CRANFIELD UNIVERSITY

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A Practical Decision Support Tool for the Design of Automated Manufacturing Systems: Incorporating Human Factors Alongside Other Considerations in the Design

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCES

PhD THESIS

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A Practical Decision Support Tool for the Design of Automated Manufacturing Systems: Incorporating Human Factors Alongside Other Considerations in the Design

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ABSTRACT

The way in which a manufacturing system is designed is a crucial determinant of its ability to meet the current competitive challenges. The existing literature and research findings draw attention to the importance of addressing human factors in the design of the manufacturing systems to face these challenges. However, the evidence gathered from the literature clearly illustrates that organisations are not fully incorporating human factors (macro- and micro-ergonomics) in the design of manufacturing systems. In addition, the current system design practices tend to relegate ergonomics evaluation to post-design, leaving ergonomists little opportunity to make significant and important changes.

This thesis details a study which investigates the role of human factors in manufacturing systems design and how it can be integrated into automated manufacturing decision-making. Focus is given to the area of manufacturing automation selection within workstation and cell design. The aim of this research is to support manufacturing systems designers to better incorporate human factors in manufacturing systems design.

A research programme has been designed to fulfil this aim. It consisted of three phases: industrial survey, decision support tool formulation, and practical evaluation. The first phase involved conducting interviews with leading manufacturing organisations in the United Kingdom to determine the work practice in industry and the need for improvements. The second phase comprised the design and development of the decision support tool in a workbook and software application. The final phase was the evaluation of the tool in collaboration with industry.

Overall the outcome of this research was a novel structured approach that deploys both the Quality Function Deployment and Failure Mode and Effect Analysis methods to incorporate human factors alongside technical, organisational, and economical factors in the decision-making process of manufacturing systems design, thereby allowing the consideration of human factors at the feasibility study stage.

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GLOSSARY OF ACRONYMS

AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
ASI	American Supplier Institute
ATM	Advanced Manufacturing Technology
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
DSS	Decision Support Systems
ES	Expert Systems
FMEA	Failure Mode Effect Analysis
FMECA	Failure Mode Effect Criticality Analysis
FMS	Flexible Manufacturing Systems
HITOP	High Integration of Technology, Organisation, and People
ICAM	Integrated Computer Aided Manufacturing
IDEF	Integrated Definition for Function Modelling
MADM	Multi-Attribute Decision-Making
MCDM	Multiple-Criteria Decision-Making
MODM	Multi-Objective Decision-Making
QFD	Quality Function Deployment
SADT	Structured Analysis and Design Technique
SIT	Sociotechnical Integration
SOTEDI	Sociotechnical Diagnostics
TQM	Total Quality Management

CHAPTER 1

INTRODUCTION

1.1 Introduction

With the advent of the new challenge to design a more flexible and reactive manufacturing system, firms are shifting their emphasis towards human aspects and are beginning to consider people as assets instead of costs. In addition, the developments in manufacturing systems and the methods by which they are designed have caused various authors to point out the importance of addressing human factors in the evaluation and design of manufacturing systems, and to call for the adoption of a balanced method based on technology, organisation, and people (Udo and Ebiefung, 1999; Karwowski et al., 2002; Oborski, 2004). Consequently, this research was inaugurated in an attempt to improve the incorporation of human factors into manufacturing systems design, to meet the new challenges and support the production of a coherent interaction between technology, organisation, and people.

This chapter introduces the reader to the research. It first outlines the research problem, then discusses the aim and objectives of the research, and finally describes the layout of the research.

1.2 Research Problem Outline

The manufacturing world is facing major pressures due to the globalisation of markets. Internal and external organisational pressures have led to increased competition, market complexity, and new customer demands. It has been noted how organisations adopt flexible, lean, or agile manufacturing systems to overcome this problem (Plonka, 1997; Womack and Jones, 2003). These strategies have different approaches and elements to address in the design of the manufacturing system, but they all depend on two common things: acquiring technology and human co-operation. In addition, these strategies place pressure on organisations to achieve coherent interaction between technology and people. The contribution that human factors practitioners can make to improving system design and workforce capabilities in current manufacturing environments is clear. However, not all organisations have the luxury of employing an ergonomist to support the decision-making and design of their manufacturing systems.

Moreover, human factors have been important in manufacturing systems design due to the considerable number of reports of unsuccessful implementations and problem associated with the lack of consideration given to human aspects (Mital and Pennathur, 2002; Udo and Ebiefung, 1999). Therefore, studies have been conducted to determine the best way to focus on the integration of humans and technology, how to justify human factors in advanced manufacturing systems, how to achieve socio-technical systems in advanced manufacturing design, etc. (Liker and Majchrzak, 1994; Vernadat, 1999; Sanchez et al., 2001).

Nonetheless, despite the importance of addressing human factors in manufacturing systems and these studies, the evidence gathered from the literature review clearly illustrates that organisations are not fully incorporating human factors in the design of manufacturing systems (Mital and Pennathur, 2002; Karwowski et al., 2002). Consequently, the problem that this thesis investigates is how to support manufacturing systems designers to improve human factors incorporation in manufacturing systems design.

1.3 Overview of Research Aim and Programme

The research aim and objectives are developed in Section 3.2. In summary, the purpose of this research is based on the above proposition that manufacturing systems designers need to improve human factors incorporation in manufacturing systems design, in order to meet the current competitive challenges. Hence, the research aim is:

> "To assist manufacturing systems designers to better incorporate human factors in automated manufacturing systems design."

To achieve this aim the following set of objectives were identified:

1. Determine from an industrial perspective how human factors are incorporated in automated manufacturing systems design, and the need for improvement.
2. Create a decision tool to support the design of automated manufacturing systems by incorporating human factors alongside technical, organisational, and economical factors.
3. Evaluate the decision tool.

The first step undertaken in this research was to further explore the research problem through a literature review, in order to understand how human factors influence automated manufacturing systems design, and what could improve human factors incorporation. Thereafter, the research programme was executed in three phases. Phase 1 was concerned with confirming the research problem by conducting a fieldwork survey to determine the work practice in industry and the need for improvements. Phase 2 incorporated the survey findings into a second literature review to produce the decision tool. Finally, Phase 3 was to evaluate the decision tool in collaboration with industry, in order to ensure whether the proposed solution supports manufacturing systems designers in addressing human factors more appropriately.

1.4 Thesis Structure

This thesis documents the research endeavour, and within this, presents a logical argument, starting with the original problem that led to the investigation, the development of a solution, and concluding with a critical discussion of the findings. The presentation of the thesis arrangement may not reflect the true sequence of events within the study. It does however, presents the content in a structured and readable manner.

The thesis is structured as follows:

Chapter 2 Reviews the human factors in manufacturing systems literature in order to define the scope of the research, and to explore the concepts and principles related to the adoption of human factors in manufacturing systems design. In addition, it provides the findings of a comparative analysis of previous and current research issues in order to highlight the gap.

Chapter 3 Sets out the research methodology through which the research process is shaped. Based on a general review of research techniques, a research methodology has been designed in order to provide a sound approach for addressing the research problem. It also discusses the means of data collection and the sampling method.

Chapter 4 Reports the findings from an investigation of current industry practice. It describes the preparation, execution, and results of a survey conducted in order to confirm the existence of the gap from an industrial perspective, and to elicit the industry's view on what improvements are required.

Chapter 5 Explores the most common decision-making techniques deployed in both manufacturing systems evaluation and design processes. The purpose of this review is to facilitate the evaluation and selection of the appropriate technique required for the development of the research solution.

Chapter 6 Presents an in-depth description of both QFD and FMEA techniques, as these were the outcome from Chapter 5. To confirm a sound judgment, it was necessary to further investigate the foundation of the techniques that will represent the mechanism of the support tool developed for this study.

Chapter 7 Describes the influential elements that are addressed in manufacturing technology evaluation and justification. The influential elements represent technology, organisation, and people issues, and are divided into sub-elements to facilitate the composition of the decision tool's evaluation elements.

Chapter 8 Applies the strengths of the techniques and theories extracted from Chapters 6 and 7; to develop a conceptual manufacturing automation decision-making framework. In addition, it defines the implementation procedure of the proposed decision tool and the means of delivery.

Chapter 9 Contains an evaluation study that tests the feasibility, usability, and usefulness of the proposed decision tool. The evaluation study involves industrial assessment and case study. Again, as in Chapter 4, the preparation, execution, and results of the evaluation study are described. In addition, it discusses the results and presents the findings from the analysis.

Chapter 10 Concludes this thesis with a review of the key research findings against the research aim, and a discussion of contributions to knowledge. In addition, it outlines the limitations of the research programme and findings in order to draw recommendations and areas for further work.

CHAPTER 2

HUMAN FACTORS IN MANUFACTURING SYSTEMS

2.1 Introduction

The purpose of this chapter is to investigate the role of humans within manufacturing systems and the relationship between human factors and manufacturing systems design, in order to portray how human factors influence manufacturing systems design and determine what are the factors and what could improve their incorporation. In addition, this chapter will describe the previous and current research studies relevant to this topic in order to highlight the gap between what is currently available and the research problem.

2.2 Manufacturing Systems

A manufacturing system is considered to be the arrangement and operation of elements (machines, tools, materials, people, and information) to produce a value added physical, informational or service product (Suh, 1998). According to Groover (2001), it is the activity that transforms inputs to outputs. In addition, the role that a manufacturing systems designer plays in devising these systems revolves around considering all the components that are necessary for a particular production process and integrating them within the constraints of available space and resources so that they function synchronously and with optimal efficiency (Rao and Gu, 1997).

Nonetheless, the evolution of manufacturing systems over the last century has changed the manufacturing designer's perception of human inclusion in manufacturing. The classical approach was to move towards the automatic factory 'Lights Out Automation' (Martin, 2002); total automation was seen as the solution to eliminate human unreliability and inefficiency. However, developments in the manufacturing industry and the methods by which the manufacturing systems are designed have induced firms to shift their emphasis towards the human aspects and to consider them as assets instead of liabilities (Groover, 2001). Figure 2.1 summarises the changes in the manufacturing environment from the 20th century towards the 21st century.

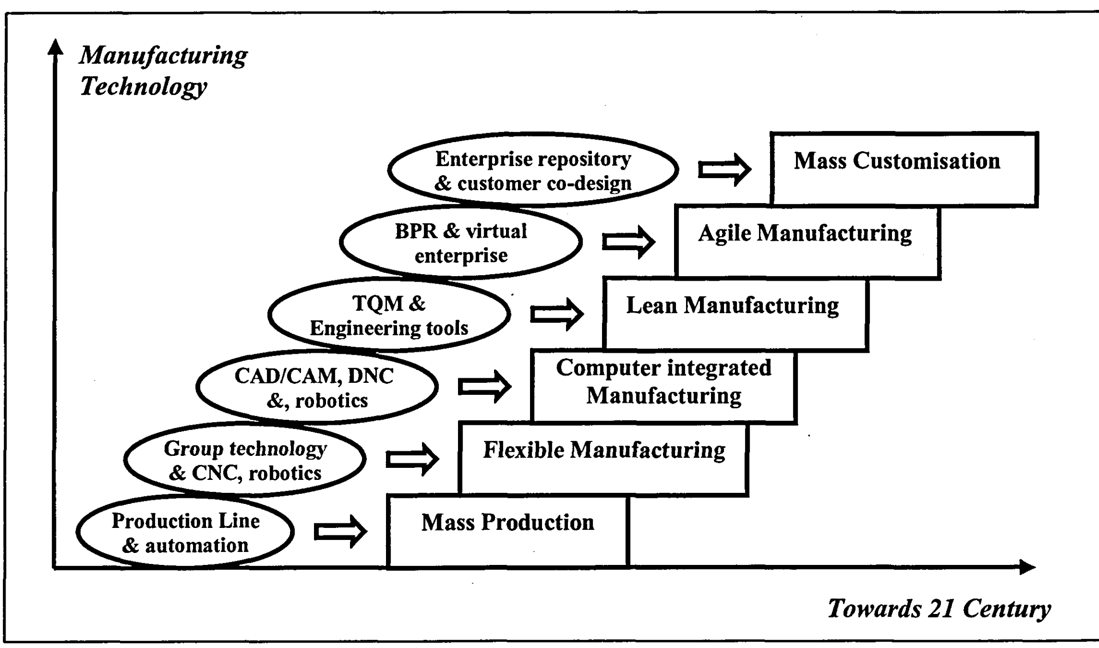


Figure 2.1: Development in Manufacturing Technology (After: Cheng et al., 1998)

Traditional manufacturing relied on mass production and focused on cost and time. When Henry Ford introduced the mass production assembly lines in 1913, the market demand was high and stable. This was one of the factors for its success. In order to remain competitive it was important to continually reduce cost. Thus, companies had to use principles of economies of scale, product standardisation, division of labour, and automation (Levinson, 2002).

During the 1970s the market growth introduced an equally important competitive factor, quality, thus attention was directed towards the achievement of efficient and effective manufacturing processes. As a consequence, the adaptation of group technology and computer numerical control (CNC) machines began to spread throughout the manufacturing industry (Duguay et al., 1997).

In the period from the 1980s to the early 1990s the economy had shifted from high growth to erratic growth, and consumers were demanding more customised products, an increased range of products, and products that would match their particular needs; all at a competitive cost and high quality, obtainable in a timely manner. At this stage the full factory automation ideology was considered to be the main goal for forerunner companies in the manufacturing industry. Consequently, the high demand in production and marketing integration to achieve flexibility resulted in mass implementation of flexible manufacturing systems (FMS) and computer integrated manufacturing (CIM) (Duguay et al., 1997).

Moreover, with the advent of globalisation and a market environment that was characterised as "dynamic" and "rapidly changing", the operation of manufacturing systems had to respond to customised and diversified production, which required a forceful production style that emphasised the flexibility of automation and the integration of people. Thus, manufacturing organisations that were designed to succeed in mass production found this step to be very difficult due to one major obstacle; the "high level of automation" (Abdel-Malek et al., 2000).

A good example would be the General Motors experience with high automation which cost them $60 billion over an eight-year period in pursuit of full factory automation to kill off the competition in the late 1970s. The US car maker found itself with oceans of incompatible automated islands and a disillusioned workforce (Automation, 1991a). According to Roger Smith (GM's chairman in January 1981), the reorganisation moved too fast and insufficient consideration was given to the people involved (Economist, 1991).

The importance of addressing people issues continued to arise as failures in advanced manufacturing technology continued to occur due to organisations failing to understand the organisational/human requirements needed to effectively operate advanced manufacturing technology (Majchrzak and Roitman, 1989; Majchrzak, 1988). As a result, research investigations into the critical role of humans and their interaction within the manufacturing enterprise continued to escalate and attracted a broader academic interest. The investigations demonstrated that through adequate consideration of people and successful technology interaction considerable benefits had been gained from automation and advanced manufacturing technology implementations (Udo and Ebiefung, 1999; Calabrese, 1995; Carr et al., 1994).

Furthermore, a new era of manufacturing operation strategies (such as lean and agile) started to appear to accommodate the competition in industry and the frequent changes in customer requirements. These strategies placed manufacturers under constant pressure to redesign their manufacturing systems based on the integration of technology, organisation, and people (Gunasekaran and Yusuf, 2002).

Moreover, in order to gain greater competitive capability organisations have started to position their strategy on product differentiation and customer intimacy. Therefore, in addition to striving towards operational excellence, the implementation of mass customisation was evolving in the manufacturing industry. The mass customisation concept has been discussed for more than a decade, but it is only in the last few years that increased implementation of this strategy can be found in practice (Piller 2005).

The term of Mass Customisation was coined by Davis in 1987 when he made the statement "The more a company can deliver customized goods on a mass basis, relative to their competition, the greater is their competitive advantage" (Davis, 1987). The essence of this concept revolves around achieving greater capability of customisation and personalisation of products and services for individual customers at a mass production price (Davis, 1996; Pine, 1993).

Therefore, the new challenge in the automated manufacturing industry involves designing flexible and reactive manufacturing systems with coherent interaction between technology and people (Paez et al., 2004). Moreover, to automate or not to automate is no longer the question; how manufacturing system designers can determine the right level of automation with human consideration is far more important (Abdul Rani et al.; 2000). To establish this it is important to elaborate on the definition of automation in automated manufacturing systems design to determine the levels of automation concerned. In addition, it is important to further investigate the role of human factors in manufacturing to determine the influential human issues in modern manufacturing design.

2.2.1 Automation in Manufacturing Systems

Automation means the replacement of both human physical and mental activities by machines (Hitomi, 1996). The persistent desire to automate in manufacturing systems is no longer an area of debate; organisations are aware of the importance of automation. Even though the expectation to attain full utilisation of automation might not be achieved, it is necessary to compete in this vigorous market environment (Vonderembse et al., 1997). The chief benefits gained through automation are as follows: increased productivity and capacity, better quality, greater efficiency, reduced labour costs; greater flexibility; and maintaining a profit at reduced capacity during periods of fluctuation (Neumann et al., 2002; Saleh et al., 2001; Somendra and Lawrence, 1995). In addition, from the point of view of human factors, specialist automation is an essential method to improve the quality of life and reduce hazardous tasks if applied wisely (Davis, 2000; Azani and Khorramshahgol, 1991; Yokomizo et al., 1985).

What is important here is to understand that automation contributes in achieving the aforementioned benefits, but there is a level at which, if it is exceeded, then the drawbacks are far more greater then the gains. As mentioned by Cahill (1999): "a plant should only adopt the appropriate level of automation to avoid the plateau in the automation cost curve. A plant that invests heavily beyond that appropriate level of automation runs the risk of making its operation too capital intensive."

This is only from a unilateral perspective, namely that of cost, but the literature has increasingly focused on economical, social, and physical repercussions of too much or too little automation. Abdul Rani et al. (2000) point to the fact that with higher levels of automation, operators' participation may be reduced, or alternatively, lower levels of automation may create heavy demands for physical workload that could lead to fatigue and stress. In addition, Bainbridge (1983), who discussed the way in which automation of industrial processes may expand rather than eliminate problems with the human operator, and Mital and Vinayagamoorthy (1987) who examined the economical feasibility of robot installation, are examples of the people who have worked in this area. They all claim that automation is useful, but only to a certain degree.

Levels of automation can be identified in both process industries and discrete manufacturing industries (Groover, 2001). The process industries are those that cultivate and exploit natural resources, such as the petroleum and mining industries, whereas the discrete manufacturing industries, such as the aerospace and automotive industries, convert the outputs of the process industries into products. Table 2.1 represents the levels of automation in the process industries and discrete manufacturing industries. However, as the scope of this study is associated with automation in manufacturing systems, only the levels of automation in the discrete manufacturing industries will be discussed.

Level	*Level of Automation in the Process Industries*	*Level of Automation in the Discrete Manufacturing Industries*
5	*Corporate level*—management information system, strategic planning, high-level management of enterprise	*Corporate level*—management information system, strategic planning, high-level management of enterprise
4	*Plant level*—scheduling, tracking materials, equipment monitoring	*Plant or factory level*—scheduling, tracking work-in-process, routing parts through machines, machine utilization
3	*Supervisory control level*—control and coordination of several interconnected unit operations that make up the total process	*Manufacturing cell or system level*—control and coordination of groups of machines and supporting equipment working in coordination, including material handling equipment
2	*Regulatory control level*—control of unit operations	*Machine level*—production machines and workstations for discrete part and product manufacture
1	*Device level*—sensors and actuators comprising the basic control loops for unit operations	*Device level*—sensors and actuators to accomplish control of machine actions

Table 2.1: Levels of Automation in the Process Industries and Discrete Manufacturing Industries (Source: Groover, 2001)

Groover (2001) categorises the levels of automation in the discrete manufacturing industries according to the application of automated systems to various levels of factory operations. He defines the automation level within the context of the entire production plant, rather than associating automation with the individual production machines. According to his interpretation five possible levels of automation exist in a production plant:

1. Enterprise level: consists of the corporate information system and concerns the business units in the organisation. It is the highest level in the automation hierarchy.
2. Plant level: represents the production system and concerns the planning and control of production and materials.
3. Cell or system level: represents the manufacturing system and concerns the control and coordination of operations, workstations, and materials handling equipment.
4. Machine level: represents the production machines and workstation technologies.
5. Device level: represents the feedback control and positioning technologies. It is the lowest level in the automation hierarchy.

In addition, he points out that at each level the adoption and amount of automation could vary. The higher the level of human intervention, the less automated an activity is considered to be, and the more machines replace human activities, the higher the level of automation is considered to be. For example, at the machine level, machines can be classified into three categories: manually operated, semi-automated, or automated.

Zimmerman (2001) elaborates on the three machine categories and describes five equipment levels. The equipment levels specified can either be applied to the entire process or to individual stations.

> Level I: is characterised as a strictly manual operation; every aspect of the processing, manipulation, and positioning of the work-piece is carried out by humans.
> Level II: is characterised as a semi-manual operation in which the operator manually positions and removes the work-piece from the processing device. At this level the process device is mechanically, electrically, hydraulically, or pneumatically powered.
> Level III: is characterised as a semi-automatic operation in which the process is automated and the operator feeds components on a one-for-one cycle basis.
> Level IV: is characterised as an automatic operation in which the process is automated and the operator loads the components in bulk.
> Level V: is characterised as a highly automated operation system where the system is supplied with bulk components by an operator or from an automated storage/retrieval system. At this level automatic in-process inspections can be performed within the process.

Furthermore, Endsley et al. (1997) present levels of automation taxonomy that apply to automation decisions in control systems. Draper (1995), on the other hand, categorises the level of automation among teleoperators according to the level of control. However, they will not be examined at this level of detail, in order to keep the research more generic.

The intention of outlining the levels of automation was to gain an in-depth knowledge of the automation within automated manufacturing systems design, to appropriately define the research study boundaries. Subsequently, referring to Groover's (2001) categorisation, the research study boundaries will be confined to automated manufacturing systems that exist within the machine level; workstation/cell technologies and design.

2.2.2 Humans in Manufacturing Systems

Today many organisations are compelled to incorporate humans into their manufacturing systems design. They are coming to terms with the hard reality that humans will remain a vital part in industry because fully automated factories based on hard automation are not yet viable, except in a few special cases (Gabriel, 2003; Mital, 1997). According to Oborski (2004), "A significant number of manufacturing systems are able to work automatically with limited contribution from employees. However, even in advanced manufacturing systems, one of the most important factors is still the human being."

Whatever the role of people may be in the manufacturing system, they are still necessary for the safe, effective, timely, and reliable running of the system. Pinochet et al. (1996) point out some of the reasons why humans have to be involved in the operation and management of advanced manufacturing technologies. They elucidate this by pointing out that CIM systems can receive information and make decisions only within limits. Even though intelligent systems have the potential to diagnose the origin of failures, intelligent machines have great difficulties in repairing the systems that have failed, difficulties in utilising analogies effectively in decision making, and difficulties in using intuition. Furthermore, Wilson (1991) reaffirms the need for humans in manufacturing by stating "Set-up, maintenance, intervention, and innovation may all be enhanced by allowing the fullest use possible of human abilities in modern manufacturing technology design". According to Calabrese (1995), "the human factor is becoming one of the main elements in determine the success of flexible integrated automation within a firm."

In addition to the importance of humans in operating advanced manufacturing systems, humans are regard as a vital component in modern manufacturing strategies. According to Forrester (1995), humans are considered to be the focal point of a lean strategy because it is a people-driven process. Furthermore, Gunasekaran (1999) points out that the flexibility of an agile strategy is greatly influenced by the involvement, collaboration, and integration of all the people in the manufacturing enterprise.

Furthermore, the argument for removing people that was often based on the assumption that labour costs were a high proportion of manufacturing cost is not necessarily the case in many of today's factories. Mital et al. (1988) carried out a comparison of manual and automated assembly methods and his conclusion was that robotic assembly is not always economical, thus manual assembly of products designed for automation may be less expensive than robotic assembly.

The growing evidence of how critical the human role is becoming in manufacturing systems signifies the need for the contribution of human factors in selecting and designing these systems, more than ever before. The importance of addressing the human factors in the workplace and user-interface design increases as technologies continue to advance and become more sophisticated (Noyes, 2001). According to Oborski (2004), "In advanced manufacturing systems, human factors play an even more important role than in the past." This focus was triggered by the automation interaction and integration complications that took place, and continue to take place through the introduction of advanced manufacturing technologies. Hawley (1996) states that "the impact of automation on humans has not always been positive. There is mounting evidence that automated systems introduce human performance problems that can result in decreased system effectiveness or even catastrophic systems failure."

Moreover, research in the design and selection of modern manufacturing systems has revealed that successful implementation can be greatly influenced by the attention paid to human factors (Genaidy and Karwowski, 2003; Smyth, 2003; Gunasekaran, 1999; Forsythe, 1997). The human factor issues that were reported to be of importance and to need investigation prior to implementation were empowerment, workforce knowledge, skills, incentive schemes, training, and pay awards. Furthermore, Kidd (1994) points out the need to consider the welfare and wellbeing of the people involved to avoid damaging attitudes and behaviours. Therefore, introducing these modern manufacturing systems necessitates changes to processes and layout; consequently implying new structures, roles and interactions on the part of the enterprise and human resources (Brennan, 1994). What is more, these new technologies would require multi-skilled employees, cross-functional training, multi-disciplinary teams, greater initiatives, higher levels of education, employee participation, employee empowerment, goal oriented culture, etc. Gunasekaran (1999) points out how these issues can influence the design of enabling technologies in an agile business practice, and the complications that employees can cause if they are unwilling or reluctant to accept them.

