional departments and project teams							
4.	Operators' influence in job routing and scheduling decisions							
5.	Free flow of knowledge amongst workers							
6.	Operators' influence in continuous improvement initiatives							
7.	Power of team leaders in relation to team members							
8.	Employees responsibility for tools, methods and quality							
9.	Leadership skills of supervisors and foremen							
10.	Professional skill of core managers and technicians							
11.	Workers' satisfaction with automated machines							
12.	Implementation of employees' suggestions							
13.	Proportion of working hours allocated to training							
14.	Opportunities to utilise knowledge acquired from training							
15.	Emphasis on on-the-job training							
16.	Reward for diversity of employees' knowledge and skill							
17.	Training through job rotation and secondment							
18.	Employees' satisfaction with pay and remuneration							
19.	Pay and promotion based on technical competence							
20.	Pay and promotion based on level of responsibility							
21.	Satisfaction with work pressure and working hours							
22.	Job security and life-long career opportunities							
23.	Safeguards against dangerous exposures and accidents							
24.	Employees' commitment to their work and the company							
25.	Social interaction amongst employees							

ELEVEN OPEN-ENDED QUESTIONS FOR THE HEAD OF MANUFACTURING

QUESTION 1

What major innovations have been introduced over the last five years in order to cope with changing customer preferences and product complexity?

QUESTION 2

What major initiatives have been introduced to make small batch manufacture more economical and profitable?

QUESTION 3

What major changes have been introduced to reduce the level of inventory of raw material, work in progress and finished goods?

QUESTION 4.

In the light of effort made to reduce inventories, how does your company cope with surges in customer demand?

QUESTION 5

5a. To what extent are your operations automated?

5b.
Specifically, to what extent would your describe your plant as consisting of rigid dedicated lines, flexible manufacturing systems (FMS) or intelligent manufacturing systems (IMS).

5c. How does the type of machine system affect ability to manufacture any volume of customer's order?

5d. What overriding considerations, for example, cost, quality and flexibility influence decisions on automation in your plant?

5e.
To what extent do you consider the type of machine system (dedicated, FMS or IMS) currently being used as adequate? What changes are likely in the next few years?

QUESTION 6

6a.
How does the type of machines used in your plant (rigid dedicated lines, FMS or IMS) determine skill and training requirements?

6b.
How does the type of machines used in your plant (rigid dedicated lines, FMS or IMS) determine team practices?

QUESTION 7

In an effort to enhance responsiveness to customer requirements, several companies are empowering their employees through training, teaming and delegation.

(a). What exactly does employee empowerment mean in your plant?

(b). Do you experience any conflicts in training and teaming needs and practices?

QUESTION 8

Several plants are redesigning manufacturing systems from batch to cellular manufacturing, in which machines are dedicated to product families.

8a.
To what extent and for what purposes is your factory part of the transition?

8b.
What costs or penalties can you attribute to the transition?

8c.
Much more specifically, how does the transition to cellular manufacturing enhance or restrict ability to manufacture any batch or order quantities?

QUESTION 9.

What changes have been introduced over the last five years in your company's relationships with the following stakeholders? What lessons were learnt?

9a. Relationship with customers

9b. Relationship with suppliers

9c Relationship with competitors

QUESTION 10.

Manufacturers are widening the brands and models of available products in an effort to extend market share. However, speculation is rife that such efforts add more to cost than to revenue and that new products should be transparent in added value.

10a
In the light of these concerns, how does your company differentiate its various models and brands from one another, and from the products of other plants?

10b
To what extent would you describe your order winning capabilities as cost driven, quality driven, flexibility driven, technology driven or speed driven?

10c
What short-term and longer-term innovation is necessary in order to enhance your ability to win more customers and orders in the next five years?

QUESTION 11.

What new technologies are crucial in winning more customers in the next few years?

