ANALYSIS OF THE UNDERSTANDING OF FLEXIBLE MANUFACTURING IN THE AUTOMOTIVE COMPONENT INDUSTRY AND SELECTION OF BEST IMPLEMENTATION STRATEGY

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DECLARATION

"I, Clive Mostert, hereby declare that:

- **The work in this dissertation is my own original work;**
- **All sources used or referred to have been documented and recognized; and**
- **This dissertation has not been previously submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification at any other recognized education institution."**

_____ _____

Clive Mostert **DATE**

ABSTRACT

In a competitive manufacturing environment a firm must be able to simultaneously produce multiple and diverse products, upgrade and redesign its products in short life cycles, and execute efficient production changeovers. This implies that the firm's manufacturing facilities should be capable of efficiently responding to the changes associated with the above abilities. These capabilities are a key requirement for building an agile manufacturing enterprise. To successfully attain these capabilities a firm must evaluate and build flexibility in its manufacturing operations. Success in manufacturing requires the adoption of methods in customer acquisition and order fulfilment processes that can manage anticipated change with precision while providing a fast and flexible response to unanticipated changes.

A review of the related literature reveals that though there has been considerable research on the subject of flexible manufacturing, insufficient attention has been devoted to the development of a comprehensive method for designing and building flexible manufacturing (FM) solutions. A significant portion of the FM research and the ensuing industrial applications have focused on highly automated metal working facilities, commonly referred to as flexible manufacturing system or FMS.

The objective of this research was to understand what the general understanding of FMS is in the automotive component supplying industry as well as to develop a strategy based on world class principles on how to implement such a strategy. The established strategy will then be used to implement a FMS at Shatterprufe a division of the PFG group. A comprehensive literature study was conducted on Flexible Manufacturing to get a good idea on what it is all about.

A questionnaire was designed based on the guidelines in the literature study in order to establish the understanding of FMS within companies in the automotive component supplying industries. Twenty five companies were selected, based on their employee numbers and potential high complexity in the parts that they manufacture. Participating companies must also be part of National Association of Automotive Component and Allied Manufacturers (NAACAM) and supplying directly to all of the local Original Equipment Manufacturers (OEM's).

Eighteen out of the twenty five companies selected did participate and return the questionnaires. Three companies replied stating that they do not have a FMS in

place and thus do not want to participate in the research. The completed questionnaires were processed and analysed using Microsoft Office Excel 2003, running on the Windows XP suite of computer packages.

The opinions of the various respondents were compared with the guidelines provided in the literature survey, in order to identify how to answer the main questions the author wanted to use as part of selecting an appropriate implementation approach for FMS at Shatterprufe.

The following were the main recommendations and conclusions:

- It is essential that the executive team at Shatterprufe realises the need of a FM programme. Based on the analysis from the theoretical research as well as from the questionnaire it should not be difficult for them to realise this;
- It is recommended that the knowledge gained from the research theory and that of the research questionnaire be used as a guideline for introduction and implementation;
- It is recommended that the employees that will be required to implement the FMS are properly trained in the basics of WCM and FMS and that they receive the necessary tools to perform their tasks;
- It is essential that everyone throughout the entire organisation is involved from the start in the development, improvement and maintenance of the system;
- It is critical that the barriers to implementation be taken seriously at the start of the whole implementation process and plans be put in place to overcome them. Make sure that there is:

    - proper understanding of the total effort required;
    - complete management support;
    - union buy-in;
    - enough training carried out;
    - change of priorities;
    - full commitment and persistence;
    - development of a good installation strategy; and
    - insurance of choosing the right approach.

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TABLE OF CONTENTS

LIST OF ABBRIVIATIONS

AVG	–	Average
CAD	–	Computer Aided Design
CAM	–	Computer Aided Manufacturing
CAPP	–	Computer Aided Production Planning (CAPP)
CEO's	–	Chief Executive Officers
e.g.	–	for example
etc.	–	and so on
FM	–	Flexible Manufacturing
FMS	–	Flexible Manufacturing System
FMSD	–	Flexible Manufacturing Systems Design
GM's	–	General Managers
i.e.	–	that is
I.E.	–	Industrial Engineering
IT	–	Information Technology
MD	–	Manufacturing Director
NAACAM	–	National Association of Automotive Component and Allied Manufacturers
OEM	–	Original Equipment Manufacturer
SA	–	South Africa
SMED	–	Single Minute Exchange of Die
SWOT	–	Strengths, Weaknesses, Opportunities, and Threats
WCM	–	World Class Manufacturing

LIST OF DIAGRAMS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

LIST OF APPENDICES

CHAPTER 1

PROBLEM DEFINITION AND DEFINITION OF KEY CONCEPTS

1.1 INTRODUCTION

In a competitive manufacturing environment a firm must be able to simultaneously produce multiple and diverse products, upgrade and redesign its products in short life cycles, and execute efficient production changeovers. This implies that the firm's manufacturing facilities should be capable of efficiently responding to the changes associated with the above abilities. These capabilities are a key requirement for building an agile manufacturing enterprise. To successfully attain these capabilities a firm must evaluate and build flexibility in its manufacturing operations. Success in manufacturing requires the adoption of methods in customer acquisition and order fulfillment processes that can manage anticipated change with precision while providing a fast and flexible response to unanticipated changes, according to Fulkerson (1997:199).

There are only a few approaches or theories that a firm may pursue in increasing the flexibility of its manufacturing operations. Firms that have traditionally prospered under the paradigm that “minimal change" and “minimal variety" lead to high productivity are thus finding it difficult to initiate flexibility efforts. In many instances, these firms have discovered that high levels of automation and a large capital investment do not necessarily translate into flexibility. What these firms need is an approach that will enable them to identify specifically what type of flexibility they need, and to what extent that flexibility is needed. Subsequently, they need methodologies that will help them incorporate flexible manufacturing in their operations.

Although there is no predominate definition of flexible manufacturing that currently exists, current definitions are similar in that they are concerned with a manufacturing system’s capability at addressing this uncertainty for adaptive, proactive, or strategic reasons.

General definitions of manufacturing flexibility include “being able to reconfigure

manufacturing resources so as to produce efficiently different products of acceptable quality" (Sethi and Sethi, 1990:290), "a system's capability to cope with a wide range of possible environmental changes", (Hyun and Ahn, 1992:251), and "the ability of a manufacturing system to change or react with little penalty in time, effort, cost, or performance", (De Toni and Tonchia, 1998:1587).

As a result of its multidimensional nature, manufacturing flexibility is not generic and cannot simply be bought, plugged in, and forgotten, thus meaning that the process cannot just be copied from somewhere else. Instead, manufacturing flexibility must be carefully justified, planned and managed in order to be successfully implemented and its potential benefits fully realised.

In flexible manufacturing theory the relevant literature can be classified into two categories, namely; flexibility types and flexibility measurement. A number of different propositions for defining flexibility types can be found in the literature, including the works of Gupta and Goyal (1989:119), Sethi and Sethi (1990:289), Suarez, Cusumano and Fine (1995:25), Olhager (1993:67) and Benjaafer and Ramakrishnan (1996:1195). These identified flexibility types typically refer to different elements and attributes of a production facility, such as machine, product, processing, operation, routing, capacity, expansion, failure, design, and system. A variety of schemes for classifying these different flexibilities have been proposed in the literature. These schemes have classified flexibility on the basis of product or process components, system operations, and aggregates, Taymaz (1989:1891); Sethi and Sethi (1990:289) and long and short term needs, Slack (1987:35); Gupta and Goyal (1989:119). In surveys by Lim (1987:44) and Slack, the following five types of flexibility seemed to be most important:

1. Machine flexibility. This refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another.
2. Routing flexibility. The routing flexibility of a manufacturing system is its ability to manufacture a product by alternative routes through the system.
3. Process flexibility. The process flexibility of a manufacturing system refers to the set of product types that the system can produce without major setups.
4. Product flexibility. The product flexibility is the ease with which new products

can be added or substituted for existing products.

5. Volume flexibility. The volume flexibility of a manufacturing system is its ability to be operated economically at different overall output levels.

In the field of flexibility measurement several measures for the aforementioned types have been proposed. Among these measures are those by Gustavsson (1984:801), Son and Park (1987:35), Mandelbaum and Buzacott (1986:119), Hutchison and Sinha (1989:47), Brill and Mandelbaum (1989:747), Schneeweiss and Kuhn (1991:80), Abdel-Malek and Wolf (1991:3) and (1994:37), Das and Nagendra (1993:2337), and Sarker, Krishnamurthy and Kuthethur (1994:512). The measures by Das and Nagendra and Abdel-Malek and Wolf are the basis for flexibility measurement in the Flexible Manufacturing Systems Design (FMSD) method. In designing measures for manufacturing flexibility it has generally been assumed that there will be only one measure for each flexibility type. Das (1996:67) introduced the concept of multiple levels of flexibility. In his five level model, level 1 is the needed flexibility, which is a function of the set of states the facility needs to attain, if it is to successfully counter all of the expected environmental changes. Level 2 is capability flexibility, which is a function of the set of states the facility is equipped to attain. Level 3 is the actual flexibility exhibited by the facility, and is always described with reference to some period of time. That is, the actual flexibility exhibited today is different from what will be exhibited tomorrow. Level 4 is the inflexibility of the facility, which is a function of the gap between the necessary flexibility and capability flexibility. Finally, level 5 is the optimum flexibility. It is noteworthy that the problem of isolating the specific flexibility needs of a given facility, despite its importance, has been relatively less investigated. In this regard, Jensen *et al*. (1996:19) illustrated the use of machine flexibility to deal with demand uncertainty, while Jordan and Graves (1995:577) proposed the concept of limited routing flexibility to handle various changes.

A few research papers report on the relationship between innovation and product manufacturing. From a review of the related literature it is observed that a disciplined process approach to innovation needs to replace the traditional trial-and-error method. Also, the emphasis should be on the need for documentation, since innovators are so busy coming up with ideas that they do not focus on improving and

recording the process. In general we can define technological innovation as function of two attributes: degree of newness and value creation. These two attributes are used to classify innovation into three types: incremental, substantial and transformational. Lefebvre *et al*. (1995:533) report on the benefits of innovation when adapting computer based technologies in administrative and production application in manufacturing firms. Their research shows that firms that are technologically innovative adapt more rapidly to market changes.

1.2 MAIN PROBLEM

The role of flexibility in the manufacturing strategy of organisations has been highlighted by many researchers. Early work by Skinner (1969:136) also identifies manufacturing flexibility as one of four manufacturing objectives, with other objectives comprising production costs, delivery, and quality. More recent research considers flexibility as a "competitive priority" that must be considered alongside other such priorities, specifically production and distribution costs, quality, delivery dependability, and delivery speed as also explained by Davies and Kochhar (2002:289); Dangayach and Deshmukh (2001:884); Cox (1989:68); Gerwin (1987:38); Wheelwright (1981:77). Previous research suggests that manufacturing objectives can be achieved by aligning these priorities with the requirements of the marketplace, Llore´ns-Montes, Garcı´a-Morales and Verdu´ -Jover (2004:525); Davies and Kochhar (2002:289); Dangayach and Deshmukh (2001:884); Kerr and Greenhalgh, 1991:196).

For having a sufficient Flexible Manufacturing System in place, various facets must be addressed. According to Slack (1988:27) the first facet to address consists of defining the organisation's flexibility requirements, secondly conducting a flexibility audit and lastly developing a flexibility action programme.

Similar to Slack, Suarez *et al*. (1991:50) suggest a three-stage approach for achieving manufacturing flexibility as well. However the three stages according to Suarez *et al* are: the need for flexibility, the implementation of flexibility, and the flexibility fit between required and actual flexibility.

Gerwin (1993:395) on the other hand proposes a sequence of four steps or phases for implementing manufacturing flexibility, specifically identifying flexibility

dimensions requiring investigation, measuring gaps, selecting methods for closing gaps, and continuous assessment.

The main problem to be investigated then is:

Does the motor component supplying Industry make use of Flexible Manufacturing Systems to assist them in being world class suppliers?

1.3 SUB PROBLEMS

- How does the literature define Flexible Manufacturing System
    - What elements does it consist of?
- Do the motor component supplying companies understand what flexible manufacturing is?
- What implementation approach would be seen as best practice for implementing a Flexible Manufacturing System?

1.4 DEMARCATION OF THE RESEARCH

In this study the empirical research will focus on motor component supplying organisations within South Africa (manufacturers supplying directly to the Original Equipment Manufacturers [OEM's]).

1.4.1 Size of organisations

All companies surveyed belong to the National Association of Automotive Component and Allied Manufacturers (South Africa) (NAACAM).

Companies selected will have a minimum of 200 employees working for them with most of them being part of an International group.

Each of the organisations selected have a wide variety of parts that they supply with a medium to very high manufacturing complexity in terms of diversity.

Manufacturing in each facility is grouped into the following major functional departments:

- Incoming raw material warehousing
- Production (various value adding processes transforming raw materials into finished goods)
- Warehousing and distribution of final completed products

- Production support departments (Quality; Logistics; New Part Development; Industrial Engineering; Finance and Engineering / Maintenance as a minimum).

1.4.2 Geographical demarcation

The empirical component of the study will be limited to, as stipulated above, only motor component supplying organisations within South Africa (SA). The majority of these companies are located in the Eastern Cape and Gauteng areas. This is mainly due to the location of the OEM's in the same area.

1.4.3 Management levels

The research questionnaire is aimed at the General Managers Manufacturing or Manufacturing Director (MD) level. In some cases Chief Executive Officers (CEO's) of the relevant organisation will also be asked to complete the questionnaire. However it is only required of one of these managers of a company to complete the questionnaire. The aim of this is to involve the decision / strategy makers in the various organisations. For ease of analysis the different management levels will be broken up as 1 = Senior Manager; 2 = General Manager and 3 = MD / CEO.

1.5 DEFINITION OF KEY CONCEPTS

1.5.1 Assessment

Assessment is the process of documenting, usually in measurable terms, knowledge, skills, attitudes and beliefs. According to Meyer and Botha (2000:21), assessment requires a consultative approach which requires the following skills:

- Determine data collection process & types/amount of data sought.
- Utilise appropriate mix of method and technology to ensure: efficiency (speed), objectivity, comparability and validity.
- Clarify boundaries of confidentiality and select a process that will: facilitate openness.
- Result in a common database.

- Represent the total system.
- Gather data: bring out existing dissatisfaction, Identify future states of change and then identify first steps of transition.
- Reduce fear of openness or vulnerability.
- Watch for new and deeper issues.
- Suspend judgment and know when you have enough data.
- Suppress hurtful comments (Meyer & Botha, 2000:22).

1.5.2 Flexible Manufacturing System

General definitions of manufacturing flexibility include “being able to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality”, (Sethi and Sethi, 1990:289), “a system’s capability to cope with a wide range of possible environmental changes”, (Hyun and Ahn, 1992:251), and “the ability of a manufacturing system to change or react with little penalty in time, effort, cost, or performance”, (De Toni and Tonchia, 1998:1587).

Wikipedia, (www.wikipedia.com) however, defines a Flexible Manufacturing System (FMS) as a manufacturing system in which there is some amount of flexibility which allows the system to react in the case of change, whether this is predicted or unpredicted. The flexibility is generally considered to fall into two categories, within which are numerous other subcategories.

The first category is machine flexibility that covers the system’s ability to be changed to produce new product types and ability to change the order of operations executed on a part.

The second part of flexibility within an FMS is called routing flexibility, which consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes, such as in volume, capacity, or capability.

According to Wikipedia the whole FMS is commonly controlled by a central computer.

1.5.3 Strategy

The strategy of an organisation is affected by the values and expectations of those who have control in and around it. Strategy can be thought of as an indication of the attitudes and beliefs of those who have most influence in an organisation. Whether a company is expansionist or more concerned with consolidation, and where the boundaries are drawn for a company's activities, may say much about the values and attitudes of those who influence strategy – the stakeholders. There are also other stakeholders such as financial institutions, the workforce, buyers and suppliers who also have an influence on strategy. Therefore for the purpose of this research, strategy can be defined as the direction and scope of an organisation over the long term, which achieves advantage for the organisation through its configuration of resources within a changing environment and to fulfill stakeholder expectations (Johnson & Scholes; 2003; 9).

1.5.4 World Class Manufacturing

Swinehart, (2000:46) summarizes the definition of world class manufacturing (WCM) as a manufacturing philosophy or ideology that is used to achieve world class manufacturer status. He further states that the essence of WCM philosophy is continuous improvement involving everyone in the organisation and that organisations that adopt this philosophy constantly seek opportunities for improvement in such key competitive areas as quality, cost, delivery, flexibility, and innovation.

1.5.5 Continuous Improvement

Logathesis (1992:19) state that there is a Japanese word describing the approach to gradual process improvement involving everybody. This word is kaizen and it is Japanese for continuous improvement. There are two distinct features inherent in the kaizen philosophy:

- There is urgency about the never ending efforts for improvements and gradual change for the better. It is within this feature that total productive maintenance is very important; and
- There is an emphasis on the process rather than on the output.

Richard Schonberger (1982:92), author of World Class Manufacturing, suggests continual and rapid improvement as an overriding goal for world class manufacturing. Further to this Masaaki Imai, the author of KAIZEN, points out that KAIZEN (which means gradual, never-ending improvement, doing "little things" better; setting and achieving ever higher standards) is the key to any organisation's competitive success.

1.6 KEY ASSUMPTIONS

The following assumptions are made:

1.6.1 Assumption 1

With an ever strengthening Rand and continual pressure from all OEM's, all motor component supplying companies need to strengthen their global competitiveness, heighten innovation, improve quality of products and services, and increase the responsiveness of the organisation to the needs and wants of customers and constituents.

1.6.2 Assumption 2

Management of the researcher's company also wishes to learn from the outcome of the assessment that will be done on FMS. Based on outcome of the theoretical analysis on best possible implementation strategies, clear work packages will be established to address deficiencies in their current system and even the consideration of a re-implementation programme.

1.7 SIGNIFICANCE OF PRIOR RESEARCH

The first step in the research was to undertake an in depth literature search on Flexible Manufacturing Systems. Particular attention was given to already established frameworks that clearly define set procedures / steps to be followed during the implementation of such a process. Sub focus was also to establish the impact of such systems on the financial results of an organisation. The literature

search entailed the usage of various library facilities to acquire relevant and appropriate sources of information. An online search through EMERALD, EBSCO host and Google databases were also conducted to obtain relevant indices.

A substantial amount of literature dealing with manufacturing flexibility has accumulated over the last ten years. The major part of this literature is devoted to defining various types of flexibilities and identifying systems that exhibit one or more of these. Some papers also deal with the issues of the measurement and or valuation of the various flexibilities. According to Ettlie (1988:63), few rigorous systematic treatments of the topic of flexibility in manufacturing, let alone empirical studies of actual manufacturing plants, have been reported that give a coherent statement of the strategic as well as tactical implications of this important dimension of manufacturing strategy. The literature makes one thing abundantly clear: flexibility is a complex, multidimensional, and hard to capture concept. At least 50 different terms for various types of flexibilities can be found in the manufacturing literature. Usually, there are several terms referring to the same flexibility type. Definitions for these terms that have appeared in the literature are not always precise and are, at times even for identical terms, not in agreement with one another. Not much work has been done to develop analytical models that deal with the concepts of flexibility rigorously, and of course, to determine the optimal levels of flexibility. As a result, the measures proposed in the literature are naive and, at times, somewhat arbitrary.

Moreover, the management of flexibility remains poorly understood. According to Jaikumar (1984:62), "With few exceptions, the flexible manufacturing systems installed in the United States show an astonishing lack of flexibility (when compared to their Japanese counterparts). In many cases, they perform worse than the conventional technology they replace. The technology itself is not to blame; it is the management that makes the difference." Baranson (1983:98) argues that the global view held by Japanese firms towards marketing and production explains why the managers there take a long term and comprehensive view towards capital investments that considers not only cost savings in labour, material, and space, but more significantly the broader strategic implications of increased flexibility (to respond to changes in consumer demands and competitive threats) and versatility (in meeting diversified market demands) in designing and producing of products. Empirical evidence also supports the view that flexibility does not get its proper due

at the time of decision making with regard to investment in manufacturing technology, (Lim 1987:44); (Krasa and Llerena 1987:73).

Over the last three decades, researchers Davies and Kochhar (2002:289); Dangayach and Deshmukh (2001:884); Cox (1989:68); Schroeder *et al*. (1989:3); Gerwin (1987:38); Wheelwright (1984:77); Schmenner (1982:78) have made it clear that flexibility is a critical component of the manufacturing strategy of organisations. A review of the literature failed however to identify research that explores in detail best management practices for implementing manufacturing flexibility. As a result, widely accepted practices that may help manufacturing managers better achieve the flexibility component of the manufacturing strategy is lacking. Previous researchers have instead focused on developing frameworks for implementing manufacturing flexibility, with most being either conceptual in nature or tested by one or a few case studies. Such frameworks, however, provide an effective starting point for developing an initial list of best practices for manufacturing managers when implementing manufacturing flexibility. Olhager and West (2002:50), Narain *et al*. (2000:202), Nilsson and Nordahl (1995a:5), Gerwin (1993:395), Suarez *et al*. (1991:50) and Slack (1988:25) have all developed fairly complete frameworks for implementing manufacturing flexibility.