Event though consideration of human factors can make a great contribution to modern manufacturing system design, the ideal of integrating ergonomics into the planning of new production processes, in practice, appears to be difficult to live up to (Jensen, 2002). In addition, Burns and Vicente (2000) state that "Too often, ergonomics is relegated to being a "post-design" evaluation, leaving ergonomists little opportunity to make significant and important design changes." Subsequently, authors are emphasising the need to move human factors upstream into the earliest phases of the design process (Jensen, 2002; Neumann et al., 2002; Burns and Vicente, 2000; Resnck, 1996).

The research described above demonstrates the importance of humans in modern manufacturing systems, and how human factors could influence the design of an automated manufacturing system and the level of automation an organisation may end up acquiring. Furthermore, what is important to bear in mind is that the human issues are not only those relating to the operator/machine interaction issues, which are generally considered in the design of manufacturing systems, but also to the social and organisational issues. Nonetheless, in practice human factors issues are most often addressed, if at all, at the phases of implementation and operation.

The analysis from both sections leads to the following interpretation:

1. Manufacturing systems designers are coming to terms with the fact that people integration is an essential part of a flexible manufacturing system design, and are interested in having a balanced consideration of both technology and humans in the planning and designing of their manufacturing system, in order to meet the new challenges. However, automation is still considered primarily as a means of increased productivity, better quality, and greater efficiency.

2. Authors are demonstrating how important incorporating human factors is in improving modern manufacturing systems design. Meanwhile, in practice organisations are still not paying enough attention to human factors.

These observations present manufacturing system designers with a new difficulty in the selection and design of manufacturing processes. It is argued that manufacturing systems designers need to be supported in improving human factors incorporation at the earliest stage of manufacturing systems design, in order for them to determine the appropriate level of automation and identify the human-automation interaction requirements to be embraced while designing the manufacturing system.

2.3 Human Factors

The following section will provide an overview of the human factors domain and the areas in which it could contribute in improving modern manufacturing systems design. This in turn will reveal what is required to support manufacturing system designers in improving their manufacturing systems selection and design to accommodate the new challenges.

Ergonomics evolved as a discipline in both Europe and America at the turn of the twentieth century. It concerns the study of humans and their work, how interaction takes place, and the effects of such interface. In essence, the name is derived from the

Greek words 'ergo' and 'noms' meaning 'work' and 'natural laws' respectively. It was originally defined by the Italian physician Bernadino Ramazzini, who was the founder of occupational medicine. However, it was not used in its current context until the Ergonomic Research Society introduced it in 1950 (Rowan and Wright, 1994; Sanders and McCormick, 1993).
Authors and specialists in the field of ergonomics have always tried to arrive at a comprehensive definition of this concept. However, due to the wide spectrum in which a large number of disciplines are interrelated, a variety of definitions have been produced. According to Sanders and McCormick (1993, pp. 5): "for those who would like a concise definition of human factors which combines the essential elements of focus, objectives, and approach, we present the following definition, modified slightly from Chapanis (1985): Human Factors discovers and applies information about human behaviour, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use."

In addition, Sanders and McCormick (1993) believe that any distinction that is made between human factors and ergonomics is arbitrary and that they are synonymous. The term ergonomics, although used in Europe, is more prevalent as human factors in USA and some other countries. It is also referred to as human engineering and engineering psychology in the military and psychology spheres (Noyes, 2001).

The spread of awareness of ergonomics was particularly noticeable at the beginning of the industrial revolution in the late 1800s and early 1900s, during which huge technological developments were taking place. It was during this era that eminent people such as Frank Taylor and Lillian Gilbreth inaugurated the focus of ergonomics towards industry (Sanders and McCormick, 1993). Both were interested in the study of adapting equipment and procedures to people, and their manifest contributions included the formulation of the principles of scientific management and time and motion studies (Taylor, 1911).

Further diversification took place after World War II, due to the numerous military encounters in which shortcomings between humans and machines were easily detected. Consequently, this led to an upheaval of interest in human factors towards man-machine interface design (Sanders and McCormick, 1993; Oborne, 1982).

In the 1970s, gender issues and workplace design became of concern in the industrial environment, due to the poor 'fit' between the human operator and his or her environment, which resulted in lives being lost and a reduction in productivity. Consequently, ergonomics practitioners were required to optimise the interactions between operators and their work environment. In addition, with the advent of the silicon chip and the subsequent rapid development of computers and automation, the focus of the ergonomics realm expanded to software design and information processing; known as 'cognitive ergonomics' (Hendrick and Kleiner, 2001).

Today, on the other hand, the human factors discipline is considered to be a critical dimension in the field of work organisation and organisational design analysis. This focus was inaugurated in 1986, as traditional ergonomics produced disappointing results in reducing work system productivity costs, improving intrinsic job satisfaction, and reducing symptoms of high job stress. Subsequently, the term 'macroergonomics' was coined to represent the ergonomics of work systems. Thereafter, the Strategic Planning Committee of the Human Factors and Ergonomics Society (HFES) has identified the unique technology of human factors/ergonomics as human-system interface technology. The human-system interface technology takes the form of guidelines, specifications, tools, etc., and constitutes the following design subparts: human-machine interface technology, human-environment interface technology, human-software interface technology, human-job interface technology, and human-organisation interface technology (Hendrick and Kleiner, 2001).

According to Hendrick (2002), the human factors/ergonomics discipline now embraces two main sub-disciplines; micro-ergonomics and macro-ergonomics. Micro-ergonomics focuses primarily on the individual or subsystem level, whereas macro-ergonomics focuses on the overall work system level.

Therefore, to investigate what and where human factors could contribute in supporting manufacturing systems managers in improving their modern manufacturing systems design, the micro-ergonomics and macro-ergonomics sub-disciplines will be explored in greater detail.

2.3.1 Micro-Ergonomics

Micro-ergonomics resembles the components of traditional ergonomics (Hendrick, 1995), which is based on the human biological sciences, namely anatomy, psychology, and psychology, to address the following aspects: anthropometry, biomechanics, work physiology, environmental physiology, skill psychology, and occupational psychology (Singleton, 1972). The ergonomist deploys this knowledge to 'fit the job to the man' rather than 'fit the man to the job', in order to maximise safety, efficiency and comfort (Oborne, 1982).

The concept of micro-ergonomics deals with specific tasks and relates to human-machine interfaces (Luczak, 1995). It embraces hardware ergonomics, environmental ergonomics, cognitive ergonomics, and work design ergonomics (Hendrick and Kleiner, 2001). The following is a brief description of these subparts:

Hardware ergonomics

Hardware ergonomics refers to the man-machine interface technology. It is primarily concerned with the study of human physical and perceptual characteristics, and is applied to the design of controls, displays and workspace arrangements (Medsker and Campion, 1997). The aim is to determine the capabilities of the operator and then to attempt to build the work system around these capabilities (Oborne, 1982).

Environmental ergonomics

Environmental ergonomics refers to the human-environment interface. It specifically deals with the human capabilities and limitations with respect to the demands imposed by various environmental modalities, such as light, heat, noise, vibration, etc. The term 'environmental ergonomics' is applied to the design of human environments to minimise the environmental stress on human performance (Medsker and Campion, 1997). The aim is to determine the capabilities and limitations of the operator and build the environmental conditions (illumination, climate, noise, and motion) around these capabilities to enhance the comfort, health, and safety of the operator and working environment (Sanders and McCormick, 1993).

Cognitive ergonomics

Cognitive ergonomics or software ergonomics refers to the user-system interface technology. It is primarily concerned with how people conceptualise and process information, and is applied to the design or modification of systems software (Medsker and Campion, 1997). The aim is to describe how work affects the mind, as well as how the mind affects the work, to enhance human-computer interaction and usability (Luczak, 1995).

Work design ergonomics

Work design ergonomics refers to the human-job interface technology (Hendrick, 2001). It involves time-and-motion study and work study, and is primarily concerned with the design of the task's breadth, depth, and complexity. The aim is to determine the most efficient work methods and job content to enhance productivity, job satisfaction, job involvement, and the quality of work life (Medsker and Campion, 1997).

The consideration of these ergonomic subparts had a tremendous impact on the safety, efficiency, and comfort of many systems throughout the world (Hendrick, 1986). In addition, the benefits gained from addressing these issues were greatly noticed in decreasing work-related musculoskeletal disorders injuries, as well as positively affecting quality and productivity (Rowan and Wright, 1994).

Therefore, in order for manufacturing system designers to consider the capabilities of the operator and attain such benefits, the following human factors issues need to be appropriately addressed: human-machine interface, human-environment interface, human-software interface, and human-job interface.

2.3.2 Macro-Ergonomics

The concept of macro-ergonomics deals with the organisation-machine aspect of the human-system interface (Medsker and Campion, 1997). It primarily concerns the overall structure of the work system as it interfaces with the system's technology. According to Hendrick and Kleiner (2001), this sub-discipline is concerned with factors in the technological subsystems, personnel subsystems, external environment, organisational design, and with their interactions, and is guided by societoechical systems theory.

Sociotechnical systems theory is a framework for studying how social and technical systems interact to affect organisational performance (Majchrzak, 1997). It is devoted to the joint optimisation and blending of both the technical and social systems of an organisation (Fox, 1995). The technical subsystems refer to the equipment, facilities, methods, programs, procedures, etc. that transfer input into output, whereas the social subsystems refer to the set of members of the organisation acting in their roles, relationships, authority structure, communication structure, learning mechanisms, etc. (Majchrzak and Roitman, 1989).

The goal of macro-ergonomics is to ensure the compatibility of the work system design with the organisation's sociotechnical system characteristics, and then to ensure that the micro-ergonomic elements are designed to harmonise with the overall work system structure and processes (Hendrick and Kleiner, 2001). Thus, addressing macro-ergonomics in manufacturing system design facilitates the move from technology-centred systems to human-centred systems; also known as anthropocentric systems. A human-centred system is seen as a necessary step to assist in the adaptation of new technology, as it deals with the process of designing a system that ensures an equal share of technical and human consideration, and aims at the full integration of human skills and technology capability to produce systems which are flexible and adaptable to new needs (Karwowski et al., 2002; Uden, 1995; Ennals et al., 1994).

The benefits gained by addressing the macro-ergonomics issues in the design of manufacturing systems will have a positive impact on the selection and adaptation of manufacturing strategy, work organisation, and technology, as the evaluation processes used in these areas do not simply involve technology, but also organisation and people (Karwowski et al., 2002; Kidd, 1990). In addition, Hendrick (1995) states that instead of the typical 10-25% improvements in productivity, health, and safety, improvements of 60-90% could be realised through successful macro-ergonomics intervention. Therefore, in order for manufacturing systems desingers to adapt the technology to the organisation and people, as well as, ensuring appropriate social and organisational consideration, the human factors issues should extend beyond the human factors of technology and include the human factors of work organisation and social networking.

2.4 Human Factors Integration Techniques in Manufacturing Systems Design

After reviewing which human factor issues are of importance to support manufacturing systems designers in their current situation, it is necessary to identify the available work that has been produced to integrate human factors into manufacturing systems design and selection. The aim of this examination is to determine how manufacturing system designers are supported in improving human factors incorporation in manufacturing systems design. The following is a brief description of the techniques frequently referred to in the human factors/ergonomics literature, within the manufacturing systems domain. They are arranged in a chronological order.

2.4.1 A Model for Hybrid System Development

Hybrid production systems are manufacturing systems that are composed of equipment that are neither completely manual nor automated. They are identified as 'Hybrid Systems' as they employ and integrate the capacities of human operators with intelligent machines (Rahimi and Hancock, 1986). Rahimi and Hancock (1986) presented a model to assist managers in making the transition to and operation of a hybrid automated manufacturing system. The model consists of three major elements which relate to the working-machine environment, human factors in management, and personal resource management. Each of these elements is further subdivided into a hierarchy structure to ease the process for managers to locate individual problem areas.

The first element includes:

- System reliability: identify and examine the areas - software, human, and hardware - that should be addressed during the design stages.
- Human performance: identify and examine the human capabilities and what to include within the job design. It covers physical/ mental workload, performance measurement, job design, task allocation, and stress.
- Worker-machine compatibility: identify and examine the interaction and interface requirements that are essential to hybrid system production. It covers human-computer interface, information-flow compatibility, and workplace design.
- Safety: identify the safety engineering solutions and hazard prevention techniques that should be addressed in interface design. It covers hazard identification, hazard prevention, and environment stressors.

The second element includes:

- Organisational design: identify the impact of technology on the organisation and automation. It covers organisational structure, work group structure, and the impact of advanced technology on managers.
- Motivation and morale: identify the impact on people, through examining organisation policy/procedures, work groups, social interaction, individual behaviour, task content, and remuneration/compensation.

- Employee relation: examine status change, supervisor responsibilities, and communication.

The third element includes:

- Training: identify and examine the essential points that should be considered to enhance the interaction and integration of the hybrid production system. It covers new procedures/development, training systems, re-training, education/simulation/integration, and knowledge /rules/skill base structure.
- Selection and placement: identify the impact of new system on employee selection and management. It considers new applicants, current employees, and selective attrition.
- Assessment/feedback: identify evaluation techniques (criteria, analysis, validation, and reassessment for new development) to be used to assess the new system design.

This is a structured system model for the integration of hybrid automated production systems into full scale operation. It would act as managerial decision aid in terms of resource allocation to achieve optimal transition between current and hybrid production, and to retain optimal productivity once transition has been achieved. However, even though the description that is presented is a comprehensive one but the information provided on the breakdown structure is minimal and left for the designer to decide and act upon.

2.4.2 Systems Design of Human-Robotic Interaction

Helander and Domas (1986) proposed a methodology for allocating tasks between humans and robots in manufacturing. The new element in this model includes the consideration of product design during the design of the manufacturing system. This approach analyses human/robot interaction and uses the information to allocate tasks to achieve the ideal design.

The framework is divided into four important stages: inventory of common tasks, resource analysis, product design, and task allocation. The following is a detailed analysis of the model:

- Long term objectives and planning restraints: this step includes the study and analysis of the goals and directions of the organisation towards automation and technology development. In addition, to the review of the product's life cycle and market change.
- Inventory of anticipated common tasks: here the designer enumerates the types of task expected to be involved in the assembly, as well as the existing and future tasks that are necessary. The classification can take different forms including method of assembly, tools needed, and cycle time.
- Resources requirements: this step includes the identification of human and robot attributes that will aid in the decision making of task allocation. In addition, it includes the acknowledgement of the requirements of each method to aid in the feasibility study.
- Design of products: at this stage the designer should refer to Design for Automation (DFA) methodology. This supports the balance distribution of tasks, due to the fact that the product is designed with consideration given to the resource analysis and constraints.
- Task analysis and allocation of tasks: the task analysis is a break down of the components of the manufacturing process into subsystems and task elements. This includes the use of several different methods such as computer simulation, checklists, and interviews. However, for the allocation of tasks, the designer uses the task analysis information to determine which type of robots are required and which jobs can be performed by humans.
- Evaluation and implications of product design: at this step the economic implications, feasibility, and job satisfaction are evaluated. The results of the evaluation will determine whether any amendments are required to the design of task allocation.

This framework represents a thorough procedure of task analysis and allocation during the design of the human-robot interaction. However, the intentions of the developers were to achieve ideal interaction within the assembly process of the manufacturing system. Therefore, this represents a solution to only a part of the manufacturing design.

2.4.3 Open System Framework

Majchrzak and Klein (1987) presented an open systems framework to depict the impact of the changes caused by automaiton. This approach views the manufacturing system as input, processes, and output. It examines the impact of technology change on each stage. Accordingly, the open system imports types of inputs:

- Technology and other resources, which are manufacturing technologies, capital resources, raw materials, and people.
- Environmental conditions, which include marketplace characteristics and external influences.
- Implementation and business strategy, which refers to the organisation's procedures towards introducing new technologies and plans.

The processes include the following four functions:

- Task structure, which refers to the jobs and skills requirements. Due to the fact that technology change affects work pace, information, coordination, discretion, variety, flexibility, and physical intervention.
- Personal systems, which refers to impact on staffing, selection, training, and compensation and reward systems.
- Formal structure, which refers to the influence on integration, formalisation of rules and procedures, and locus of decision making authority.
- Informal organisation, which refers to impact on informal communication networks, power distribution, culture, and future vision.

Finally, the open system outputs; at this stage the results of change impact can be evaluated through the examination of individual attributes and behaviour, group and inter-group behaviour, and organisation outcomes.

This framework directs attention towards the fact that to achieve better impact of technology, the organisation's processes should be managed appropriately and evaluated accordingly. However, it only evaluates the outcome from introducing technology and acts as a guideline, but the specific details needed to perform the change are not included. In addition, the framework does not address the micro-ergonomic aspects it is mainly focused on macro-ergonomics.

2.4.4 A Framework for Managing Hybrid Systems Design

Rahimi et al. (1988) developed a framework for managing hybrid production systems which is comparable to the hybrid systems development model by Rahimi and Hancock (1986). This framework supports managers in the development, implementation, and assessment of hybrid systems. It is based on the interacting elements of humans and machines in high-technology systems.

It consists of the following three elements: human resource utilisation, worker-machine environment, and intelligent machines. To a high degree both approaches are similar in the areas that should be addressed by the engineers and managers. Nonetheless, the following are the new subdivisions added to reinforce the management of the hybrid:

- Job responsibility: this addresses the information needs, discretion, and output priority. The act of introducing intelligent machines will affect the responsibilities of operator's job and the amount of worker interaction.
- Personal policies: this addresses pay, job security, and career development. The additional responsibilities and new working procedures will require management to change and review their organisational policies in order to secure minimal resistance and maximum satisfaction.

This is a useful methodology for the design and integration of hybrid automated production systems. It addresses the organisation and people needs and complications to ensure greater adaptation to the new or improved manufacturing systems design. In addition, it is an expansion of the hybrid systems development model described above. Nonetheless, the information provided on the structure is minimal and left for the designer to decide and act upon.

2.4.5 Criterion-Based Task Allocation Model

Clegg et al. (1989) presented a task allocation model that provides the required support for the designer during task allocation design to meet the requirements for usability. It was developed in the absence of usable aids to enable engineers and others to make relatively systematic criterion-based decisions on which functions in advanced systems should be automated, and which should be undertaken by humans.

The model embraces four criteria to aid the designer during task allocation design: technical feasibility, health and safety, operational requirements, and function characteristics. In addition, it consists of seven phases as follows:

1. Specifying the goals and objectives of the manufacturing system.
2. Identifying and examining the specification and human factors requirements.
3. Development of the system functions and sub-functions.
4. Examination of constraints and revision of allocation.
5. Task allocation distribution with consideration to the four criteria.
6. A comprehensive study from financial, specification, and output perspectives by the implementation of the produced design.
7. Implementing the design.

This model addresses the allocation procedure of functions and requires the designer to conduct a systematic process to justify their allocation during the manufacturing system design. It focuses on improving the human-machine task allocation methodology in manufacturing systems design. However, it does not address the macro-ergonomic aspects it is mainly focused on micro-ergonomics

2.4.6 The Dual Design Approach

Bohnhoff et al. (1992) describe the dual design approach, which is used as a solution to find a balance between human action and machine action. The approach is a set of principles to ensure the appropriate development of both technical and human aspects of human-machine systems. It compromises two concepts; one deals with the technology-based design, and the other deals with the working process-based design. The tasks are distributed according to the concept that as more attention is focused on technology, the level of automation increases, and vice versa with the human-based concept.

This approach resembles a concept where designers have to use both people and technology subparts in parallel to obtain an optimum balance. The weaknesses, advantages, and disadvantages of both subparts have to be compared, analysed, and continually examined to find the ideal interaction. However, it is only concerned with specific task allocation and does not provide a detailed breakdown of the human and technological subparts.

2.4.7 Designing Human Centred CIM Systems

Endsley (1993) presented an approach for achieving a human-centred design in advanced manufacturing systems. His approach views the design of interfaces for automated systems from two perspectives:

- The allocation of known interface guidelines, which includes the use of human-computer interface and control/display design guidelines.
- The macro-level issues in human-automation interfaces, which addresses the impact of automation on work organisation, and should include the following

methodologies: level of decision automation, system design process, and a situation awareness oriented approach.

This approach is a methodology to help designers evaluate their human-computer interface design. It deploys the method devised by Sanders and McCormick's (1987) to consider the humans up front in the initial stages of the design cycle, and situation-awareness theory to support operators in making the decisions necessary to achieve various goals and achieve a user-centre design. However, the scope of evaluation is limited to micro-ergonomic aspects.

2.4.8 ACTION

Gasser et al. (1993) describe the ACTION theory that forms the core of the knowledge in the decision support tool. ACTION is a computer-based decision support system to aid designers in selecting the ideal sociotechnical systems design features. It is deployed to assist business re-engineering and organisational or technological change by helping to improve the integration of technology, organisation and people in manufacturing enterprises.

The ACTION organisation design and analysis system was built upon the knowledge and insights gained from the HITOP (High Integration of Technology, Organisation, and People) and HITOP-A (High Integration of Technology, Organisation, and People-Automated) projects. It uses a multi-level constraint-based representation of organisational features, including business objectives, unit structure, skills needed, performance monitoring/reward system, decision making discretion, employee values, coordination attributes, etc., to both evaluate existing organisation design and to help develop new ones.

This is a very useful tool to align the interactions among the technology, organisation, and people features in the organisation. It involves management and designers collaboration to comprehend the impact of different organisational, technology, and strategy choices. However, the tool does not address the micro-ergonomic aspects it is mainly focused on macro-ergonomics.

2.4.9 Function Allocation Techniques

Mital et al. (1994a) undertook a comprehensive study of the available techniques for function allocation that designers tend to use in the distribution of tasks to humans and machines. The following is a description of the techniques presented:

- Fitts (1951) is considered to be one of the pioneers in the field of task allocation, and developed the renowned Fitts List, which comprises a listing of the aspects at which humans appear to be superior, and those that are better undertaken by machines. However, the MABA-MABA (men are better at - machines are better at) approach does not provide a systematic procedure for designers to follow.
- Paul et al. (1979) undertook a study to determine the differences between robots and humans in a specific assembly. For their research they used Maynard et al.'s (1948) Methods-Time Measurements (MTM), and their proposed Robot-Time and Motion (RTM) method. This is a detailed breakdown of the activities in each task to determine the time cycle to identify which one out performs the other.
- Nof et al. (1980) developed a job and skills analysis approach for function allocation. It involves two sequential steps; Robot-Man Chart (RMC) and Job and Skills Analysis (JSA), directed towards material handling tasks and to certain fabrication and assembly tasks. The RMC identifies jobs that can be performed by either robots or humans according to individual manipulation, control, energy, and interface differences. Nevertheless, the JSA identifies the time and skills required and the comparison is based on physical structure, motion control, and intelligence.
- Price (1985) developed a systemic approach for arriving at a hypothetical allocation. It is a five-step approach with four principle rules, namely:

mandatory allocation, balance of value, utilitarian and cost based allocation, and allocation of function for effective or cognitive support.

- Madni (1988) proposed an unconventional method of task allocation through the use of a software model, known as Human-Machine Allocation Network-Based Environment. It consists of task modelling, function allocation option generation and evaluation, and analysis of the options. However, it has been criticised for the difficulty in use and amount of generalisation of tasks allocated.
- Mital et al. (1987) studied task allocation with a detailed review towards economic considerations. The model examines the economic feasibility of a robot installation from the points of view of the company and the government. Conversely, task allocation should not only be based on the capabilities and limitations of humans and machines, but also on sound economic analysis.
- Genaidy and Gupta (1992) attempted to combine the work measurement technique and the JSA technique to come up with an intuitive procedure for task assignment. However, with the addition of the missing factors, inadequacies were observed in the depth and specification of information to solve the function allocation problem.

Accordingly, Mital et al. developed a series of decision making flow charts for task allocation to be used for optimising assignment of functions (Mital et al., 1994b). The decision making analysis constitutes a set of mandatory generic questions that must be answered. These include: requirements of complex decision making, physical ability of humans to perform the task, safety considerations, and economic considerations. In addition, it views the distribution of tasks from three main perspectives:

- Capabilities/limitations: this relates to technical and information workload, and interpretation.
- Economical: this relates to financial consideration and availability.
- Safety: this relates to physical and psychological aspects.

This method is very simple, and does not detail the specific requirements that must be included in the design. In addition, it is only capable of supporting designers at the initial stages of the design process to justify which job can be done by machines and humans.

These approaches are methodologies to help designers either improve the design of task allocation or evaluate automation selection. They involve the user and engineers to achieve effective task allocation in the manufacturing system design; thus, they only extend to micro-ergonomic evaluation.

2.4.10 Human/Machine Interaction Evaluation Model

Stahre (1995) developed a model based on Sheridan's (1987) supervisory control model and Rasmussen's (1985) level of human behaviour, to evaluate human/machine interaction in modern manufacturing systems.