SIX OPEN-ENDED QUESTIONS FOR ANY TWO DEPARTMENTAL HEADS OUTSIDE THE MANUFACTURING FUNCTION

(A) MARKETING
(B) PRODUCT DESIGN GROUP
(C) MANAGEMENT ACCOUNTS
(D) INFORMATION TECHNOLOGY
(E) PURCHASING

QUESTION 1

In about the last 5 years, what major windows of opportunity opened for your company and what changes in operational activities did they compel on your department?

QUESTION 2

In about the last 5 years, what major crises from the business environment threatened your company? What new operational initiatives did the crises compel on the activities of your department? What lessons were learnt?

QUESTION 3

In about the last five years, what other initiatives were introduced in your department, with a view to facilitating speedy response to changing market and customer requirements?

QUESTION 4

Please identify and expatiate on some currently unavailable methods and technologies, which are crucial in your department's efforts to enhance the company's performance.

QUESTION 5

What improvements and innovations are crucial in your department's operations so that your company can continue to win more customers' orders in the next five years?

QUESTION 6

Over the last five years, what changes have evolved in your department's relationship with the manufacturing department, with a view to enhance productivity and timely response?

APPENDIX 3

CASE STUDY QUANTITATIVE SCALES RETAINED

CHANGE DRIVERS	Impacts on business performance	
	Most harmful	Most helpful
Competition from foreign products	A, B, D	
High value of the pound sterling	A, B, C, D	
Manufacturing technology advances		B, C, D
Advances in information technology		A, D
Speedy introduction of new products	D	A, B, C
Emphasis on custom production		B, C
Customer shifts	A, B, C, D	
European Union directives	A, B	

COMPETITIVE OBJECTIVES	Current attainment		Future aspirations	
	Low end	High end	Low end	High end
Lower production costs				B, C, D
First to market with new products	A, B			A, B, C, D
Leading technology products		A, C		A, B, C
Better after sales/ tech support		A, C, D		A, C, D
Greater on-time deliveries				A, B, C, D
Lower delivery lead time				A, B, C, D
Superior quality of design		B, D		B, C, D
Higher quality conformance		B, C		B, C, D
Swift response to demand surges		C		A, C, D
Lower rework and warranty costs				C, D
Modular/upgradeable products				B, C
Lower production cycle times				C, D
Lower product failure rates				C, D
Manufacture to order		B, C		B, C, D

Direction of change in business performance measures in the last five years	Sharp decrease	Sharp increase
Sales turnover	D	B
Profit after tax	A, D	B
Market share	D	
Customer loyalty (repeat orders)	D	B
Value-added to throughput		B, C
Utilisation of fixed assets e.g. machines	D	C
Returns to company owners		B
Process and product innovation		C
Growth and expansion prospects		A, C
Support to community or environment	B	
Performance relative to competitors	D	

Manufacturing system design (Unifying scales)	Low end	High end
JIT purchasing and scheduling		B, D
Company-wide TQM		B, C, D
Operators' continuous improvement initiatives		C, D
Easy machine and equipment changeovers		A, C
Standalone CNC machines	A, B, D	
Computer integrated CNC machines	A, B, D	C
Integrated CAD/CAM systems	A, D	
Materials moved by automated guided vehicles	A, B, C, D	
Automated storage and retrieval systems	A, B, C, D	
Use of robots in repetitive tasks	A, B, D	
Automated process control of quality	A, B, D	C
Computer-aided process planning		B, C
Standalone workstations operating in parallel	A	B, C, D
Workstations integrated into flow lines		A, B, C, D
Sequential arrangement of machines	D	A, B, C
Output (%) not fully processed in cells		B, C
Tools/ fixtures dedicated to product families	B	A, C, D
Capacity flexibility for demand changes		A, C, D
Range of skills required within each cell		C, D
Complex machines with high training needs	B, D	
Small scale specialised machines	B, D	
Movement of work in progress across cells	A, C	
Movement of skilled workers across cells	A, C	
Machine duplication within cells	A, B	
Professional skill of managers and technicians		A, D
Emphasis on on-the-job training		B, D
Safeguards against exposures and accidents		B, C
Peer consensus as against superior authority	A, B	
Harmony among departs and project teams	C, D	
Operators' influence on job routing/ scheduling	C, D	
Free flow of knowledge amongst workers	C, D	
Power of team members relative to leaders	A, C, D	B
Working hours (%) allocated to training	A, B, C, D	
Satisfaction with work pressure and hours	B, C	
Long term contracts with suppliers	B	A, C, D
Open competitive tendering for supplies		B, C, D
Materials delivered just in time to the plant		B, C
Suppliers' role in continuous improvement		A, C, D
Suppliers' role in new product introduction		A, C, D
Suppliers' lead time requirements		B, C
Investment in supplier companies	A, B	
Joint bidding for contracts	A, D	
Collaborative product design and manufacture	A, B, D	C
Sub-contracting with competitors	B, C, D	
Sharing of plant facilities with competitors	A, B, C, D	
Risk sharing by suppliers and customers	A, B, C	
Supply chain information networking	B, C, D	
Knowledge sharing with competitors	B, C, D	