According to Gerwin, in the first phase, identifying flexibility dimensions requiring investigation, senior managers must identify the specific aspects of flexibility (for example [e.g.] range and speed) they believe are necessary to compete. Gerwin further gives an example from the telecommunication industry, where the time aspect of product flexibility is required to successfully compete, as being the “first to market a successful product is almost a guarantee of substantial market share.” The same principles apply to the glass industry.

Nilsson and Nordahl (1995) developed and tested a framework for implementing manufacturing flexibility, focused on identifying flexibility needs at three levels:

- Specifically strategic
- Production system

- Production resource.

At the strategic level, input (that is [i.e.] flexibility found in the relationship between an organisation and its suppliers) and output (i.e. flexibility found in the relationship between an organisation and its customers) flexibility are identified. Examples include product and volume flexibility. At the production system level, various characteristics of the organisation's production system are identified. Such characteristics include batch sizes, capacity, and production lead times. At the production resource level, the various characteristics of the potential resources used to achieve flexibility are identified. Examples include labour skills and machine set up times. These three levels are connected using matrices which ultimately help managers determine which flexibility types are required and how it will be achieved. This framework of Nilsson and Nordahl describes the aspects close to perfection that are required to be analysed. Thus specific detail to this will be given during the research.

Organisations in South Africa have been more and more exposed to the competitive environment in the international market. The need to compete on an equal basis with international competitors has grown year by year with still no end. A well established Flexible Manufacturing System will assist organisations in becoming more competitive, locally and globally.

1.8 RESEARCH METHODOLOGY

From the setting of the problem it can be concluded that the research project is suited to the qualitative research method as it supports adaptation and innovation. The methodological approach supports interpretativism as it involves social sciences in the form of management and leadership by means of questions.

A questionnaire was set up and distributed to various motor component supplying organisations. A copy of this questionnaire can be seen in Appendix 1. The questionnaire was aimed at the decision makers in the organisation in terms of the once deciding what strategies to follow in the various organisations. Thus General Managers (GM's) in manufacturing, Manufacturing Directors (MD) and Chief Executive Officers (CEO's) will be aimed at to complete a questionnaire.

The objective is to receive one completed questionnaire from each company participating.

Each question will be numbered for simplicity reasons. For the ease of answering, most questions will be based on a rating number or simply only requiring a Yes or NO. In order to speed up answering time most of these answers can be selected by means of a drop down menu or simple tick box. The participant has only to select his / her best fit answer.

Some questions was repeated in a different structure to test for consistency in feedback answers.

A total of 25 companies were approached to participate in the questionnaire.

A statistical analysis of the data received was done for analysis purposes. Special attention was given to ranges in samples to ensure consistency and accurate interpretation.

The process of completing a questionnaire can be time consuming and expensive; however this method offers the advantage that response rates tend to be high and comprehensive data can be collected (Collis & Hussey, 2003:176).

The questionnaire was to be proofread before sending out for completion.

The researcher will be using thus a qualitative research strategy making use of questionnaires, interviews and doing physical observations.

1.9 OBJECTIVES OF THE STUDY

The objective of this study is to document the evolution of the understanding of the concept of flexibility in manufacturing. In order to do this, it is necessary to first review briefly the economic and organisational literature on flexibility that dates back to the early 1920s and the late 1950s, respectively. The second part will then be to survey the substantial literature on manufacturing flexibility, most of which has accumulated over the last ten years since the advent of the flexible manufacturing system (FMS). The main focus will be concerned with discrete parts manufacturing, which includes job shops, assembly lines, flexible transfer lines, and FMSs including flexible assembly systems. To accomplish this task, an attempt was made to try to

classify various flexibilities that have appeared in the literature and organise the survey around them. The purpose here is not to develop a detailed taxonomy. Rather, it is to facilitate an overview of the various flexibilities and their interrelationships that have been reported in the literature.

Furthermore an attempt was made to analyse the various implementation strategies that exist and derive to a simple conceptual framework that can be used by any organisation when embarking on implementation of a flexible manufacturing system.

A questionnaire was also to be completed by participants in the motor component supplying industry and a general understanding of what they perceive FMS is, is to be derived from this. The questionnaire / aim of the research is also to establish the use of FMS in the working area. Are companies REALLY using FMS to be world class and remain competitive?

1.10 OUTLINE OF THE DISSERTATION

The study include the following chapters.

Chapter 1: PROBLEM DEFINITION AND KEY CONCEPTS

Chapter 2: LIETRATURE STUDY (FLEXIBLE MANUFACTURING SYSTEMS)

Chapter 3: THE EMPIRICAL STUDY

Chapter 4: ANALYSIS AND INTERPRETATION OF THE RESEACH

Chapter 5: CONCLUSIONS AND RECOMMENDATIONS

1.11 SUMMARY

The above section has focused at briefly giving an introduction to what Flexible Manufacturing System is by quoting definitions from Sethi and Sethi (1990), Hyun and Ahn (1992) as well as De Toni and Tonchia (1998).

An attempt was also made, briefly to explain some other definitions such as World Class Manufacturing; Continuous Improvement and Strategy, terms that will be used intensively over the next few chapters.

The last section of chapter 1 consists of briefly explaining what the objective of this research paper is all about as well as clearly defining the various chapter headings that will be used.

The remainder of this research paper will consist of analysing in detail previous research theory to clearly establish the true meaning of Flexible Manufacturing as well as establishing best implementation strategies. In Chapter 3 the researcher will attempt to analyse the various research techniques that are available and deriving the best one that will be suitable to be used for this research paper. The last two chapters will be used to analyse the findings of the questionnaire that was sent out as well as concluding with certain recommendations based on the findings. In the conclusion a best implementation strategy will also be suggested for ensuring effective use of the determined FMS and thus also answering the main problem statement as well as all the sub problems.

CHAPTER 2

RESEARCH THEORY

2.1 INTRODUCTION

With the emergence of new microprocessor technologies, the concept of flexibility in manufacturing has become a key consideration in the design, operation, and management of manufacturing systems. A substantial amount of literature dealing with manufacturing flexibility has accumulated over the last ten years. The major part of this literature is devoted to defining various types of flexibilities and identifying systems that exhibit one or more of these. Some papers also deal with the issues of the measurement and/or valuation of the various flexibilities. According to Ettlie (1988:63), few rigorous systematic treatments of the topic of flexibility in manufacturing, let alone empirical studies of actual manufacturing plants, have been reported that give a coherent statement of the strategic as well as tactical implications of this important dimension of manufacturing strategy. The literature makes one thing abundantly clear: flexibility is a complex, multidimensional, and hard to capture concept. At least 50 different terms for various types of flexibilities can be found in the manufacturing literature. Usually, there are several terms referring to the same flexibility type. Definitions for these terms that have appeared in the literature are not always precise and are, at times even for identical terms, not in agreement with one another (see also Swamidass 1988:69). Not much work has been done to develop analytical models that deal with the concepts of flexibility rigorously, and of course, to determine the optimal levels of flexibility (see also Slack 1987:36). As a result, the measures proposed in the literature are naive and, at times, somewhat arbitrary.

Moreover, the management of flexibility remains poorly understood. According to Jaikumar (1984:62), "With few exceptions, the flexible manufacturing systems installed in the United States show an astonishing lack of flexibility (when compared to their Japanese counterparts). In many cases, they perform worse than the conventional technology they replace. The technology itself is not to blame; it is the management that makes the difference. Baranson (1983:98) argues that the global view held by Japanese firms towards marketing and production explains why the

managers there take a long term and comprehensive view towards capital investments that considers not only cost savings in labour, material, and space, but more significantly the broader strategic implications of increased flexibility (to respond to changes in consumer demands and competitive threats) and versatility (in meeting diversified market demands) in designing and producing of products. Empirical evidence also supports the view that flexibility does not get its proper due at the time of decision making with regard to investment in manufacturing technology, (Lim, 1987:45; Krasa and Llerena, 1987:102).

The objective of this study is to document the evolution of the understanding of the concept of flexibility in manufacturing. In order to do this, it is necessary to first review briefly the economic and organisational literature on flexibility that dates back to the early 1920s and the late 1950s, respectively. The second part will then be to survey the substantial literature on manufacturing flexibility, most of which has accumulated over the last ten years since the advent of the flexible manufacturing system (FMS). The main focus will be concerned with discrete parts manufacturing, which includes job shops, assembly lines, flexible transfer lines, and FMSs including flexible assembly systems. To accomplish this task, an attempt will be made to try to classify various flexibilities that have appeared in the literature and organise the survey around them. The purpose here is not to develop a detailed taxonomy. Rather, it is to facilitate an overview of the various flexibilities and their interrelationships that have been reported in the literature.

Furthermore an attempt will be made to analyse the various implementation strategies that exist and derive to a simple conceptual framework that can be used by any organisation when embarking on implementation of a flexible manufacturing system.

2.2 FLEXIBILITY: A HISTORIC PERSPECTIVE

Concern about flexibility is certainly not new. It has arisen in numerous economic and organisational contexts in the last 70 years.

2.1.1 The economic view

Early discussion appears in Lavington (1921:23), who draws a connection between random changes and the value of flexibility by considering the "risk arising from the

immobility of invested resources." Later, in the context of the theory of the firm, Stigler (1939:68) considers a plant to be flexible if it has a relatively flat average cost curve. Marschak and Nelson (1962:43) argue that Stigler's notion of flexibility varies inversely with the slope of the marginal cost curve. This is further discussed in section 2.3.7 under volume flexibility. This also means that minimum average costs vary inversely with flexibility, or as Stigler put it, "flexibility will not be a 'free good': a plant certain to operate x units of output per week will surely have lower costs at that output than will a plant designed to be passably efficient from x/2 to 2x units per week." By a simple example, Marschak and Nelson conclude that the relative desirability of a flexible plant (i.e., volume flexibility) increases as the variation in market price (as measured by variance) increases and as the ability to predict market price before making an output decision increases. Mills (1984:74) takes these ideas one step further and shows how endogenous flexibility is determined in competitive markets with demand fluctuations.

Hart (1940:56) recognises that the postponement of decisions until more information comes in; that is to say, the preservation of flexibility, is a fundamental means of meeting future uncertainty (also explained further by Tintner, 1941:299). That individuals might have a preference for postponement of choice in the absence of risk and uncertainty is explored by Koopmans (1964:245). Klein and Meckling (1958:356) regard the process of research and development of a new product as one in which the developer gradually acquires knowledge about the difficulty of alternative ways of completing this task and makes a sequence of decisions, each allocating a new part of his budget and each appropriate to the knowledge so far accumulated. Massé (1968:43) formulates a problem of choosing between rigid and flexible capital investments by taking into account explicitly the cost of adoption of these investments to changes in future environment.

Rosenhead *et al*. defined and measured flexibility by the number of optional alternatives left over after one has made an initial decision. Henry (1974:1008) showed that if a model is simplified by replacing all random variables with their means, then the simplified model may more readily choose an inflexible "irreversible decision" than the original model might. Miller (1986:85) shows that the relaxation of the assumption of independent demand in standard inventory models leads to ordering of less inventories (i.e. more flexibility).

Jones and Ostroy (1984:15) consider explicitly the cost of switching from one action in this period to another in the next. Their analysis brings out an important behavioural principle:

The more variable are a decision maker's beliefs, the more flexible is the position he will choose. They emphasise: "The way flexibility is used to exploit forthcoming information may be dictated by attitudes toward risk; but flexible positions are attractive not because they are safe stores of value, but because they are good stores of options."

Not surprisingly, therefore, following Black and Scholes (1973:638), there have been attempts to compute the value of flexibility, viewed as a hedge against future uncertainty, using their option price formula. Further examples are also given by Andreou (1988:38), Triantis and Hodder (1989:78), He and Pindyck (1989:62), and Richard (1989:202).

To conclude, Jones and Ostroy indicate that there has been a long tradition of isolated recognition that flexibility choice is a component of a wide range of economic decisions. They surmise that its limited role in conventional microeconomic theory is perhaps due to the difficulties of defining flexibility in a way that has universal application and of obtaining formal results without model-specific qualifications.

2.1.2 The organisational view

There is substantial literature dealing with the concept of flexibility in an organisational context. Feibleman and Friend (1945:234) define organisational flexibility as the ability of an organisation to suffer limited change without severe disorganisation. Ashby (1956:29) has proposed the law of requisite variety, which stipulates that the organisation be complex in proportion to the complexity of the external stimuli it must deal with. March and Simon (1958:45) have introduced the concept of organisational slack that provides an organisation with the excess resources to cope with internal as well as some environmental uncertainties. Burns and Stalker's (1961:76) organic structure (as opposed to mechanistic structure), Emery and Trist's (1960:84) sociotechnical system, Walton's (1980:48) high commitment systems, and some forms of decentralised, divisionalised, project management, and matrix structures refer to models of organisation that have the

flexibility to operate responsively in a rapidly changing environment. Examples of this are described by Child (1982:57).

Recently, especially in the context of flexible technologies, new organisational forms have been evolving beyond the traditional hierarchical or functional structure. One class of organisational arrangements that is capable of much faster response to changing environment than functional structures may be called product focused forms. These are organised around the output functions rather than around the input functions that characterise traditional functional organisations. Each is organised "with the grain" to accomplish the particular tasks at hand (Lindholm, 1975:38). These arrangements complement many of the flexible technologies. They have newer names, such as group technology cells, parallel assembly cells, product verkstad (a Swedish term that literally means product shops and could be translated as flexible focused factories), plants within plants, and network organisations. Preece (1986:369) has defined a concept of structural flexibility, which is concerned with the extent to which the structure of an organisation facilitates or hinders responsiveness of members of the organisation to change. This change could be initiated from within the organisation itself or it could be a reactive change in response to changes in the economic, social, or political environment of the organisation. Another specific concept of labour flexibility has been developed by the Institute of Manpower Studies in the United Kingdom (U.K.). Atkinson (1985:25) further describes more examples. Three main types of labour flexibilities have been identified. Numerical flexibility concerns the readiness with which the number of people employed can be adjusted to meet fluctuation in the level of demand; functional flexibility concerns the readiness with which the tasks performed by workers can be changed in response to varying business demands; financial flexibility is the extent to which compensation practices encourage and support the other two flexibilities that the firm seeks. Following Feibleman and Friend (1945:234), Kozan (1982:240) defines work group flexibility as the group's ability to adjust its activities to changing conditions without these adjustments resulting in disorganisation. He also develops and tests a measure for it in steady-state functioning.

The work on flexibility at the level of individual behaviour can be seen in Rokeach (1960:95) and Harvey, Hunt and Schroeder (1961:75). The latter authors view

cognitively complex people as more flexible. People who are flexible are more able to deal with conflict and ambiguity.

2.1.3 The manufacturing context

Finally, the history of flexibility in the context of manufacturing will be discussed. Diebold (1952:63) recognised flexibility to be essential for medium and short run manufacturing of discrete parts. As a break from the traditional philosophy of machine design that had the product rather than the operation in view, Leaver and Brown (1946:192) and Diebold suggested machine designs in terms of functions to be performed. Leaver and Brown (1946:200), in what can be called a fascinating, ahead of its time article, proposed a series of small, functionally oriented machines that could be "plugged" together. Considering their design to be economically unjustifiable, Diebold proposed his own concept of a machine that can simultaneously perform a bundle of functions that are related. Furthermore, it is noteworthy to mention that Diebold also envisioned a concept that is reminiscent of flexible manufacturing as we know it today. He wrote, "If we could couple a group of production machines, or similar machines designed around the bundle of functions concept, by some form of inexpensive and flexible material handling equipment, and add a control mechanism to do the work normally done by the operator, we would have a factory completely automatic in terms of direct operation, although there would still be need for considerable indirect labour."

Needless to say, these designs remained largely on the drawing board until the advent of microprocessor technology. In practical terms, flexibility was viewed as a trade off against efficiency in production and dependability in the marketplace as described by Abernathy (1978:104); Wheelwright (1981:68) and Hayes and Wheelwright (1984:69). The extreme situations of job shops being flexible but inefficient and Detroit type mass production (Groover, 1987:128) or automated transfer lines being efficient but inflexible are well known in the literature. How to extend flexibility to large-scale production without sacrificing efficiency was not known until the late 1960s. Herbert Simon (1977:48) recognised that humans are more flexible than machines and raised two questions:

1. What are the prospects for matching human flexibility with automatic devices?

2. What are the prospects for matching human skills in particular activities by reducing the need for flexibility?

Simon goes on to say, "The second question is a familiar one throughout the history of mechanisation; the first alternative is more novel."

Simon relates the second question to the principle of homeostatic control of the environment, i.e., environmental control as a substitute for flexibility. He cites some examples of this principle in work. One is the smooth road, which provides a constant environment for the vehicle, thus eliminating the advantages of flexible legs. Another, more relevant example for our purpose is that of automated transfer lines. In these lines, work in process is presented, by means of transfer mechanisms, to successive machine tools in proper position to be grasped and worked, eliminating the sensory and manipulative functions of workers who formerly loaded such tools by hand. Thus, according to Simon, "We see that mechanisation has more often proceeded by eliminating the need for human flexibility replacing rough terrain with a smooth environment than by imitating it."

In contrast with mechanisation, the development of FMSs beginning in the early 1970s provided Simon's novel first alternative as well as Diebold's bold vision. This implementation is part of a larger movement of duplicating the capabilities of the sensory organs, the manipulative organs, the locomotive organs, and the central nervous system. Simon has conjectured that "automation of the functions wholly within the central nervous system will be feasible long before automation of comparably flexible sensory, manipulative or locomotive functions" In the arena of flexible manufacturing, we see that the automation of symbol manufacturing, and perhaps thinking, has already happened. The automation of the more complex eye-brain-hand sequences seems to have just begun (see section 4.9 on programme flexibility defined by Jaikumar 1984:64).

With flexible manufacturing, it becomes possible to bring the efficiency of mass production to batch production of multiple products. Instead of economies of scale, the efficiency in batch production is captured by the term economies of scope as described by Panzar and Willig (1981:269); Goldhar and Jelinek (1983:142) and Talaysum, Hassan, Winsnosky and Goldhar (1986:245). The efficiency of the mid volume, mid variety production is largely accomplished by a drastic reduction or

elimination of setup costs and times required for switching from the production of one product to another.

In the next section, the concept of manufacturing flexibility is described in more detail.

2.2. THE CONCEPT OF MANUFACTURING FLEXIBILITY

Flexibility of a system is its adaptability to a wide range of possible environments that it may encounter. A flexible system must be capable of changing in order to deal with a changing environment. According to Kickert (1985:6), flexibility can be considered as a form of metacontrol aimed at increasing control capacity by means of an increase in variety, speed, and amount of responses as a reaction to uncertain future environmental developments. Flexibility in manufacturing means being able to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality. An earlier definition goes back to Ropohl (1967:644) where he considers manufacturing flexibility as the property of the system elements that are integrally designed and linked to each other in order to allow the adaptation of production equipments to various production tasks.

Jaikumar (1984:65) emphasises the fact that flexibility in manufacturing is always constrained within a domain. Jaikumar explains that such a domain should be defined in terms of portfolio of products, process, and procedures and should be well understood by product designers, manufacturing engineers, and software programmers. The domain should be planned, managed, and with learning expanded. Amendola and Gaffard (1986:96) also elaborate on this concept.

There are other limitations on manufacturing flexibility that are required to be defined. These include the speed and the cost of response as described by Riebel (1954:62); Swoboda (1964:48); Gustavsson (1985:801); and Garrett (1986:18). Other limitations are the amount of required reinvestment as described by Tarondeau (1986:54) and the extent of interruptions in the existing system as described by Fiore (1984:49).

With regard to environmental uncertainties, it should be understood that manufacturing flexibility is required in order for a firm to cope with both internal

changes and external forces as explained by Garrett (1986:19). The internal disturbances for which flexibility is useful include equipment breakdowns, variable task times, queuing delays, rejects, and rework as written by Buzacott and Mandelbaum (1985:404). Behrbohm (1985:75); Zelenovic (1982:319); Garrett (1986:20) and Maier (1982:64) explain that the external forces refer largely to the fundamental uncertainties of the competitive environment. These uncertainties may be current or potential. Moreover, their probabilistic nature may not always be known. Uncertainty may exist for level of demand, product prices, product mix, and availability of resources. Uncertainty may arise out of actions of competitors, changing consumer preferences, technological innovations, new regulations, and so on (etc).

Thus, manufacturing flexibility clearly has major implications for a firm's competitive strength. This significant role of manufacturing flexibility makes it a part of the firm's strategy. Skinner (1985:136) define Strategy as, "a set of plans and policies by which a company tries to gain advantage over its competitors". Hayes and Wheelwright (1984:71) consider flexibility as one of the dimensions of the competitive strategy of a business along with price (and therefore, cost), quality, and dependability. Furthermore, priorities assigned to each of these dimensions determine how the business positions itself relative to its competitors.