The model identifies the tasks considered complicated by the operator and specifies the requirements and support needed. It incorporates the following five steps:

1. The operator answers a questionnaire that relates to their work, work environment, and occupational hazards. The aim is to identify the general opinions about the operator's working situation.
2. The operator's tasks and sub-tasks are identified.
3. A second questionnaire is used to grade the different levels of complexity within each task.
4. Individual interviews are conducted to clarify and understand the difficulties faced by the operator.
5. Evaluation of the tasks using the combination of the two theoretical models - supervisory control model and level of human behaviour - to analyse and transform difficult tasks into a qualitative specification for training, decision support, and education.

This model was exemplified with an operator decision-support prototype tool called Albert. Albert is a rule-based decision support system based on an expert system shell. The system includes decision support for automatic error detection, manual error detection/repair, and training tools for start and restart procedures.

This is a useful model to enable manufacturing cell evaluation and identify the operator's needs for training, decision support, and education. It establishes exactly where and what type of support an operator will require to achieve an effective interaction between humans and machines. In addition, it is used at a stage that precedes the design of the manufacturing system. However, it only addresses the operator's role and supervisory control levels to evaluate the human/machine interaction in manufacturing systems design. In addition, it focuses on human/machine interactions largely from a micro-ergonomic perspective, therefore, excluding the wider organisational and environmental concerns.

2.4.11 Human Centred Computer Integrated Manufacturing Systems Evaluation

Uden (1995) conducted a study on evaluation techniques with the intention of proposing an approach that aids the designer in evaluating the human centred system design, and draws his attention to the user's point of view. The approach presented employs Job Application Design methodology in order to attain participatory design.
In addition, it refers to two kinds of evaluation that are recommended for evaluation; formative and summative. The formative evaluation is conducted prior to the implementation and is done after each of the following stages: the requirements analysis, initial design, and specification, whereas the summative evaluation is conducted after implementation. The later phase includes a review of the available evaluation techniques; analytical, expert, observation, survey, and experimental evaluation. The selection and feedback is gained by incorporating a co-operative evaluation technique.

This approach is a methodology to help designers to evaluate their human computer integrated design, and involves the user and engineers to achieve a better human centred computer integrated manufacturing system. However, it only addresses micro-ergonomics.

2.4.12 Knowledge Based System

Pinochet et al. (1996) identified and summarised principles that have appeared in the human factors, manufacturing, and management literature with the aim of attaining the ideal Sociotechnical Integration (STI) of Advanced Manufacturing Technologies (AMT). This led them to the development of a knowledge based system called Socio Technical Diagnostics (SOTEDI), which helps in diagnosing the degree of STI.

The knowledge based system embraces 37 STI principles that are addressed in the following six stages:

1. The company and AMTs: represents the external and internal factors in which the organisation works.
2. The planning for AMTs: represents the combination of technology and organisation.
3. Technology selection: represents the human-centred approach, cost justification, and the compatibility of specification and equipment.
4. Implementation: represents the organisation's considerations when implementing the AMT.
5. Operation: represents the work organisation factors needed to achieve the ideal interaction.
6. Evaluation: represents the assessment of the implemented design in terms of both human and technical impact.

The software comprises a set of questionnaires that the user answers, and accordingly an average rating is calculated to obtain the level of STI. The higher the percentage the better the integration, thus, organisations can assess what they need to focus on to improve the level of STI.

The model is considered to be a good guide for understanding what should be incorporated because it gives a breakdown of the elements that a designer would go through to design the sociotechnical system, and by responding to the criteria of the software the user can determine what elements were not included in the design. However, the tool does not address the micro-ergonomic aspects it is mainly focused on macro-ergonomics.

2.4.13 KOMAPSS

Grote et al. (2000) developed a method for function allocation in automated work systems. The method takes into account an integral consideration of people-related, technological, and organisational factors in the design of work systems, in order to support interdisciplinary design teams in deciding about function allocation in automated systems. The method focuses on three levels of analysis:

1. Human-machine system, which includes the interaction between a human operator and the technical system(s).
2. Human operator's work tasks, which contains all the tasks the human is responsible for as part of his/her job.
3. Work system, which refers to the overall organisation unit.

The KOMPASS method consists of three phases. The first phase is an expert analysis of the existing systems, and 18 criteria are used to for the analysis. These criteria have been adapted from existing concepts and instruments developed within the frameworks of humanistic psychology, action theory, and sociotechnical systems theory. The second phase is the formulation of the design approach, and 6 steps are used to for the analysis. Finally, the third phase is where the design requirements are determined, and 2 steps are used for the analysis.

The KOMPASS method is a suitable approach for supporting the design team in integrating people, technology, and organisation in the allocation of functions. It addresses areas where existing methods for complementary systems design have failed to consider them, specifically in human-machine systems analysis. However, it does not provide sufficient help in defining the project goals or the composition of the design team. In addition, throughout the 18 criteria, the micro-ergonomics issues were not apparent, and consideration was mainly focused on job design and macro-ergonomics issues.

2.4.14 TOP-Modeller

Majchrzak and Gasser (2000) presented an automated knowledge-based design, decision support, and simulation package called TOP-Modeller (TOP stands for Technology, Organisation, and People), which is a continuation of the HITOP-A (High Integration of Technology, Organisation, and People-Automated) tool. HITOP-A is a prototype software tool that was built on the sociotechnical systems theory to allow a design team to conduct a structured approach for planning the introduction of technology and assessing the readiness of the current organisation to implement the necessary human infrastructure. The TOP-Modeller tool, on the other hand, is a commercial-quality product that resembles HITOP-A in function.

The TOP Modeller is a software tool that is designed to aid managers in making difficult judgement-based strategic decisions that impact their technology and organisation. It consists of fourteen sets of features that are used to help managers to ensure that changes in strategic direction are supported by existing practices, procedures, and people. The process involves describing and refining an organisation's strategic vision, describing the organisation's current (as-is) state for structuring its organisation and technology, comparing the as-is state to the ideal best practice, and deciding which gaps to close first.

This is a tool that involves management and the designers to determine what sort of support is required to design a sociotechnical system. It can be deployed to improve the design of the manufacturing system to be more people and organisation oriented. However, the tool does not address the micro-ergonomic aspects it is mainly focused on macro-ergonomics and assessing the readiness of the organisation to implement the necessary human infrastructure.

2.4.15 Ergonomic Evaluation of Manufacturing System Design

Hunter (2002) presented a study using high-level 3-D computer graphics simulation and other engineering analysis tools to investigate the ergonomic advantages of one manufacturing system design over another. According to Hunter, the design of a manufacturing system directly affects the physiological and ergonomic functions. Thus, by using this approach, a manufacturing system design can be developed concurrently with ergonomic and safety considerations.

In this approach a computer simulation tool called ENVISION/ERGO, produced by Delmia, is deployed to aid the designer to address the ergonomic, anthropometric, physiological, and safety issues during the process of design. Furthermore, it simulates and analyses products, processes, and manufacturing systems. The level of detail it provides extends to the design of the manufacturing cell or workstation, jigs and fixtures, and work station support equipment.

In addition, this approach incorporated the following software assessment tools: Rapid Upper Limb Assessment (RULA), Kilocalorie Comparison, 30 Second Rule, and Cumulative Trauma Disorders. The designers would use them to reduce or eliminate workplace hazards during the workstation design and layout.

This approach provides a structured and detailed examination of the user-machine interface and interaction process. It focuses on providing the operators with the safest and healthiest work environment while providing the manufacturing operation with a system that is robust, flexible, economical, and profitable. However, it only addresses micro-ergonomics.

2.4.16 Computer-Integrated Manufacturing, Organisation, and People (CIMOP)

CIMOP is a software application developed by Kantola and Karwowski in 1999, for evaluating computer-integrated manufacturing, organisation, and people system design (Karwowski et al., 2002). Five evaluation modes are used to determine the overall system design quality: computer-integrated manufacturing system design, organisation subsystem, technology subsystem, information systems subsystem, and people subsystem. The critical design factors are quantified to enable the evaluation of existing or new computer-integrated manufacturing system design.

The evaluation process is based on 75 critical design factors, which are extracted from research carried out within the following disciplines: human-centred computer-integrated manufacturing, manufacturing organisation design, manufacturing system design, information systems in manufacturing, flexibility, maintainability, human-computer interaction, and human-machine system design.

The evaluation team would use the CIMOP method to aid them in determining whether a particular system design should be implemented or improved. In addition, the intended users of this tool are companies with an existing computer ingenerated manufacturing system, and companies designing, redesigning, or implementing a new computer integrated manufacturing system.
This is a useful tool to establish where exactly and what type of support is required to achieve an effective integration of the manufacturing system. It can be deployed to improve the design and the evaluation of computer integrated manufacturing systems. However, the tool does not address the micro-ergonomic aspects it is mainly focused on macro-ergonomics.

2.4.17 The Joint Cognitive System

Piccini (2002) developed a methodological framework to support designers of control systems and human-machine interfaces. His model was based on modern theories of supervisory/cognitive control and human-centred design principles.

The model comprises five stages; the first two deal with techniques and the final two deal with implementation and validation.
The first three stages - system features, human features, and human–machine interaction features - are interconnected, and by integrating the information from the system and human features, a comprehensive model is produced.

The systematic issues represent the functional requirements that incorporate:

- Structural model: to provide the description of the system, goals and technical analysis.
- Functional/behavioural model: to provide details on the specific processes, subsystems, and components of the system.
- Contextual/environmental model: to provide details on the working environment and what affects or alters human performance.

The human factors represent the operator characteristics that should be included for the formalisation and organisation of knowledge about the role. In this phase the determination of automation level takes place, the distribution of tasks between the human operator and the control system.

The human-machine interaction features are a representation of the inputs from previous stages. This consists of a reference supervision model to link the systemic and human elements. According to Piccini, he has used for his methodology the most representative and validated model existing in the literature; namely, the "supervisory control model" and "nested control loops".

The fourth stage constitutes the actual design phase - the translation of the human system interaction information and its implementation in a control system and interface design, through the development of generic and high level guidelines.
Finally, the design is validated using the following techniques: a top-down assessment, a bottom-up assessment, and a human reliability assessment.

This methodology is related to computer control, and emphasises the human system interaction, but with respect to the design of the control system. The human features and system features are related to the interface that results from different levels of the interaction and the participation that takes place. Therefore, only addressing micro-ergonomics

2.4.18 A Sociotechnical Method for Work Systems Design

Waterson et al. (2002) describe a new method for allocating work between and among humans and machines. It is a method that allows the end user to consider a range of factors relevant to function allocation, including aspects of job, organisational, and technological design. The method is presented in the form of a flowchart and consists of series of stages:

1. Formation of overall view of the systems.
   The user first develops a number of alternative choices for how the systems could work, and then identifies the potential advantages and disadvantages of each choice, using eight criteria, to facilitate selection. Once selection is made the characteristics and requirements of the system is determined, along with the task description.
2. Initial mandatory allocations.
   This stage applies to mandatory allocations where no detailed evaluation is necessary. However, the tasks for which the allocation decision remains open are considered further, in order to determine allocation between humans and machines.
3. Provisional allocations between humans and machines.
   In this stage the various allocation options are considered and evaluated against qualitative and quantitative criteria, in order to determine the order of preferences for allocations.
4. Provisional allocations between humans.
   This stage involves allocating work among the humans working in the system. The user first identifies the different human roles within the system, and then

develops a range of alternative role designs. Thereafter, eight criteria are used to determine the suitable role design. However, where tasks may feasibly be allocated to more than one role, they are further examined in the next stage.

5. Provisional dynamic allocation.

In this stage dynamic allocation is reviewed to include the option to change an allocation during system operation and investigate the constraints that apply to a particular allocation context.

6. Global examination of allocations.

This stage involves the re-examination of all the allocation decisions that have been made while using the method, to ensure that the decisions meet the overall view of the system and requirements.

7. Proposed allocations.

This is the final stage of the method where the allocation alternative preference and human and machine roles are described.

The overall aim of this method is to support the design of new systems to identify feasible allocation options and decide which are the most appropriate. The method incorporates decision criteria that extend beyond psychological or technical consideration during task allocation. It considers aspects of financial, legal, organisational, and environmental constraints. However, there were a number of criticisms reported during the testing of the method. Difficulty arose when examining the interdependencies between the decision criteria. In addition, there was insufficient focus on the evaluation of individual roles, and concerns on how the method could be integrated with existing system design techniques.

2.5 Human Factors Integration Techniques Comparative Analysis

The aforementioned models and approaches are represented in a tabular format to facilitate the analysis of the methods reviewed. They are assessed against a set of features that emerged from an iterative review process. The review process involved two passes through the literature. The first pass identified the important issues and themes in the literature, and suggested features by which the authors themselves argued that their methods should be judged. The second pass evaluated each of the methods described in the literature against the features chosen in the first part. Table 2.1 depicts the areas where ample research has been conducted and which issues require further attention, which in turn will assist in forming a solution to support manufacturing system designers facing the current situation.

By viewing table 2.1 it can be noted that fifteen of methodologies focus on operational and task level, and are intended for deployment at the design stage. In addition, computer integrated manufacturing design, human/machine interaction design, and sociotechnical design have more or less equal focus, while automation selection has the smallest share of attention. The methodologies that are devoted to automation selection are mainly confined to task allocation deployment. Furthermore, they are less directed towards the management/factory level and the evaluation stage.

It was also noticed that thirteen of the methods were practically evaluated in industry. The evaluation was reported as either being in the form of case studies or application trials. However, the extent to which they had been applied in industry was not mentioned.

Last but not least, it is surprising that only five of the methods address both macro- and micro-ergonomics. In addition, the methods that address micro-ergonomics exceed those which address macro-ergonomics. Seven were found to be devoted for addressing micro-ergonomics specifically.

Therefore, following in the footsteps of such researchers and attempting to address the research problem, it is believed that developing a decision tool that would raise the profile of human factors and highlight the organisation's most appropriate automation level at the earliest stages of manufacturing systems design is likely to be of benefit to the manufacturing industry and academic domain.

Model or Approach \ Features	Management/Factory Level	Operation/Task Level	Design Stage	Evaluation Stage	(Macro-) Ergonomics	(Micro-) Ergonomics	Automation Selection	Computer Integrated Manufacturing Design	Human/Machine Interaction Design	Sociotechnical Design	Practical Evaluation
Optimisation of Hybrid Production System (Rahimi and Hancock, 1986)	X	X	X		X	X		X			
Systems Design of Human-Robotic Interaction (Helander and Domas, 1986)		X	X		X	X			X		
Open System Framework (Majchrzak and Klein, 1987)	X	X	X		X					X	X
A Framework for Managing Hybrid Systems (Rahimi et al., 1988)	X	X	X		X	X		X			
Criterion-Based Task Allocation Model (Clegg et al., 1989)		X	X			X	X				
The Dual Design (Bohnhoff et al., 1992)		X	X			X			X		X
Designing Human Centred CIM Systems (Ensley, 1993)		X	X			X			X		X
ACTION (Gasser et al., 1993)	X	X	X		X					X	X
Function Allocation Techniques (Mital et al., 1994)		X	X			X	X				X
Human/Machine Interaction Evaluation Model (Stahre, 1995)		X		X		X			X		X
Human Centred CIM Systems Evaluation (Uden, 1995)		X		X		X		X			
Knowledge Based System (Pinochet et al., 1996)	X	X	X		X					X	X
KOMPASS (Grote et al., 2000)		X	X		X	X	X		X	X	X
TOP-Modeller (Majchrzak and Gasser, 2000)	X	X	X		X					X	X
Ergonomic Evaluation of Manufacturing System Design (Hunter, 2002)		X		X		X		X			X
CIMOP (Karwowski et al., 2002)	X	X	X	X	X			X			X
The Joint Cognitive System (Piccini, 2002)		X	X			X			X		X
Sociotechnical Method for Work Systems Design (Waterson et al., 2002)	X	X	X		X	X	X		X	X	X

Table 2.2: Human Factors Integration Techniques

It is apparent that there is a need to design a decision making model that will enable organisations to define the level of automation that is most appropriate to them, as well as enhancing the human-automation interaction. In addition, the competitive analysis revealed that there does not exist a methodology for automation selection that is capable of addressing management/factory level and operation/task level as well as macro- and micro-ergonomics at the evaluation stage.

Therefore, what is sought here is considered to be a step towards the design of a manufacturing automation decision tool that targets both management level and task level and addresses both macro-and micro-ergonomics. The solution is targeted at automation selection within workstation and cell design. By using the proposed decision tool manufacturing system designers can be guided in defining what level is appropriate for them and to identify the human factors criteria to focus on in the design and implementation phase. Consequently, this will help in avoiding the pitfalls of over-automation and will reduce the risk of insufficient human-automation corporation, which leads to the failure of manufacturing systems to deliver cost effective and flexible organisation.

2.6 Chapter Summary

'Human factors in manufacturing systems' is a broad generic term which covers a wide range of fields. This chapter highlighted the current situation in manufacturing systems design and the significance of addressing human factors in attaining greater improvements. It investigated the research problem in greater detail and defined the scope of the research. The literature review facilitated the comprehension of the main areas where human factors can influence manufacturing automation and design, therefore revealing those human factor issues which need to be addressed in order to meet the current challenges. In addition, the comparative analysis of human factors integration techniques demonstrated the importance of addressing these issues and identified the areas where research could be further conducted to enhance human factors incorporation into manufacturing systems design.

Accordingly, a solution was outlined that was capable of supporting the manufacturing industry as well as contributing to the academic domain. The solution consists of designing a decision tool that would raise the profile of human factors and highlight the organisation's most appropriate automation level at the earliest stages of manufacturing systems design. It is targeted at automation selection within workstation and cell design.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The human factors in manufacturing systems literature review focused on what has been discussed and was presented with regard to human factors incorporation in manufacturing systems design. The results highlight the need to increase the level of emphasis placed on the application of human factors in the earliest stages of manufacturing systems design in order to support manufacturing designers facing current challenges. This chapter defines the research aim and objectives that have been developed to assist in fulfilling this need. In addition, it describes the research strategy and methodology followed to develop the research programme.

3.2 Research Aim and Objectives

The design and improvement of manufacturing systems is a constant and dynamic task within manufacturing organisations. Manufacturing systems designers are continually being pressured to review their manufacturing systems in order to respond rapidly to market changes. In addition, with the advent of the new challenge to design a more flexible and reactive manufacturing system, they are striving to produce a coherent interaction between technology, organisation, and people, in order to meet this challenge. The problem is that despite the importance of addressing human factors in manufacturing systems and the current techniques available in order to achieve this, the evidence gathered from the literature review clearly illustrates that organisations are not fully incorporating human factors in the design of manufacturing systems.

Accordingly, the aim of this research is '*to assist manufacturing systems designers to better incorporate human factors in manufacturing systems design.*'

In order to fulfil the aim of this research, three objectives are identified, namely, to:

1. Determine from an industrial perspective how human factors are incorporated in automated manufacturing systems design, and the need for improvement.
2. Create a decision tool to support the design of automated manufacturing systems by incorporating human factors alongside technical, organisational, and economical factors.
3. Evaluate the decision tool.

3.3 Research Strategy

To meet the research objectives, a number of methodologies were reviewed to design an appropriate research programme. The rationale for not deriving a methodology from the models or approaches reviewed in the literature review was due to number of reasons. Firstly, this thesis sets out to create a new solution. Secondly, there is a dearth of academic literature concerning their application and effectiveness within industry. Finally, the study area covers a wide span of issues and perspectives, which required the definition of an appropriate research methodology to meet the research aim.

3.3.1 Research Design

The activity of designing a framework for the research project requires the researcher to determine the research design strategy. This will ensure high compatibility between the research purpose, questions, methods, and sampling strategy (Robson, 2002). According to Robson (2002), the design strategy can either be fixed or flexible.

A fixed design calls for a tight pre-specification of the design study before the main research data collection takes place. It is theory-driven, as the researcher is able to specify in advance the variables to be included and the exact procedure to be followed. In addition, it covers the following types of design: true experiment, single case experiment, quasi-experiment, and non-experiment design. The data are almost always in the form of numbers, and thus this type of design is often referred to as a quantitative strategy.

However, a flexible design is considered less pre-specified and the design emerges and develops during data collection. Moreover, the types of design it deals with are commonly case studies, ethnographic studies, and grounded theory studies. The data are typically non-numerical (usually in the form of words), and thus it is often referred to as a qualitative strategy.

The research design strategy for this study is regarded as being a flexible design, as the research design was not strictly defined at the initial stages of the research. At the initial stages the research purpose, question, method, and sample strategy were drafted to ensure that they were inter-related, and that they coincided with the research objectives. In addition, it was anticipated that the research evolution would be greatly influenced by both the literature and industrial surveys.

3.3.2 Research Purpose

Research studies can be classified into groups based on what the research is trying to accomplish. Wisker (2001) identifies five common classifications that are used by researchers, and they emphasise the point that a research project can involve more than one of these approaches. However, the three most common approaches are reviewed here. Table 3.1 illustrates the three classifications of research purpose.

Classification	Purpose of the Enquiry	Suitable Research Method
Exploratory	• Find out what is happening, particularly in little-understood situations • Seek new insights • Ask questions • Assess new phenomena in a new light	Usually, but not necessarily, qualitative
Descriptive	• Portray profile of persons, events, or situations • Extensive previous knowledge requirement	May be qualitative and/or quantitative
Explanatory	• Seeks explanation of situation • Seeks explanation of problem	May be qualitative and/or quantitative

Table 2.3: Classification of the purposes of enquiry (Source: Robson, 1993)

According to Blaikie (2000), exploratory research is used when a research project examines a new interest, or when the subject of study is relatively new. It is typically done to satisfy the researcher's curiosity and desire for better understanding, to test the feasibility of undertaking a more extensive study, or to develop the methods to be employed in any subsequent study. Further, it addresses the 'What' questions, and the steps are not well defined because the direction of enquiry frequently changes.

Descriptive research aims to test and present a picture of the specific details of a situation or relationship. It finds out more about a phenomenon and describes it with detailed information. This type of research focuses on the 'What' questions, and is conducted within a well defined subject.

Explanatory research is adopted when the research deals with validating an issue that is already well known and investigated. It goes beyond giving focus to a topic or providing a picture; it examines the reason why it exists, and seeks to study the cause and effect relationships between two or more phenomena. This approach answers the 'Why' questions, and is employed in an investigated subject area.

Subsequently, due to the research quest to develop a new solution to the main research question 'What is needed to enable manufacturing systems designers to improve human factors incorporation in automated manufacturing systems design?' this research study employed the exploratory approach.

3.3.3 Time Dimension

Different research objectives and questions require the selection of an appropriate time dimension. Some research studies give a snapshot of the investigated area at a single point in time, while other studies provide a moving picture of the events under investigation over extended time periods (Robson, 2002).
According to Babbie (2001, pp. 101), "Time plays many roles in the design and execution of research, quite aside from the time it takes to do research." He refers to two principle options to deal with the issue of time in the design of a research, namely, cross-sectional studies and longitudinal studies.

Cross-sectional study involves observations of a sample or phenomenon at one point in time. It is the simplest and least costly; however, it cannot fully capture the process or change. Research that involves such a time dimension can be applied to all research approaches, but is most consistent with exploratory and descriptive research (Babbie, 2001).

Longitudinal study, on the other hand, represents studies that permit observations of the same sample or phenomenon over time. It is more complex and costly; however, it provides a clear picture of the process or change. This type of observation can be adopted in any research approach, but is frequently applied with the exploratory and explanatory approaches (Babbie, 2001).

Accordingly, the time dimension study chosen for this research was the cross-sectional type. It corresponded to the directions of the research design and approach. In addition, it was important to examine specific industry sectors at a single period in time, in order to comprehend the current situation and clarify the process of manufacturing automation decision-making.

3.4 Research Method

The research method refers to the way in which data collection and analyses are interpreted, which will further dictate the techniques to be used in the research design. Two research methods are available; one produces quantitative data, while the other focuses on producing qualitative data. Quantitative research concerns the collection and analysis of data in numeric form to measure variables and verify theories, hypotheses, or questions. Qualitative research, on the other hand, concerns the collection and analysis of data in many forms; primarily non-numeric, to extract and analyse information from the empirical materials. The use of words rather than numbers permits depth rather than breadth of meaning and understanding (Robson, 2002).

Table 3.1 demonstrates the type of research method that is most suitable for each research approach. In addition, in accordance with the research design and approach determined earlier, this research fits the qualitative research description. However, for methods of data collection both numeric and non-numeric data are deployed in this research. Robson (2002, pp. 164) states the following: "In principle (and not uncommonly in practice), so-called qualitative designs can incorporate quantitative methods of data collection." The reason for choosing to combine both methods of collection data was due to the significant advantage this would have on the analysis and interpretation of data. Deploying quantitative methods of data collection facilitates the extraction of information that is useful to verify certain research questions, whereas qualitative methods of data collection will enable further information to be gained into the issues that need greater depth and analysis.

3.4.1 Research Technique

Four basic data collection techniques are used for gathering research data: experiments, historical review, case studies, and surveys (Neuman, 2003; Robson, 2002).