Operational flexibility measures	Current capabilities		Future aspirations	
	Low end	High end	Low end	High end
Easy adjustment of machines to manufacture a wide range of end-products				A, B, C
Ability to manufacture standardised and customised product models	A, D	B, C		B, C
Manufacture new products without additional investment in equipment				A, B, C
Alternative operations routes and sequences	A, B, D		A, D	B, C
Ease of re-routing production at minimal cost in order to balance workload				B, C
Ease of re-routing production at minimal cost when a machine fails.	B, C, D		D	A, B, C
Ease of adjusting volume of production to random fluctuations in customer demand	C, D		B	A, D, C
Ease of adjusting volume of production to turbulent customer shifts	B, D		B	C, D
Flexible batch sizes at same unit cost			B	A, D
Workers' s adaptability to different tasks		A, D		A, B, C, D
Adjustability of number of employees	B, C			A, B, D

APPENDIX 4

PUBLICATIONS FROM THE RESEARCH

The interim outcomes of research being reported in this thesis have been presented in a number of national and international conferences and they were published in the conference proceedings. Specifically, seven papers were presented and published. Three of the papers were extended and submitted for journal publication. One of the three papers has been accepted for publication while the remaining two were returned for modification and re-submission. The three papers were submitted to the International Journal of Operations and Production Management, Integrated Manufacturing Systems and the International Journal of Production research.

The following are the details of refereed conference and journal papers submitted for publishing including those already accomplished and those in progress.

A. Conference Papers already published

Adeleye, E. O., Yusuf, Y.Y. and Sivayoganathan, K., 1999. Agile Manufacturing: Towards a contingency theory". In Advances in Manufacturing Technology, Bramley A.N. et al ed. Proceedings of the 15th National Conference on Manufacturing Research. University of Bath, UK, 6-8 September, 265-270.

Adeleye, E. O., Yusuf, Y.Y. and Sivayoganathan, K., 2000. Leanness, Agility and Manufacturing Performance in the UK. In Responsive Production and the Agile Enterprise, Forrester, P. et al. ed. Proceedings of the 4th International Conference on Managing Innovative Manufacturing. Aston Business School, Birmingham, 17-19 July, 19-27.

Adeleye, E. O., Yusuf, Y.Y. and Sivayoganathan, K., 2000. Towards Agile Manufacturing: An Exploratory Study of Models of Competition and Performance Outcomes in the UK. Proceeding of the 16th International Conference on Production Research, Czech Technical University, Prague, 30 July - 3 August. [CD ROM]

Adeleye, E. O., Yusuf, Y.Y., Sivayoganathan, K. and Al-Dabass, D., 2000. An exploratory study of the impact of automation and employee empowerment on competitive capabilities.

Proceedings of the 16th International Conference on Production Research, Czech Technical University, Prague, 30 July - 3 August. [CD ROM]

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C. Refereed Journal Paper [Already accepted and forthcoming]

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