It follows, therefore, that decisions regarding manufacturing flexibility arise from strategic considerations. Its development requires considerable managerial attention and can no longer, as in the past, be relegated as technical detail. Hayes and Wheelwright (1984:72) go even further when they say that the potential of manufacturing in general as a competitive weapon and the concept of using manufacturing as a strategic asset have been almost always overlooked by management. According to Skinner, it is not always easy to grasp the interrelationship between manufacturing operations and corporate strategy. What is required is the concept of manufacturing strategy, which in the words of Hayes and Wheelwright "consists of a sequence of decisions that, over time, enables a business to achieve a desired manufacturing structure (i.e, capacity, facilities, technology, and vertical integration), infrastructure (i.e., workforce, quality, production planning / material control, and organisation), and a set of specific capabilities (that enables it to pursue its chosen competitive strategy over the long term)."

Behrbohm (1985:75) as well as Maier (1982:49) state that manufacturing flexibility must, therefore, be a permanent preoccupation and not just an improvisation. It is much more than simply buying an FMS according to Garrett (1986:26). The idea that flexibility cannot just be bought but must be planned and managed is a crucial one as stated by Beste (1958:75); Meffert (1969:780); Rempp (1982:176); Jaikumar (1984:63); Gustavsson (1985:803); Ranta (1988:39) as well as Stecke (1989:288).

Management of manufacturing flexibility must invariably come to terms with the question of what are the "optimal" levels of various types of flexibilities. The answer to this question requires that management identify and be able to measure the various flexibilities that the manufacturing system must have in order to gain maximum competitive advantage. This is certainly a difficult question, and will be addressed in the next section.

2.3. DEFINITIONS, PURPOSES, MEANS, AND MEASUREMENT OF VARIOUS FLEXIBILITIES

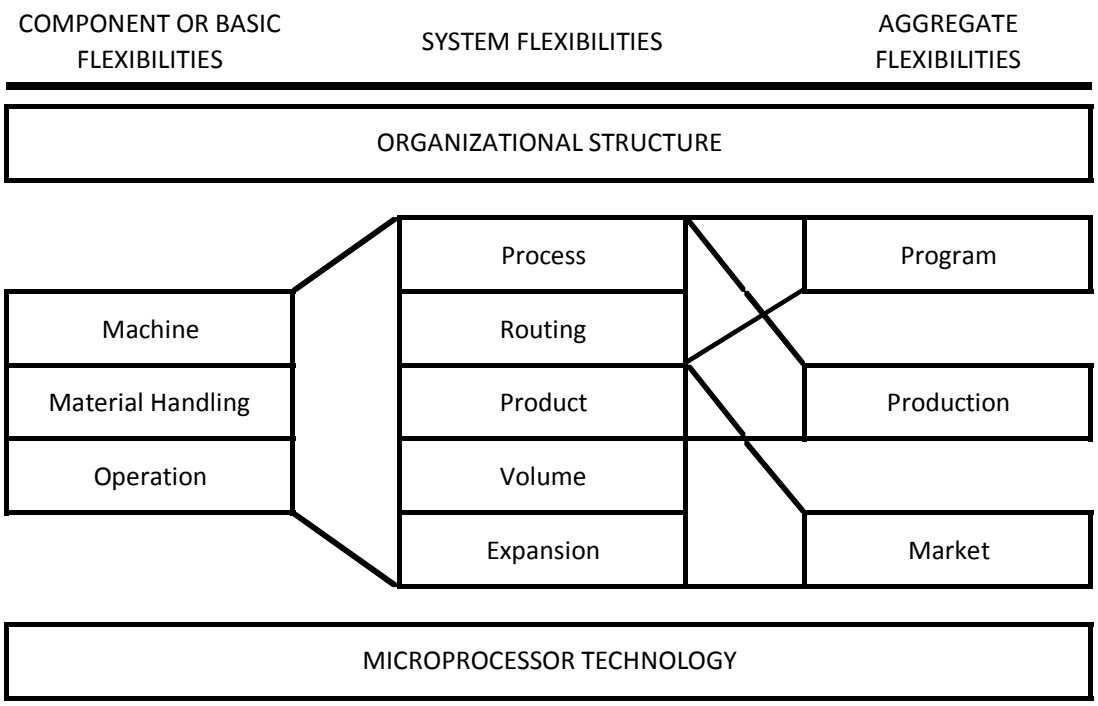
The following section will carefully look at the different kinds of flexibilities that are reported in literature, and define each one of them. Some of the derived definitions may not be identical to some of the existing definitions in literature. This is due to a degree of modification that is required due to terminology not being standardised, and in some cases, the definitions of particular flexibilities that exist in the literature do not agree. After having settled on the definitions of the various flexibilities, an attempt will be made to discuss each of them in terms of their purposes, operational as well as strategic, the means to obtain them, and suggested measurements and/or valuation. While the purposes of a flexibility express why it is needed, the means refer to the firm's technological and managerial responses to that need.

Manufacturing flexibility can be grouped in 11 categories. These are machine, material handling, operation, process, product, routing, volume, expansion, programme, production, and market flexibilities. Thus the following section will be grouped accordingly.

The first three categories refer to flexibilities of the important components of the system, i.e., machines, material handling system, and the parts to be produced, respectively. The remaining flexibilities apply to the manufacturing system as a

whole. Figure 1 below provides a convenient overview of the various flexibilities under consideration, with further explanations being done in section 2.4. The reference that will be followed most closely is that of Browne, Dubois, Rathmill, Sethi, and Stecke (1984:58), with slight deviation occasionally.

Figure 1 - Linkage Between various Flexibility types



Source: Sethi *et al.* (1990:297)

Before beginning to define these flexibilities, it should be noted that a sophisticated computer and information technology and a flexible organisational structure underlie each of them, both at the component and at the system levels (see Figure 1). It is because of this technology that flexibility in manufacturing has become possible without a considerable sacrifice in efficiency. Generally speaking, a cellular architecture with distributed information seems to be most favoured. While Kusiak (1986:101) has defined the concept of computer system flexibility measured by its adaptability to the changing functions, this paper shall not do so. The choice is rather to indicate the computer hardware / software requirements during the discussion of individual flexibilities. Also, these flexibilities cannot attain their full potential without the support of an appropriate organisational structure. While the notions of labour

and organisational flexibilities exist in the literature, a detailed treatment of this vast subject is neither possible nor appropriate for this paper. The preference is to indicate particular organisational considerations whenever needed in the discussion of individual flexibilities.

For this research the researcher will only focus on seven flexibility types, namely; machine; material handling; operation; process; routing; product and volume flexibilities.

2.3.1 Machine flexibility

Machine flexibility (of a machine) refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another. In assembly systems, the term machine refers usually to an assembly robot. Typical operations are drilling holes up to $^{1}/_{4}$" diameter, grinding case-hardened steel to specified tolerances, assembling parts of certain shapes and sizes, and so on. It should be noted that it is allowed for these operations to include the specification of the input material, such as its hardness or ductility. With regard to the prohibitive effort, it is usually expressed in terms of time and cost. It would certainly rule out redesigning the machine completely. On the other hand, it might not exclude changing the tools in the tool magazine.

This definition, while not contradictory, is different from the one provided by Browne, Dubos, Rathmill, Sethi and Stecke (1984:73). It is closer to that of Carter (1986:108), who defines it to be the universe of possible uses of the machine and the ease of converting from one use to another. Riebel (1954:76) agrees on this as well as in the section on equipment flexibility by Son and Park (1987:193). Scharf's Einsatzflexibilitaet (1975:57) emphasises the former part of the definition whereas Bergner's Ruestflexibilitaet (1979:43) emphasises the latter part. Tarondeau (1986:57) defines separately the term input flexibility to emphasise the variations in the input stock the machine can accept.

The motivation for this definition lies in how useful the definition is in assessing the contribution of the given machine toward the manufacturing flexibility of a system, not yet fully specified and subject to major changes in the long run, of which the

machine will become an element. Such an assessment may enable one, for example, to make an informed decision to buy or not to buy the machine.

2.3.1.1 Purposes

According to Ranta (1989:72), "The machine level provides the basic framework for flexibility. Software functions cannot help to provide any extra flexibility, if the machines are hard and expensive to change." In other words, machine flexibility is necessary for other flexibilities. At its own level, machine flexibility allows lower batch sizes and resulting savings in inventory costs, higher machine utilisations, production of complex parts, shorter lead times for new product introductions, and better product quality realisations in the face of random variations in input quality.

2.3.1.2 Means

Technological sources of machine flexibility are numerical control, easily accessible programmes, rule-based languages, sophisticated part-loading and tool-changing devices to ensure easy changeability of work pieces and tools, size of the tool magazine, availability of sufficient pallets and fixtures, number of axes, automatic chip removal, adaptive control to optimise metal removal, diagnostic software, integration with CAD/CAM, and so on. Thus multipurpose, multiaxis, adaptable CNC machining centres are highly machine flexible. Lim (1987:44) has studied 12 firms with different FMS designs and concluded that the weakest part in machine flexibility seemed to be the unavailability of automated fixture assembly and mounting. According to Jaikumar (1984:64), group technologies attempt to improve machine flexibility, in contrast to FMSs, which improve process flexibility as defined in section 2.3.4

Machine flexibility requires considerable attention on the part of management. Operators need to be trained to acquire programming, maintenance, and diagnostic skills. Gerwin (1989:78) states that quality circle activities along with the authority of workers to stop production as in Japan can result in gradual changes that increase machine flexibility. For this, machines must be installed in a way so as to avoid physical limitations that would inhibit these changes, (Ranta and Alabian 1988:78).

Regarding what the future holds for machine flexibility, "the big problem," according to Ranta (1989:104), "still is to integrate basic tooling functions, turning, drilling and milling, into a universal machining center .... Electronic and software development

will yield completely new prospects in this respect it might help to create real (machine) flexibility in a cost efficient manner .... One radical innovation which would change the whole picture is laser processing. If the technical reliability of lasers increases, they could become an effective means of increasing flexibility (milling, drilling and turning by the same tool; no tool maintenance and drift; flexibility of software; applicability to different materials)."

In the context of assembly systems, Boothroyd (1982:111) describes a Universal Assembly Centre. Here, since a universal (generic or flexible) gripper that will grip any part would be prohibitively expensive, one requirement for such a centre is that the parts have been designed so that they can be fed in one of the "programmable" feeders and gripped by the "universal" gripper.

2.3.1.3 Measurements

The first aspect of machine flexibility can be measured by the number of different operations that a machine can perform without requiring more than a specified amount of effort. Brill and Mandelbaum (1987:78) suggest a measure weighted over a given set of tasks. The weights reflect the relative importance of the tasks and the effectiveness with which the machine can perform them. To measure the second aspect, several authors have emphasised the effort in terms of time and or cost required in switching from one operation to another. Examples of this can be seen by Riebel (1954:77); Swoboda (1964:95) and Wildemann (1977:84). Son and Park (1987:196) measure it in terms of the opportunity of the machine to add value to raw materials or, more specifically, by the ratio of the total output and the idle cost of the machine for a given period.

Other measures include the number of tools or the number of programmes that the machine can use, the extent of variations in key dimensional and metallurgical properties of the raw input stock the machine can handle as stated by Gerwin (1987:39), and the rate at which the machine becomes obsolete when a new product is introduced. This last measure, suggested by Gustavsson (1984:804) and Lam (1988:29), can be expressed as:

Investment's residual value for the desired new model / Original investment in the machine

Of course, it must be noted that this measure depends, in general, on what the new product is.

2.3.2 Material handling flexibility

Flexibility of a material handling system is its ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves. The definition covers loading and unloading of parts, transporting them from machine to machine, and eventually storing them under varying conditions of the manufacturing facility.

This definition is consistent with the discussion in Diebold (1952:70), Stecke and Browne (1985:180), Eidenmueller (1986:618), Peter (1984:268), Kusiak (1986:101), and Chatterjee, Cohen, Maxwell and Miller (1984:58, 1987:74). The latter authors define the ability of the material handling system in terms of physical location of each group of machines, the linkages between each pair of groups and between each pair of machines within each group, and the times for every possible move between machines. From these it is possible to define the set of all possible material paths that can be supported in the factory. Peter emphasises buffer sizes, the ability to accommodate different parts of different shapes and sizes, and the readjustment of paths in case of expansion. The definition also subsumes the pallet fixture flexibility defined by Newman (1986:210). This flexibility determines the degree of freedom available to part loading schedules.

2.3.2.1 Purposes

Material handling flexibility is very important for various system flexibilities under consideration. Having a flexible material handling system increases availability of machines and thus their utilisation and reduces throughput times. According to Rattner, Orne and Wallace (1988:45), material handling robots and automated storage and retrieval systems increase the information processing capabilities of the production system.

2.3.2.2 Means

Material handling flexibility can be attained by having transporting devices such as forklift trucks and push carts and an appropriate layout design. In highly automated facilities, devices such as automated guided vehicles, robots, and computer control, which can send parts to new paths in cases of blocking and machine breakdowns,

would be needed to acquire material handling flexibility. Having a number of general-purpose fixtures will also increase the flexibility. Newman describes a system that allows approximately 350 different parts to be mounted on only four different fixture attachments, which in turn are mounted on a general-purpose fixture. Handling the part once it arrives at the machine is also important. Thus, automatic tool changers and multi axis robots among others will enhance material handling flexibility.

As discussed in section 2.3.1.2, robots with flexible grippers and intelligent interfaces (tactile sensors, vision, signal processing) are at present prohibitively expensive.

Drawing on impressions from work organisation designs in Sweden, Kolodny (1985:208) emphasises better layouts, more space, cleaner environment, better ergonomics, and the use of autonomous work groups to improve material handling flexibility in assembly environments. Parallel assembly arrangements allow an assembler not to be impeded by a person who might be slower or might be experiencing a problem. Changes such as local testing and inspection in the assembly process increase the cycle time and may considerably expand the required skills of assemblers as they must learn to test, inspect, adjust, and repair products, as well as to assemble them. This may call for work-group arrangements that group several operators and their material into a physically bounded area. Various manual and motor-propelled jigs and fixtures rotate parts and assemblies through several axes and adjust to the needs of a range of assemblers. This means improvements in ergonomics and a better health and safety environment. With personal access of materials, operators in a work group become more independent of staff and systems and are more able to plan and control their own work activities. This provides a better opportunity for flexibility than in the traditional dyad consisting of a superior and a subordinate.

2.3.2.3 Measurements

Chatterjee *et. al.* (1987:43) define a universal material handling system that can link every machine to every other machine. Then the material handling flexibility of a given system can be expressed by the ratio of the number of paths that the system can support to the number of paths supported by the universal system. Note that this ratio also gives an indication of the inhibition of manufacturing flexibilities, especially the routing flexibility to be defined later, due to the material handling system.

Stecke and Browne (1985:181) have ranked the following systems in order of increasing flexibility: belt conveyors, powered roller conveyors, power-and-free conveyors, monotractors or monorails, towlines, and automated guided vehicle systems. While their emphasis is on the evaluation of various material handling devices in terms of their influence on different flexibilities proposed in Browne *et al*. (1984:74) and on the overall production flexibility, Klarhorst (1981:112) and Knipschild (1986:677) identify important characteristics of the devices and weight these characteristics to obtain a measure of their material handling flexibility. Newman (1986:212) has estimated the increase in FMS performance that would result by increasing material handling flexibility through the use of general-purpose fixtures.

2.3.3 Operation flexibility

Operation flexibility of a part refers to its ability to be produced in different ways. Operation flexibility is a property of the part, and means that the part can be produced with alternate process plans, where a process plan means a sequence of operations required to produce the part. An alternative process plan may be obtained by either an interchange or a substitution of certain operations by others. Thus, a part that permits operations to be performed in alternate orders or using different operations in an interchangeable fashion would possess operation flexibility.

A process will be considered to have operation flexibility if parts that are being produced in the system possess operation flexibility and if the material handling system is able to deliver parts to machines in different possible orders. The definition of the operation flexibility of a process is consistent with Browne *et al*. (1984:59), Maier (1982:52), and Chatterjee *et al*. (1987:46).

2.3.3.1 Purposes

Operation flexibility of parts contributes to various system flexibilities, especially the routing flexibility. Browne *et al*. (1984:20) state that operation flexibility of a process allows for easier scheduling of parts in real time and increases machine availability and utilisation, especially when machines are unreliable.

2.3.3.2 Means

Operation flexibility of a part derives from its design as described by Maier (1982:52). The design should allow the parts to have surfaces that are easily accessible for

various operations. Parts that are assembled from standardised components or parts that are modular according to Gustavsson (1985:803); Besson (1983:78) and Ranta (1988:75) are likely to exhibit operation flexibility. Systems such as CAD/CAM, computer-aided process planning (CAPP), and group technology make it easier to design parts possessing operation flexibility.

2.3.3.3 Measurements

Operation flexibility of a part can be measured by the number of different processing plans for its fabrication.

2.3.4 Process flexibility

Process flexibility of a manufacturing system relates to the set of part types that the system can produce without major setups.

This definition is similar to the one in Browne *et al*. Another preferred term is mix flexibility used by Gerwin (1982:108) and Carter (1986:109). Buzacott (1982:47) uses the term job flexibility, which relates to the ability of the system to cope with changes in jobs to be processed by the system; Rempp (1982:178) and Behrbohm (1985:36) use the term Einsatzflexibilitaet; Friest, Granow and Inclen (1984:219), Kegg (1984:42), and Melcher and Booth (1987:49) use the term part mix flexibility; and Yamashina, Okamura and Matsumotol (1986:406) call it variant flexibility. Falkner (1986:96) considers a system to be process flexible if the manufacturing costs are relatively stable over widely ranging product mixes. The use of the term short term flexibility by Warnecke and Steinhilper (1982:345) emphasises the set of parts that can be produced in the short run.

2.3.4.1 Purposes

Browne *et al*. (1984:72) and Ranta and Alabian (1988:79) state that the main purpose of process flexibility is to reduce batch sizes and inventory costs. This can be accomplished even when there are shifts in the product mix demanded by the market. Carter (1986:110) refers to this purpose as that of insurance in the short term. Carter also emphasises that process flexibility allows machines to be shared and thus minimizes the need for duplicate or redundant machines. Process flexibility, according to Gerwin (1989:80), satisfies the strategic need of being simultaneously able to offer to customers a range of product lines.

2.3.4.2 Means

Process flexibility of a system derives from the machine flexibility of machines, operation flexibility of parts, and the flexibility of the material handling system composing the system. Ranta (1988:82) emphasises the need for supporting planning flexibility along with machine flexibility in ensuring process flexibility. Multiskilled workers who can handle different products and the ability to transfer a variety of fixtures and tooling into and out of the system enhance process flexibility as stated by Gerwin.

2.3.4.3 Measurements and valuation

An obvious measurement would be the volume of the set of part types that the system can produce without major setups. One could perhaps use group technology concepts to define the set of part types. Volume may be expressed by the number of different part types in the set according to Browne *et al*. (1984:76); Ancelin (1986:64) and Gerwin (1987:40), if they can be counted, and if not, by the range of sizes, shapes, and other relevant measures. As expressed by Proth (1982:12), all tooling, fixtures, and other manufacturing resources must be available within the manufacturing system and must allow for possible extremes of mix variations.

Jaikumar (1986:69) and Ettlie (1988:77), in their surveys of FMSs, asked the firms to count the number of part types produced in their FMSs as a measure of process flexibility. Carter (1986:112) proposes to measure it by the extent to which product mix can be changed while maintaining efficient production. Warnecke and Steinhilper (1982:349) measure it by the changeover cost between known production tasks within the current production programme. Ettlie uses average changeover time as a second measure of process flexibility in his FMS survey. Carter suggests that the average changeover time should be viewed in comparison to average cycle time of machines. Son and Park (1987:201) measures it by the ratio of the total output and the waiting cost of parts processed for a given period.

Buzacott (1982:53) focuses on the infeasibility components, that is, parts that the process cannot produce. He uses the set of all jobs that cannot be processed by the system multiplied by the probability that such a job in fact will be required to be processed in the future. However, Jaikumar has pointed out that without restricting the domain of interest, the set of parts that cannot be processed would be arbitrarily

large compared with the set of parts that can be processed. Thus, the notion of infeasibility is difficult to measure. Moreover, any FMS is designed for a restricted domain of a particular family of parts. Jaikumar argues that the family of parts intended for the FMS to produce should be viable in the long run. While the choice of such a family is very important, one needs only to consider flexibility within such a domain once it is chosen.

Jaikumar measures process flexibility by the expected values of a defined portfolio of products that can be processed through the system of limited resources for a given set of contingencies. He formulates a stochastic mathematical programme from which one can derive "shadow costs" of the reduction of contingencies, such as machines and tools being unavailable. The motivation behind his formulation is an attempt to measure the market value of process flexibility. Moreover, Jaikumar insists that this valuation is an underestimate, since it does not take into account the value of "the skill generated within the people working with the system and the advantages of the management philosophy and culture which goes with it;' which can often be quite large. Mandelbaum and Buzacott (1986:122) use the decision theory approach to derive the value of having a process-flexible system as opposed to an inflexible system. Andreou (1988:43) has suggested the use of the option price formula of Black and Scholes (1972:640) to compute the value of process flexibility in a given situation. Triantis and Hodder (1989:83) incorporate downward-sloping marginal profit curves for products in the firm's product mix and a production capacity constraint. They also allow downward-sloping demand curves for the underlying assets constructed as proxies for the manufacturing cost structure. This results in complex exercise decisions for the options or the contingent claims which comprise the value of the production system.

In the case of two products and two underlying uncertainties, Triantis and Hodder derive an explicit formula for the value of the process flexible production system as also described by He and Pindyck (1989:75).