1. Experiments: are natural science research method, usually conducted in laboratories or in real life. They are used mostly for explanatory research that addresses a well-focused question. This type of technique deals with quantitative research that involves the study of variables and the relationships between them. In addition, researchers use this approach to examine causality links between variables, and to test hypotheses (Neuman, 2003). It is the easiest research technique to replicate because of the controlled conditions in which the experiments are conducted.
However, when the experiment technique is used in social science research, it is not suited to addressing questions that may require looking at conditions across an entire society or decade, but rather, it is better suited to investigating issues that have a narrow scope or scale.

2. Historical review: is a research method that investigates a situation as a whole to provide an overall understanding of the study. According to Neuman (2003), it traces the development of an idea or shows how a particular issue has evolved over time. This approach integrates and summarises what is known in an area, and demonstrates how it is linked to the current research through the review of history and development of knowledge. In other instances, this approach is used to conduct a historical-comparative research to examine aspects of social life in a past era or across different cultures. This research method depends on theory and historical data collection. It is similar to the case study approach because it starts with a loosely formulated question that is refined during the research progress, and is usually used for descriptive studies (Neuman, 2003). According to qualitative research design, in both historical research and case study research, the researcher notes what is occurring at different points in time and recognises that when something occurs, it is often important.

3. Case study: this technique refers to an intensive investigation of a single unit or a small number of case studies over a period of time. Investigation is conducted at the micro level on a number of cases to understand or provide a solution based on a larger scale population. This method is useful where a researcher needs to understand a particular problem or situation in greater depth, and gain rich information on the phenomenon in question. In addition, it provides holistic and meaningful

characteristics of real-life events (Yin, 2003). In other situations, it seeks to document individual case outcomes for evaluation purposes, with the aim of identifying individual differences or unique variations (Patton, 1987). It mostly involves the use of very detailed qualitative data to present information about the studied case (Neuman, 2003), which can be a person, an event, a time period, or a community.

4. Survey: a survey is a simple way of gathering respondents' answers in a short time period. The purpose of this is to give the researcher a picture of what many people think or report doing. A sample or a smaller group is used in the circumstances of a large population to ease the process of data gathering and interpretation. As a research method it is usually associated with the idea of asking groups of people questions that would lead to a better understanding of the phenomenon under study, as described by Blaxter et al. (1996). Robson (2002) sums up the features of a survey as the collection of information in a uniform manner from groups of people, a selection of samples of individuals from a known population, and the use of questionnaires or structured interviews.

Moreover, the survey is one of the most widely used methods of data collection. It tends to be cheaper, more widely dispersed, and quicker than most other methods mentioned so far. In addition, it allows the researcher to generalise the results and further explore relationships between variables for a large sample of respondents. However, this technique does not provide the same degree of control that a researcher could get from an experiment, or the level of in-depth investigation that is yielded by a case study.

The nature and aim of this research points towards the adoption of the survey technique. It necessitates the collection of data, which depends on eliciting the perceptions and experiences of the people involved within this domain. In addition, it is able to present a picture of what these people think and do.

However, as the outcome of this research involves producing a decision tool to support manufacturing systems designers better incorporate human factors in automated manufacturing systems design, the decision tool produced would need to be evaluated. According to Robson (2002, pp.202) "The purpose of an evaluation is to assess the effects and effectiveness of something, typically some innovation or intervention: policy, practice, or services." Therefore, an evaluation study will be performed to facilitate the assessment of the decision tool by potential users. The evaluation study will combine an evaluation by comparison, evaluation by demonstration, and evaluation by application. The evaluation by application process will necessitate the adoption of the case study technique. The survey technique and the evaluation study are further analysed and classified in Chapters 4 and 9 respectively.

3.4.2 Research Sampling

In a research project, the researcher has a choice of either taking a whole population or selecting a sample from a population. A sample provides a representation of the population from which it is selected by ensuring an equal chance of all members/units in the population being selected. The sampling approach is mostly favoured by researchers when there is a large population. It enables an economical and time-effective approach to conducting the survey, rather than targeting the whole population (Neuman, 2003).

There are various types of sampling process, divided into two main categories. One type is referred to as "probability samples", which represents a known probability of respondents, while the other type, "non-probability samples", represents an unknown probability. Non-probability sampling methods are conducted when the sample cannot represent the whole population because it is unknown or difficult to quantify. Conversely, the probability sampling method is employed when there are precise or statistical descriptions of large populations (Blaikie, 2000). Moreover, Neuman (2003) mentions that in a probability sample, every population element must have a known and non-zero chance of being selected.

The sampling frame for the population in question is known and can be quantified. The work is being targeted towards the manufacturing industry, and the unit of analysis that is used is "manufacturing organisations". This confirms the suitability of adopting the probability sampling approach in this study. According to Neuman (2003), there are five types of probability samples; namely simple random sampling, systematic sampling, stratified sampling, cluster sampling, and random-digit dialling.

1. Simple random sampling is the basic approach upon which the other types are modelled, and is the easiest method. In simple random sampling the researcher derives the sample from an accurate sampling frame. The researcher numbers all the elements in a sample frame then uses a random-number table to select the elements and include them in the sample.

2. Systematic sampling follows the same procedure as simple random sampling. However, it differs in the selection approach as it requires the researcher to select the elements using sampling intervals, rather than a random-number table. The sampling interval allows the researcher to select elements from a sampling frame by skipping elements in the frame before selecting one for the sample.

3. Stratified sampling first divides the population into subpopulations (strata), and then draws the elements by either deploying simple random sampling or systematic sampling procured. This process allows the researcher to produce samples that are more representative of the population, as the researcher is able to control the relative size of each stratum, rather than letting random processes control it.

4. Cluster sampling is a unit that contains the final sampling element, but can be treated temporarily as a sampling element itself. The research first samples clusters, each of which contains elements, then draws a second sample from within the clusters selected in the first stage of sampling. It is used when the researcher either lacks a good sampling frame for a dispersed population, or when the cost to reach a sampled element is very high. However, as this process draws several samples in stages, sampling errors are introduced at each stage, and it becomes less accurate.

5. Random-digit dialling is considered to be a special sampling technique, where the general public is interview by telephone. However, it differs from the standard

method of sampling for telephone interviews as the published telephone directory is not the sampling frame. The researcher identifies active area codes and exchanges, and then randomly selects four-digit numbers. This approach is tedious and less accurate, as some selected numbers could be disconnected, and it misses out people with unlisted numbers.

Subsequently, simple random sampling was found to be the most appropriate procedure with regard to the time constraint of this research and the degree of focus required to attain the objectives.

3.5 Research Programme

The research programme presents an overview of the research methodology developed for conducting this research study. It is aligned with the chosen research strategy, design, method, and techniques. In addition, it is formalised in a manner that reflects and satisfies the objectives of the research.

3.5.1 Overview of Research Methodology

The research programme involves three phases, namely industrial survey, decision tool design, and decision tool evaluation. The first phase involves a fieldwork survey to determine the work practice in industry and the need for improvements. The second phase comprises design and development of the research solution. The final phase is to evaluate the decision tool in collaboration with industry, in order to determine the level of satisfaction with the research solution. Figure 3.1 depicts an overview of the research methodology developed for realising the research objectives.

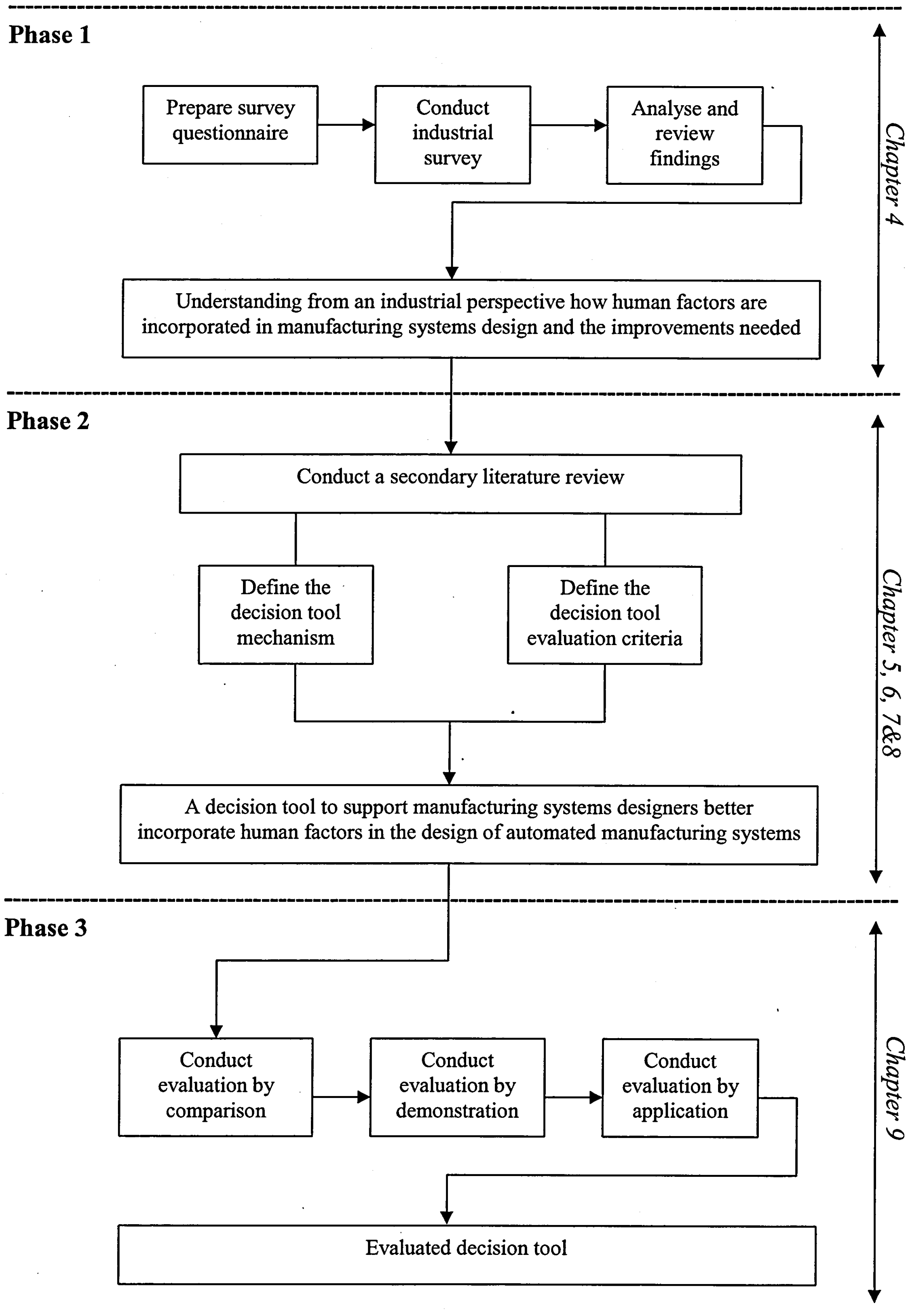


Figure 3.1: Research Methodology Overview

Phase 1:

The first phase involves deploying the survey technique outlined in the research technique. A survey study is to be conducted in the manufacturing industry using both quantitative and qualitative data collection methods to authenticate the literature review findings and to acquire industrial input. Amalgamating both academic and industrial perspectives is an essential step towards determining the characteristics of the solution, as the solution needs to be a contribution to knowledge, in addition to being an industrial remedy.

Phase 2:

The second phase comprises incorporating the survey findings with a second literature review to facilitate the design and production of the decision tool. The secondary literature review is conducted in order to determine the mechanism to be deployed in performing the required activities, and to establish the evaluation elements of the decision tool. Thereafter, the research solution is to be produced in an executable format.

Phase 3:

The third phase is the final phase in the research programme. This phase involves the case study technique outlined in the research technique. The research solution produced is to be evaluated within the manufacturing industry. The evaluation study combines an evaluation by comparison, evaluation by demonstration, and evaluation by application to assess contribution of knowledge and end user satisfaction with the produced solution.

3.6 Chapter Summary

This chapter has introduced the strategy, method, and research programme applied in the development of the research methodology. It has defined the means and techniques set out to achieve the research objectives. In addition, it has illustrated the manner in which the research methodology has been set up to encapsulate academic and industrial input in the development of the research solution.

The research methodology proposed includes three phases, each phase embracing three stages with an anticipated outcome. Phase one has been planned to enable the researcher to conduct an industrial survey, in order to validate the research purpose from an industrial perspective and support second phase fulfilment. Phase two has been planned to incorporate the survey findings with a second literature review to facilitate the development of the decision tool. Finally, the third phase has been planned to evaluate the research solution.

CHAPTER 4

INDUSTRIAL SURVEY

4.1 Introduction

The main issue identified from the literature review in Chapter 2 is that there is a need to support manufacturing systems designers to better incorporate human factors at the earliest stages of manufacturing automation design in their design. This chapter presents the industrial survey conducted to validate this need from an industrial perspective and to elicit the industry's view on what improvements are required. It describes the execution of the survey process and the results, which is followed by a detailed discussion of the findings.

4.2 Survey Technique

Section 3.4.1 provided an overview of the survey technique and concept; however, this section describes the approach in greater detail and defines the means by which the data will be collected.

A survey is a particular method of data collection and analysis. It is a process of asking people a number of questions in a written questionnaire or during an interview, in order to gain information about the respondents' beliefs, opinions, characteristics, and past or present behaviour (Neuman, 2003). In a survey all the respondents answer the same questions through which the researcher may investigate many things at one time, measure many variables, or test several hypotheses This process can be done at a fixed point in time (snapshot) or at varying points in time for comparative purposes, during which the researcher employs either the survey questionnaire or the interview schedule approach. A survey questionnaire consists of set questions that are read out and filled in by the respondent, whereas the interview schedule is a set of questions that are read out and filled in by the interviewer.

Most surveys involve the use of a questionnaire to collect data. Questionnaires can be administered through the following three main methods: self-administered questionnaires, face-to-face interviews, and telephone interviews (Babbie, 2001). Table 4.1 provides a comparison of the three approaches to survey data collection.

- Self-administered questionnaires refer to an approach whereby the respondents are asked to fill in the answers by themselves. The most common form of self-administered questionnaire is the mail survey.
- Face-to-face interviewing is a method of data collection in which the interviewer asks the questions in the presence of the respondent, and completes the questionnaire.
- Telephone interviewing is an alternative form of face-to-face interview, whereby the interviewer contacts respondents by phone to ask the questions and record the responses.

Aspect of survey	*Self-completion questionnaire*	*Face-to-face interviews*	*Telephone interviews*
Resource factors			
Cost	LOW[a]	High	Low/medium
Length of data collection period	Long	Medium/long	SHORT
Distribution of sample	MAY BE WIDE	Must be clustered	MAY BE WIDE
Questionnaire issues			
Length of questionnaire	Short	MAY BE LONG	Medium
Complexity of questionnaire	Must be simple	MAY BE COMPLEX	MAY BE COMPLEX
Complexity of questions	Simple to moderate	MAY BE COMPLEX	Short and simple
Control of question order	Poor	VERY GOOD	VERY GOOD
Use of open-ended questions	Poor	GOOD	Fair
Use of visual aids	Good	VERY GOOD	Not usually possible
Use of personal/family records	VERY GOOD	Good	Fair
Rapport	Fair	VERY GOOD	Good
Sensitive topics	GOOD	Fair	Fair/GOOD
Data-quality issues			
Sampling frame bias	Usually low	LOW	LOW (with RDD[b])
Response rate	Difficult to get high	Medium/VERY HIGH	Medium/high
Response bias	Medium	LOW	LOW
Control of response situation	Poor	GOOD	Fair
Quality of recorded response	Poor	GOOD	Fair

Table 4.1: Comparison of Approaches to Survey Data Collection (Source: Robson, 2002)

The comparison in Table 4.1 highlights the issues to consider in the selection of a data collection method. From the comparison it was realised that the self-administered approach has a poor rating in collecting open response from the respondents, and that it was more appropriate for closed questions. In addition, using the telephone interview approach would not be useful either in gaining in-depth focus, or asking complex questions.

Subsequently, the face-to-face interview approach appeared to be the most appropriate for this research, as it allows for a more interactive discussion and a better understanding of the issues raised in an investigation.

4.2.1 Face-to-Face Interview

Blaikie (2000) points out that there are devotees of two extreme approaches in face-to-face interviews: structured interview and the "free range" interview. The first type requires the interviewer to have a standardised set of questions, and to follow the wording of questions exactly. The second type, however, involves non-standardised questions, and the interviewer generates the questions during the conversation.

In addition, Robson (2002) mentions a commonly used middle ground of "semi-structured" interviews. In this approach the questions are prepared in advance, but the interviewer is free to modify the wording and order of questions, in addition to giving explanations, prompting and probing the interviewee when necessary. Furthermore, he points out that this approach is widely used in flexible designs.

Therefore, the semi-structured interview technique mentioned by Robson was the most appropriate technique to be used in this research, due to the study being clearly defined in its purpose, while requiring flexibility to attain greater depth when deemed necessary. As outlined in section 3.2.1, this research design is of the flexible type.

4.2.2 Questionnaire Design

The questions were developed and based on the research aim and objectives. They were written and organised in a way that meets the objectives of the research question, the respondents, and the type of survey selected. It is very important to design the questionnaire carefully so that it can fully address the researcher's areas of concern and elicit as much useful information as possible in order to answer his/her questions (Robson, 2002).

Furthermore, Patton (1987) indicates that a researcher has to clearly understand what questions to ask, and he points out six kinds of questions that can be asked. Of these, the following five were adopted for the construction of the questionnaire:

- Experience/behaviour questions: these are aimed at eliciting descriptions of experiences, behaviours, actions, and activities that have been encountered.
- Opinion/belief questions: these are aimed at describing cognitive and rationality issues behind values, intentions, desires, and goal setting.
- Feeling questions: these are aimed at understanding the emotional reactions, such as satisfaction or confidence, to a certain issue.
- Knowledge questions: these are aimed at eliciting factual information.

- Background/demographic questions: these are aimed at eliciting the characteristics of the respondent being questioned.

In addition, he points out that the quality of responses will be affected by the sequence of questions, the degree of detail the question covers, and the wording of the questions asked. Consequently, the sequencing of the questionnaire was designed in a way that enabled the respondents to gain a clearer understanding of the objectives of the investigation as the intensity and complexity of the questions evolved. Care was taken to ensure a gradual flow and focus of direction throughout the questionnaire. In addition, the questions were mainly developed from the literature review. They were based on open-ended questions in order to allow for more in-depth investigation, and to preclude any restrictions on the content and manner of response. In addition, closed questions were used to investigate simple enquiries and a Likert ranking scale was used to collect quantitative data. Finally, they were designed in a simple and understandable way to make it clear what was being asked, and where complex questions existed, probes and follow-up techniques were employed to increase the richness of the data being obtained. The combination of questions in a sentence (double-barrel) and the loading of questionnaire content and context were avoided as much as possible.

4.3 Survey Preparation

The face-to-face interview was arranged into three stages: five minute briefing, fifty minute questionnaire completion, and five minute debriefing. However, prior to undertaking the interview, the following activities had to be performed:

- Selecting and acquiring participants.
- Preparing interview material.
- Ensuring interview questionnaire validity and reliability.
- Conducting pilot test.

4.3.1 Participant selection

The research sampling strategy outlined in the research methodology chapter in section 3.3.2 illustrated the selected approach of simple random sampling from a population. This section defines the representatives of the population and the approach to acquiring the sample.

Sampling is closely linked to the generatlisablity of the findings in an enquiry. Generalisability refers to the extent to which the findings of the enquiry are more generally applicable (Robson, 2002). Black (1993) lists five methods for determining representatives of a population:

1. Whole population, where all findings will apply to the whole population.
2. Random selection from a specified population,
3. Purposive sampling from a specified population, where some attempt has been made to select a representative sample through specific criteria or characteristics related to variables that are to be controlled.
4. Volunteers, where a sample is generated by quota, accident, convenience, etc.
5. Unidentified group, where the description of the sample or sampling technique is not sufficiently clear either to indicate the population or to justify any generalisability.

The representative selection technique used in this research was based on option (2), which corresponds with the research sampling strategy. The organisations targeted for the survey spread from highly automated to human-intensive manufacturing environments. The focus was on organisations that are involved in the aerospace, automotive, food, and pharmaceutical industries/activities, in order to facilitate a confident generalisation of the results.

For information on the manufacturing industries targeted, the Financial Analysis Made Easy (FAME) database was used. This database enables the user to classify manufacturing companies according to a wide range of criteria, such as type of activities, turnover, number of employees, location, etc. Therefore, to enable a better selection of manufacturing organisations that were within a reasonable distance and which conducted automation investment on an evolving basis, the classification was limited to organisations that existed within the southern and eastern part of the UK, with a workforce not less than 200 employees, and an annual turnover that exceeded one million pounds.

Having opted for the face-to-face interview method, 60 organisations were targeted for interviewing. This number was considered to be sufficient to cover the number of organisations that resulted from the database search. The sample was randomly selected using the simple random sampling technique. Thereafter, the FAME database was used to obtain the contact details of each manufacturing organisation within the sample. The organisations were contacted by telephone to identify the people involved in the manufacturing operations and design process. The intention was to target the individuals in the organisation who would manage and take part in the design of the manufacturing system, as the questionnaire addresses both the decision-making process in addition to the design process.

Letters were despatched to named contacts or to the operations director of the organisation. 60 replies were received, of which 19 resulted in positive contacts. A breakdown of the sample frame that illustrates the number of positive responses received from each sector is presented in Table 4.1.

Industry	Number of Positive Responses
Aerospace	8
Automotive	6
Food	3
Pharmaceutical	2
Total	19

Table 4.2: Industrial Survey Sample

4.3.2 Interview Material

The interviews were conducted with the aid of a semi-structured questionnaire (Appendix A.1), which served primarily as a checklist. The structure of the questionnaire was developed to address the current practices of the manufacturing industry. The investigation was intended to study the decision-making and manufacturing system design processes; to identify the extent to which human factors influence the process, in addition to validating the purpose of this research from an industrial perspective. The formulation of the questions was mainly developed from the queries raised through the literature review.

The questionnaire consists of five sections. The first section relates to general organisational information, and includes questions about the respondent's position and the organisation, such as number of employees and annual turnover. Section two relates to automation level information in the organisation, and involves questions that address the organisation's level of automation and drivers, in addition to questions that deal with awareness of over-automation and concerns about how to attain an ideal automation level. Section three gathers information on the methodology, and includes questions relating to the procedures adopted in the manufacturing systems design, plant efficiency and satisfaction. Section four addresses the area of human factors to measure the extent of their consideration and integration. It includes questions that investigate how human factors/ergonomics are considered, as well as satisfaction with such integration. Finally, section five examines the decision-making process and influential elements. It includes questions that collect information on the formality of the decision-making process, the criteria considered, the financial/supportive techniques deployed, and experiences of 'automation backfire' (Bainbridge, 1983). In addition, this section gathers information on the significance and employment of the proposed model.

4.3.3 Interview Questionnaire Validity and Reliability

A poorly designed questionnaire will not only provide data that will mislead the researcher or will not enable him to confirm conclusions, but will also have an affect on the reliability and validity of the results. Reliability refers to the degree to which the method of conducting the study and the results can be reproduced and replicated. Validity, on the other hand, indicates the degree to which the survey measures what it is supposed or intended to measure (Oppenhiem, 1992).

Therefore, to avoid any error or misunderstanding caused by straying from the aim of the questionnaire, or by a poorly worded question, the design of the questions focused on the goals of this survey and the principles of questionnaire design outlined by Neuman (2003). In addition, to increase the validity and reliability of response, a pilot test was carried out.

4.3.4 Pilot Test

The interview questionnaire was pre-tested using colleagues and department staff at Cranfield University. The tests were administered in the presence of the researcher with the objective of assessing the comprehensibility and readability of the questions being asked. This resulted in improvements in the wording of question phrasing and structure. In addition, the time for completing the questionnaire was monitored to enable a confident estimate of the total amount of time required from the participants. The estimated time required to complete the questionnaire was found to be from 40 to 50 minutes.

Once the questionnaire was pre-tested and amended, it was ready to be piloted. The first three interviews conducted were used as pilot studies, with the aim of ascertaining how closely the questions addressed the research aims and the topic being investigated through the resulting answers. The answers indicated that some of the questions required restructuring to provide more elaboration and to address additional issues highlighted in the interviews. A few modifications were added to the questionnaire, and consequently the pilot responses were included in the main study frame.

4.4 Interview Process

Prior to conducting the interviews, an ethical proposal was sent to Cranfield University Ethics Committee to obtain their consent (Appendix A.2). In addition, a letter was sent to the targeted organisations explaining the objectives of both the research and the questionnaire, and indicating the sort of questions involved (for more details, see Appendix A.3). Attempts were made to address either the manufacturing or operations director.

Once approval was received the interview was conducted. The interview was administered using an interview protocol document developed for the evaluation study in order to ensure standardisation, and adhering to good practice in interviewing. The interview protocol document was developed in accordance with the skills in interviewing and interview protocol outlined by Oppenheim (1992) and Robson (2002) (see Appendix A.4 for a review). The following represents the procedure undertaken to carry out the survey interview (Robson, 2002):

Briefing

The briefing started with a brief introduction to explain the research aim and the purpose of this interview. This was followed by ensuring the confidentiality of both the respondent and the organisation, in addition to outlining the interview structure.

Administering the questionnaire

The different sections of the questionnaire were briefly outlined to the respondent. Thereafter, the questions in each section were asked. Where the respondent agreed, the answers were recorded on a dictaphone to simplify transcription. This approach was possible in all interviews except one. In addition, some organisations provided an observational tour of their manufacturing operations after the questionnaire session.

No actual data was collected from the observations, other than to put the answers into context.

Debriefing

The debriefing was conducted at the end of the interview. At this stage the participant was provided with an overview of what would follow this stage, during which permission was asked for future assistance.

4.5 Qualitative Data Processing

The raw data gathered through the qualitative data collection technique had to be coded in order to transform the textual material into conceptual categories and standardised analysis. According to Oppenheim (1992) the coding process applies abbreviations or symbols to a segment of words, and is usually derived from the research questions and key concepts. It allows the researcher to quickly identify, pull out, and then cluster all the segments relating to a particular question. The aim of coding the data is to aid the researcher in analysing and discovering patterns that have been generated by prior theory.

The coding of raw data was carried out after the interview was completed; however, the range and meaning of the code numbers were decided in advance. The conversion of data into numerical codes assisted in the codebook construction. A codebook that described the variables and listed the assignment of codes to the attributes composing those variables was produced in the office. It contained the exact wordings of the questions asked, together with the numerical values that had been allocated to every answer category, and the coding frame. The coding frame was developed with the aid of a classification scheme guidelines proposed by Oppenheim (1992), and the main sample response.

4.6 Survey Result

After coding the data gathered, an Excel spreadsheet was used for the data management and interpretation process. Excel was seen as the most appropriate application of the available data processing tools due to its simplicity in gaining an overall representation of the data, and the fact that there was no intention of studying any form of colouration or linearity at this stage. In addition, where necessary, results within a section were grouped into an individual chart in order to enable a representation of the results in an overview picture, which leads to a better examination of the outcome.

4.6.1 General Information Section Outcome

This section includes questions on the number of employees working at the organisation, and annual turnover. This provided information about the establishment, in terms of the human intensity and market share. It was noticed that 12 organisations in the sample frame had a workforce of more than 500 employees, and 16 organisations generated an annual turnover that does not exceed 1 billion pounds.
In addition, there is a question relating to the position of the interviewee, in order to ensure the participant's appropriateness for this investigation. It was apparent that all the participants were from the manufacturing management and operations positions.

4.6.2 Automation Level Section Outcome

This section addresses the level and drivers of automation in the organisation. It includes a question that addresses the respondent's definition of automation in order to understand how the respondent perceives automation, and to provide reassurance that the interview is conducted within the research area. The results indicate that 13 respondents consider automation to be the replacement of the human element or intervention, and the rest defined it as the application of machines or computer systems.

Various motives for automation acquisition are presented in Figure 4.1. It reveals that production cost and product quality are the most influential drivers for acquiring automation. Health and safety, productivity, and flexibility were highlighted as drivers for automation, but had lower significance than did production cost and product quality. Agility was not considered as a driver for automation in any of the responses, thus it was removed from the data representation. The other responses gathered for pursuing automation were to obtain new technology, process capabilities, and customer compatibility.

Figure 4.2 illustrates the level of automation and reveals that 5 of the respondents interviewed place themselves at the medium automation level. However, 12 respondents have judged their level of automation according to the amount of combined manual and automated activities carried out in the plant. The rest made their assumptions based on benchmarking against other organisations in the same industry and on the amount of product volume and variety.

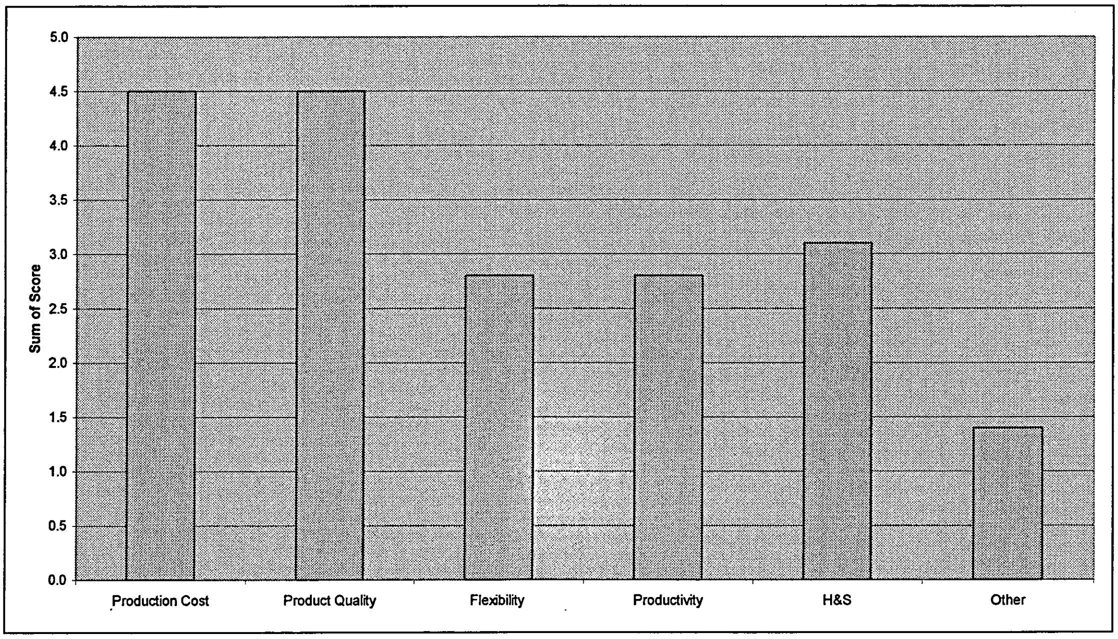


Figure 4.1: Automation Drivers

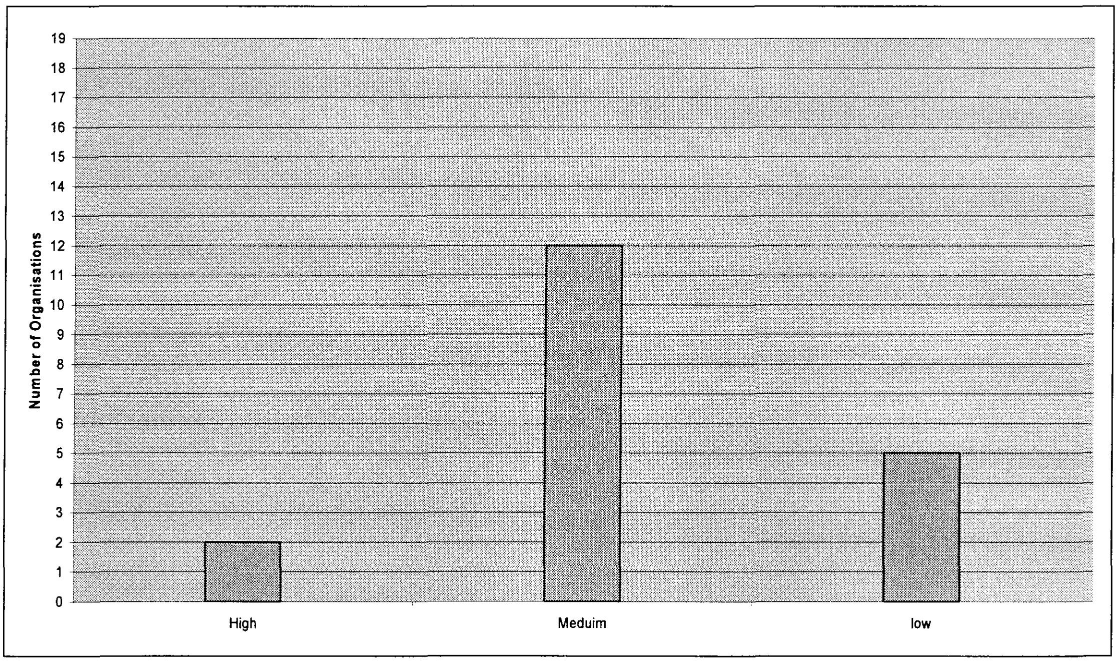


Figure 4.2: Automation Level

However, regarding the awareness of the risk of over-automation, 16 respondents were aware that a risk of over-automation existed, and 14 respondents declared that identifying the ideal level was an area of concern to them. Examples of some of the qualitative results obtained in the form of descriptive comments to the automaton level section in the survey questionnaire are presented in Table 4.1.

Question Number	**Descriptive Comments**
5. Automation definition	"Is the use of hardware and software to replace humans", "Removal of operator"
8. Judgement of automation level	"Compare manual operations against machine operations" "By the amount of machinery relative to people employed"
12. Risk of over automation and how it is avoided	"Yes. The danger is you can rely too much on machines but when they break down you face flow distribution." "Financial justification", "Simulation"
12. Importance of ideal level of automation	"Yes, a wrong decision can affect the efficiency and effectiveness of the operations"

Table 4.3: Automation Level Qualitative Responses

4.6.3 Manufacturing System Design Section Outcome

This section presents the data gathered on the manufacturing system design methodology. A number of questions are combined into one graph to give an overview of the manufacturing system design data analysis (Figure 4.3). It illustrates that 9 respondents follow a structured approach, and 15 respondents deploy a cross-functional involvement, which includes a mixture of management personnel, manufacturing designers, technical engineers, and operators. It also includes the number of respondents (7 respondents) who call in specialised expertise during the design phase to aid them in the design and decision-making.

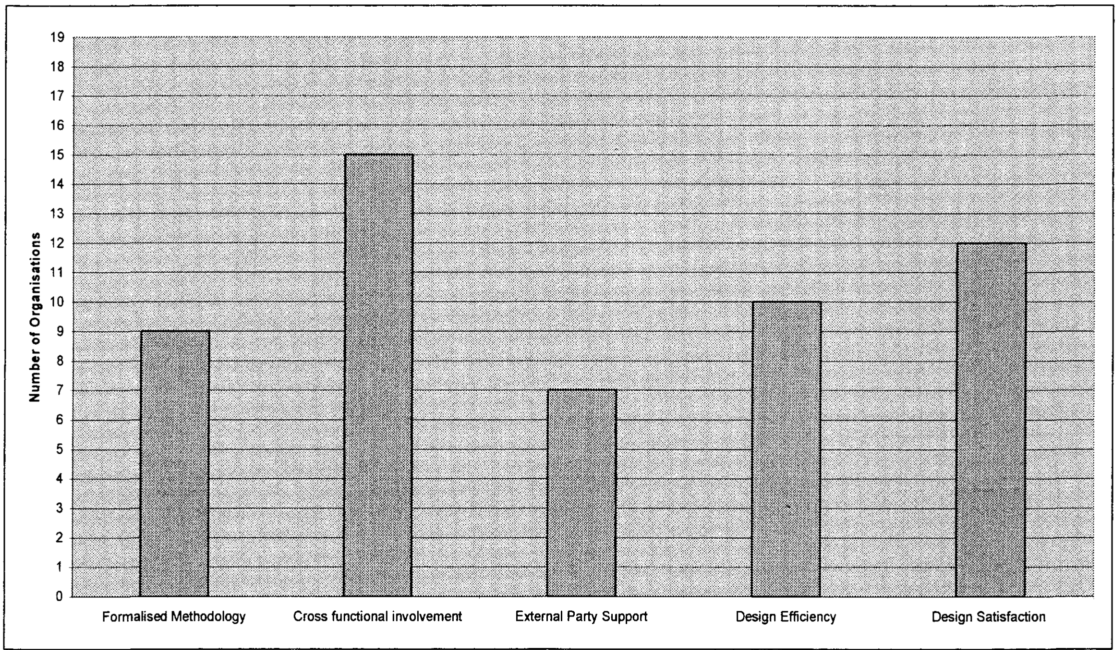


Figure 4.3: Manufacturing System Design

Regarding the support tools, Figure 4.4 presents the tools used by organisations during the design of their manufacturing system. It is apparent that simulation is the most widely used approach, with 8 respondents depending on it in their design. Integration Definition for Function Modelling (IDEF0) is in second position, with 5 respondents depending on it in their design. In addition, Failure Mode Effect Analysis (FEMA) was reported by 4 respondents, and Computer Aided Design (CAD) by 2 respondents.

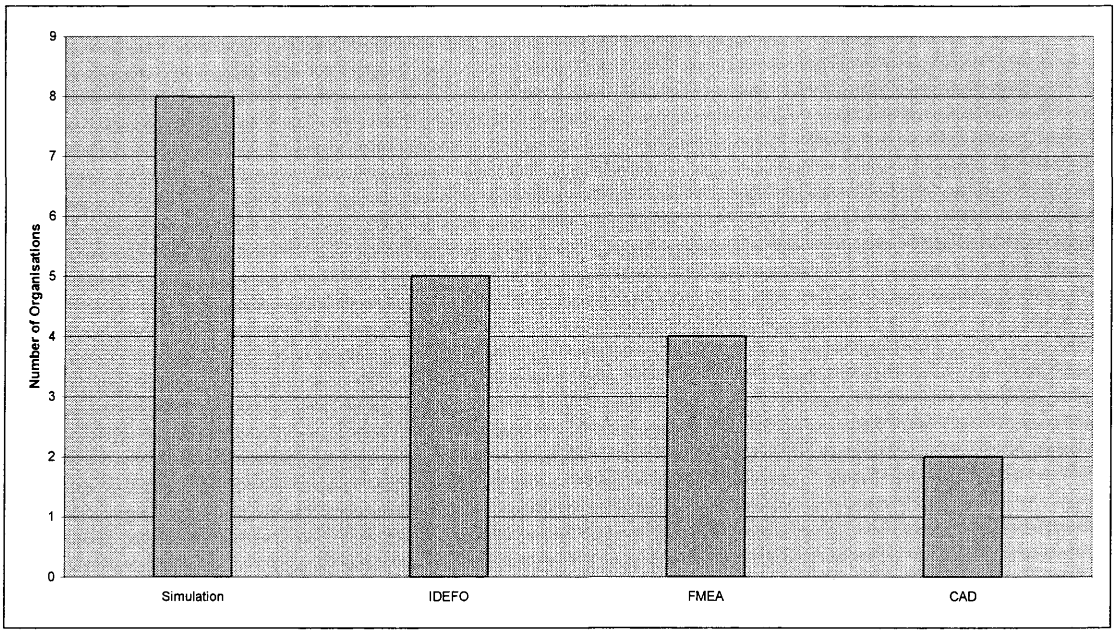


Figure 4.4: Design Tools

However, the factors concentrated on during the design phase are presented in Figure 4.5. The most important factors considered during the design phase are process (time and capability) and safety. 11 of the respondents stated that these issues must be verified throughout the design and implementation. However, the other factors, reported by 6 respondents, correspond to quality, production flow issues, and supplier capabilities.

In addition, this section includes a representation of the respondents' views on the plant's efficiency and satisfaction (Figure 4.3). 10 of the respondents reported gaining the expected efficiency from their manufacturing system investment, and 12 respondents reported that they are satisfied with their manufacturing design procedure. Examples of some of the qualitative results obtained in the form of descriptive comments to the manufacturing systems design section in the survey questionnaire are presented in Table 4.2.

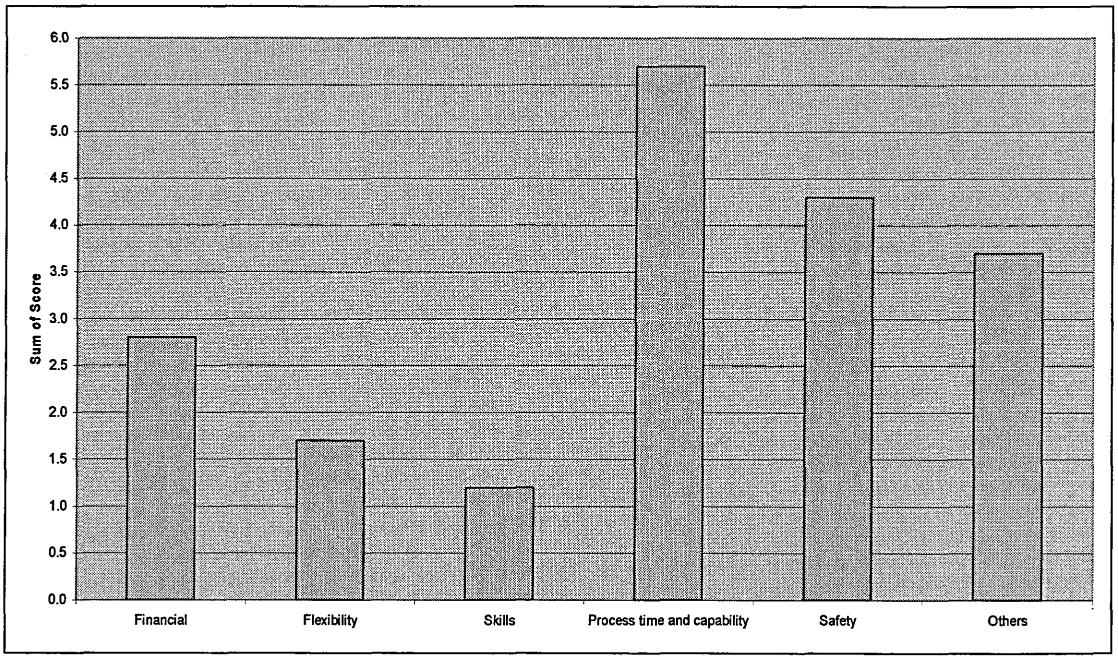


Figure 4.5: Manufacturing Systems Design Factors

Question Number	Descriptive Comments
11. Follow a structured methodology	"No, because the work type keeps changing" "No, we just depend on simulation"
13. Use External party	"No, to preserve confidentiality and the knowledge"
15. Attain expected efficiency and productivity	"No, 6.5 million investment didn't reduce the number of employees, the people were not trained, and H&S record was appalling"
16. Satisfied with design procedure	"No, because not stable design process" "No, because too many factors and short period"

Table 4.4: Manufacturing Systems Design Qualitative Responses

4.6.4 Human Factors Section Outcome

This section presents the data gathered on the number of operators and the level of automation in the plant. Throughout the organisations interviewed, it was found that in 14 organisations there were between 50 and 500 operators working on the production floor. The ratio of automated to manual work stations indicates that 16 of the organisations interviewed were using a semi-automated manufacturing approach.

In addition, all of the respondents declared that human factors were considered in the decision and design of their manufacturing system. However, regarding the participants' satisfaction with amount of emphasis and integration, around 14 respondents were satisfied. Examples of some of the qualitative results obtained in the form of descriptive comments to the human factors issues section in the survey questionnaire are presented in Table 4.3.

Question Number	Descriptive Comments
19. Human factors & ergonomics consideration	"Yes, using guidelines" "Yes, depending on experience and H&S guidelines"
20. Satisfied with human interaction and integration	"No, problems with night and day shift when taking over" "No, difficulty in communication" "Training and skills issues need addressing"

Table 4.5: Human Factors Issues Qualitative Responses

4.6.5 Automation Decision-Making Section Outcome

This section presents the data gathered on the automation decision-making process. A number of questions are combined into one graph to give an overview of the decision-making process data analysis (Figure 4.6). It illustrates that 10 respondents followed a structured approach, and 17 respondents deployed a cross-functional involvement, which includes contributions from management personnel, manufacturing designers, technical engineers, and operators. It also shows that 3 respondents used support tools to aid them with their decisions. The tools mentioned are Integration Definition for Function Modelling (IDEF0) and Failure Mode Effect Analysis (FMEA).

In addition, this figure includes a representation of the respondents' satisfaction with the decision-making process and automation failure encounters. 12 respondents were satisfied with the current decision-making approach. However, 11 respondents reported mismatch and shortcomings as a consequence of automation, sometimes refereed to as 'automation backfire' (Bainbridge, 1983).

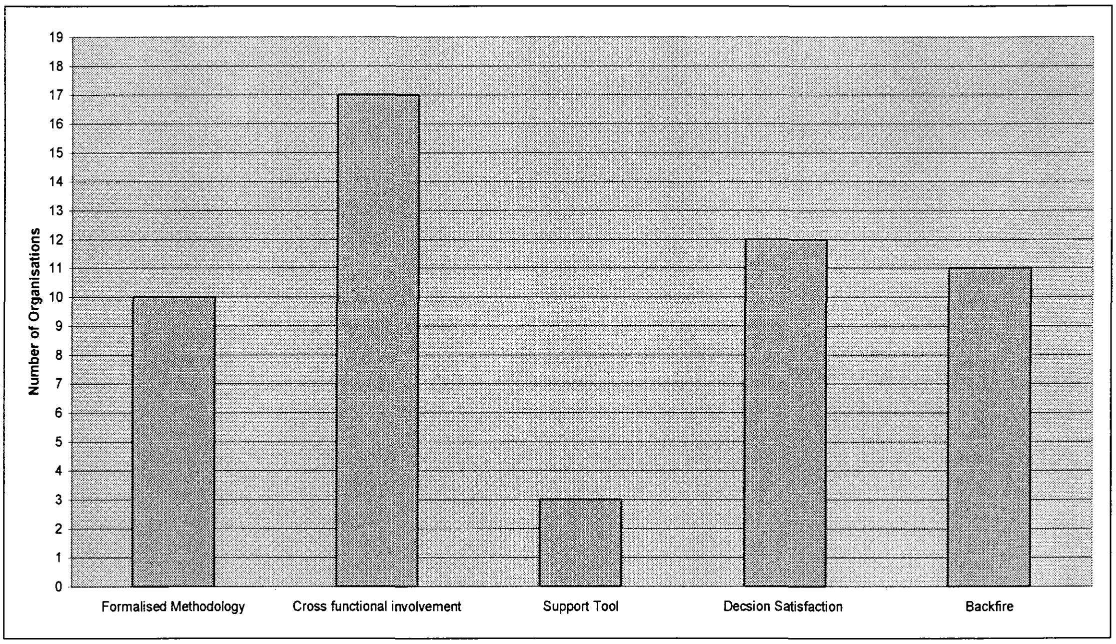


Figure 4.6: Automation Decision Making Process

Moreover, this section presents data on the influential elements that are considered within the decision-making process. Figure 4.7 illustrates that the most important factor in the decision-making process is considered to be health and safety ($\bar{x}$ = 4.9). It also shows that social factors, which are an example of macro-ergonomics issues, are the least important factor considered ($\bar{x}$ = 3.4). Other elements mentioned included new technology and customer influence.

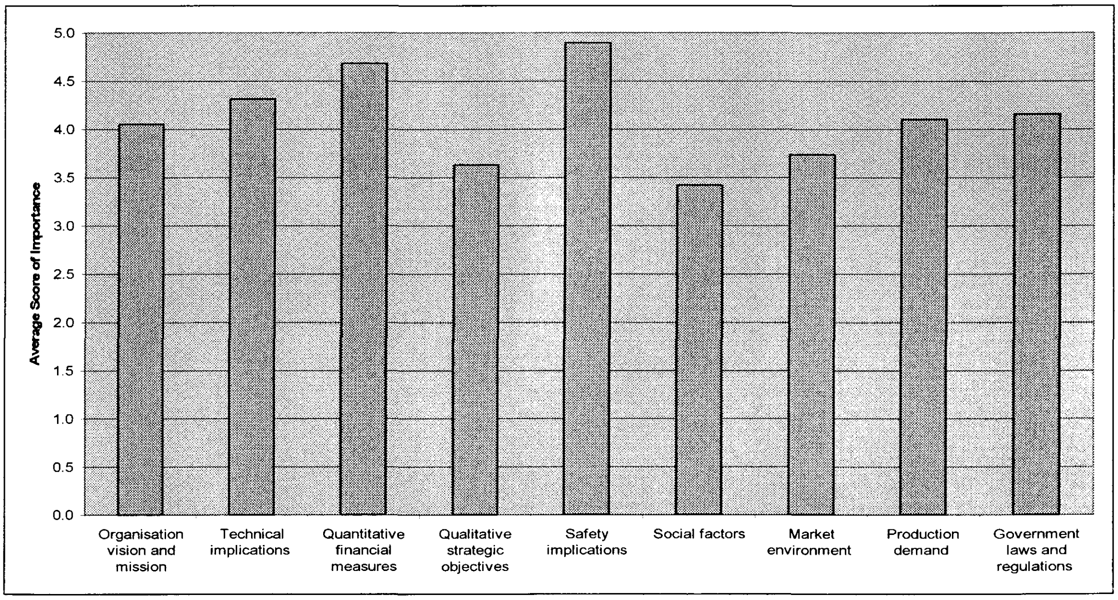


Figure 4.7: Decision Making Influential Elements

The financial justifications used are presented in Figure 4.8. It reveals that the payback method is the approach most commonly adopted to justify the investment; 16 respondents have mentioned using it. Moreover, 8 of the respondents adopt the net present value and the internal rate of return score in addition to the payback justification. The Modified Minimum Annual Revenue Requirement was not considered as a financial justification for automation investment in any of the responses, thus, it was removed from the data representation. Whereas, the other responses(reported by 6 respondents) gathered showed the use of Discounted Cash Flow.