2.3.5 Product flexibility

Product flexibility is the ease with which new parts can be added or substituted for existing parts.

In other words, product flexibility is the ease with which the part mix currently being produced can be changed inexpensively and rapidly. It should be kept in mind that the addition of new parts will invariably involve some setup. This distinguishes product flexibility from process flexibility. What is required for product flexibility is that the setup does not involve inordinate amounts of time and cost. It should also be emphasised that the new parts in the definition above cannot be arbitrary. It is important to note that in Lim's (1987:46) survey of FMSs in the United Kingdom, 11 out of 12 reporting companies considered flexibility in manufacturing to mean product flexibility.

The definition is consistent with Browne *et al*. (1984:56), Gerwin's (1982:109) and Falkner's (1986:97) parts flexibility, Mandelbaum's (1978:122) action flexibility, Zelenovic's (1982:321) design adequacy, the dynamic flexibility of Cohendet and Llerena (1987:79), short product life flexibility of Yamashina *et al*. (1986:407), and parts-change flexibility of Freist *et al*. (1984:220) and Kegg (1984:64). This definition also subsumes Gerwin's (1982:109) design change flexibility, as well as the changeover and modification flexibilities of Gerwin and Tarondeau (1989:169). Hedrich (1983:78) and Maier (1982:56) define a related concept of Fertigungsredundanz, by which they mean a system with a built in redundancy to carry out tasks that are currently not needed.

2.3.5.1 Purposes

Product flexibility allows the company to be responsive to the market by enabling it to bring newly designed products quickly to the market, according to Carter (1986:111) and Gerwin and Tarondeau (1989:172). Since the future product designs are usually unknown, it becomes important to design and develop the production facility to be product flexible. According to Hayes and Schmenner (1978:105), smaller companies in many industries often adopt a strategy of competing on the basis of product flexibility, i.e., their ability to handle difficult, nonstandard orders and to lead in new product introduction. It should be noted that Tombak (1988:48), in an extensive econometric study finds, that product flexibility is more important in the growth phase of a product than in its mature phase. Therefore, in the markets that are rapidly in flux due to short and uncertain product life cycles, product flexibility along with a sophisticated computer-aided design capability provides the company with a formidable competitive weapon.

2.3.5.2 Means

Product flexibility depends on machine flexibility, material handling flexibility, operation flexibility, efficient CAD/CAM interface, CAPP, group technology organisation, use of similar part programming routines, rapid exchange of tool and dies, flexible fixtures, etc. Gerwin (1989:80) suggests keeping the amount of hard tooling to a minimum and off lining conversion of a part of the system if required, so that the rest of the system continues to operate. Moreover, software should be designed so that it can readily be changed when new products appear in order to facilitate rerouting of products while some of the work stations are being converted off line. Ranta (1988:79) advocates modular system software for accomplishing such tasks. Gustavsson (1984:805) links product flexibility to the manufacture of products assembled from standardised parts. Here the product is differentiated only in the later stages of its production. This can be compared with Tarondeau's (1982:178) “différenciation retardée” and also explained by Benassy, Bloch, Ferré, Philip, Rostan, Saivage and Vayssieré (1986:82) and Hollard and Margirier (1986:106).

Jaikumar (1984:76) emphasises the incorporation of systematic learning obtained from the production of product in the current portfolio to nurture the product flexibility of the system. That means workers must be willing and able to continually learn new operating procedures (Gerwin 1989:81).

2.3.5.3 Measurements and valuation

Product flexibility can be measured by time or cost required to switch from one part mix to another, not necessarily of the same part types as stipulated by Browne *et al*. (1984:65); Buzacott (1982:55); Zelenovic (1982:321) and Warnecke and Steinhilper (1982:348). Hollard and Margirier (1986:73) suggest that this cost should be expressed in relation to the total production cost. Son and Park (1987:200) measure this cost by the ratio of total output to setup costs for a given period. In his comparison of FMSs in Japan and the U.S., Jaikumar (1986:73) uses the number of new parts introduced per year as one of the measures of product flexibility. Jaikumar (1984:66) emphasises the benefit aspects of product flexibility by measuring it in terms of total incremental value of new products that can be fabricated within the system for a defined cost of new fixtures, tools, and part programmes. This value can be obtained by certain shadow prices in an appropriately formulated stochastic mathematical programming problem. Kulatilaka (1988:250) also develops a

stochastic programme that solves for the value of product flexibility together with the dynamic operating schedule of the production process. Furthermore, he proposes to modify existing capital budgeting techniques to incorporate special features of flexibility.

Triantis and Hodder (1989:81) indicate how their model of obtaining the option value of process flexibility can be extended to include switching or setup costs associated with adjusting the product mix. This extension would then provide one with the option value for product flexibility.

2.3.6 Routing flexibility

Routing flexibility of a manufacturing system is its ability to produce a part by alternate routes through the system.

Alternate routes may use different machines, different operations, or different sequences of operations. Typically, these different machines (e.g., lathe and milling machines or two brands of grinders) are those capable of essentially the same processes. It should be noted that routing flexibility is different from operation flexibility in the sense that the former is the property of a system while the latter is that of a part. Even a part with a single specified operations sequence, i.e., no operation flexibility, may still be processed using different routes through the system. It is also different from the material handling flexibility, which is the property of a specific component of the system. Thus, with the existing material handling subsystem, only some of the routes, by which it is possible to produce a part under a universal subsystem, may be feasible.

The definition is similar to Falkner (1986:101), Freist *et al.* (1984:220), Kegg (1984:39), Buzacott's (1982:60) scheduling flexibility, Jaikumar's (1984:69) process flexibility, and Durchlauffreizuegigkeit of Herrman and Pferdmenges (1980:667), Maier (1982:52), and Behrbohm (1985:41). It is also consistent with Gerwin (1982:113), Buzacott (1982:55), and Browne *et al.* (1984:65), although these authors emphasize the system's ability to reroute parts in case of a machine breakdown.

2.3.6.1 Purposes

Routing flexibility allows for efficient scheduling of parts by better balancing of machine loads. Furthermore, it allows the system to continue producing a given set

of part types, perhaps at a reduced rate, when unanticipated events such as machine breakdowns, late receipt of tools, a pre emptive order of parts, or the discovery of a defective part occurs, as also described by Gerwin and Tarondeau (1989:173). Thus, it contributes toward the strategic need of meeting customer delivery times. Routing flexibility also facilitates capacity expansion if needed according to Ranta and Alabian (1988:73).

2.3.6.2 Means

Routing flexibility comes about by having multipurpose machines, machines with overlapping process envelopes, pooling of identical machines into machine groups (Stecke and Kim 1989:22), system control software, versatility of material handling system, and operation flexibility of parts. According to Falkner (1986:102), some planned underutilization of machines (or, redundancy in machines) is needed in order for the system to be able to be rescheduled and maintain the overall production rate in case of a machine breakdown. Gray, Seidmann and Stecke (1988:72) and Zhou and Wysk (1989:604) point out the importance of an effective, integrated tool management system, while Gerwin (1989:81) indicates the need for software aids for rearranging production schedules when necessary.

Schonberger (1982:93) emphasises the importance of labour flexibility in his study of Japanese firms. More specifically, work group structure facilitates cooperation needed in case of machine breakdowns. Workers need to have an intimate knowledge of the system to prevent damage and to reroute production as also explained by Gerwin.

A survey of 12 FMSs by Lim (1987:48) revealed that the systems had very little or no routing flexibility. Lim writes:

> “The lack of routing flexibility reflected both the state of technology and management requirements for the systems. Routing flexibility, whether potential or actual, would require both software and hardware capabilities which might be beyond the resources of suppliers or the inclination of individual companies. Having different routes for each part, for instance, would not only entail extra memory capacity but also require some real-time reasoning power on the part of the supervisory computer (intelligence) in order to "understand" the nature of a breakdown, "sort" out the next best

alternative, "transmit" the diagnostics and necessary instructions on the altered route and updated schedule to appropriate sub-systems including the operative(s) and support personnel. Apart from duplicating processing assignments, this flexibility would also require tooling and machine tool redundancy, all of which meant substantially greater capital costs and longer project time."

2.3.6.3 Measurements

Several alternative measures for routing flexibility have been proposed in the literature. Chatterjee *et al*. (1987:52) and Chung and Chen (1989:28) state that the obvious measures are the average number of possible ways in which a part type can be processed in the given system, and the ratio of existing number to possible number of links between machines in the given system as expressed by Carter (1986:111) and Primrose and Leonard (1984:74). Another network based measure in terms of entropy has been suggested by Yao (1985:143), Yao and Pei (1987:48), and Kumar (1986:131). Routing entropy is defined to be the entropy measure of the information contained in the list of operations and machines from which the next operation and the machine must be chosen. Note that this is a dynamic measure that changes over time. Chung and Chen also suggest a measure for the strategic value of routing flexibility by percentage reduction in total job completion time due to its presence when compared with use of fixed routes.

Browne *et al*. (1984:52) and Ancelin (1986:66), have developed measures that emphasize the system's ability to handle unanticipated events. These measure percentage decrease in throughput because of a machine breakdown according to Buzacott (1982:62) and Browne *et al*. (1984:58) or the cost of the production lost as a result of expediting a pre emptive order.

2.3.7 Volume flexibility

Volume flexibility of a manufacturing system is its ability to be operated profitably at different overall output levels. Note that only feasible output levels are under consideration here. This definition is similar to the ones in Browne *et al*. (1984:53), Gerwin (1982:113), Maier (1982:58), Behrbohm (1985:40), Freist *et al*. (1984:220), and Kegg (1984:43). It is also similar to the demand flexibility of Son and Park (1987:199). Volume flexibility has some degree of interchange ability with Slack's

(1987:39) delivery flexibility – the ability to change planned or assumed delivery dates.

2.3.7.1 Purposes

Uncertainty in the level of demand impedes the strategic objective of increasing and maintaining market share. A case in point is the costly efforts of General Motors during the mid 1980's to stimulate the market and maintain capacity in the face of declining sales as explained by Gerwin (1989:80). Volume flexibility permits the factory to adjust production upwards or downwards within wide limits. Hayes and Schmenner (1978:106) point out that successful companies in cyclic industries like furniture often exhibit this trait. According to Slack (1987:39), volume flexibility has two aspects: speed of response and range of variations, the former being useful in the short term and the latter in the long term.

2.3.7.2 Means

If costs were to modelled by only fixed (constant) and variable cost components, a system with given fixed and variable costs is more volume flexible than another system that chooses to have relatively higher fixed cost in order to have relatively lower variable cost. As shown in the following section 2.3.7.3., average manufacturing cost of the former system will be less sensitive to volume changes than that of the latter. However, costs are usually nonlinear, and there are important adjustment costs that are associated with volume changes.

In these cases, a highly automated FMS may be volume flexible because it allows the firm to produce without a large amount of labour, which is difficult and expensive to adjust both downward and upward. Bylinsky (1983:52) cites the case of the Yamazaki plant near Nagoya, Japan, employing only 215 people (in contrast with 2500 in a conventional factory) and having a maximum capacity of turning out $230 million worth of machine tools a year. In this plant, it is claimed that the sales can be reduced to $80 million a year, if need be, without laying off workers. To quote Bylinsky, "the plant illustrates (yet) another aspect of economy of scope: with flexible automation, a manufacturer can economically shrink production capacity to match lower market demand."

Gerwin (1989:91) suggests that workers must possess skills that can be used elsewhere when production volume decreases. He also recommends excess

modular capacity that remains unused except after breakdown occurs. Then the high capacity facilitates a quick return to normal production and in process inventory levels. Ranta (1988:105) emphasises the importance of subcontracting network, and Monden (1981:42) suggests a JIT approach for volume flexibility.

2.3.7.3 Measurements and valuation

Browne *et al*. (1984:75) measure volume flexibility by how small the volume can be for all part types together with the system still being run profitably. This really measures only the downside volume flexibility. An obvious generalization would be to measure volume flexibility by the range of volumes in which the firm can run profitably. Gerwin (1987:41) measures it by the ratio of average volume fluctuations over a given period of time to the production capacity limit. Falkner (1986:99) suggests, as a measure of volume flexibility, the stability of manufacturing costs over widely varying levels of total production volume.

To further elaborate, consider the simple paradigm of fixed cost F and constant variable cost c per unit of production. Then the total cost TC(V) and the average cost AC(V) are

TC(V) = F + cV, AC(IO = (F + cV)/V,

where V denotes the volume of production. It is easy to see that the (negative) elasticity of the average cost with respect to volume is F/(F + cV). The elasticity increases with F and decreases with c.

Following Marschak and Nelson (1962:44), if the total cost function TC(V) is increasing and convex, then volume flexibility can be defined by 1/TCVV. Note that AC(V) is a U-shaped curve. Also, in the special case of the quadratic total cost TC(V) = F + CV + V2/2ø, the volume flexibility 1/TCVV = ø

Ancelin (1986:69) proposes the amount of slack capacity as a measure of volume flexibility.

More specifically, his measure is the following Potential Requirement Ratio (PRR):

PRR = *total available time – (required time + maintenance time) / required time*

= *non-required time – maintenance time / required time*

Thus, PRR represents a portion of the non-required time that can be mobilised for processing. Son and Park (1987:196) measure it by the ratio of the total output and the inventory / shortage costs of finished products and raw materials for a given period.

Market valuation of volume flexibility can be obtained as the shadow price associated with the constraint that the demand should be met in an appropriately formulated mathematical programming problem. This measure is related to the one above in the sense that a slack capacity implies a zero shadow price.

2.3.8 Market flexibility

Market flexibility is the ease with which the manufacturing system can adapt to a changing market environment.

This concept emphasises the importance of market orientation in manufacturing. Especially in rapidly changing markets, the interface between production and marketing functions becomes crucial. It should be obvious that market flexibility of the manufacturing system complements its production and programme flexibilities.

Gerwin and Tarondeau (1988:92) refer to product, process, and volume flexibilities as market oriented flexibilities. In addition, they include modification flexibility to allow for uncertainties that exist at the time of product design as to which product attributes customers desire. With modification flexibility, a potential exists for implementing minor design changes in a given product. Market flexibility subsumes the distribution flexibility of Ranta (1988:79), which includes the inventory, transport, and administrative means of creating flexibility in place, time, size, and assortment of deliveries to achieve customer satisfaction.

2.3.8.1 Purposes

Market flexibility is important for a firm's survival in environments that are constantly in flux. Environments change because of rapid technological innovations, change in customer tastes, short product life cycles, uncertainty in sources of supply, etc. This is also further elaborated by Hutchinson and Holland (1982:215) as well as by Fine and Li (1988:63). Market flexibility allows the firm to respond to these changes without seriously jeopardising the business. Additionally, market flexibility enables the firm to cash in on new business opportunities before its less flexible competitors

are able to. Market flexibility is essential if the firm's market strategy emphasises customised products and frequent product changes, as also explained by Goldhar and Jelinek (1983:145).

2.3.8.2 Means

As markets change, the manufacturing system may be required to process new products, cope with fluctuating production volumes, and even to undergo capacity changes. Thus product, volume, and expansion flexibilities contribute to market flexibility. Market flexibility requires that the process of production planning and inventory controls be closely integrated with such marketing functions as market forecasts, product development, and customer relations. Moreover, good relationships with suppliers and well developed distribution channels are also essential for market flexibility. An example would be a successful implementation of an MRP II (Material Requirement Planning) class software with user intervention as also explained by Dogan and Davis (1989:610).

2.3.8.3 Measurements

Market flexibility can be expressed as a weighted measure of efforts in terms of time and cost required to introduce a new product, to increase and decrease production volume by a specified amount, and to add a unit of capacity. Abadie, Cohendet, Héran, Krasa and Llerena (1988:91) explain that market flexibility can also be measured by the shortage cost or the cost of delay in meeting the customer orders.

2.4 LINKAGE BETWEEN VARIOUS FLEXIBILITIES

Having described various flexibilities in detail, it is noted that figure 1 on page 26 summarises the linkages that have been reported to exist between them. Ollus and Mieskonen (1989:358) describes a figure that is similar to the one in figure 1. The figure indicates that flexibilities of components contribute to the various flexibilities of the system. These in turn influence the aggregate flexibilities as shown. Viewed from another perspective, the firm's manufacturing strategy dictates the extent of system flexibilities and, in turn, of component flexibilities that the firm must possess. The figure also indicates that the structure of organisation and microprocessor technology underlies all of the flexibilities.

Figures indicating the need for flexibilities to deal with variety and uncertainty in the short and long terms and a hierarchy between flexibilities are also given in Slack

(1987:40); as well as Browne *et al*. (1984:75) and Yilmaz and Davis (1987:210). Slack emphasises that the response aspect of a flexibility is needed in the short run while the range aspect is needed in the long run. Yilmaz and Davis characterize flexibilities in terms of three attributes; at times, after a time, and over time. According to them, machine and routing flexibilities can be related to flexibility at times; operating, process, and product flexibilities can be related to flexibility after a time; and volume, expansion, and production flexibilities can be related to flexibility over time.

2.5 IMPLEMENTING MANUFACTURING FLEXIBILITY

Although researchers such as Davies and Kochhar (2002:289); Dangayach and Deshmukh (2001:884); Cox (1989:68); Schroeder *et al*. (1989:3); Gerwin (1987:38); Wheelwright (1984:77) and Schmenner (1982:78) have made it clear that flexibility is a critical component of the manufacturing strategy of many organisations, a review of the literature failed to identify research that explores in detail best management practices for implementing manufacturing flexibility. As a result, widely accepted practices that may help manufacturing managers better achieve the flexibility component of the manufacturing strategy is lacking. Researchers have instead focused on developing frameworks for implementing manufacturing flexibility, with most being either conceptual in nature or tested by one or a few case studies. Such frameworks, however, provide an effective starting point for developing an initial list of best practices for manufacturing managers when implementing manufacturing flexibility. Olhager and West (2002:50), Narain *et al.* (2000:202), Nilsson and Nordahl (1995a:5), Gerwin (1993:395), Suarez *et al.* (1991:52) and Slack (1988:25) have all developed fairly complete frameworks for implementing manufacturing flexibility.

To achieve manufacturing flexibility, Slack recommends a three-phase approach consisting of defining flexibility requirements, conducting a flexibility audit, and developing a flexibility action programme. The flexibility requirements to address uncertainty are obtained by understanding the competitive strategy of the organisation. The second phase of achieving manufacturing flexibility involves conducting a flexibility audit. The purpose of the audit is to determine the current system capabilities in terms of range and speed (i.e. time to make the required

changes). Using product flexibility as an example, information obtained from a flexibility audit may include:

1. limits on what new products or modifications could be designed or made given current production capabilities; and
2. the lead time required for a new product or modification given current production capabilities.

The third phase involves developing flexibility action programmes to narrow the gap between the required flexibility and the current production capabilities. To achieve this phase, Slack recommends evaluating flexibility types on a scale, which reflects their relative importance to competitiveness.

Similar to Slack Suarez *et al*. (1991:50) suggest a three stage approach for achieving manufacturing flexibility. These three stages are the need for flexibility, the implementation of flexibility, and the flexibility fit between required and actual flexibility. The first stage is focused on determining the types and levels of flexibility needed to adequately address uncertainty. Once managers have identified the required types and levels of flexibility, attention turns to implementing these flexibility types and levels. The required types and levels of flexibility are achieved by implementing various flexibility source factors, including accounting and information systems, product development process, labour policies, worker training and skills, relationship with suppler and distributors, production management techniques, and production technology. During stage three, flexibility fit, managers review the required configuration of flexibility, as identified in stage one, to the actual configuration of flexibility, as implemented in stage two. If a gap exists between the required and actual flexibility, then via a feedback mechanism, the flexibility source factors are re-examined and adjusted.

Gerwin (1993:395) proposes a sequence of four steps or phases for implementing manufacturing flexibility, specifically identifying flexibility dimensions requiring investigation, measuring gaps, selecting methods for closing gaps, and continuous assessment. In the first phase, identifying flexibility dimensions requiring investigation, senior managers must identify the specific aspects of flexibility (e.g. range and speed) they believe are necessary to compete. Gerwin (1993) gives an

example from the telecommunication industry, where the time aspect of product flexibility is required to successfully compete, as being the "first to market a successful product is almost a guarantee of substantial market share." In addition to identifying the required flexibility types, managers must also determine if excess flexibility is desired. Excess flexibility may be desired to redefine uncertainty or to bank flexibility. In the second phase, measuring gaps, the required, potential and actual performance levels of the desired flexibility types are identified and measured. Required levels of flexibility are derived from managers during the first phase and by surveying customers. The assessment of potential flexibility is determined by manufacturing engineers, while the actual levels of flexibility are obtained from the performance data of the organisation. During the third phase, selecting methods for closing gaps, managers address any gaps between the required, potential, and actual level of manufacturing flexibility. Any gaps identified are prioritised with managers determining if the potential gains from achieving the desired level of flexibility are greater than the costs associated with obtaining it. The final phase, continuous assessment, ensures any required, potential, and actual flexibility gaps are being closed and that the required flexibility is still needed. This phase is achieved by the implementation of effective measurement systems and a top management steering committee with the primary function of detecting "the need for changing which flexibilities are considered relevant" (Gerwin 1993:400).