In addition, to identify the value and applicability of the proposed model in the manufacturing industry, data were gathered on the respondents' willingness to use such a model once produced. It has revealed that all of the interviewees have stated approval of use and willingness to support the research. Examples of some of the qualitative results obtained in the form of descriptive comments to the automation decision-making section in the survey questionnaire are presented in Table 4.4.

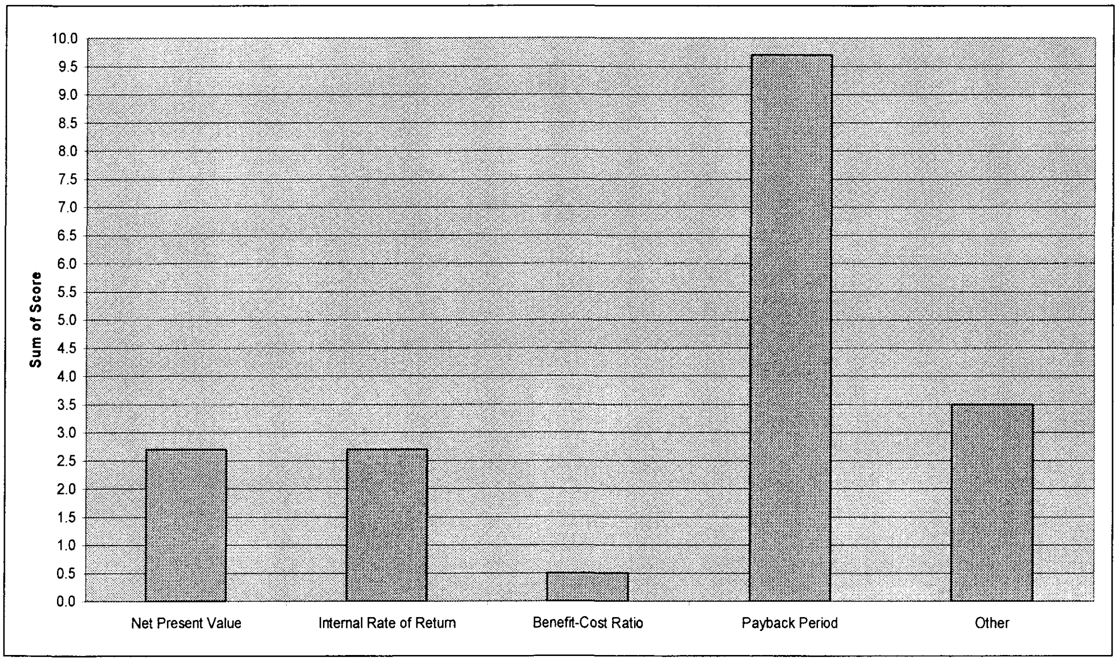


Figure 4.8: Financial Justification Methods

Question Number	Descriptive Comments
27. Satisfied with the decision-making process	"No, you can bring other factors into that such as personal motives and political factors" "No, it does not work in an integrated way" "No, training, skills, social issues all done on experience rather than on analytical"
20. Encountered automation backfire	"Yes, we have moved far to fast in automation and didn't handle the human resources right, which lost us the benefit of the automation" "In some cases we have bought sophisticated equipment, however, the operators were not able to function on it due to lower skills" "Yes, production mix could not cope with production schedule and we had to go back to manual operation"
20. Use proposed research solution	"Yes, if it doesn't take more effort" "Yes, it will standardise our operations" "Yes, if it will prompt people to ask the right questions" "Yes, it could be a further improvement"

Table 4.6: Automation Decision-Making Qualitative Responses

4.7 Discussion

The results are discussed and analysed in this section to bring together the main findings of the industrial survey. The discussion is set out in a similar manner to the results outline to simplify display and maintain uniformity.

4.7.1 General Information Section Analysis

The results from section one illustrate that most of the participants were representing manufacturing systems designers. It also showed that the majority of organisations were representing manufacturing industries that employed a large workforce. This confirmed that the nature of information required was obtained from the right people and the right industry segment.

4.7.2 Automation Level Section Analysis

Section two revealed that there was approximate agreement on the term 'automation' and what it stands for. Automation can have various definitions because it can relate to soft and hard applications of equipment, and depending on which end it is looked at, the definition can shift from machine application to software integration. It was clear that participants were focusing on the machine application side of automation, and this was essential in order to be confident that a mutual understanding existed between the interviewee and interviewer.

In addition, from Figure 4.1 it was noticed that production cost and product quality were considered as main drivers for automation. All of the elements mentioned were or had an influence on automation acquisition, but it was the intention to identify the main drivers to enable a better analysis of the objectives. It was identified through further probing that the interviewees considered automation to be a solution to cost reduction through labour minimisation, whereas it provided a solution to quality improvement through increased process reliability and elimination of human error. The elements all proved to be drivers, with the exception of agility. However, the findings also show that in some instances customers were considered as drivers in terms of the prerequisite to match their technology and capabilities. Other instances show that it was used as a means to gain new technology to facilitate competitive advantage.

Figure 4.2 presents the intensity of automation in the organisations interviewed. It shows that the majority represent manufacturing industries that rely on both automated and human contributions. The basis upon which a judgement was made of the automation level was the proportion of automation that existed. In some instances interviewers placed themselves at the medium level, even though the level of automation that existed in the plant was very high. The reason for doing so, as they saw it, was because in other areas of production, there were high levels of human intervention, especially in areas such as assembly. Therefore, on an overall spectrum, they saw themselves as being in the medium range.

Some participants, on the other hand, also used rationality to determine the level of automation. They compared the amount of automation they had with other organisations in the same industry. Furthermore, it was noted that some interviewees were using volume and variety as a measure to determine their level of automation, thus, a high variety and low volume would indicate to them that they were at the low level of the spectrum. This demonstrates that there is no specific or standardised approach to defining the level of automation within which an organisation functions.

In addition, the awareness of the risk of over-automation is significant. The interviewees who were aware of the risk all reported that they feared over-automating when designing their manufacturing systems or processes. They see automation as a solution to generate improvements, and the only constraints to acquiring more are financial and technical capabilities. However, the approach they use to prevent over-automation is through conducting thorough feasibility studies and financial justification.

The area of the ideal automation level did not generate as much attention. The respondents who were concerned about this indicated that this would improve their flexibility, in addition to cost effectiveness. However, the respondents who were not concerned explained that this was an area worth looking into, but to them other manufacturing problems had to be dealt with first, before investigating this area.

4.7.3 Manufacturing System Design Section Analysis

Section three results, displayed in Figure 4.3, give an overview of the current manufacturing systems design methodology and characteristics. Apparently more than half of the respondents did not follow a formalised approach; they select and design their manufacturing systems purely on experience and knowledge. It was also noticed that they depend on input from the manufacturing engineers and designers in the design. This explains the high percentage of adoption of a cross-functional approach in the design phase. Therefore, the manufacturing systems designers used the cross-functional approach to ensure that all areas of the design were covered. Furthermore, support tools were used in the design phase, but overall this represents few respondents who relied on such techniques, and of the tools mentioned, the majority were using simulation.

Most of the respondents did not use or consult external bodies during the design of their manufacturing systems. However, they mentioned that the suppliers contributed to the design. Some respondents indicated that it was intentional not to involve external bodies to capture the skills and techniques obtained through this process in addition to competitive concerns.
Health and safety issues in the design appear to be one of the most important areas to concentrate on, according to the responses. They believe that the safety of the work environment and workforce is the area of first concern due to the hazardous consequences of not getting it right. All the factors mentioned in Figure 4.5 were areas of focus during the design, and they were reported according to the design approach and management aim.

However, 9 of the respondents replied that their efficiency was not as anticipated from their investment, and that it could be better. The satisfaction rate with the design procedure was not very high either. Reasons for most of the reports of dissatisfaction were: non-formality in the design procedure, insufficient time to go through all the design phases, insufficient consideration to implementation, and the fact that there was room for improvement. In addition, it was noted that due to the lack of formalised procedures, respondents reported annoyance with going through the whole process every time starting from scratch, and in one instance, fear of not being able to ensure good design and implementation due to reliance on internal people who switch positions to project managers for different automation investments.

4.7.4 Human Factors Section Analysis

The data indicates that the investigation was mostly conducted in manufacturing environments whose operators numbered between 50-500. This dependence on human intervention reflects a reasonable evaluation of the type and level of human factors considered in the manufacturing industry.

The ratio between automated and manual workstations indicates that most of the automated processes required human monitoring, and assembly was where human intervention was most heavily required. Even in the highly automated manufacturing plants it was realised that operators were a necessity, and that their intervention was required, especially in indirect jobs such as loading/unloading.

In addition, after more detailed investigation, it was revealed that all the respondents who reported on the consideration of human factors and ergonomics in the decisions and design of their manufacturing systems were actually considering 'human factors' to mean compliance with health and safety regulations. Therefore, upon further investigation it was discovered that only 7 of the respondents had health and safety officers and a formal risk assessment. These results provide a clear picture of how organisations perceive and consider human factors in their manufacturing facilities and automation decisions. They also confirm the relatively low importance of human factors in the decision-making process that was identified from the questionnaire survey.

In addition, from the replies on the level of consideration and satisfaction with integration, it was obvious that not all were satisfied. This helps in providing a clear picture of how they perceive and consider human factors in their manufacturing facilities. On the other hand, what has been described is only part of human factors; focusing on health and safety is one aspect of the field, but there are other areas that are involve in micro- and macro-ergonomics, such as user/machine interface, job restructuring and redesign, workgroup structure, skills, etc.

4.7.5 Automation Decision-Making Section Analysis

Overall 10 of the respondents were found to have a formalised decision-making process, and only 3 respondents were using support tools to enhance their decision-making. However, the degree of analysis and the structure of decision processes differed between business units. In addition, when the nature of the support tools was discussed in more detail, it emerged that some of them were not decision support tools as such, although they could be used in the decision-making process. The tools mentioned are mainly design methodologies that are used as structural procedures in the design of manufacturing systems. The data showed that the respondents who mentioned using decision support tools had actually repeated the same answers that were given for the design of their manufacturing system. Therefore, it indicates that the respondents actually consider them as decision and design support tools.

In addition, Figure 4.6 illustrates that 11 of the respondents had encountered a situation where they automated a process, and only during implementation did they realise that it did not give the required flexibility, process capabilities or output, due to operators' resistance and difficulties in human/machine interface integrating, thus they had to revert to manual operation. Furthermore, one respondent reported that insufficient skills had led to an increasing in the time for implementation. These issues supported the high degree of concern about the risk of automation and the necessity of achieving a balance.

Figure 4.6 also shows that 12 of the respondents were satisfied with the decision-making process. However, the respondents who were not satisfied reported dissatisfaction due to manufacturing system designers facing problems with regard to incorporating all the influential elements from the beginning. It is during the design and implementation phases that unanticipated issues were raised and had to be dealt with. In most cases the issues related to technical and human resources aspects. Moreover, in some interviews participants stated that personal judgement and inter-departmental politics affected the decision, in addition to the great financial influence.

The influential elements results confirm the importance of health and safety to the respondents; this was both the most important of the decision-making influential elements and the most important factor considered in the design. The financial justification techniques were mostly payback, as illustrated in Figure 4.8. In most cases the respondents were using a maximum payback period of two years and less. What had not been anticipated, however, was that macro-ergonomics issues (understood by those surveyed as 'Social issues') were considered the least important factor in the decision making process.

Two other elements were brought to the attention of the researcher, namely new technology and customer influence. It was discovered that some organisations' decisions were influenced by the advancement of technology to maintain a leading position, and in other instances by their customers, to maintain compatible technology and product standardisation.

The amount of support observed from the respondents demonstrated their willingness to review the outcome of this research and help in any way they could, which indicates the validity and worth of developing the proposed tool for the manufacturing industry. Reported responses on how useful it would be to them were that it would provide a clear focus, standardisation throughout the business, validation and reassurance of decision-making, and would create ownership through removal of judgemental and emotional influences. Other respondents elaborated on how it could save time and prompt people to ask the right questions.

Overall this analysis provided a clear picture of the respondents manufacturing systems design weakness in addressing human factors and the high rate of dissatisfaction. In addition, it was obvious that there was an essential need to appropriately address human factors in the decision-making process. The key findings from this section is summarised in Table 4.5.

Automation level section key findings	• There was a strong indication of the need to identify the ideal level of automation, as even those who were not concerned stated that it was an area worth looking into. • The awareness of the risk of over-automation is considered significant. • The approach used to prevent over-automation is through conducting financial justification.
Manufacturing systems design section key findings	• More than half of the respondents did not follow a formalised approach in selecting and designing their manufacturing systems. • More than half of the respondents were dissatisfied with the design process.
Human Factors issues section key findings	• It was realised that operators were a necessity, and that their intervention was required. • Human factors consideration was interpreted as compliance with health and safety requirements. • Only 7 of the respondents had health and safety officers and a formal risk assessment. • Not all respondents were satisfied with the amount of people issues emphasis and integration.
Automation decision-making section key findings	• The decision-making support tools mentioned were mainly design methodologies. • Human factors consideration in the decision was health and safety consideration. • The macro-ergonomics issues were the least important factor in the decision making process. • More than half of the respondents had encountered a situation where they automated a process and had to go back and rely on manual operation. • Positive responses to review the outcome of this research.

Table 4.7: Survey Key Findings

4.8 Chapter Summary

The results and analysis obtained from the industrial survey validated the conduct of this research from an industrial perspective. The survey results highlighted the available methodologies and identified the constraints that are facing the manufacturing industry regarding this topic. In addition to capturing the industry's view on what improvements are required, and interest in the solution proposed in Section 2.5.

CHAPTER 5

MANUFACTURING SYSTEMS DECISION-MAKING TOOLS

5.1 Introduction

This chapter and the following two Chapters; 6 and 7, are considered as a secondary literature review, as they contain the theoretical investigation conducted to facilitate the design of the research solution. The purpose of this chapter is to provide an overview of the decision-making tools available for manufacturing systems selection, in order to determine the appropriate mechanism required for the development of the decision tool for this research. It presents a brief description of the techniques referred to in decision-making literature, followed by a review. The techniques strengths and weaknesses are then analysed to advocate appropriate selection.

5.2 Decision-Making Tools Review

The survey results in section 4.6.3 pointed out a number of decision-making support tools used by manufacturing mangers in automation selection. The tools mentioned were Integration Definition for Function Modelling (IDEF0) and Failure Mode Effect Analysis (FEMA). However, a review of the most widely applied decision-making techniques was seen as a necessary step to derive a solution that is based on a firm evaluation process and judgment. Therefore, a literature search was conducted on manufacturing systems and strategic decision-making in the manufacturing domain. There are numerous decision-making tools available in the manufacturing industry, some of which are used for specific purposes and others that are used for general applications. However, this study will review and focus on the general application tools.

Decision-making support tools can be applied manually or through software applications. There is a vast literature on decision-making techniques; however, to narrow the scope of the investigation the researcher focused on studying those tools that are used at acquisition and strategic level, which have been applied in the manufacturing field, and which can solve discrete problems and multi-variable problems. Based upon these criteria the following applications have been selected: Decision Tree, Weighted Ranking, Grid Analysis, Flowchart Diagram, Failure Mode Effect Analysis, Integrated Definition for Function Modeling, Artificial Intelligent Systems, Fuzzy Logic, Quality Function Deployment, and Analytical Hierarchy Process.

The review will highlight what each tool is best used for, according to problem situation, level of problem complexity, and solution time, thereby, enabling adequate evaluation and selection of the appropriate mechanism required for the development of the research decision tool.

5.2.1 Decision Tree

A decision tree is a technique that is used for analysing problems involving risk, uncertainty, and probabilities. It helps the user to choose between several courses of action. The tree diagram graphically displays the alternatives and their outcomes at different stages, in sequential events. It is a highly effective structure that enables the user to investigate in a balanced form the risks and rewards associated with each possible outcome. In addition, Kendall and Kendall (1992), point out how the decision tree can be deployed in systems analysis for identifying and organising conditions and actions in a completely structured decision process.

The decision tree consists of branches and nodes. The nodes are either in the shape of squares or circles, squares representing decisions and circles represent uncertain outcomes. From the decisions lines are drawn towards each possible solution/action. Thereafter, each possible outcome is assigned with a value and a probability of uncertainty to make a decision.

This technique is a highly effective structure within which the user can lay out options and investigate the possible outcomes of choosing those options. It is widely deployed in decisions that consist of actions that have to be accomplished in a certain sequence, and when each condition is not relevant to each other (Kendall and Kendall, 1992). The type of decisions applicable to this tool is considered to be those of low to medium complexity. Furthermore, it is simple to apply and does not consume large amounts of time to perform.

5.2.2 Weighted Ranking

Ranking means to assign a position to something relative to other things (Jones, 1995). This is the theme used in weighted ranking, which involves working out the importance of a number of alternatives relative to each other in a systematic way. It is conducted by following simple instructions. Jones (1995) demonstrates how weighted ranking can be applied in nine steps:

1. Listing of criteria for ranking.
2. Conducting pair-rank.
3. Selecting top criteria and weighting them in percentiles (sum equalling 1.0).
4. Constructing weighted ranking matrix.
5. Pair-ranking all items by each criterion, specifying number of votes for each item.
6. Multiplying the number of votes by the respective criterion's weight.
7. Summing the weighted values for each item.
8. Determining final ranking.

9. Conducting a sanity check.

Jones (1995) suggests the use of weighted ranking to increase the confidence in the validity of the ranking. He also recommends that this tool be used as a minimum when ranking is important.
This approach is suitable for ranking alternatives that are considered to have simple or medium problem complexity. In addition, it is simple to apply and has a quick solution time.

5.2.3 Grid Analysis

This technique is used for aiding the decision-maker in situations that include a number of alternatives and many factors to be considered. In addition to determining the intangible values of the factors, it adopts the Paired Comparison Analysis technique. Paired Comparison Analysis is a technique of comparing each option with the other option and assigning a score to show how important it is. The paired comparison is conducted by deciding which of the two options is more important according to a scale from 0 (no difference) to 3 (major difference).

Therefore, once the relative importance of each factor is determined, the grid analysis can be conducted (Jones, 1995). The following illustrates the grid analysis procedure:

1. Listing of alternatives and factors.
2. Computing relative importance of factors.
3. Comparing each alternative against each factor according to a scale from 0 (poor) to 3 (very good).
4. Multiplying the values of the alternatives by the relative importance of each factor.
5. Summing up the weighted scores.

The tool's framework for comparing each alternative against all others is suitable for solving problems of simple to medium complexity. In addition, this approach is easy to conduct and can be quickly performed.

5.2.4 Flowchart Diagram

A flowchart is a diagrammatic representation that illustrates the sequence of operations to be performed to get the solution to a problem. It is a useful technique for representing either the processing and decision logic flows or the flow of an entire system (Modell, 1996). For this investigation the focus will be on reviewing the earlier application, namely representing decision logic flows. Flowcharts are used in decision-making to show the flow of a decision process from its inception to its completion.

The sequence of the separate steps and decision points to follow in order to reach a solution are visually presented through processing and decision symbols. The decision points are depicted as a diamond shape, with result outcomes indicated as a branch from the symbol. The branch may either lead into a process, join the mainstream later in the processing flow, or loop back to some earlier point in the processing flow (Modell, 1996).

The advantage of the flowchart diagram is that it allows the user to create a holistic view of the entire process, while keeping various aspects of that process in perspective. It can be applied for solving complex problems. However, the amount of technical detail required on each step or decision will depend on the complexity of the decision problem. In addition, it is easy to follow and construct.

5.2.5 Failure Mode and Effect Analysis

Failure mode and effects analysis (FMEA) is a disciplined approach used to identify potential failures of a product or service and then determine the frequency and impact of the failure. FMEA was originally designed for safety improvement, to prevent accidents from occurring, then application followed in areas of quality improvement, product design, and process development (McDermott et al., 1996).

The following is the procedure for constructing an FMEA:

1. Review the process.
2. Brainstorm potential failure modes.
3. List potential effects of each effect.
4. Assign a severity rating for each effect.
5. Assign an occurrence rating for each failure mode.
6. Assign detection rating for each failure mode and/or effect.
7. Calculate the risk priority number for each effect.
8. Prioritise the failure modes for action.
9. Take action to eliminate or reduce the high risk failure modes.
10. Calculate the resulting risk priority number as the failure modes are reduced or eliminated.

This technique is applied in industry to aid designers in manufacturing system design and product development. It is suitable for solving complex problems. However, it may require considerable time to accomplish when considering complex processes or products.

5.2.6 Integrated Definition for Function Modelling

Integrated Definition for Function Modelling (IDEF) was introduced by Douglas T. Ross in the early 1970s, and the U.S. Air Force Program for Integrated Computer-Aided Manufacturing (ICAM) standardised it and made it a public subset of the Structured Analysis and Design Technique (SADT) (Ross, 1980). There are different IDEF versions available for process modelling. However, for the purpose of this investigation the focus will be on IDEF0, which is used to create graphical representations of system activities for function modelling, as the study relates to manufacturing system design and decision-making.

The application of the IDEF0 method is commonly used for computer integrated manufacturing system design to better understand how to improve manufacturing productivity. The outcome of this process is a model that considers activities, information, and interface constraints simultaneously. In addition, this model is composed of three types of information: graphic diagrams, text, and glossary (Ross, 1980).

The graphical language diagram represents the function as a box and the interfaces to or from the function as arrows entering or leaving the box. The initial diagram is called A-0 diagram, from which the child diagram is created and further decomposition is constructed to form a hierarchical series of diagrams that gradually display increasing levels of detail (Ross, 1980).

The IDEF0 method is suitable for modelling complex systems and decision processes. It is a technique that is applied to model the decisions, actions, and activities of an organisation or system in order to support process management and process improvement. The analyst uses this technique for reengineering or redesign of business processes during manufacturing system design to identify what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong. In addition, the solution time will vary in accordance with the complexity of the problem and elements involved.

5.2.7 Artificial Intelligence

Artificial Intelligence (AI) is a technique that applies computer science to help machines find solutions to complex problems. It involves performing mechanical computations using human knowledge to solve problems that normally would require human intelligence. Expert Systems (ES) and Decision Support Systems (DSS) together represent the most widespread types of management support systems. These systems represent expert knowledge as data or rules to solve problems (Turban, 1988).

An artificial intelligence technique consists of a knowledge base, inference engine, control mechanism, working memory, and the user interface. The expert systems solves complex problems by adopting an IF-THEN-ELSE structure and asking a series of 'Yes' or 'No' type questions (Iran et al., 2002). Decision support systems are used to aid the user in exploring alternatives and considering their ramifications by asking 'what-if' type questions (Kendall and Kendall, 1992).

Kolli et al. (1994) categorise the expert system and decision support systems under the heading of multi-criteria nondeterministic methods, and provide a review of where the applications were developed for handling the problem of evaluating investment in advanced automated manufacturing systems.

This technique allows complex problems that include monotonous mathematical calculations and subjective elements to be solved efficiently and in a reasonable time frame. However, the inflexibility of use becomes apparent when the decision-maker wishes to include additional criteria, which will necessitate reprogramming the software.

5.2.8 Fuzzy Logic

Fuzzy logic is a mathematical way of dealing with rules stated in words or other terms whose meanings overlap, and was conceived by Lotfi Zadeh in 1965 (Sheridan, 1994). Fuzzy logic is an extension of conventional Boolean logic (completely true and completely false) to handle the concept of partial truths that fall between completely true and completely false (Lugg, 1999). In addition, the fuzzy expert system is an expert system that uses fuzzy logic to deal with multi-variant problems (Dubois et al., 1995). It incorporates an IF-THEN rule-based structure to arrive at a definite solution.

According to Lugg (1999) description of the inference process, the input values are transformed into linguistic values, in order to represent the degree of membership (membership function) of an element in a fuzzy set. This step is known as the fuzzification process. The membership functions can be presented in many different forms, such as triangular, trapezoidal, exponential, or singleton.

The fuzzification process necessitates the development of a knowledge base in order to provide the information required for the inference calculations. The knowledge base contains the data base and rule base information. The data base consists of information which defines and links the linguistic definitions with the input values, whereas the rule base consists of expert knowledge that applies IF-THEN rules to map (relate) input membership functions to the output membership functions.

An inference engine uses the information stored in the knowledge base and performs the mathematical computations to deliver a fuzzy output value. The outcome from this step is then defuzzified to obtain a final crisp value. This step is known as a defuzzification process. There are many defuzzification methods available to carry out this step. The most commonly used methods are: the max-membership method, centroid method, weighted average method, and mean-max membership method.

According to Wilhelm et al. (1991), fuzzy logic application is suitable for dealing with complex problems that include non-quantitative factors in a practical time frame. However, the inflexibility of this approach becomes apparent when the decision-maker wishes to include additional criteria, which will necessitate reprogramming the software.

5.2.9 Quality Function Deployment

The Quality Function Deployment (QFD) approach is a systematic procedure for defining customer needs and interpreting them in terms of product features and process characteristics (Groover, 2003). The systematic analysis helps developers avoid rushed decisions that fail to take the entire product and all the customer needs into account (Cohen, 1995).

The QFD methodology is a structured multiple matrix-driven process. The first of these matrices is called the "house of quality". The construction of the house of quality consists of six stages (Groover, 2003):

1. Identifying customer requirements (voice of the customer "whats").
2. Identifying product features needed to meet customer requirements (design requirements "hows").
3. Determining technical correlations among product features.
4. Developing relationship matrix between customer requirements and product features.
5. Comparative evaluation of input customer requirements.
6. Comparative evaluation of out put technical requirements.

According to Revelle et al (1998), the application of QFD can take two forms, either as a four-matrix model or a thirty-matrix model, known as the "matrix of matrices". The four-matrix model is a progression of the house of quality matrix to relate the customer requirements to successive design requirements, to component characteristics, to process requirements, and finally to quality procedures. To link matrices the "hows" are transferred to the successive matrix to become the "whats". The matrix of matrices provides more depth and is adopted for projects that require a more detailed understanding.

The tool is applied to relate customer requirements to the design and manufacture of products, and to link the marketing, engineering and manufacturing functions of the enterprise (Johnson, 2003). In addition, it is suitable for complex problems and is considered to be time-consuming according to Cohen (1995).

5.2.10 The Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is an approach that is deployed to solve discrete problems involving few alternatives and many criteria. Multiple-criteria decision-making (MCDM) support tools fall into two main categories; multi-attribute decision-making (MADM) or multi-objective decision-making (MODM). The MADM tools deals with discrete decisions where the decision alternatives are predetermined, whereas MODM tools consider continuous problems and have been studied under the general classification of operations research, or discrete problems such as linear programming (Bhushan and Rai, 2004).

AHP is a process of decomposition by hierarchies and synthesis by finding relations through informed judgement (Saaty, 1980). It depends on pairwise comparison to allow all important tangible and intangible factors to be included and measured. The process involves five steps (Boucher and MacStravic, 1991):

1. Breaking down the decision into a hierarchy of decision elements.
2. Collecting input data by pairwise comparison of decision elements.
3. Checking the consistency of the input data using the maximum eigenvalue method.
4. Computing the relative weights of the decision elements as the eigenvector of the pairwise judgement matrix.
5. Aggregating the relative weights of the decision elements in order to obtain a numerical outcome.

The consistency index of the informed and random or unrelated judgements is measured by calculating the eigenvectors and corresponding eigenvalues. The consistency index should be less than 0.1 to satisfy validity of judgments. However, judgmental revision method is applied in the instance where the consistency index is higher than 0.1 to improve the consistency. Saaty (1980) indicates the technique's suitability for modelling unstructured problems that have all alternatives specified in advance with independent hierarchy elements. However, he points out that caution should be exercised when formulating the comparison questions and definition of the elements to prevent ambiguity and controversial arguments.

Several reports document operational difficulties and deficiencies with the application of AHP. Belton (1986) points out the ambiguity inherent in the term "weights" and "scores" that are used in the pairwise comparisons of alternatives, as well as questioning the limitations of the ratio scale and the approach of the questioning procedure used to establish the relative weights of importance. Boucher and MacStravic (1991), however, criticise the non-existence of a theoretical framework for modelling the decision-making. Furthermore, Dyer (1990) questions the appropriateness of AHP as a procedure for ranking alternatives, pointing out the operational difficulties and the arbitrary rankings that occur when the principle of hierarchic composition is assumed.

The AHP has been widely applied to decision-making situations that deal with automated manufacturing selection and justification (Wabalickis and Ghosh, 1988; Mohanty and Venkataraman, 1993; Luong, 1997; and Yusuff, 2001). In addition, there were instances where the AHP was used in combination with other applications such as expert choice and simulation models to facilitate decision-making in the design and planning stage (Madu and Georgantzas, 1991; Tabucanon et al, 1994; and Shang and Sueyoshi, 1995).

Therefore, the AHP technique can be considered for solving complex decision-making problems. However, the calculations involved might be tedious, especially in consistency validation. In addition, Boucher and MacStravic (1991) state that for large evaluations involving more alternatives, the number of judgements required by the AHP can become something of a burden.

5.3 Summary of Decision-Making Tools

The decision-making techniques considered are summarised in this section. The review of the tool's situation application, level of problem complexity, and solution time are to be used to facilitate the evaluation and selection of an appropriate mechanism for the research solution.
The decision tool to be developed for this research is required to support manufacturing designers in incorporating human factors in the evaluation of

automated manufacturing systems, in addition to determining the most suitable alternative. Therefore, the technique to be deployed will need to be able to solve problems of a complex nature. In addition, as manufacturing automation selection variables vary according to the size and type of the manufacturing organisation, it is believed that it is better to avoid techniques that restrict user modification. Accordingly, after assessing the techniques against these requirements, the Decision Tree, Weighted Ranking, Grid Analysis, Artificial Intelligence, and Fuzzy logic methods were filtered out.

This leaves Flowchart Diagram, Failure Mode and Effect Analysis, Integrated Definition for Function Modelling, Quality Function Deployment, and Analytical Hierarchy Process techniques as possible alternatives to select from. The difficulties of technique application and time requirements to reach a solution were considered at this point, to further focus the selection outcome.

The Flowchart Diagram was felt to be more appropriate for breaking down a decision process, while the Integrated Definition for Function Modelling method is not intended as a comparative method of evaluating different alternatives and does not readily facilitate risk analysis. Therefore, they were eliminated. In addition, the Analytical Hierarchy Process was eliminated due to the prioritisation procedure it employs, which requires the user to follow through only the elements with the highest score at each level of the hierarchy, and the complexity of its consistency validation process.

At this point the Failure Mode and Effect Analysis and Quality Function Deployment methods needed to be evaluated against each other to reach an outcome. However, with further reasoning it was envisaged that rather than selecting one method, a more creative approach could be produced by combining both techniques. As such, the Quality Function Deployment method was selected as an approach to reach a decision, and the Failure Mode and Effect Analysis method was selected to conduct the decision risk assessment.

5.4 Chapter Summary

This chapter has reviewed various decision-making techniques discussed in manufacturing literature in order to determine the technique to be deployed in developing the research solution. The assessment was performed in the light of the problem situation, level of problem complexity, and solution time. The outcome was the proposition to use both Quality Function Deployment and Failure Mode and Effect Analysis techniques for the decision tool's mechanism.

CHAPTER 6

QUALITY FUNCITON DEPLOYMENT AND FAILURE MODE EFFECT ANALYSIS

6.1 Introduction

The Quality Function Deployment and Failure Mode Effect Analysis techniques were described earlier; in Chapter 5, for comparison purposes. However, to provide an understanding of the procedure involved in the formulation of the decision tool methodology, both techniques are reviewed thoroughly in this chapter. This chapter consists of a comprehensive description of the QFD and FMEA techniques. In addition, it describes their various applications and benefits to determine their deployment feasibility in new settings.

6.2 Quality Function Deployment (QFD)

This section presents the relevant QFD academic literature. It addresses the QFD concept, framework, and deployment process; in order to provide the basis of the structure and implementation process used to support manufacturing systems designers determine the most appropriate manufacturing automation option. In addition, it describes the QFD applications and strengths to determine the technique's capability in improvising the manufacturing automation selection process.

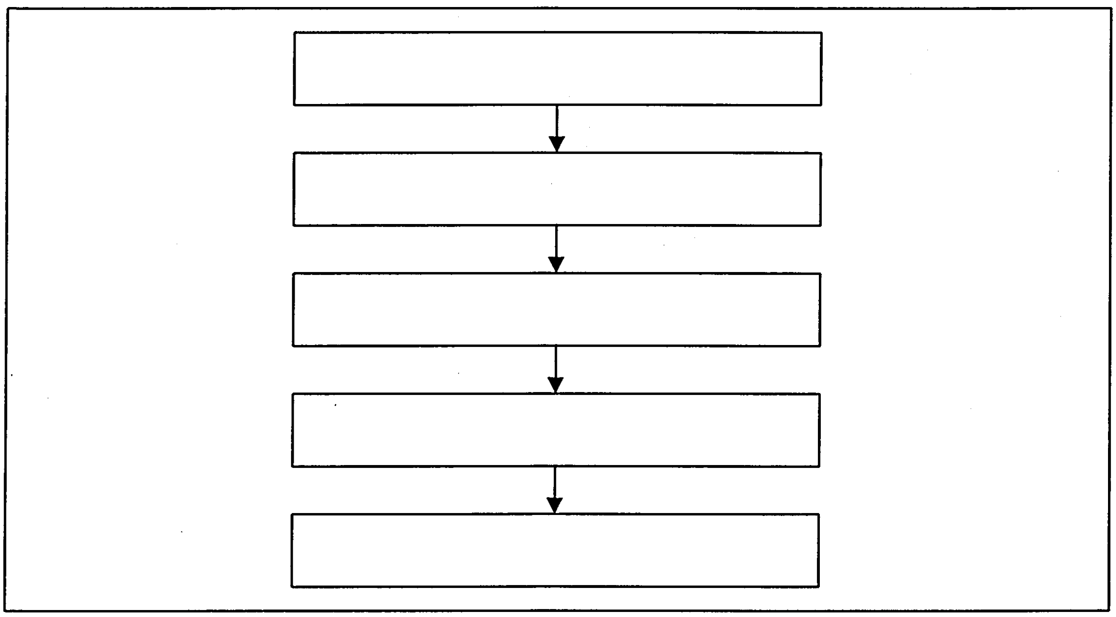
6.2.1 Quality Function Deployment Concept

The QFD technique is a comprehensive method for matching customer requirements to engineering characteristics of a product. It is an adaptation of some of the total quality management tools, as it was developed as a tool contributing to the attainment of Japanese quality standards in industry (Cohen, 1995). In addition, Akao (1990, pp. 3) defines QFD as "a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demands into design targets and major quality assurance points to be used throughout the production stage."

When Akao introduced the QFD technique in 1967, it was mainly targeted at engineering applications, which are normally associated with product development and design. The main purpose of the methodology was to ensure that quality was built into new products in the early stages of design. It was first used in 1972 at the Kobe Shipyard of Mitsubishi Heavy Industries and was referred to as the Quality Tables. Then, it was enhanced by the development of a matrix of customer demand and quality characteristics. Since then the technique has gained a wide acceptance and recognition worldwide, and application goes considerably beyond product and service design (Zairi, 1993 and Cohen, 1995).

The QFD mechanism is designed in a manner to help designers to capture customers' requirements and ensure that they are dealt with at the product design stage. The approach is based on a series of techniques that enable engineers to capture, prioritise and structure the broad intangible and immeasurable requirements into tangible objectives and relevant product specifications (Cohen, 1995). In other words, it is a process that translates the customer requirements into organisation requirements that can be incorporated in the research, development, engineering, manufacturing, and marketing of the product (Franceschini, 2002).

Moreover, it enables the production unit to grasp the notions of quality assurance at the stage of planning, even before going into production of new goods. The crucial point of the QFD technique is that it recognises the significance and importance of the



represent both verbal and observed actions. Therefore, management tools such as Kano's Model, Affinity Diagram, Tree Diagram, Matrix Diagram, Prioritisation Matrix, etc. are used to help the development team to categorise and prioritise the primary and secondary customer requirements. However, to translate the requirements into specifications of the item being developed, matrices are used (Cohen, 1995).

6.2.3 House of Quality Implementation Process

The House of Quality is the first matrix used to describe the basic process underlying QFD. It is a very complex matrix in the sense that it consists of several matrices attached to each other, as shown in Figure 6.2.

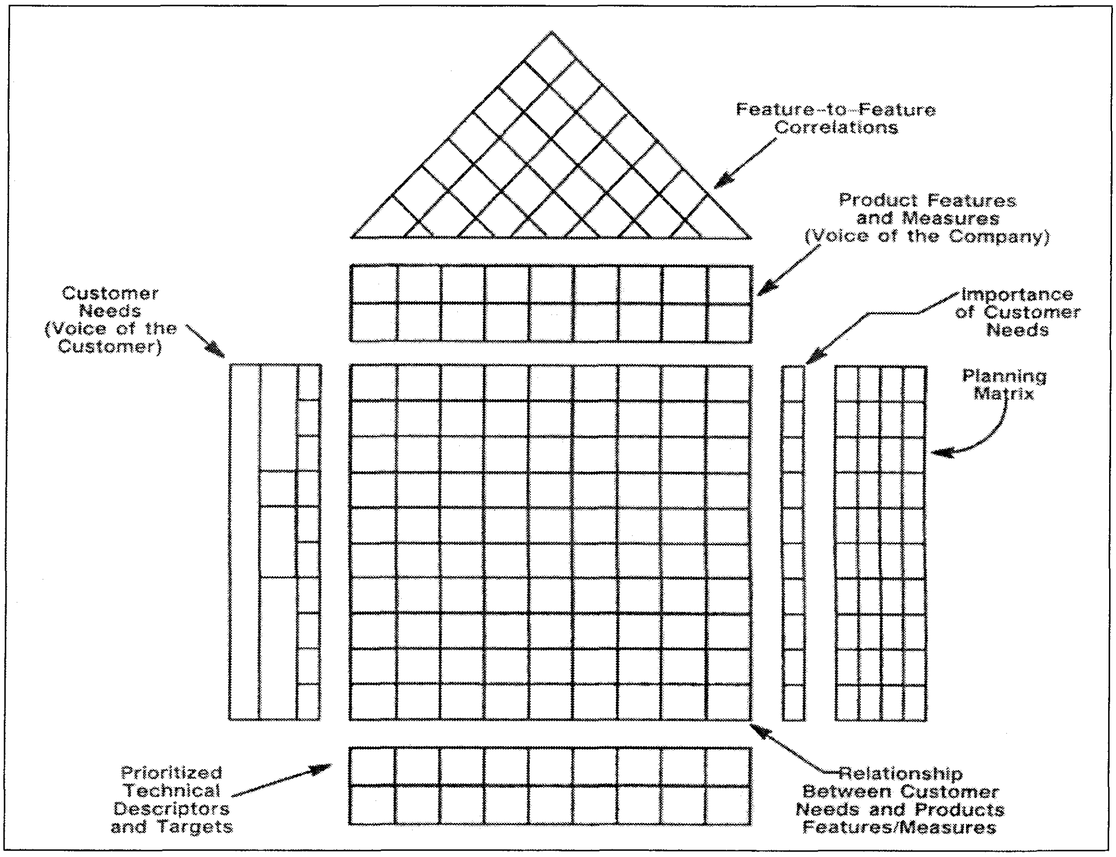


Figure 6.2: House of Quality Matrix (Shillito, 1994)

The following is a description of the implementation process and consists of an explanation of the depicted matrices (Cohen, 1995):

Step 1- Determining the customer requirements

The first step is to identify and define the customer requirements qualitatively. This step involves completing the room of the HOQ known as the 'Whats' room, or the 'Voice of Customer' room. The Voice of Customer is a technical term within QFD to represent the customer's wants and needs, which are normally derived from the unspoken and spoken words of the customer. It is a verbal or observational description of what is it that the customer wants, needs, or would be delighted with. In addition, the capture, interpretation, and categorisation of these inputs is conducted through the application of certain marketing and management techniques, as mentioned earlier.

Step 2- Prioritising the list

This step is established to determine how important the customer needs are and to evaluate the market. It involves completing the rooms of the HOQ known as 'Customer Importance' and 'Planning Matrix'. The customer importance room represents the significance weight of each voice in the customer's overall satisfaction needs. The available methods that can be used for prioritising vary from establishing a simple rating scale; i.e. 1 to 5 to a complex analytical hierarchy prioritisation. In any circumstances there should be a written description of the rating to promote consistency across raters.

Moreover, the planning matrix room represents a market evaluation of the company's product. The prioritisation is based on competitive analysis with major competitors' products.

Step 3- Establishing design requirements

The third step is to translate customer requirements into design requirements. This step involves completing the room of HOQ known as 'Hows' or 'Voice of the company'. They are measurable attributes that are stated in the organisation's internal language. In addition, they can be developed using an affinity diagram and tree diagram.

Step 4- Determining the relationship between the customer needs and design requirements

This step constitutes the largest volume of work as it is the largest section in the matrix, and involves completing the room of the HOQ known as 'Relationships'. The relationship matrix examines the correlation between the Whats and the Hows, and assesses each customer need against the design requirements to determine the relationship strength.

Accordingly, a strength measure; representing weak, medium, and strong relationship; is entered into each cell in the relationships matrix to reflect the extent to which the customer need contributes to the technical attributes. Various symbols are used to distinguish the relationship's strength, and the most common is the numerical value (1, 3, and 9) (Cohen, 1995). In addition, in circumstances were there are negative relationships a negative sign is included (Shillito, 1994).

Step 5- Prioritising technical targets

This step represents establishing technical attributes in order of importance. It involves the summation of the effects of all customer needs on each technical attribute to determine importance. In addition, this step includes establishing target measures of engineering characteristics, as well as competitive analyses of other manufacturing measures of the same variables.

The highest technical attributes outcome corresponds to those attributes that will have the greatest overall impact on customer satisfaction if achieved. This result is one of the most important outcomes of using QFD.

Step 6- Establishing correlation matrix

This step is established to indicate the way in which the technical attributes support or impede each other. It involves completing the room of the HOQ known as 'Roof' or 'Feature-to-Feature Correlation'. The purpose of understanding the correlation is to enable the designers to identify the design bottlenecks where further research and development is required.

Accordingly, a correlation measure; representing either positive or negative impact; is entered into each cell in the correlation matrix to reflect the extent to which the technical attributes support or impede each other.

6.2.4 Beyond House of Quality

As mentioned earlier the QFD process also involves constructing a set of interlinked matrices. Therefore, reviewing the process that follows the House of Quality application is necessary, as the process from capturing the manufacturing systems designers' voice to identifying the most suitable manufacturing automation alternative would require a set of interlinked matrices.

From the basic House of Quality process stem two popular approaches; the American Supplier Institute (ASI) approach and the Matrix of Matrices approach. They deploy the same technique as the House of Quality, but were developed to assist the designers in organising and carrying out the process up to the stage of defining the quality measures. The ASI approach constitutes four matrices, where as the Matrix of Matrices further expands into thirty matrices (Revelle et al., 1998). Therefore, the American Supplier Institute approach will be briefly reviewed.

-American Supplier Institute (ASI) approach

The ASI approach, known as the 'Clausing model', is a set of QFD matrices to translate customer requirements into quality measures, as shown in Figure 4.3. It extends the House of Quality procedure to provide the detailed requirements that must be met throughout the development, manufacturing, and inspection of the product. Each phase provides the key requirements and their priorities for the next level (Franceschini, 2002):

> -Phase 1 (product planning matrix) - The individual requirements are logically categorised and specified to be translated into technical specifications that are measurable.

-Phase 2 (part or subsystem deployment matrix) - The conversion of technical specifications into critical parts or subsystems that cause the essential functions to be performed.

-Phase 3 (process planning matrix) - The operations necessary for the best suitable manufacturing process are established to translate the desired part characteristics into operations specifications.

-Phase 4 (quality control matrix) - The operation limits necessary are established to effectively obtain the required quality characteristics.

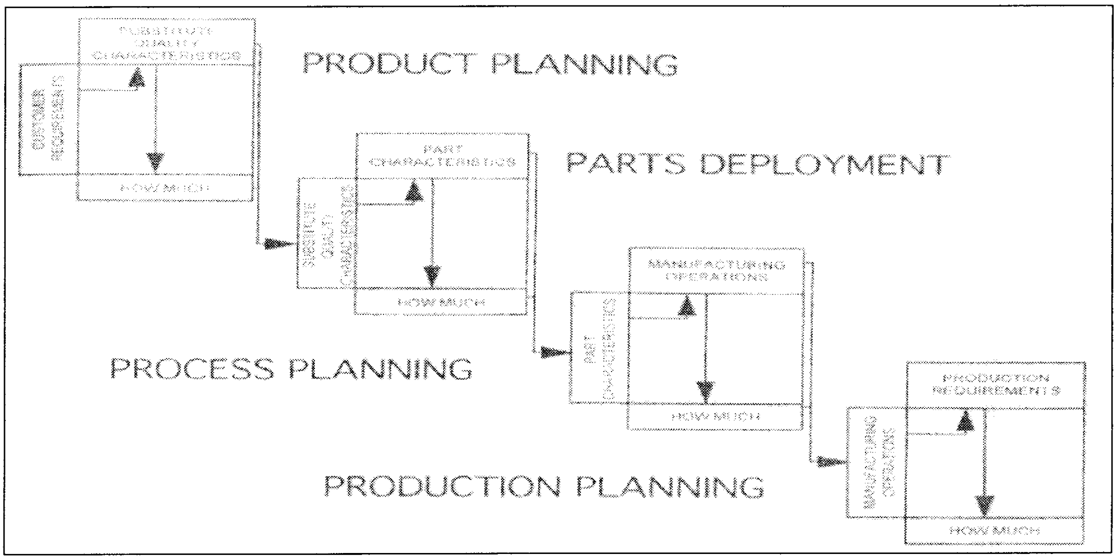


Figure 6.3: Quality Function Deployment Matrix Series (Groover, 2003)

6.2.5 Quality Function Deployment Applications

The QFD has primarily been applied for planning and managing product development activities. However, further enhancements and refinements to the basic conceptual framework have also taken place. There are special applications where the initial concept has been extended into areas of total quality management, strategic product planning, organisation planning, cost deployment, software, and service (Cohen, 1995). Day (1990) demonstrates how the QFD concept is applied in non-product related applications. Moreover, Revelle et al. (1998, pp. 7) state that "Although many firms use QFD matrices for designing products or services, some firms have used it to create their strategic plan."

The following highlights some of the reported QFD applications to address different realms and conditions:

Total Quality Management (TQM)

As TQM is considered a strong element in achieving customer satisfaction, it depends on the existence of methods such as policy deployment and reengineering to link between customer needs and the organisation's functions. However, companies are recognising that the QFD is a cost-effective approach to link or align the organisation's activities to best meet the needs of the customer.

In addition, the manner in which companies are applying QFD facilitates the formulation of customer needs at a very high level and their deployment into corporate objectives (Cohen, 1995).

Organisation planning

In the area of organisation planning the QFD is used to facilitate the selection of an organisation schema (Johnson, 1998). The management criteria represent customers' input and the reorganisation proposals represent concept options. This approach aids management in concept evaluation and realising the targets advantages and disadvantages.

In addition, the QFD is applied to match the organisation's work to its objectives. The customer requirements are matched against the organisation's primary functions, which are determined by means of a brainstorming process and an infinity diagram, to determine relationships and understand how each of their processes affects their customers' needs (Cohen, 1995).

Cost deployment

In the area of accounting the QFD approach is used to allocate known development costs to the customer needs. It aids management in determining whether they are paying too much to support unimportant needs.

The costs represent the 'Hows', and the customer needs represent the 'Whats'. In addition, fractional values are estimated to state the degree to which the cost contributes to the customer satisfaction performance targets. The sum is compared to the priorities of the 'Whats', thereby indicating how serious any misalignment of costs to priorities is, and determining the need to redesign (Cohen, 1995).

Service

The QFD is applied to help in the redesign of higher education services. It is deployed as a mean to achieve improvements in the educational domain by transferring the customer's needs into the service attributes and the associated process characteristics. According to Franceschini (2001), one of the applications was used to facilitate the design of a training course. The process was divided into three phases: design contents, design of providing process, and design of quality control process. It was applied to help a training agency to ensure that customer requirements were embedded in the course design.

Strategic investments

Naik and Chakravarty (1992) presented a framework that deploys QFD to link manufacturing technology acquisition with strategy. The selection process was based on strategic, operational, and financial evaluation. In addition, the manner in which the QFD process was adopted ensured the feasibility of the investment within the organisation constraints and its consistency with the competitive strategy of the firm.

Furthermore, Nimmons (1996) developed a method that deploys QFD to improve the design of cellular manufacturing systems. The QFD matrices concept is used to relate the features of cellular manufacturing to strategic performance improvement objectives.

The above examples illustrate that when applied in its broadest sense the technique can support business operations improvements in general, in addition to its original intended use for product design and production enhancement. Therefore, the QFD technique has been proven as a versatile method that can be employed to address a wide range of business and organisational situations that require decision making in a multitude of criteria or requirements.

6.2.6 Quality Function Deployment Benefits

There are several potential tangible and intangible benefits that can result from the application of QFD. Revelle et al. (1998) highlight a summary of these benefits. However, the appropriateness of the QFD as a method for this research is confirmed by the following benefits:

- Lower time and cost in the design and development of the product. The planning activity takes place at an earlier stage, leading to major reduction in most late engineering changes (Cohen, 1995; Zairi, 1993).
- Produces sound information to make good decisions. The up-front determination of product process requirements and the ability to have traceability back to the customer needs ensures consistency and early identification of high-risk areas (Revelle et al., 1998).
- The involvement of a cross-functional team, necessary to complete the tables and matrices, ensures more efficient allocation of resources and collaboration of departmental subdivisions (Franceschini, 2001; Zairi, 1993).
- Facilitates multidiscipline teamwork. The ability to generate and maintain involvement within the team over the entire product development cycle advocates synergy and favours the elimination of personal prejudice (Franceschini, 2001).
- Establishes and maintains documentation. The ability to have a recorded interpretation of customer needs and product design decisions allows future reference and decisions improvement (Revelle et al., 1998; Zairi, 1993).
- Encourages transfer of knowledge and application to other projects by the team members (Revelle et al., 1998).
- Highlights and integrates all the significant factors, based on measurable tangible and intangible customer needs, into a winning product design (Revelle et al., 1998).
- Conceives new applications that do not fit the model of product development. According to Cohen (1995, pp. 21), "as with any versatile tool, the applications of QFD are limited only by one's imagination."