Nilsson and Nordahl (1995a:5) and (1995b:6) develop and test a framework for implementing manufacturing flexibility focused on identifying flexibility needs at three levels, specifically strategic, production system, and production resource. At the strategic level, input (i.e. flexibility found in the relationship between an organisation and its suppliers) and output (i.e. flexibility found in the relationship between an organisation and its customers) flexibility is identified. Examples include product and volume flexibility. At the production system level, various characteristics of the organisation's production system are identified. Such characteristics include batch sizes, capacity, and production lead times. At the production resource level, the various characteristics of the potential resources used to achieve flexibility are identified. Examples include labour skills and machine set up times. These three levels are connected using matrices which ultimately help managers determine

which flexibility types are required and how it will be possible to successfully achieve them.

Narain *et al*. (2000:202) suggest the first step in implementing manufacturing flexibility is the identification of the uncertainties that exist as a result of the organisation's competitive situation. These uncertainties are then evaluated against the capability of the organisation to address such uncertainties. This evaluation is performed using a strengths, weaknesses, opportunities, and threats (SWOT) analysis. Based on this SWOT analysis, the competitive strategy for the organisation is formed which, in turn, dictates the manufacturing, marketing, and other functional strategies. The manufacturing, marketing, and organisational strategies are then used to determine the strategic level flexibility. Strategic flexibility addresses long term issues such as capacity expansion and processing of the entire universe of part types, and is achieved using a combination of production, expansion, and market flexibility. The strategic flexibility is then used to identify the operational and tactical flexibility needed to achieve the organisational strategies. Operational flexibility is used to achieve goals addressing product quality, product costs, frequent introduction of new product designs, fluctuation in demand, and processing of different product mixes. Operational flexibility is achieved using a combination of machine, product, labour (i.e. the ease of increasing / reducing the workforce), material handling, routing, and volume flexibility. Tactical flexibility is used to address issues such as reduced product life cycles, variety of materials to be processed, inventory difficulties, and uninterrupted operation for a long duration and is achieved using a combination of process, operations, programme, and material handling flexibility. Narain *et al*. suggest that some flexibility types and levels chosen may conflict or overlap one another. As a result, the strategic, operational, and tactical flexibility types and levels must be reconciled by determining what flexibility is necessary, sufficient, and competitive. Managers may not have the resources to implement all the required flexibility types and levels at once, and therefore the required flexibility types must be prioritised. This prioritisation is also needed to help design, justify, implement, and maintain the specific organisational and technological tools (e.g. FMS, employees with broad skills, versatile machine tools, flexible facility layout) needed to achieve the required manufacturing flexibility. As the competitive

environment and organisational strategies often change, audits are needed to ensure the tools selected continue to help achieve the organisational strategies.

Vokurka and O'Leary-Kelly's (2000:485) framework highlights some of the shortcomings of existing implementation and management frameworks from Slack (1988:25) and Gerwin (1993:395) and thus discuss important issues that must be considered when developing a new framework. This framework identifies four exogenous variables that are believed to influence the firm's choice of manufacturing flexibility types, which will in turn influence business performance. These variables are organisational strategy, environmental factors, organisational attributes, and technology. Environmental factors address the environmental uncertainty faced by the organisation and include both the uncertainty currently existing, as well as uncertainty that the organisation is expecting to face in the near future. Organisational attributes focus on the design characteristics of the organisation (e.g. organisational structure) as well as the behavioural aspects of employees and managers (e.g. work force skills and experience, managerial actions and interactions). Vokurka and O'Leary-Kelly, similar to Hayes and Wheelwright (1984:22) and Gupta and Somers (1996:204), also suggest that business strategy influences the type of manufacturing flexibility adopted. Finally, Vokurka and O'Leary-Kelly suggest that technology will also impact the type of manufacturing flexibility required. Technology not only includes the capability to implement flexible manufacturing systems (FMS) and advanced manufacturing technology but also includes issues such as the scale and age of technology and technology complexity, interdependence, and workflow integration.

Olhager and West (2002:50), using a case study, highlight how the concept of quality function deployment can be used to link market requirements to the organisation's requirement for manufacturing flexibility and ultimately achieve manufacturing flexibility. They suggest that organisations should first examine the customer needs and expectation to identify the "competitive priorities" (i.e. quality, delivery speed, delivery dependability, cost, product range, and innovativeness) required by the organisation and which can be achieved by increasing manufacturing flexibility. Such priorities are then weighted based on their ability to win customer orders. Next, benchmarks are conducted to determine from a customer perspective how the

competitive priorities relate to those of major competitors. Using a “house of flexibility”, the flexibility types (e.g. volume, product mix, new product) required by the organisation are identified. With the flexibility types identified, objective measurements are identified to track the performance of the flexibility types selected. To achieve the desired manufacturing flexibility types and levels, flexibility source factors are identified, implemented, and measured.

As evident from the above discussion, the frameworks developed by Olhager and West, Narain *et al*., Vokurka and O’Leary-Kelly, Nilsson and Nordahl, Gerwin, Suarez *et al*. and Slack each highlight specific practices managers should implement in order to achieve manufacturing flexibility. However, a number of practices also exist that are common among a number of these frameworks. Such practices include:

1. Manufacturing managers must consider organisational design, technical capabilities, uncertainty, and the competitive, manufacturing, and marketing strategies when selecting manufacturing flexibility types, levels, and tools.
2. Manufacturing managers must understand that while flexibility is an effective means to address uncertainty, it is only one dimension, or component, of a manufacturing strategy, and can improve business growth and financial performance.
3. Manufacturing managers must understand how flexibility can be achieved by non-technical means.
4. Manufacturing managers must determine the current production capabilities, and narrow any gaps between required flexibility types and levels and current production capabilities.
5. Manufacturing managers must identify flexibility types in terms of their range, mobility, and uniformity and understand that manufacturing flexibility can occur at different organisational levels (i.e. strategic, tactical, and operational). Therefore, managers will need to prioritize the required manufacturing flexibility types; as sufficient resources may not exist to implement all the required flexibility types at the required levels of range, uniformity, and mobility.
6. Manufacturing managers must focus on aligning the required, potential, and actual types and levels of flexibility, understand that a number of strategies

exist to address uncertainty (i.e. adaptation, redefinition, banking, and reduction) and that required flexibility may change as it is being implemented.

7. Manufacturing managers must ensure that the required flexibility will be periodically measured and evaluated as organisational strategies and uncertainty changes.

2.6 SUMMARY

Because of the multidimensionality of flexible manufacturing it is evident that several types of flexibilities can be defined. The above section has attempted to analyse and define some of these flexibility types which have been considered to be of most importance in order to survey the literature. The literature indicates that not one flexibility type seems to outweigh the other and that each one can be seen as being important in different contexts. It is thus extremely important to carefully analyse ones organisational needs when selecting the dominant type of flexibility.

It must be taken into consideration that there is a definite link between the various flexibility types as could be seen in figure 1 on page 26.

An attempt was also made to survey the various implementation strategies that exist. It is clear that various researchers have tried to establish what they believe is the best implementation strategy. It is however evident in the literature that one CANNOT simply copy and paste a flexibility system from one company to the other. For this reason it is clear the any company wanting to embark on a FMS implementation has to adapt any suggested strategy to what would work in the organisation / fit their culture.

The remaining part of this document will focus on establishing what the general understanding on FMS is in the automotive component supplying industry in South Africa. An attempt will also be made to establish what is seen to be the biggest stumbling blocks in implementation and what type of flexibility is believed to be the most important.

The next chapter reflects on research theory.

CHAPTER 3

RESEARCH THEORY

3.1 INTRODUCTION

In chapter two Flexible Manufacturing Systems were discussed in depth, looking at how literature defines FMS as well as how one should measure individual flexibility types. In addition, chapter two also looked at how literature suggests one should go about implementing FMS.

The purpose of this chapter is to evaluate various research methodologies and select the most suitable methodology for analysis of this research paper.

Much has been written about social science research. Some authors follow a more philosophical approach to research design, while others follow a pragmatic approach. The importance of including both schools of thought in a study of social science research is increasingly emphasised by contemporary social scientists, Leedy (1993:143); Yin (1994:93); Neuman (1994:65); Rosnow & Rosenthal (1996:74); Leedy & Ormrod (2001:90).

The focus of this chapter is to establish an appropriate research strategy for a given research problem. The research strategies must be applicable to the nature of the problem. It will be assumed that the nature of the research problem, the objectives of the research and the methodology of the research, focus the research strategy towards qualitative research.

3.2 RESEARCH DESIGN

3.2.1 The concept of research

Various definitions can be given of the concept research. Mouton and Marais (1992:7) define research as a collaborative human activity in which social reality is studied objectively with the aim of gaining a valid understanding of it. Another definition states that research can be seen as a process of expanding the boundaries of one's ignorance, Melville & Goddard (1996:14). The Oxford Dictionary

(1995:1169) defines research as the systematic investigation into sources in order to establish facts and reach new conclusions or collate old facts by the scientific study of the subject or by a course of critical investigation. Finally, Leedy (1993:11) and Leedy and Ormrod (2001:4) define research as studious inquiry or examination, having for its aim the ***discovery*** of new facts and their correct ***interpretation***.

A closer look at this definition reveals the importance of the italicised words, in comprehending the nature of basic research. These ideas are listed below:

- If there is no discovery, there is no research.
- There must be the interpretation of data for the enlightening awareness of what the facts mean.
- Research must always answer questions to solve problems.
- Research is a human activity that promotes critical thinking in a cross-functional approach.
- Effective research is rational, systematic and is guided by constructive, critical assumptions and measurable data (Leedy 1993:12).

3.2.2 The concept of design

Yin (1994:20) defines design as the preparation of a working plan aimed at systematically assembling, organising and integrating data, in order to solve the research problem. Leedy and Ormrod (2001:91) state that research design includes the planning, visualisation of the data and the problems associated with the employment of the data in the entire research project. The Oxford Dictionary (1995:1169) states that design is a preliminary plan, concept or purpose.

From the above definitions research design can be interpreted as the preparation of an action plan aimed at organising and integrating data in an overall framework in order to solve the research problem. Basic to design are four fundamental questions that must be resolved with respect to the data:

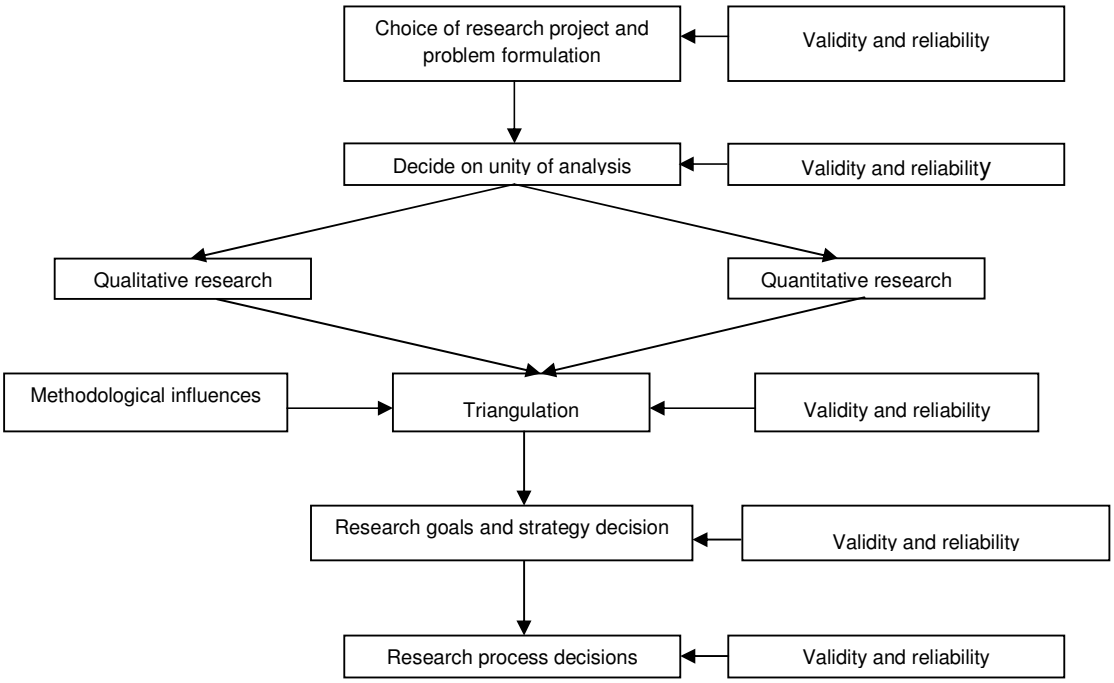
- What is the data needed?
- Where is the data located?
- How will the data be secured?
- How will the data be interpreted?

3.2.3 Validity and reliability

There does seem to be a broad consensus amongst theorists on a framework for research design. Some researchers focus on the philosophical aspects of design (Mouton & Marais 1992; Dooley 1995), while others have developed useful pragmatic frameworks (Yin 1994; Neuman 1994).

The views of these authors have been consolidated into a conceptual model of decision steps. This model, as illustrated in Diagram 1, forms the foundation on which the research design for this research project has been based, as shown below.

Diagram 1 - A conceptual model for research design



Source: Structure of literature study and theoretical model.

With any type of measurement, two considerations are very important. One of these is validity and the other reliability. Validity is concerned with the soundness, the effectiveness of the measuring instrument. The following questions can be asked: does the measuring instrument measure what it is supposed to measure? What is the accuracy of the measurement?

There are several types of validity. The more common types according to Struwig and Stead (2001:139); Leedy and Ormrod (2001:103) are:

- Face validity – relies basically upon the subjective judgement of the researcher.
- Criterion related validity – employs two measures of validity, the second as a criterion check against the accuracy of the first measure.
- Content validity – is the accuracy with which an instrument measures the factors or situations under study.
- Construct validity – is any concept such as honesty that cannot be directly observed or isolated.
- Internal validity – is the freedom from bias in forming conclusions in view of the data.
- External validity – is concerned with the generalisability of the conclusions reached from a sample to other cases.

Reliability deals with accuracy. According to Leedy and Ormrod (2001:31), it is the extent to which, on repeated measures, the indicators yield similar results. Reliability in quantitative research projects can be evaluated by doing a correlation, thus repeating a question in a questionnaire. Reliability asks one question above all others, with what accuracy does the measurement, test, instrument, inventory or questionnaire measure what it is intended to measure?

The focus of research design is to maximise the validity and reliability of the research findings. According to Leedy (1993:128), the use of human subjects in research raises the question of ethical standards and should not go without careful scrutiny.

3.3 METHODOLOGICAL APPROACHES

There are three important contemporary methodological research approaches, namely: the positivist, interpretative and the critical approaches. Researchers usually adopt one of these approaches and then formulate a strategy that is consistent with the approach selected by them.

3.3.1 The positivist approach

The positivist approach is the approach used in the physical sciences, and believes society is organised according to scientific observations and experiments (Dooley 1995:5). With this paradigm it is always possible to establish a cause and effect relationship between variables systematically and statistically. Scientists supporting positivism would argue that the general laws of science would be just as applicable to the social sciences as to the physical sciences. Positivist research is likely to do quantitative research and use experiments, surveys and statistics (Gummesson 1991:152).

3.3.2 The interpretative approach

According to the interpretative approach, doubt is expressed over the question whether it is always possible to establish cause and effect between variables in the social sciences. An example: can the effect of poor project management decision making on a project always be linked to a specific objective cause? The interpretative approach represents a reaction against unqualified application of positivism in the social sciences. Instead of trying to explain causal relationships by means of objective truth and statistical analysis, hermeneutics provides a process to interpret, understand or reconstruct reality. Language, pictures, sound, text and symbols play a central role in qualitative projects and replace quantitative data such as facts and figures as the primary sources of information (Neuman 1994:61).

3.3.3 The critical approach

The critical approach is based on the argument that the researchers cannot distance themselves from people in their research. They have to empower people through their research in order to bring about social justice. The relative success of research in South Africa may in the future be measured against its ability to conform to the requirements of the critical approach. It is important to state that there is no specific method or technique associated with this research approach and this method or technique does not seem to be that important.

3.3.4 Models and modelling

This research proposes to attempt to formulate a generic model of excellence in project management. Mouton and Marais (1994:138) describe the term “model” as one of the most ambiguous in the vocabulary of the social scientist. The terms

“model” and “theory” are frequently used as synonyms. Mouton and Marais (1994:138) continue that a model performs a heuristic function as opposed to a theory that performs an explanatory function.

Fellows and Liu (1997:61) view modelling as the process of constructing a model representing a designed, actual object, process or system or a representation of a reality.

Emory and Cooper (1991:64) point out that there are three types of models, viz. descriptive models, that seek to describe the behaviour of the elements in a system; explicit models, that seek to extend the application of the current theories; and finally simulation models, that replicate current phenomena.

According to Gains and Shaw (2004), the goal of research is to create a theoretical picture of the object of study which resides in the empirical world. All the theoretical knowledge, concerning empirical things, makes up a more or less complete picture of the empirical world. The researcher’s task is to construct a model of the objects of study into the world of theory.

According to Audet and d’Amboise (2001), understanding a phenomenon that has barely been researched requires a qualitative approach that is both adaptive and innovative to give insight to this phenomenon. Strategic scanning must be done to gain an in-depth knowledge of the organisation’s environment. Audet and d’Amboise (2001) define strategic scanning as the collection, dissemination and interpretation of information related to a company’s environment. Further, scanning is directed towards those sectors that are the most strategically uncertain. To conclude, it is sometimes difficult to define what is relevant in advance; it only becomes apparent through research and analysis.

3.4 QUANTITATIVE VERSUS QUALITATIVE RESEARCH

Quantitative research is usually associated with positivism and qualitative research with interpretativism. It is best to visualise the distinction between quantitative and qualitative research as a continuum. All research methods could be placed somewhere between the extremes of pure quantitative and pure qualitative research.

It is, however, plausible to indicate whether research projects have a more qualitative or more quantitative nature. This in turn would play an important role in decisions on processes to follow and measuring instruments to select. A summary of the main differences between qualitative and quantitative research is given in Table 1.

Table 1 - Differences between qualitative and quantitative research

Quantitative	*Qualitative*
• Test hypothesis that researcher begins with. Hypotheses are stated explicitly and are formulated beforehand.	• Capture and discover meaning once the researcher becomes immersed in data. Hypotheses are frequently undeclared or stated in the form of a research goal.
• Concepts are in the form of distinct variables. Concepts have an ambiguous meaning.	• Concepts are in the form of themes, motifs, generalisations, taxonomies. Concepts can be interpreted in a number of ways.
• Measures are systematically created before data collection is standardised. The researcher remains largely aloof.	• Measures are created in an ad hoc manner and are often specific to the individual or researcher. The researcher is involved with the events/ phenomena.
• Data are in the form of numbers from precise measurement.	• Data are in the form of words from documents, observations and transcripts.
• Theory is largely causal and is deductive.	• Theory can be causal or non-causal and is often inductive.
• Procedures are standard, and replication is assumed.	• Research procedures are particular, and replication is very rare.
• Analysis proceeds by using statistics, tables or charts and discussing how what they show relates to hypotheses.	• Analysis proceeds by extracting themes or generalisations from evidence and organising data to present a coherent, consistent picture.

Source: Neuman (1994:317); Mouton and Marais (1992:159).

An important choice that researchers face is the research method to be used. Leedy (1993:145) believes that the answer to this question can be found in the nature of the data, the problem of the research, the location of the data, obtaining of data and the intention with the data. If the data is verbal, the methodology is qualitative, if it is numerical, the methodology is quantitative.

3.4.1 Qualitative research

Qualitative research relies on interpretative and critical approaches to social sciences. The aim of qualitative research is to study individuals and phenomena in

their natural settings in order to gain a better understanding of them. It is also evident that qualitative research does not follow a fixed set of procedures. The researcher will, however, need to develop a set of strategies and tactics in order to organise, manage and evaluate the research (Neuman 1994:317; Dooley 1995:258). Scientists who wish to describe everyday life from the point of view of the phenomenological perspective prefer qualitative research. Quantitative researchers manipulate figures and statistics, while the data of the qualitative researcher is in the form of words, sentences, and paragraphs. Qualitative research is more at risk in terms of validity and reliability, (Miles & Huberman 1994:2).

Mouton and Marais (1992:155) define qualitative research projects as those in which the procedures are not strictly formalised, while the scope is more likely to be under-defined, and a more philosophical mode of operation is adopted.

3.4.2 Characteristics of qualitative research

- It is not always easy to describe the meaning of qualitative research.
- It is not always possible to classify methods in terms of the level of qualitativeness.

According to Miles and Huberman (1994:7), these features can be referred to as core and recurring features for naturalistic studies, configured and used differently in any particular research tradition.

3.4.3 Inductive versus deductive logic

According to Patton (1987:15), qualitative research methods are particularly orientated towards exploration, discovery and inductive logic.

- Inductive designs begin with conjecture, guesses, ideas and expectations.
- No hypotheses are designed, nor are any theory building exercises performed.
- Data is collected through observation, interviews and other qualitative methods.
- The product of the research is a new model, theory or hypothesis.

Quantitative research methods, on the other hand, support deductive reasoning and analysis. Deductive designs begin with an explicit conceptual framework developed from existing theory and models. It requires the formulation of specific research

hypotheses leading to a theory-building exercise. A known data collection instrument, the fixed alternative questionnaire, is used to collect the data. The hypotheses are accepted or rejected and a causal relationship between variables is established (Miles & Huberman 1994:44; Dooley 1995:65).

3.4.4 Choosing the most appropriate qualitative research method

The model shown in Table 1 can solve the problems of a qualitative method.

Table 2 - Research method selection model

	Form of research question	**Requires control over behavioural events?**	**Focuses on contemporary events?**
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis	Who, what, where, how many, how much	No	Yes/No
History	How, why	No	No
Case study	How, why	No	Yes

Source: Adapted from Yin (1994:6).

The most appropriate research method or strategy to use depends on three conditions:

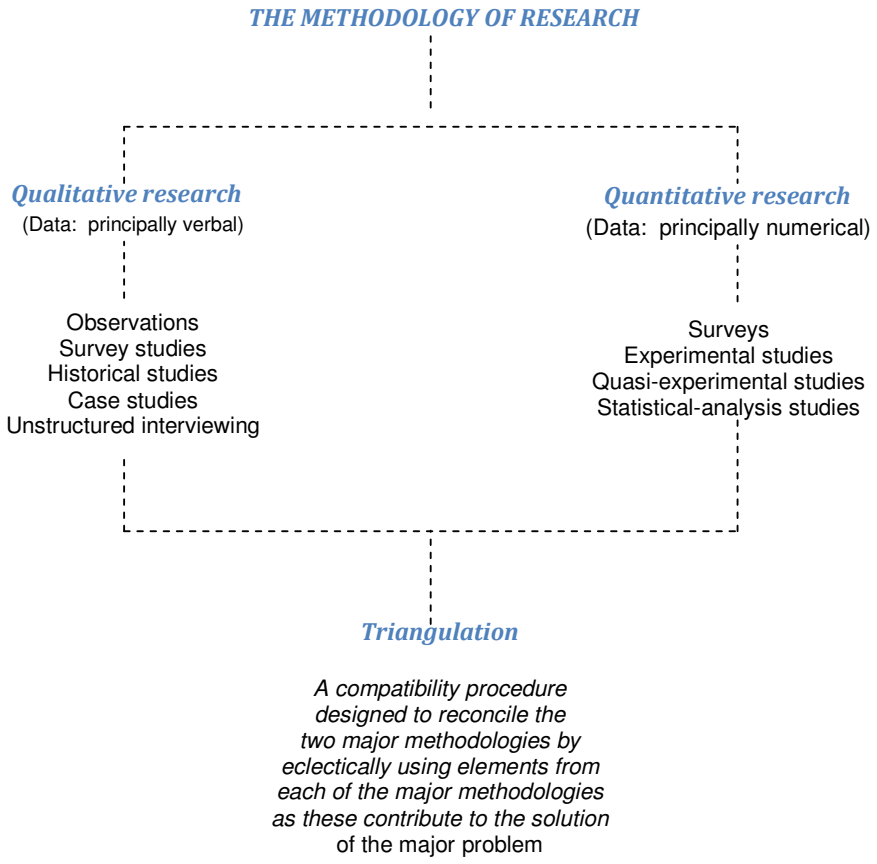
- The type of research question posed;
- The extent of control an investigator has over actual behavioural events;
- The degree of focus on contemporary as opposed to historical events.

3.4.5 Triangulation

Leedy (1993:143) describes the situation where it is possible to combine qualitative research methods with quantitative research methods in the same project. This process is called triangulation and many research projects could be enhanced considerably if a triangulation approach were taken. According to Struwig and Stead (2001:19), the triangulation method could include various methods such as

interviews, Likert type questions and focus groups. The interactions between quantitative and qualitative research are illustrated in Diagram 2.

Diagram 2 - Interaction between quantitative and qualitative research



Source: Adapted from Leedy (1993:145)

3.5 CHOOSING THE MOST APPROPRIATE RESEARCH METHOD

From the setting of the problem it can be concluded that this research project is suited to the qualitative research method as it supports adaptation and innovation. The methodological approach supports interpretativsm as it involves social sciences in the form of management and leadership by means of questions.

This research was conducted in a qualitative manner by sending out questionnaires to key people from various companies, who are directly involved with the setting and implementation of different strategies for their respective organisation.

Questionnaires were sent out to 25 different motor component supplying companies inside South Africa. The two main focus areas in terms of demographics were the Eastern Cape and Gauteng.

Accompanying each questionnaire was a letter stating the purpose as well as the confidentiality of all information received.

The aim of the research questionnaire was firstly to establish the percentage of suppliers that have effective FMS's in place and secondly, to determine what the general understanding of FMS is in this industry.

The various companies were selected based on their degree of current complexity (medium to very high) as well as with a workforce of 200 plus employees thus aiming at bigger type organisations in terms of people employed.

3.6 CONCLUSION

A formal systematic approach to research design is crucial to ensure that a research project conforms to the principles of validity and reliability. The research design decisions guide the researcher in effectively addressing the research problem. A qualitative approach is the most appropriate research strategy for this research project. Questionnaires, interviews and observations are the main methods of data collection.

The following section will dissect the responses to each question and establish the general understanding in the workplace regarding FMS against that of the theory in chapter two. This will then be concluded by a summary of the findings as well as concluding with the most probable FMS implementation strategy.

CHAPTER 4

ANALYSIS AND INTERPRETATION OF THE RESEACH

4.1 INTRODUCTION

For ease of analysis the questionnaire was broken up in three section (Section A – C). Section A was set up to establish a quick description of the participant and his or her organisation (Age; Position in Company; Size of organisation in term of number of employees and commodity type). Section B was set up to give the researcher an idea of complexity levels at each participating organisation and also what the participant believed was the type of strategy that their organisation is following. Section C, the last section, was aimed at establishing the degree of knowledge of FMS that each organisation has. It was also set out to establish if these organisations are making use of FMS and the methodology they choose to use in implementing this system.

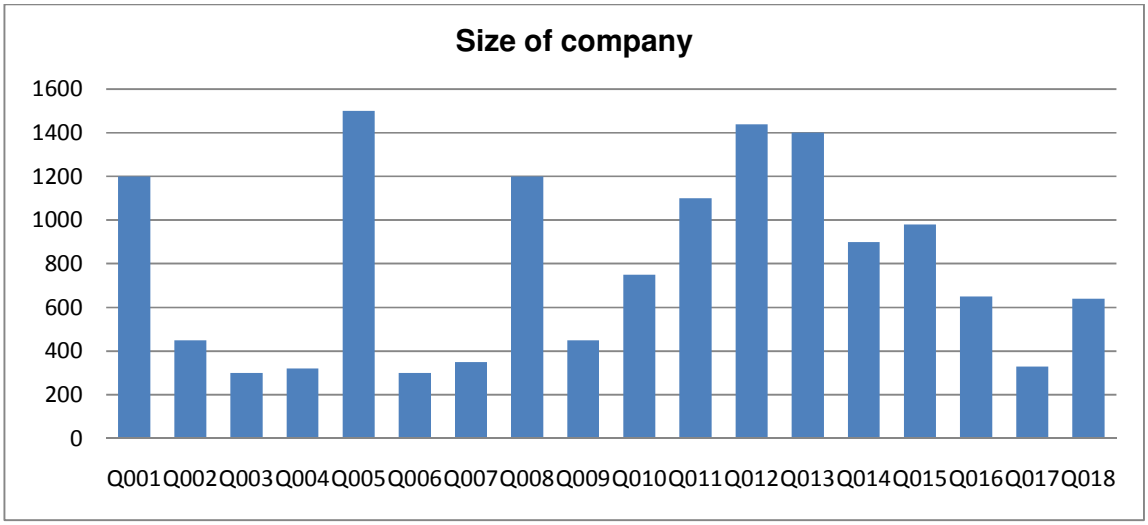
Appendix 6 shows a statistical table of the results received from the research questionnaire. Analysis of the mode; median; quartiles; sample sizes; min observation; max observations; min values and max values are presented.

4.2 ANALYSIS OF SECTION A OF RESEARCH QUESTIONNAIRE

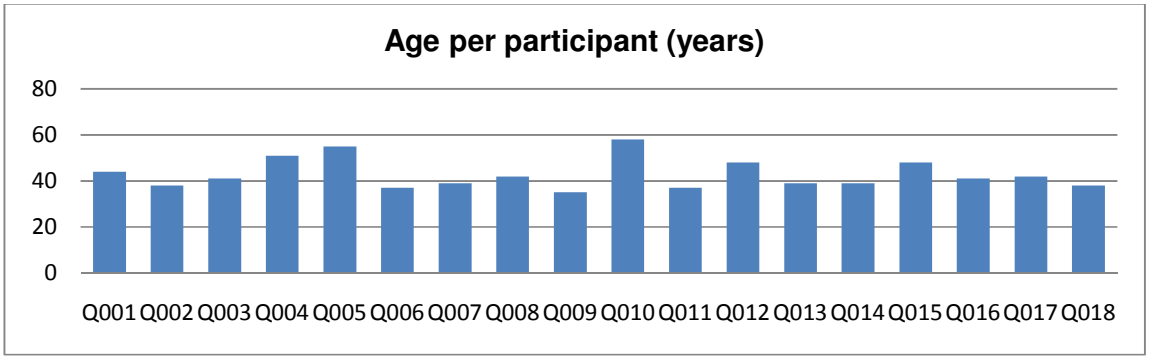
Section A of the research questionnaire consisted of some standard questions establishing some background information of the person completing the questionnaire as well as information of the company.

The following three graphs represent the data received.

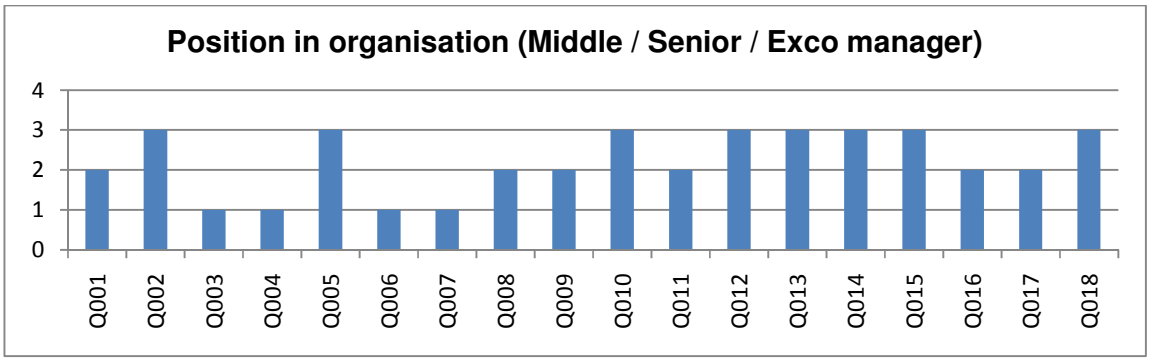
Graph 1 - Size of each company (number of heads)



Graph 2 - Age analysis of each participant



Graph 3 – Position / job in organisation



The average size of the organisations participating, as illustrated in the first graph is 792 employees. Not illustrated is the commodity types that ranged from rubber; glass; wiring; sheet metal; and so on. A total of fourteen different commodity types was covered during this research. All organisations also formed part of NAACAM.

The average age of the participants was 42, thus indicating that all of them had had a degree of experience behind them. The mode for the position of the participator equalled three (3) thus indicating that most of the responses came from individuals that were high up in the organisation (either the Manufacturing Director or the CEO of the company).

4.3 ANALYSIS OF SECTION B OF RESEARCH QUESTIONNAIRE

Section B of the questionnaire, focused on understanding the current complexity of each of the participating companies. It is clear that there is a higher need for organisations with a high complexity level to have flexible systems in place to remain efficient and competitive.

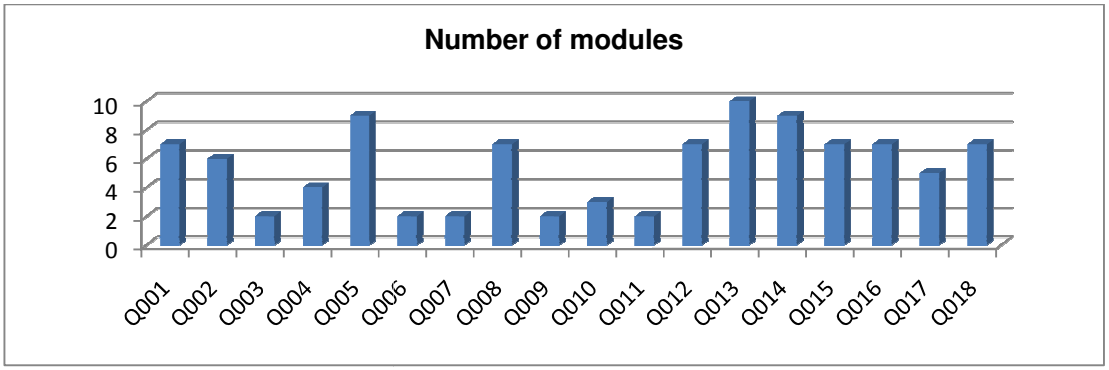
Each organisation was asked to list one (1) or two (2) of their products in their portfolio. From there a more detail analysis looked at the number of different modules per product as well as the total number of parent parts that are being manufactured for that specific product. Each company was then also asked to list the total number of variations per product (each part can have more than one variation). As part of the analysis the participants were also asked to list the percentage of parts that are non-variable.

The second part of this section focused on what the participant foresaw as the degree of complexity for their organisation. For a clearer understanding of the company each participant was asked to define their product strategy.

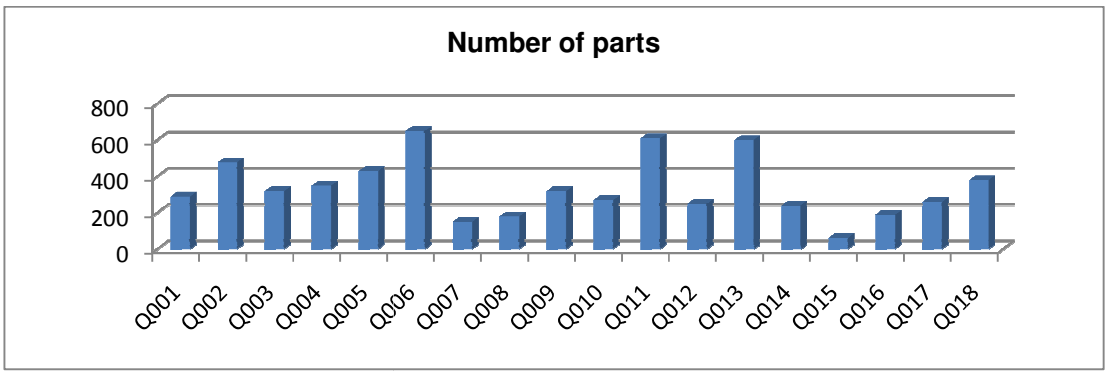
The last part of this section looked at the percentage split in the product range between core; modular and new parts.

The mean amount for the number of modules per company equated to just over five (5) with a mode of seven (7). Number of parts produced between the organisations ranged from a minimum of 62 to a maximum of 650 (range = 588). On the same data the average amount of parts equated 335.The average amount of total variations equated to 859, with the average amount of products that are non variable equating to only 8.72 percent. All of this can be seen in the following graphs.

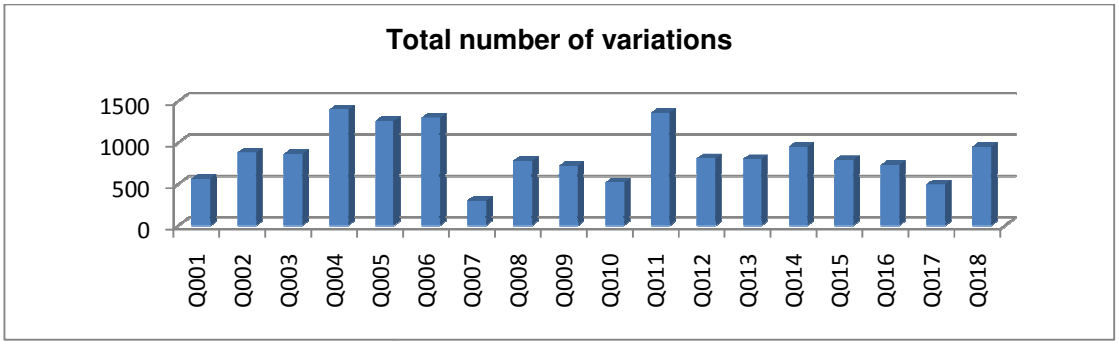
Graph 4 - Number of modules on averaged / product group



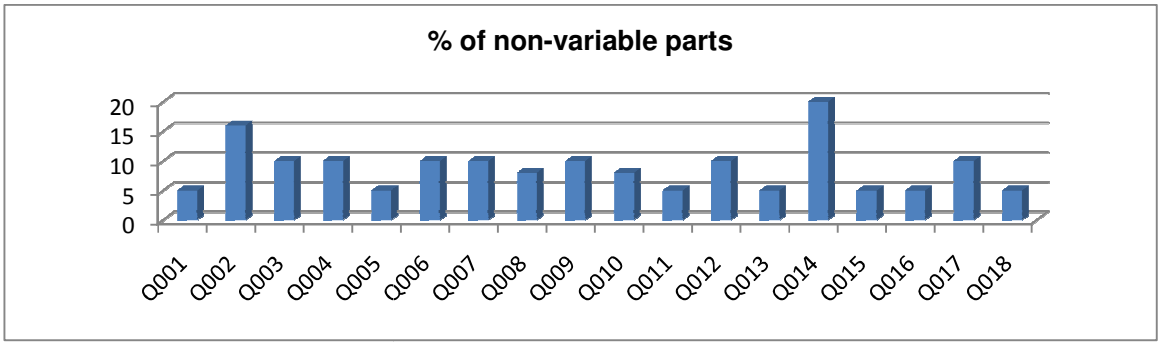
Graph 5 - Number of parts / product graph



Graph 6 - Total number of variations in one product group



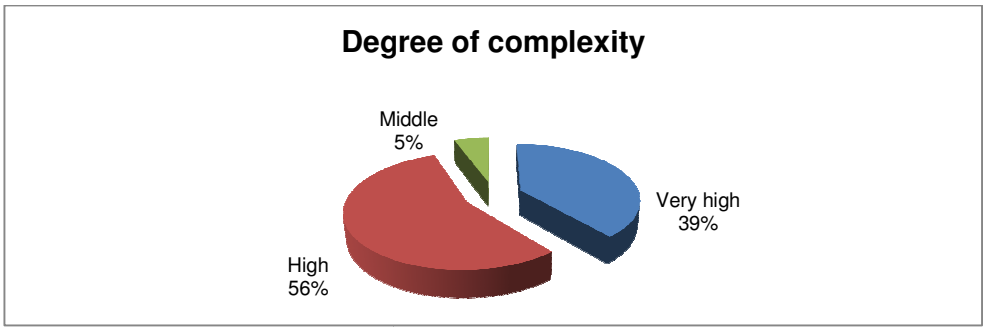
Graph 7 - Percentage of parts that are non variable per product group on average



Based on the above information it is clear that for every part on average that the group of companies are producing there is on average two and a half (2.5) different variations. With the vast amount of different products in the product range, 335 on average per organisation, excluding the number of variations to them and with only just over eight percent of their average components being non-variable, it can be agreed that all these companies faces a fair degree of part range complexity.

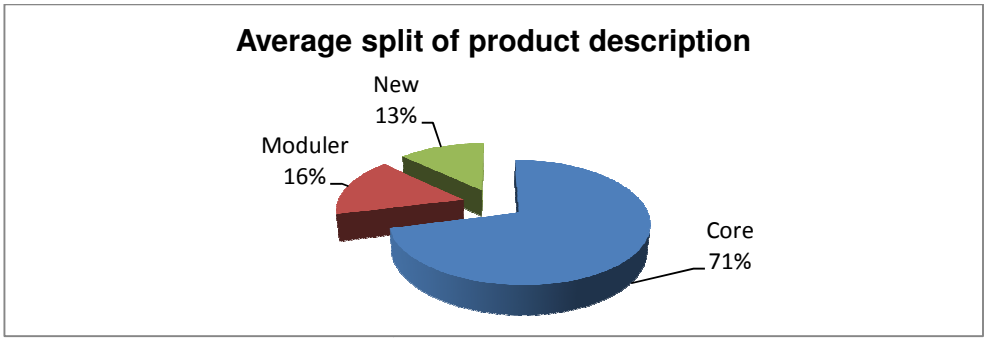
When asked to rate their current degree of complexity, 56 percent of the participants indicated a high degree of complexity, 39 percent indicated very high and only five (5) percent indicated middle as shown in the graph below.

Graph 8 - Rated degree of complexity



The following graph indicates the average breakdown of core versus modular versus new products that each organisation does.

Graph 9 - Average split between Core, New & Modular parts



From the above it is clear that most of the work done by each organisation is core manufacturing.

The data from section B clearly indicates that there is definitely a fair degree of complexity involved in the group of organisations that agreed to participate in this research. In order for these companies to remain competitive it is crucial for their survival to be one step ahead of the competition and continuously coming up with innovative ways to remain profitable. With the requirement of supplying more than one / various customers there is a great need to be quickly responsive to customer demands.

Seeing that all of the organisations do require some sort of programme to remain competitive and ahead of the competition, the following section will look at analysing their understanding of FMS as well as the usage of such a system.

4.4 ANALYSIS OF SECTION C OF RESEARCH QUESTIONNAIRE

As stipulated in section 4.3, this section looked at the general understanding of FMS by each organisation and determined if they are actually making use of such a system.

Question 1 – How would you define Flexible Manufacturing systems (FMS)?

Appendix 2 lists the various responses received on this question. It is clear that there are certain key words that are common in all the definitions given by each participant.

- Being flexible
- Quick changeover

- Adapting to market demands
- Ability to produce a large number of parts
- Minimum disruptions
- Running effectively and efficiently
- Adapting with minimum cost and time.

Most of these points stated above generally coincide with the definitions of Sethi and Sethi (1990:289) “being able to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality,” Hyun and Ahn (1992:251) “a system’s capability to cope with a wide range of possible environmental changes”, and (De Toni and Tonchia 1998:1587) “the ability of a manufacturing system to change or react with little penalty in time, effort, cost, or performance.”

From the responses in Question 1 it is clear that generally all participants do understand the definition of FMS

Question 2 – Does your organisation have a FMS in place?

Sixty six (66) percent of the participating companies indicated that they do have a FMS of some degree in place in their organisation.

Question 3 – If yes to the above question, what process did your organisation follow to implement their FMS strategy (List in bullet points)?

Appendix 3 lists the responses received from each participant. From the results it is found that not one company followed exactly the same implementation strategy. However some key words / points are fairly common between them. Two of the participants, however, did not follow an implementation strategy at all. From the answers given it is evident that their FMS was a byproduct of other systems that they have embarked on (other world class manufacturing techniques).

Some key points that can be extracted from the answers given:

- Establish degree of flexibility needed
- Identify current bottlenecks
- Generate concepts

- Create flexibility innovation data base
- Establish capital constraints
- Design flexibility solution
- Complete economic analysis of proposed solution
- Formalise the flexibility solution.

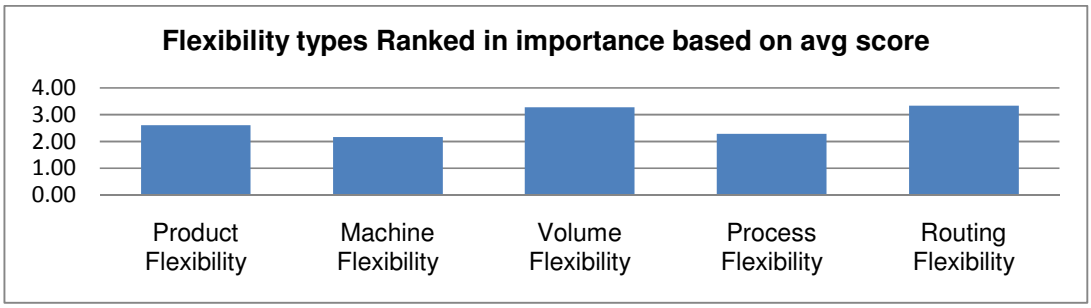
Question 4 – Would you say that having a FMS is a key strategy to remain competitive?

One hundred (100) percent of the respondents indicated that this is a key strategy to remain competitive. This is very surprising seeing that only sixty six percent of participants indicated that they have a FMS in place.

Question 5 – From an agility perspective how would you rank the following five flexibility types? (1 - 5 where 1 = most important)

- Product Flexibility
- Machine Flexibility
- Volume Flexibility
- Process Flexibility
- Routing Flexibility

Graph 10 - Ranking of flexibility types among participants



From the responses it is clear that the participants do not believe that there are just one flexibility type that stands out but a combination of flexibility types.

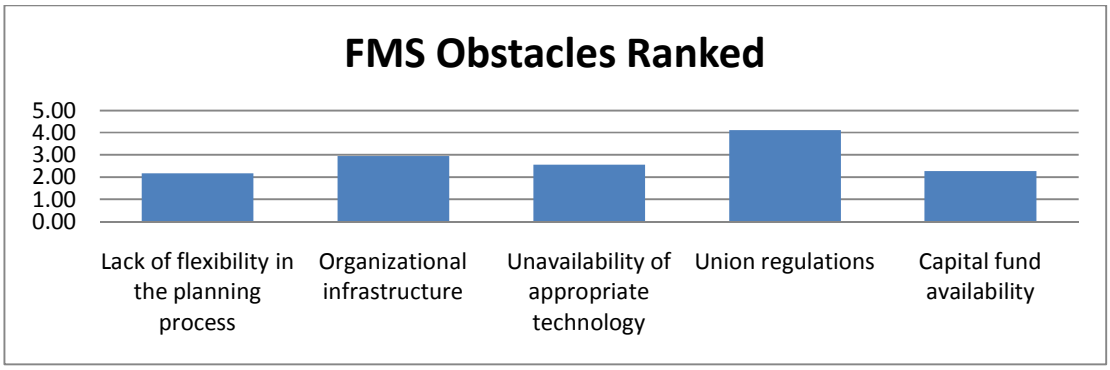
From the above graph however it can be seen that Machine flexibility is deemed to be most important, just ahead of Process flexibility. Routing flexibility is deemed to be the least important scoring at three point three three (3.33) on average.

However it is important to realise that not only one type of manufacturing flexibility can stand out. The importance of the various flexibility types depends on the need of the individual organisation. What might be important for one company may not be important to another, based on their needs.

Question 6 – How would you rank the following obstacles in implementing FMS with 1 = biggest obstacle & 5 = lowest obstacle?

- Lack of flexibility in the planning process
- Organisational infrastructure
- Unavailability of appropriate technology
- Union regulations
- Capital fund availability

Graph 11 - Average ranking of obstacles in implementation



Lack of flexibility in the planning process was rated as the biggest obstacle for implementing a FMS. Forty four (44) percent of the respondents picked the planning process as their number one obstacle. Capital funding was a close second with unavailability of appropriate technology being third. The obstacle given the lowest ranking for implementing FMS seems to be Union regulations. This in a South African environment where unions play an integral part of decisions / strategies, can be seen as a big positive.

Question 7 – In your own words what would you define as the main objectives of FMS?

Appendix 4 lists each participants' response to this question. Key points from the results received are:

- Gain market share
- Improved efficiency
- Quick change over / reaction
- Adaptable
- Reacting to customer demands
- Reduced downtimes

It is clear that manufacturing flexibility is required in order for a firm to cope with both internal changes and external forces as explained by Garrett (1986:19). The internal disturbances for which flexibility is useful include equipment breakdowns, variable task times, queuing delays, rejects, and rework as written by Buzacott and Mandelbaum (1985:404). Behrbohm (1985:75); Zelenovic (1982319); Garrett (1986:20) and Maier (1982:64) explain that the external forces refer largely to the fundamental uncertainties of the competitive environment. These uncertainties may be current or potential.

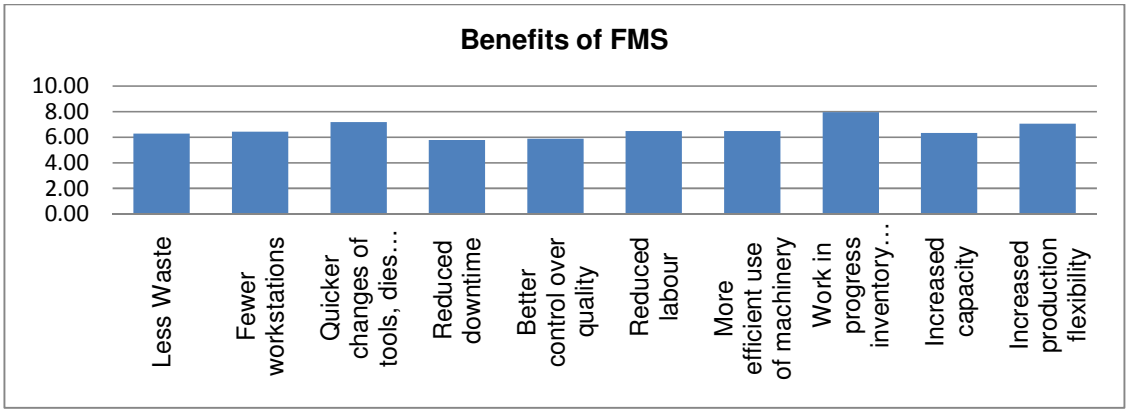
Question 8 – On a scale of 1 - 10, where 10 = highest, how would you rank the following benefits of a FMS?

- Less Waste
- Fewer workstations
- Quicker changes of tools, dies and stamping machinery
- Reduced downtime
- Better control over quality
- Reduced labour
- More efficient use of machinery
- Work in progress inventory reduced
- Increased capacity
- Increased production flexibility

Although this question can be seen as a duplication of the previous question, this is to test for consistency in the previous answers given.

The graph below represents the results from this question

Graph 12 - Ranking of various benefits per participating company



From the above graph it is evident that the general belief is that not just one benefit will rise above all the others. One will rather see a range of benefits when implementing FMS. If required to rank, it seems that reduced Work In Progress (WIP) will be one of the main benefits that will be achieved. Very close second and third benefits from the above graph are quicker change over and increased production flexibility. Reduced downtime can however be seen as the lowest benefit from an FMS.

Question 9 – Should a firm's overall strategy and manufacturing strategy coincide?

One hundred percent of the respondents indicated that the two strategies must coincide.

Question10 – Explain briefly

Appendix 5 lists the responses from the representatives from each company. Some key points from the answers given are:

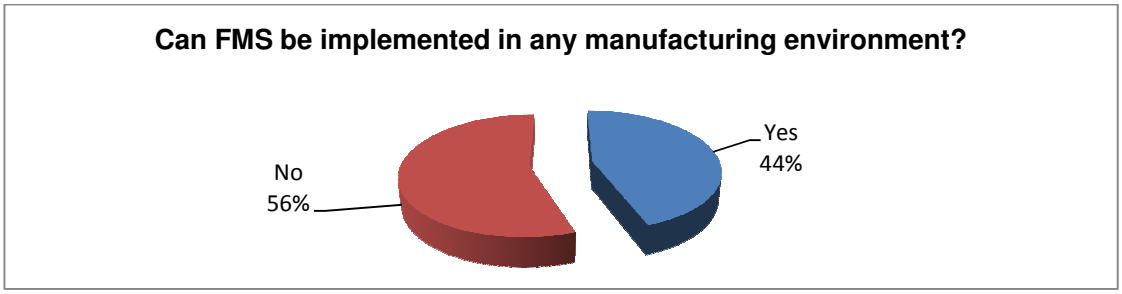
- Conflict within the organisation
- Working towards common goal
- Manufacturing strategy determines overall strategy
- Strategic objectives coincide
- Alignment
- Harmony

Johnson & Scholes (2003:9) suggest that strategy can be defined as the direction and scope of an organisation over the long term, which achieves advantage for the

organisation through its configuration of resources within a changing environment and to fulfil stakeholder expectations.

Question 11 – In your personal opinion do you believe that a FMS can be implemented in any manufacturing environment?

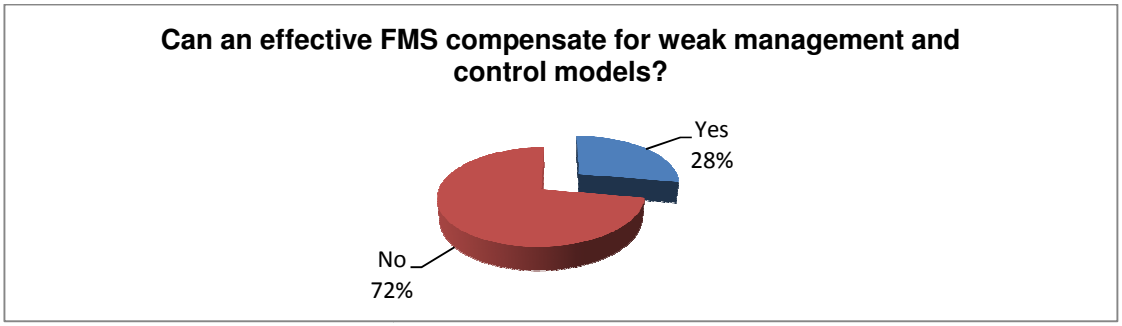
Graph 13 - Analysis of FMS implementation capability in any manufacturing environment



As shown in the graph above fifty six (56) percent of the respondents indicated that that FMS cannot be implemented in any manufacturing environment

Question 12 – Can an effective FMS compensate for weak management and control models

Graph 14 - Analysis of compensation ability of FMS for weak management & controls



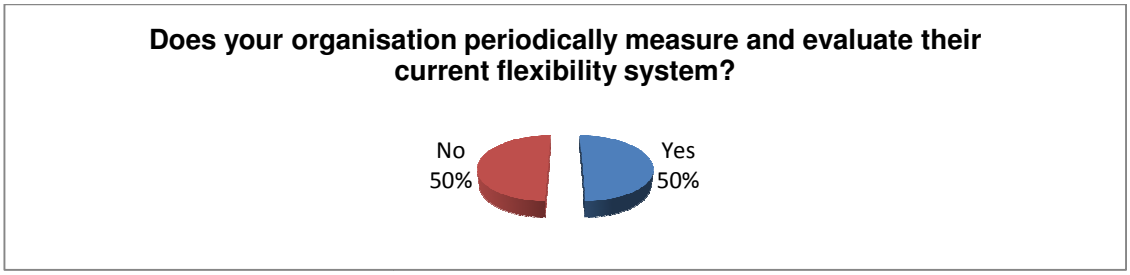
Twenty eight percent of the participants do believe that that an effective FMS can compensate for weak management and control models. This, however, cannot be the case. Weak management and control models will cause the FMS to fail. One of the critical success factors for FMS is the management team. Their key job to ensure an effective system is to implement and enforce discipline and ensure that all controls in place are adhered to.

Question 13 – Do you think that manufacturing flexibility can occur at different organisational levels (i.e. Strategic; tactical & operational)?

Ninety four percent believed that manufacturing flexibility can occur at different levels in the organisation.

Question 14 – Does your organisation periodically measure and evaluate its current flexibility system as changes occur to the company strategy or any uncertainties in the market?

Graph 15 - Analysis of each company's regular evaluation of their current flexibility system



This question was split right down the middle with fifty percent on each side.

This result is actually alarming considering that sixty seven (67) percent of all participants do have an effective FMS in place according to them. This means that twenty five (25) percent of the companies that have an effective FMS in place do not measure and evaluate their system regularly. In chapter 2 it became clear that each flexibility type can be measured. Without measurement the company will never know how really effective their current system is nor where to improve. Reaction to changes in the market will thus also not be possible.

Question 15 – Do you think that a FMS can be copied and pasted from another company or even another sister company?

Sixty seven (67) percent of the participants again believe that one will be able to copy and paste a FMS from another company into another.

Beste (1958:75); Meffert (1969:780); Rempp (1982:176); Jaikumar (1984:63); Gustavsson (1985:803); Ranta (1988:39) as well as Stecke (1989:288) all explain

that flexibility cannot just be bought, copied and pasted, but must be planned and managed and adapted to the individual organisations culture before implementation.

4.5 SUMMARY

The purpose of chapter 4 was to analyze and interpret the data obtained through the statistical analysis of the research questionnaire on flexible manufacturing systems in the automotive supplying industry. The analysis and interpretation was undertaken in terms of the objectives stated in chapter 1.

The evaluation done by the researcher indicates that most of the participants in the research do understand the basics methodology and definition of Flexible Manufacturing Systems as well as the importance of it. However not all are using it in their respective organisations.

Chapter 5 will focus on conclusions, as well as the recommendations to answer sub-problem:

- What can be suggested as best practice for implementing a flexible manufacturing system?

The answer to the above-mentioned question will be based on the findings from the questionnaire conducted as well as the literature study conducted. Problems and limitations encountered during the research, as well as opportunities for further research will be highlighted as well.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

In this final chapter a summary will be provided of the main findings that can be concluded from the theoretical research that was conducted as well as from the primary research that was done.

The conclusions that have been reached with respect to the main problem and sub-problems will also be stated. Lastly, recommendations for future research and suggestions for the application of the findings will be presented.

5.2 PROBLEMS AND LIMITATIONS

During the course of the research project, no problems were encountered.

5.3 SUMMARY OF THE STUDY

This section entails firstly the main reason for choosing this research topic. Secondly a summary of the findings based on the main problem statement as well as the sub problems will be done. This section will then conclude with a review of the research project

5.3.1 Reasons for the research

The rapid changes in the business environment due to its unique characteristics, the increase in international competition among companies, shrinkage of markets, and diffusion of information technology (IT) through organisations have put pressure on businesses to continually review and adapt their traditional manufacturing strategy. In fact, there is a constant search for new ways to achieve a competitive advantage through new manufacturing techniques. Therefore, increasing knowledge and coordination of the company's processes that cross its manufacturing functions become a main requirement of many companies seeking a competitive advantage. Shatterprufe South Africa is one of the companies that are facing these challenges

and require a change from their old traditional manufacturing strategy of mass production.

Undoubtedly, a combination of external and internal factors including population growth, weak infrastructure, foreign debt, increasing inequalities between individuals, groups and regions has prevented many developing countries from achieving significant socio-economic improvements.

Global competitors operating in global markets almost always tend to have world class performance. World class manufacturing (WCM) has often been characterised by three core strategies of customer focus according to Kinni (1996:58):

- customer focus, quality and agility (i.e. the ability to quickly, efficiently and effectively respond to change),
- and six supporting competencies; employee involvement (EI), supply management, technology, product development, environmental responsibility and employee safety, and corporate citizenship according to Kinni (1996:58).

Shatterprufe South Africa, a family owned business and for most of the past, operating in a monopolistic environment in South Africa, was never exposed to competition; thus did not really require to implement WCM techniques. With the ever changing market conditions and opening of new trade agreements this is changing very fast and now the organisation is faced with competition from other international companies being able to produce the same goods at half the price.

For all these reasons Shatterprufe have now had to come up with an innovative new manufacturing strategy to enable them to become world class as well as competitive in the process.

5.3.2 The problem statements

The main problem identified in this study was:

Does the motor component supplying Industry make use of Flexible Manufacturing Systems to assist them in being world class suppliers?

The following sub-problems were identified in order to make the main problem more researchable.

Sub Problem One

- How does the literature define Flexible Manufacturing system?
    - What elements does it consist of?

This sub-problem was addressed in chapter 2 by a literature review of Flexible Manufacturing Systems, defining the various flexibility types as well as their definitions, purpose, means and how each type can be measured.

From this it was found that there are mainly eleven types of various flexibility types; namely machine; material handling; operational; process; routing; product; volume; expansion; programme; production and market flexibility. The first three types can be defined as component or basic flexibilities, while the next five types can be grouped under system flexibilities. The last three in the list can be grouped or defined as aggregate flexibilities.

Chapter 2 also looked at linkage between the various flexibility types as well as proposing a few implementation strategies. A few strategies are suggested but emphasis was placed on the fact that each organisation MUST look at what will work for them by assessing the own requirements as well as looking at the own organisational culture.

Sub problem two

- Do the motor component supplying Industry companies understand what flexible manufacturing is?

To answer this question a questionnaire was designed looking at the fundamentals of FMS. Questions such as defining in your own words what FMS is, as well as rating various flexibility types and obstacles, were asked. The analysis of this questionnaire, done in chapter 4 of this research paper, enabled the researcher to get a clear understanding of this sub problem.

From the responses received and data analysed it was clear that all participants did understand in principle what FMS is, as well as what the aim of such a system is.

Sub problem three

- What implementation approach would be seen as best practice for implementing a flexible manufacturing system?

Based on the results obtained from the questionnaire that were presented in chapter 4 and the literature review in chapter 2, a recommendation on what implementation approach, that would be seen as best practice for implementation of a FMS at Shatterprufe will be presented.

The implementation of an effective FMS is proposed to be done in three phases. Phase one looks at identifying the environmental changes that the organisation is finding itself in and phase two focuses mainly on the primary design of the actual system. Phase three the last phase of the implementation process focuses on the economical analysis of the suggested system and ensuring that it will also make financial sense to implement. The proposed implementation is explained in the following paragraph:

Phase 1: Identify Environmental changes

The first phase of the method consists of only one step, the manufacturing flexibility audit. The research indicates that the change experienced by a manufacturing facility can be divided into two distinct classes on the basis of their source: external and internal. External changes (EC) are a consequence of a market stimulus, and are generated by either customer behaviour or supplier constraints. It should be noted that facilities have limited control over the external changes that occur. At best, facilities can only try to minimise the impact of these changes. Internal changes (IC), on the other hand, originate from within the facility, and are thus more likely to be controlled by management. In all cases the change will be recurring, though the change cycle time will vary greatly. One time changes or changes with cycle times longer than four years are not considered. Flexible manufacturing is unlikely to account for effects of these changes. As the first step in the Flexible Manufacturing

Systems Design (FMSD) process, the purpose of the flexibility audit is to identify and quantify the flexibility related changes being experienced by the facility. This change information is not readily retrieved from accounting records. Rather, it is known to the operating managers and supervisors, and the approach is to retrieve it from this source using the flexibility audit. The audit does not provide a flexibility solution; it only provides direction to the FMSD process. The audit must be designed in the form of a structured questionnaire and presented to a select group of managers and supervisors. The audit is made of seven targeted questions, details of which are reported in Das and Patel (1999:82). Typically, all members of the design team will individually respond to the audit questionnaire.

The responses are summarised into an audit report. The audit report summarises and prioritises the identified changes. Analysis of the audit questionnaire response occurs in two stages. The purpose of the first stage is to generate a list of consolidated changes. This is needed since the same change may be expressed differently by another member. In the second stage the goal is to prioritise the changes from most important onwards.

Phase 2: Design a flexible manufacturing solution

Initially in this phase the concern is with relating the identified changes to potential flexibility types, and then evaluating the needed flexibility. This requires that additional data about each identified external and internal change are first collected. The team will use the data to identify which flexibility types are most likely to provide a viable solution. Using a combination of technology reviews and process analysis, the team will examine each change in the context of the common flexibilities. The objective is to narrow down which flexibility types can be used to counter each change. The identification process helps the team to focus its development efforts, and hence reduce the total effort.

The next step in this phase is to evaluate the needed level of the identified flexibility types. Some theories propose a scheme for taking the audit results and actual data from the manufacturing operation to generate a measure for the needed flexibility. Measures are executed at the specific level that is the need for each flexibility type is made in the context of an identified change. The measurement variables include

process variables, differentiation variables, and product mix.

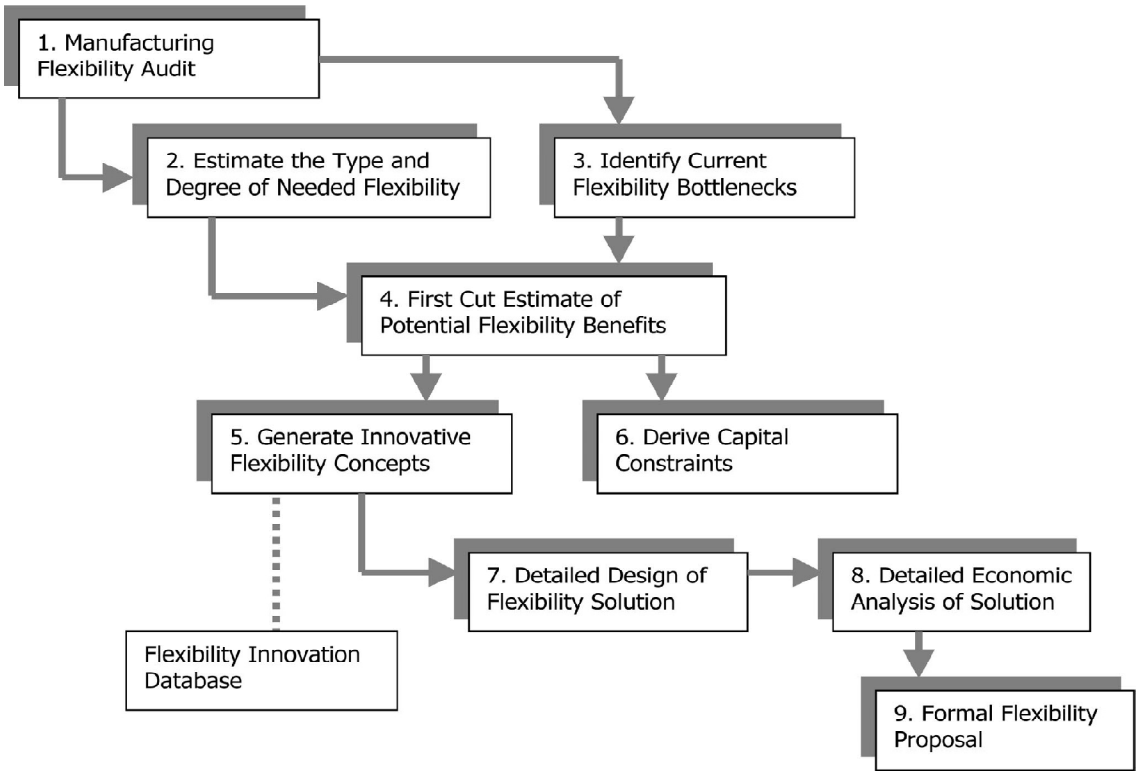
Once the needed measures are available, the team can begin the process of formulating each FM solution in detail. Key issues during this phase are the generation of innovative ideas for adding the needed flexibility. It is recommend that individual team members or sub teams of two be allowed to generate initial solution concepts. To initiate innovation, management needs to plant seeds that instigate new perspectives or approaches. These seeds would be representative of new techniques and equipment that are backed by commercially available resources. Each idea will be converted into an implementation project. It is expected that project specific technical resources must be accessed to support this activity. Human resource and cost concerns should be evaluated in the context of the company's operating environment. A first cut estimate of the potential benefits that could be gained from each FM solution (such as shorter lead times, reduced setup costs, and so forth) should be listed at this point. At the end of this step, a detailed design of the FM solution must be presented. At this point the design document should include the required skills, technologies, and equipment, a process plan for implementing the solutions, and the required management and administrative oversight.

Phase 3: Economic analysis of the FM solution

The purpose of phase three in the method is to relate the potential benefit to the company in acquiring each flexibility type. This is done through a process that calibrates the economic impact of the flexibility to the degree of needed flexibility. The affordability and benefits of innovative technologies are often not easily quantified. It is also extremely important to define the capital constraints within which the flexibility solutions must be developed. It is suggested that to ensure project success it is important to get an estimate of the potential economic benefits, and define capital and non capital constraints, as early as possible. This permits the development team to eliminate solutions that do not meet affordability limits or are unlikely to be implemented as early as possible. The key assumption here is that the earlier two phases will generate several FM solutions. Management then needs to evaluate these based on both tangible and intangible measures. This evaluation will enable them to then select solutions for final implementation. It is expected that the proposed solutions will vary both in their requirements and their affordability. The

main objective of the proposed procedure is therefore the selection of the most effective and affordable technology solution from the proposed alternatives. The procedure is structured in three ascending levels of detail. According to the significance of the flexibility solution to the company, management has to choose the level of detail in the analysis that is commensurate with the size of investment and the intensity of effort made. Analysis and fishbone diagram techniques, as well as financial analysis models (payback period and/or ABC costing) can be used interactively with the input of management to arrive at the final recommendation. It should be mentioned that the primary feature of the procedure is that it provides an integrated and systematic approach, and considers the business aspects as well as the constraints of the firm in the solution that it recommends. Additionally, the procedure allows for simple, detailed analysis, explicit consideration of organisational implementation problems, as well as taking into account intangibles. Diagram 3, Proposed steps in designing a FMS shows the complete suggested implementation process.

Diagram 3 - Proposed steps in designing a FMS



Source: Abdel-Malek *et al* (2000:191)

5.4 RECOMMENDATIONS

- It is essential that the executive team at Shatterprufe realises the need of a FM programme. Based on the analysis from the theoretical research as well as from the questionnaire it should not be difficult for them to realise this.
- It is recommended that the knowledge gained from the research theory and that of the research questionnaire be used as a guideline for introduction and implementation.
- It is recommended that the employees that will be required to implement the FMS are properly trained in the basics of WCM and FMS and that they receive the necessary tools to perform their tasks.
- It is essential that everyone throughout the entire organisation is involved from the start in the development, improvement and maintenance of the system
- It is critical that the barriers to implementation be taken seriously at the start of the whole implementation process and plans be put in place to overcome them. Make sure that there is:
- proper understanding of the total effort required;
- complete management support;
- union buy-in;
- enough training carried out;
- change of priorities;
- full commitment and persistence;
- development of a good installation strategy; and
- insuring that the right approach have been chosen.

5.5 CONCLUSION

According to Ettlie (1988: 56), few rigorous systematic treatments of the topic of flexibility in manufacturing, let alone empirical studies of actual manufacturing plants, have been reported that give a coherent statement of the strategic as well as tactical implications of this important dimension of manufacturing strategy. The literature makes one thing abundantly clear: flexibility is a complex, multidimensional, and hard to capture concept. At least 50 different terms for various types of flexibilities can be found in the manufacturing literature. Usually, there are several terms

referring to the same flexibility type. Definitions for these terms that have appeared in the literature are not always precise and are, at times even for identical terms, not in agreement with one another. Not much work has been done to develop analytical models that deal with the concepts of flexibility rigorously, and of course, to determine the optimal levels of flexibility. As a result, the measures proposed in the literature are naive and, at times, somewhat arbitrary.

In conclusion, the systematic procedure for implementation of a FMS stipulated in this chapter will be a good reference for Shatterprufe to use when implementing a strategy that is in line with flexible manufacturing. The recommendations made must, however, be looked at and will if properly implemented form the basis of an effective FMS at Shatterprufe.

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Appendix 1 - Flexible Manufacturing Research Questionnaire

FMS QUESTIONARE

PERSONAL & COMPANY INFORMATION

Name of Company	_____	Your Name	_____
Commodity type	_____	Age	_____
Size of organization	_____	Position in Company	_____

PRODUCT INFORMATION

1 Please fill in the following table for **two** typical products of your company/organization:

Product	Number of modules	Number of parts	Total number of variations	Percentage of non-variable parts
1. _____	_____	_____	_____	_____%
2. _____	_____	_____	_____	_____%

2 Which product strategy do you follow?

- ☐ Technology & innovation leadership
- ☐ Market Leadership
- ☐ Niche Products
- ☐ Luxury-class Products
- ☐ Mass (high - volume) products
- ☐ Platform engineering with high variants
- ☐ Product defined by production strategy (outsourcing, modular manufacturing, etc)
- ☐ Strategic components & badge-engineering
- ☐ Differentiation by design
- ☐ Other: _____

3 Please estimate the complexity of the modules/systems/components/parts/etc. developed by your company

☐ Very high ☐ High ☐ Middle ☐ Low

4 What is the percentage of core, modular and new products in your comapny?

Core: _____ (%) | Modular: _____ (%) | New: _____ (%)

FMS UNDERSTANDING

1 How would you define Flexible Manufacturing systems (FMS)

_____

_____

2 Does your organization have a FMS in place?

3 If yes in above question, what process did your organization follow to implement there FMS strategy? (List in bullet point)

_____

_____

4 Would you say that having a FMS is a key strategy to remain competitive?

5 From an agility perspective how would you rank the following 5 flexibility types? (1 - 5 where 1 = most important and 5 = least)

Product Flexibility	
Machine Flexibility	
Volume Flexibility	
Process Flexibility	
Routing Flexibility	

6 How would you rank the following obstacles in implementing FMS with 1 = biggest obstacle & 5 = lowest obstacle

Lack of flexibility in the planning process	
Organizational infrastructure	
Unavailability of appropriate technology	
Union regulations	
Capital fund availability	

7	In your own words how what you define the main objectives of FMS?

8	On a scale of 1 - 10, where 10 = highest, how would you rank the following benefits of a FMS?	
	Less Waste	
	Fewer workstations	
	Quicker changes of tools, dies and stamping machinery	
	Reduced downtime	
	Better control over quality	
	Reduced labour	
	More efficient use of machinery	
	Work in progress inventory reduced	
	Increased capacity	
	Increased production flexibility	

9	Should a firm's overall strategy and manufacturing strategy coincide?	

10	Explain briefly

11	In your personal opinion do you believe that a FMS can be implemented in any manufacturing environment?	
12	Can an effective FMS compensate for weak management and control models	
13	Do you think that manufacturing flexibility can occur at different organizational levels (i.e. Strategic; tactical & operational)?	
14	Does your organization periodically measure and evaluate their current flexibility system as changes occur to the company strategy or any uncertainties in the market?	
15	Do you think that a FMS can be copied and pasted from another company or even another sister company?	

Appendix 2 - Question 1 – How would you define Flexible Manufacturing systems (FMS)

1	It is the ability of an organisation to produce multiple product ranges to accommodate market demand
2	It is a manufacturing system where there is some amount of flexibility that allows the system to react to change. It falls into 2 categories, machine flexibility (ability to change order of operations executed on apart) and routing flexibility (Use multiple machines to perform same operation an a part)
3	This is a method on how to run your business effectively to provide a wide range of products with minimum disruptions and be competitive in the market
4	Enable a company too achieve the most out of as little as possible
5	Flexibility to produce a large variety of parts families through a production facility using quick change-over for various differing volumes of similar processes & routings.
6	Manufacturing systems capable of accommodating the greatest mix of parts with the least amount of variation of the machine.
7	The easiest way of manufacturing, yet the most successful way (profitability and productive) Labour skills and competency
8	Manufacturing environment that is able to change and adjust to ever changing complex market demand.
9	It's a system that allows for some flexibility in a process in case of some changes.
10	Being able to adopt to market requirements with minimum cost and time
11	CNC machining
12	Manufacturing environment that is able to change and adjust to ever-changing complex market demand.
13	A system of interdependent components with alternative configuration abilities facilitating flexible outputs
14	A system of interdependent components with alternative configuration abilities facilitating flexible outputs
15	A system of interdependent processes with which in various planned configurations achieves a variable output.
16	This is a manufacturing system where the processes, systems and machinery are setup in such a way that allows for quick and easy changes over of products, machines and processes to satisfy the rapidly changing market demand.
17	Your systems must be structured to enable short time changes and enable decisions to be changed easily to suite priorities. This must be under pinned by flexible MRP and other systems
18	A system that enables a company / organisation to quickly adapt to changes in the market place without incurring major losses or increased costs

Appendix 3 - Question 3 – If yes in above question (Do you have a FMS in place), what process did your organisation follow to implement there FMS strategy? (List in bullet point)

1	Establish the degree of flexibility needed; Look at benefits; Design a solution & implement
2	Audit current process; Establish needed flexibility; Generate concepts; Design a solution for implementation
3	Brainstorming exercise; Generate ideas; Design a proposal for implementation
4	Formed part of world class manufacturing drive
5	Estimate type and degree of needed flexibility; Generate various concepts; Design a potential solution; Economic analysis of solution; derive at formal solution for implementation
6	Complete audit on current system; Identify current flexibility Bottlenecks; Look at 1st cut of savings / benefits; Establish if there is any capital constraints; Detailed design of proposed solution; Implement solution through out organisation
7	Establish need for a flexibility system; Brainstorm potential ideas; Establish savings that will be achieved; Formalise ideas; Implement new system
8	Investigate need for a flexible system; Analyse potential savings; Brainstorm possible ideas; Formalise ideas; Implement new system with proper communication
9	Complete a manufacturing flexibility audit; Estimate what type of flexibility is required; Create some flexibility ideas with a recording database; do a detailed design of the proposed system; Create a formal proposal for implementation
10	Part of manufacturing system for group; Identify flexibility bottlenecks in current process; Implement world class manufacturing techniques such as SMED / KANBAN / 7 wastes to improve
11	Identified the current flexibility constraints; Brainstorm improvement ideas; Estimate potential savings; Establish if there is any capital requirements; Design the best solution for the company; Implement
12	Agree on the need for a FMS; Establish the with team the type and degree of the required flexibility; Create innovative flexibility concepts; Complete a economic analysis of the proposed solution; Formalise the solution for implementation

Appendix 4 - Question 7 – In your own words how what you define the main objectives of FMS?

1	To gain more market share. To be prepared for a change in the market. To secure new business.
2	Higher labour productivity, better machine efficiency, improved quality, higher volume
3	Quick change over, low cost and high productivity levels with big product range.
4	To enable a organisation to be as versatile as possible with as little recourses as possible
5	Flexibility to produce what is needed, when it is needed, in the shortest possible time, at the lowest cost, through a common facility/machine, whilst maximising labour costs & quality.
6	To reduce changeovers and associated tooling. This would result in an increase in the time available for manufacturing of product.
7	The easiest way of manufacturing, yet the most successful way (profitability and productive)
8	The main objective is to ensure that the company has the infrastructure and means to adapt to an ever increasing market demand. Customer is king. Manufacture the right product at the right time at the right price.
9	To have a fully automated process that has little or no human handling
10	Meeting customer demands and satisfaction
11	Cutting flexibility / WIP reduction / speed / quality / less manning / greater volume output /
12	The main objective is to ensure that the company has the infrastructure and means to adapt to an ever increasing market demand. Customer is king. Manufacture the right product at the right time at the right price.
13	The main objective is sustainable competitive advantage
14	N/A
15	Objective of FMS is the ability to change a production line effectively to satisfy changing demands
16	With the world wide market being in the global competitive state that it is having a FMS will allow an organisation to compete for a wider variety of business to keep them competitive in the market.
17	To enable you to adapt to customer, market, product and financial fluctuations
18	Quick and rapid changes without incurring major downtime or loss in costs

Appendix 5 - Question10 – Should a firm's overall strategy and manufacturing strategy coincide? Explain briefly

1	The overall goals of the firm must be aligned with manufacturing, otherwise there will be conflict within the organisation as to how decisions are made and how resources are used.
2	The company should work towards a common goal
3	You need to run FMS in conjunction with your current management system
4	The manufacturing strategy is based on the overall strategy
5	Manufacturing is the backbone of the strategy where the biggest value-add takes place in a company
6	Overall and manufacturing strategies are co-dependent. It the 2 are not aligned, this might result in any progress being made in one sphere being negated by what is perceived as progress in the other
7	Working towards achieving the same goal
8	The overall strategy should be aligned with the manufacturing process. Forecasting what the manufacturing plant is able to do versus what is foreseen as important for the company to survive in the market
9	Manufacturing and the firms should work hand in hand to achieve the best results. Pulling in different directions leads to chaos
10	Everyone have to work towards the same goal
11	It's all about thinking long term investments / benchmarking against competitors /
12	The overall strategy should be aligned with the manufacturing process. "Correct sizing" - manufacturing versus sales
13	If it did not match the strategy, the strategic objective would not be achieved
14	In order to achieve the firm's overall objective the manufacturing division would have to adapt it's strategy for the firm's goal to be achieved.
15	An overall strategy must always steer a business manufacturing requirements.
16	N/A
17	No industry could be successful if all layers is not aligned
18	To create complete harmony in the firm ALL should be working toward the same strategic objectives

Appendix 6 - Statistical analysis of research questionnaire

	A1.1	A1.2	A1.3	B1.1.1	B1.1.2	B1.1.3	B1.1.4	B1.2	B1.3	B1.4.1	B1.4.2	B1.4.3
n	18	18	18	18	18	18	18	18	18	18	18	18
Mean	792.11	42.89	2.22	5.44	335.00	859.33	8.72	3.00	1.67	71.06	16.06	12.89
SD	430.99	6.54	0.81	2.75	164.35	308.36	4.13	2.09	0.59	20.47	16.82	15.56
Min	300	35	1	2	62	300	5	1	1	30	0	0
Q1	375	38.25	2	2.25	242.5	722.5	5	2	1	70	0	6.25
Median	700	41	2	6.5	305	805	9	2	2	70	15	10
Q3	1175	47	3	7	417.5	950	10	3	2	87.5	23	15
Max	1500	58	3	10	650	1400	20	7	3	100	60	70
Mode	1200	39	3	7	320	950	5	2	2	70	0	10

	C1.1	C1.2	C1.3	C1.4	C1.5.1	C1.5.2	C1.5.3	C1.5.4	C1.5.5	C1.6.1	C1.6.2	C1.6.3	C1.6.4	C1.6.5
n	Description	18	Description	18	18	18	18	18	18	18	18	18	18	18
Mean		1.33		1.00	2.61	2.17	3.28	2.28	3.33	2.17	2.94	2.56	4.11	2.28
SD		0.49		0.00	1.50	1.25	1.32	1.18	1.33	1.25	1.00	1.46	1.23	1.18
Min		1		1	1	1	1	1	1	1	1	1	1	1
Q1		1		1	1	1	2.25	1	2	1	3	1.25	4	1
Median		1		1	3	2	3	2	3	2	3	2	4.5	2
Q3		2		1	4	3	4	3	4.75	3	3	3.75	5	3
Max		2		1	5	5	5	5	5	4	5	5	5	5
Mode		1		1	1	1	3	3	2	1	3	2	5	1

	C1.7	C1.8.1	C1.8.2	C1.8.3	C1.8.4	C1.8.5	C1.8.6	C1.8.7	C1.8.8	C1.8.9	C1.8.10	C1.9
n	Description	18	18	18	18	18	18	18	18	18	18	18
Mean		6.28	6.44	7.17	5.78	5.89	6.50	6.50	7.94	6.33	7.06	1.00
SD		2.72	2.75	2.01	2.44	2.08	2.43	3.11	1.98	2.63	3.04	0.00
Min		1	1	3	2	2	1	1	4	2	1	1
Q1		3.5	5.25	7	4	4.25	6	4.5	6	4.25	5.25	1
Median		8	7	7	6	5.5	7	7.5	9	6.5	8	1
Q3		8	7.75	8.75	7	7.75	7.75	9	9.75	8	9.75	1
Max		10	10	10	10	9	10	10	10	10	10	1
Mode		8	7	7	7	5	7	9	9	8	8	1

	C1.10	C1.11	C1.12	C1.13	C1.14	C1.15
n	Description	18	18	18	18	18
Mean		1.56	1.72	1.06	1.50	1.33
SD		0.51	0.46	0.24	0.51	0.49
Min		1	1	1	1	1
Q1		1	1.25	1	1	1
Median		2	2	1	1.5	1
Q3		2	2	1	2	2
Max		2	2	2	2	2
Mode		2	2	1	1	1