6.3 Failure Mode Effects Analysis (FMEA)

This section presents the relevant FMEA academic literature. It addresses the FMEA concept, framework, and deployment process; in order to provide the basis of the structure and implementation process used to support the manufacturing systems designers specify and assess the associated risk with the chosen manufacturing automation option. In addition, it describes the FMEA applications and strengths to determine the technique's capability in conducting a decision risk assessment.

6.3.1 Failure Mode Effects Analysis Concept

The Failure Mode Effects Analysis (FMEA) and the Failure Mode Effects Criticality Analysis (FMECA) are systematic methods of identifying and preventing product problems before they occur. The FMECA is an extension of FMEA and they are very similar in the manner of addressing general qualitative considerations. However, FMECA differs from FMEA as it takes into account the criticality of each mode of failure.

According to the British Standard 5760/5 (1991) "FMEA is a method of reliability analysis intended to identify failures, which have consequences affecting the function of a system within the limits of a given application, thus enabling priorities for action to be set." The technique was initially developed within the aerospace industry in the 1960s for safety reasons, explicitly to prevent accidents from occurring. Thereafter, the technique was adopted by the automotive industry for use as a quality improvement tool (McDemott et al., 1996).

In the safety arena it is used to evaluate the impact of system and equipment failures on mission success and the safety of personnel or equipment. However, in the automotive industry the tool is being deployed at the earliest stages of product and process development to aid engineers in the reduction or elimination of the need for corrective action after product production.

The focal part of an FMEA study is to generate a Risk Priority Number (RPN) for each failure mode; the higher the risk number, the more serious the failure could be, and the more important it is that it is addressed by the design team, thus allowing it to be used as a checklist to identify particular causes or fault modes where a failure would have the most severe effects. This results in considerable financial savings as the product is still in the initial design stage (Revelle et al., 1998).

6.3.2 Failure Mode Effects Analysis Framework

The FMEA process is generally conducted by a team of specialists to bring a variety of perspectives and experiences to the project. It is a process that requires a cross-functional team from various departments. The team size is usually four to six people, but the minimum number of people will be dictated by the number of areas that are affected by the FMEA. Management plays an important part in defining the boundaries of freedom, while the team leader defines the scope (McDemott et al., 1996).

The overall structure of the FMEA resides in the following three steps: identification of failure mode (severity), assessment of probability of failure occurring for each mode (occurrence), and pinpointing the operating or other processes that can produce the failure mode (detection). It commences with the team determining the potential failure modes, through to gathering data for occurrence, detection, and severity ranking, up to the stage of presenting the FMEA report for product modification and the development of the control process, as shown in Figure 6.4 (Teng and Ho,1996).

The application of FMEA is best suited at the initial design and development stages. It is applicable either on hardware or functional application. In the hardware application the actual hardware failure modes are being analysed. However, in the functional application, the functional features are the ones being analysed for failures (McDemott et al., 1996).

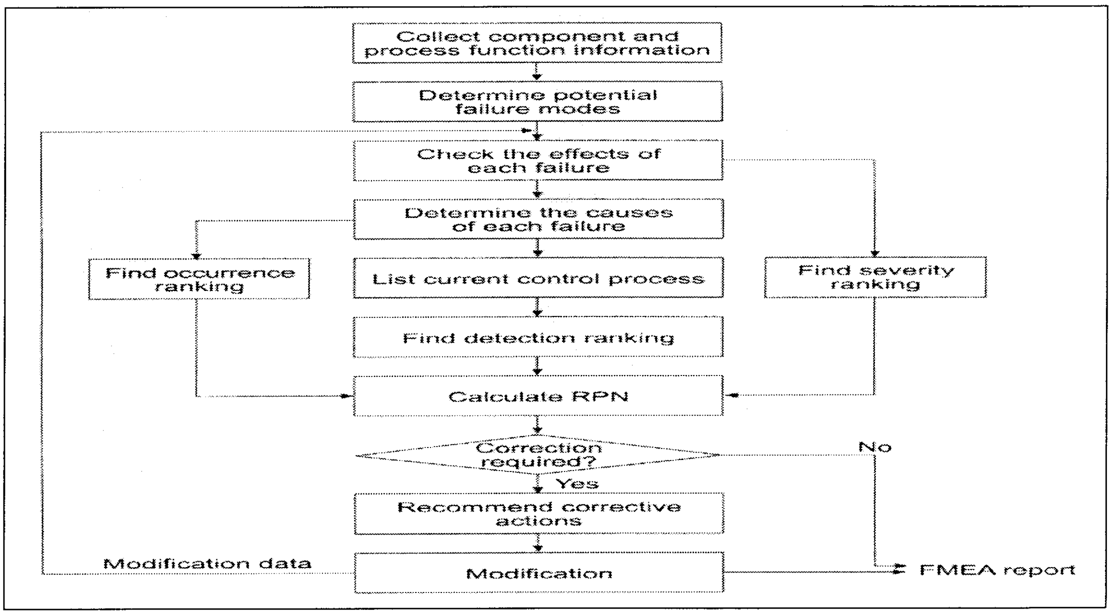
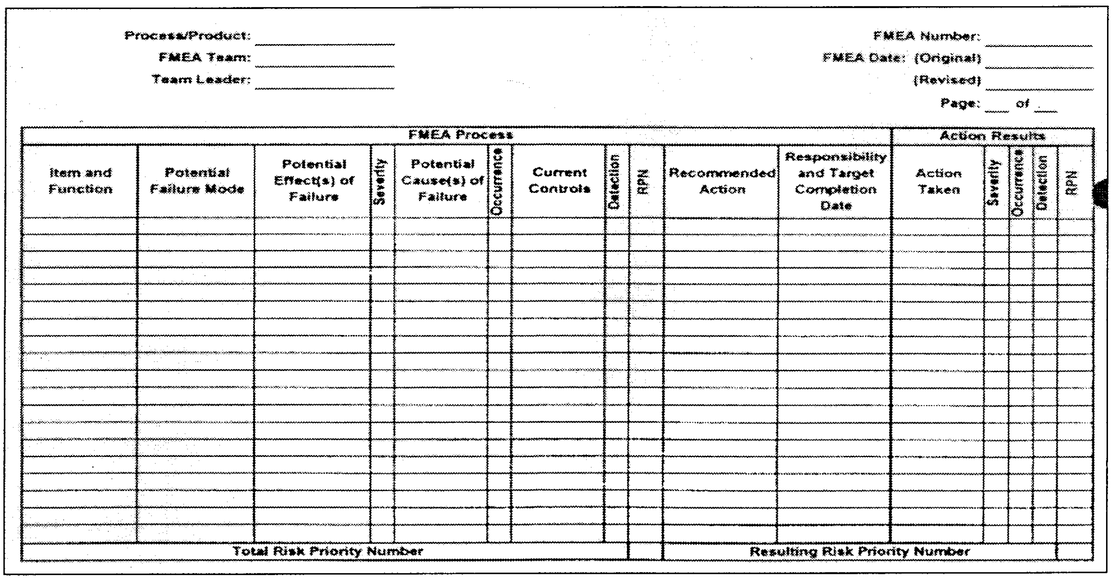


Figure 6.4: The FMEA Procedure (Teng and Ho,1996)

6.3.3 Failure Mode Effects Analysis Implementation Process

FMEA is often referred to as a "bottom up" approach as it functions by the identification of a particular cause or failure mode within a system in a fashion that traces forward the logical sequence of this condition through the system to the final effects. The documentation of this approach is administered through a hierarchical tabular worksheet, as shown below in Figure 6.5.



Process/Product: ______
FMEA Team: ______
Team Leader: ______

FMEA Number: ______
FMEA Date: (Original) ______
(Revised) ______
Page: ___ of ___

FMEA Process											Action Results				
Item and Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Occurrence	Current Controls	Detection	RPN	Recommended Action	Responsibility and Target Completion Date	Action Taken	Severity	Occurrence	Detection	RPN
Total Risk Priority Number									Resulting Risk Priority Number						

Figure 6.5: Failure Mode and Effects Analysis Worksheet (McDemott et al., 1996)

The following is a description of the FMEA implementation process, which also explains the contents of the worksheet (McDemott et al., 1996):

Step 1- Review the process

The initial step after appointing the team members and leader is the review of the product or system being worked on. The objective of this review is to ensure that the team members have an opportunity to clarify their understanding of the FMEA scope and working boundaries.

Step 2-Brainstorm potential failure modes

To facilitate the identification of failure modes a brainstorming session is organised. The aim of this session is to generate all the potential failures that could affect the product. Once this is achieved the activity of failure categorisation into groups takes place. This will aid the data transformation into the FMEA sheet.

Step 3-List potential effects of each failure mode

In this step the team examines each failure mode and envisages the potential effects of the failure should it occur. It is important to sustain a thorough examination of the potential effects as this step is crucial for risk rating assessment, thus, an If – Then process is recommend to complement this step.

Step 4- Assigning severity ratings

The severity rating is an estimation of how serious the effects would be should a failure occur. The rating is commonly based on a 10-point scale, with 1 being the lowest rating and 10 being the highest. A clear and concise description for the points is necessary to maintain congruent rating understanding. In addition, a combination of expert knowledge and experience is used to estimate the values.

Step 5- Assigning occurrence ratings

This step involves determining the rate of occurrence for each failure mode. It applies the same rating scale as in the severity scale, and requires a clear description for each point. The process of establishing occurrence estimates will depend on how likely a failure mode is to occur, and at what frequency. This is commonly derived through actual failure data and knowing the potential cause of failure.

Step 6- Assigning detection ratings

A detection rate is nominated for each failure mode and represents how likely a failure is, or how its effect will be detected. The detection depends of the sort of existing controls deployed. The rating is commonly based on a 10 point scale to estimates the likelihood of detection. In the case of no current controls, the likelihood of detection will be low, thus, the item receives a high rating.

Step 7- Calculating the Risk Priority Number (RPN)

The RPN is calculated for each failure mode by multiplying the severity rating by the occurrence rating, multiplied by the detection rating. The purpose of calculating the risk priority number is to determine how important it is the associated risk, and to enable a comparison between the revised RPN and the original RPN once the recommended actions have been instituted.

Step 8- Prioritising the failure modes for action

In this step the failure modes are ranked in order of importance, from the highest RPN to the lowest RPN. This aids the team in determining the items to attend to first. In addition, the application of a Pareto diagram and a cut-off RPN limit are recommended to facilitate this activity. Setting a cut-off RPN limit would mean that any failure modes with an RPN above that point are of interest to the team, and those below that are left alone for the time being.

Step 9- Taking action to eliminate or reduce the high-risk failure modes

The purpose of this step is to identify and implement actions to eliminate or reduce the high-risk failure modes. Problem solving techniques are excellent tools to apply for such activities.

Step 10- Calculating the resulting RPN as the failure modes are reduced

This is the final step in FMEA implementation and represents the calculation of the new RPNs to enable the team to compare and contrast the results with the original RPNs. The new RPN calculations will involve setting new ratings for severity, occurrence, and detection for where actions were taken. Consequently, a totally new RPN will be derived, and depending on the team's satisfaction with the result, will determine whether additional work should be done to further reduce them.

6.3.4 Failure Mode Effects Analysis Applications

Even though the FMEA has primarily been applied for product or process risk assessment, it has been used outside its original setting. The following is a review of some of the FMEA applications in different settings:

Project management

In the area of project management the FMEA is used to facilitate project risk management. It starts by considering possible risk items (failure modes), and then proceeds to predict all their possible effects. In addition, this approach does not give each risk a priority ranking number or quantify the effects, as it is considered a qualitative process to enable project managers to concentrate on examining the characteristics of each risk (Lock, 2003).

Service

The National Center for Patient Safety applies the FMEA technique for Veterans Affairs Patients Safety risk assessment. A Healthcare Failure Modes and Effects Analysis have been designed for identifying risks to patient safety and reducing medical/health care errors. It is a restructure of the basic FMEA steps and alteration of the risk priority number (DeRosier et al., 2002).

Business administration

In the area of accounting the FMEA is applied to aid management in ensuring that the annual budget is realistic, and accounts for potential emergency expenses. However, in the area of marketing it is applied to minimise the miscommunication of vital information during the corporate brochure design (McDemott et al., 1996).

Moreover, McDemott et al. (1996) present some of the support processes where FMEA has been applied or is potentially applicable with some modification. These include information systems/technology, human resource, and purchasing. Interestingly enough is their suggestion in purchasing applications, as it coincides with the intentions of this research. They point out that "Prior to purchasing a major piece of equipment, an FMEA can be conducted to anticipate problems with different purchase options. This information can be used to improve purchasing decisions as well as to develop installation plans once the equipment is purchased (McDemott et al., 1996, pp. 57)."

The above examples demonstrate the possibility of deploying the FMEA technique to support business operations assessments. The indication of such deployment reassures the selection of this technique for conducting a decision risk assessment process.

6.3.5 Failure Mode Effects Analysis Benefits

The FMEA is a plain risk assessment tool which is used to avoid expensive modifications at later stages. The benefits reported in FMEA literature are more or less along the lines of how important the FMEA is in identifying potential failures and preventing them. The following are some of the reported benefits that amplified the likelihood of selecting this technique as a support technique to the QFD:

- The FMEA is a forward-looking approach as it helps in identifying improvements early in the development process, when relatively easy and inexpensive changes can be made (Johnson, 1998).
- It is a great technique for assessing which risks will or must be taken, and determining ways to mitigate their consequences (Johnson, 1998).
- It is a technique that can be used by non-technical as well as technical employees of all levels (McDemott et al., 1996).

- FMEA process standardises the approach and establishes a common language that can be used within companies (McDemott et al., 1996).
- Dale and Best (1988) perceive that FMEA and QFD are complementary as the first is targeted at satisfying customer expectation and the second at preventing failure to satisfy.
- Johnson (1998) points out that when used before implementation, FMEA could provide the initial risk analysis needed to make good decisions or meet the requirements of sound project planning.

6.4 Chapter Summary

In this chapter an explicit description of both the QFD and FMEA concept and methodology has been presented. The aim was to provide a comprehensive description of the framework involved in each technique to outline the foundation upon which the structure and implementation process of the decision tool is designed. In addition, the indication of the reported various applications and benefits endorsed the possibility of utilising both techniques for the purpose of this investigation and in the proposed manner.

CHAPTER 7

INFLUENTIAL ELEMENTS IN MANUFACTURING SYSTEMS SELECTION

7.1 Introduction

Identifying the techniques that represent the research solution mechanism is not sufficient to build a decision tool for incorporating human factors in manufacturing systems design. What is essential, besides the selection process, is to determine the elements against which the manufacturing automation options will be evaluated. This chapter describes the influential elements that are addressed in manufacturing technology and justification. The purpose of this review is to draw attention to the vital evaluation issues pertaining to technology, organisation, and human factors in order to facilitate identification of the decision tool's evaluation elements and sub-elements.

7.2 Influential Elements within the Decision-Making Process

The gap identified in Chapter 2 highlighted the importance of addressing human factors, and particularly micro-ergonomics and macro-ergonomics, at the earliest stages of manufacturing systems design. Accordingly, the proposed decision tool should address these issues to ensure appropriate human factors incorporation in manufacturing systems design. However, the design of a decision tool that specifically addresses macro-ergonomics and micro-ergonomics may not be convincing to the manufacturing systems designers, as the manufacturing systems justification and selection process includes several other factors. Consequently, by developing a decision tool that facilitates macro- and micro-ergonomics evaluation, in addition to the influential elements in manufacturing systems selection, this gap could be addressed, and its application within industry promoted.

The process of identifying influential elements initially involved compiling a list of the elements that could be related to technology, organisation, and human factors in manufacturing systems selection and design. The list was compiled by reviewing the elements highlighted in the advanced manufacturing technology literature, the human factors literature, and the industrial survey results.

7.2.1 Review of Influential Elements within the Decision-Making Process

As the aim of this research is to produce a decision tool that incorporates human factors in addition to the conventional manufacturing systems evaluation issues. The secondary literature search conducted to identify the influential elements within the decision-making process was performed in two stages.

The first stage involved a literature search to identify the influential elements from the human factors literature in manufacturing. It was constrained using date and field specifications. The date was restricted to 1970 to 2005, and the field was restricted to the following areas: human factors and manufacturing systems design, ergonomics and manufacturing systems design, human-centred design principles, human-machine interface design, and socio-technical systems design.

The second stage involved a literature search to identify additional influential elements from the manufacturing systems justification and evaluation literature. The date was restricted to 1970 to 2005, and the field was restricted to the following areas: manufacturing technology evaluation, advanced manufacturing technology justification and implementation, and flexible manufacturing systems evaluation and justification.

The academic literature search was based on journals, books, and conference papers. The following resources were used to undertake the literature search:

1 Cranfield University library catalogue,
2 ProQuest/ABI,
3 EBSCO Business Source Premier,
4 Compendex,
5 INSPEC,
6 Engineering Village 2 database,
7 IEEE Xplore, and
8 Recent Advancement in Manufacturing (RAM).

As the outcome from this process resulted in the review of a substantial number of references, it was necessary to deploy an affinity diagram technique to facilitate the identification and arrangement of the elements (Kendall and Kendall, 1992; Jones, 1995). Figure 7.1 presents the outcome of the literature review. The technology and organisation factors were found to play a major role in the advanced manufacturing automation selection and implementation process. The human factors represent the micro- and macro-ergonomics issues. The issues were labelled as technology and organisation integration and technology and people integration, to embody the socio-technical system issues in addressing technology, organisation, and people issues.

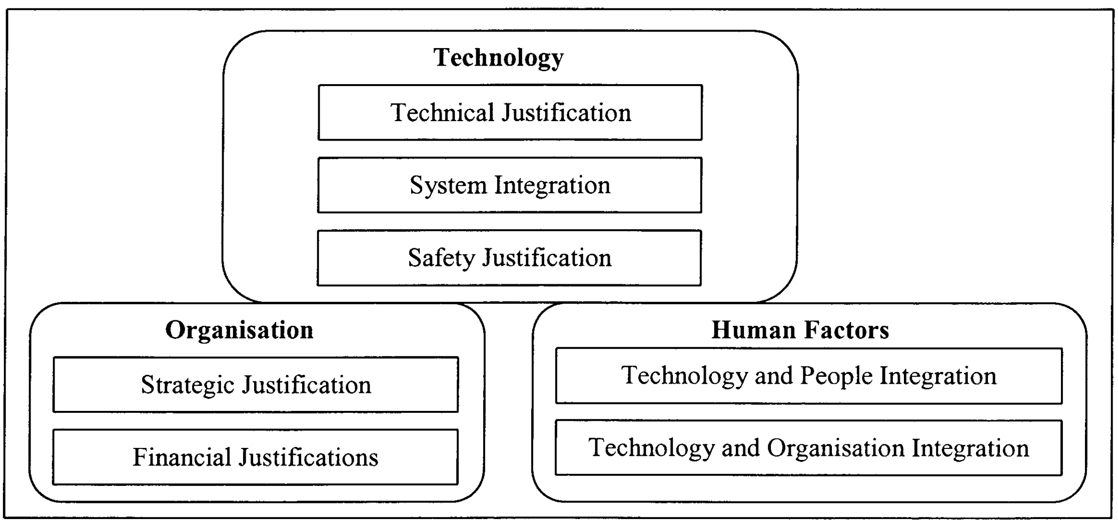


Figure 7.1: Influential Elements in Manufacturing Systems Selection

7.3 The Decision Tool Evaluation Elements

Once the influential elements were determined, they were treated as the main evaluation elements. Furthermore, the data gathered from the secondary literature review to identify the main evaluation elements was deployed to extract the sub-elements and their measures. Both the evaluation elements and sub-elements had to be assessed against predetermined criteria to enable selection justification. The selection process was carried out by establishing a screening process extracted from the work of Baines et al. (2005), who have developed a complex approach using four criteria and a scoring scale for identifying the principle factors used in their framework for human performance modelling. For this examination a rather less complex screening process was developed using three criteria in order to meet the intentions of this literature review within a realistic time frame. The elements were chosen from the literature by subjectively evaluating them against the following three criteria:

1 General relevance: evidence that both the elements and sub-elements are related to the manufacturing systems selection or design process.

2 Specific relevance: evidence that both the elements and sub-elements specifically relates to either the evaluation or the implementation process.

3 Credibility: a minimum of three sources must denote that each element is an essential factor to consider in manufacturing systems evaluation or successful implementation process. However, for the sub-element a minimum of three sources must indicate that it is an essential factor in addressing each criterion.

Table 7.1 presents the outcome from the screening process. The process of managing and organising the elements and sub-elements was administered by deploying the tree diagram technique (Jones, 1995).

Evaluation Elements	**Sub-Elements**
Technical justification	Productivity
	Flexibility
	Quality
	Support and test equipment
	Maintainability
	Technology supplier
	Longevity
Systems Integration	Hardware systems
	Software systems
Safety Justification	Machinery
	Work environment
Strategic Justification	Short-term strategic manufacturing objectives
	Long-term strategic manufacturing objectives
Financial justification	Economic justification
	Investment cost
	Unit cost
	Installation cost
	Operation cost
Technology and People Integration	Workstation design
	Physical workload
	Mental workload
	User/machine interaction
Technology and Organisation Integration	Organisational work procedure
	Organisation structure
	Work group
	Personnel polices
	Job design

Table 7.1: Manufacturing Systems Evaluation Elements and Sub-Elements

The following is a description of the identified evaluation elements and sub-elements, in addition to the means of measuring them. The measures are provided as examples and a guide of the types of measurement that would be appropriate to support the manufacturing systems designers during the evaluation process.

7.3.1 Technical Justification

According to Slagmulder and Bruggeman (1992) the aspects of strategic and financial issues are essential for automated technology evaluation; however, there are technical elements that influence the acquisition of automated manufacturing systems that are necessary to address, such as productivity, quality, flexibility, and tooling specifications. Therefore, technical elements were incorporated into the evaluation elements to enable the manufacturing systems designers address the impact of technical implications on their decision.

In addition, to sustain an organised and concise approach to address the technical issues, the technical elements were divided into two categories; primary and ancillary sub-elements, to enable adequate consideration of the technical issues. Table 7.2 lists three references that indicate the importance of the technical sub-elements.

Prime technical sub-elements	**Reference**
Productivity	Martin (2002), Sambasivarao et al. (1995), Randhawa and West. (1992)
Flexibility	Kara et al. (2002), Saleh et al. (2001), Abdel-Malek et al.(2000)
Quality	Martin (2002), Saleh et al. (2001), Sandlberg (1992)
Ancillary technical sub-elements	**Reference**
Support and test equipment	Groover (2001), Zimmerman (2001), Greenwood (1988)
Maintainability	Zimmerman (2001), Shafer (1999), Dean Johns (1995)
Technology supplier	Groover (2001), Zimmerman (2001), Saleh et al. (2001)
Longevity	Martin (2002), Zimmerman (2001), Dahlen and Bolmsjo (1996)

Table 7.2: References of the Technical Sub-Elements

7.3.1.1 Prime technical sub-elements

The main technical elements that were reported in the literature as technical evaluation criteria or which could influence the decision-making process have been associated with productivity, flexibility, and quality specifications. Therefore, to enable the manufacturing systems designers to address these primary issues, primer technical sub-elements were incorporated to address this evaluation element. The primer technical sub-elements are:

Productivity

Productivity plays an important part in the technical justification of manufacturing technology. According to Randhawa and West (1992), increased productivity was one of the issues that led many industries to either automate their existing operations or replace existing operations with automated technologies. In addition, productivity was considered as an influential driver for acquiring automation by 12 of the respondednts interviewed in the survey.

Many measures of productivity are possible, and according to Hill (1995) the two types of productivity measurement that are commonly used are labour and total-factor (or multi-factor) productivity. However, productivity here will not only represent a measure of output per labour hour or machine hour, but will also stand for the most common productivity measures that have been reported in the literature of technology evaluation and selection. Therefore, to ensure that the automation investment option satisfies the productivity technical issues, the compatibility of the automation option will be measured based on the extent to which the following elements results match the manufacturing systems designers operation requirements:

- Capacity

Capacity is the maximum output of a system in a given period under ideal conditions (Heizer and Render, 1995). Therefore, the compatibility of automation option will be determined by the extent to which it satisfies the manufacturing systems designers maximum output rate requirements.

- Throughput

Throughput is a measure that is sometimes known as throughput rate. It is defined as the average output of a production process (machine, workstation, line, plant) per unit time (e.g., parts per hour) (Hopp and Spearman, 2000). Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers throughput rate requirements.

- Cycle time

Cycle time is a measure that is sometimes known as flow time and throughput time. It is defined as the average time between completion of two discrete units of production (Lee and Schniederjans, 1994). Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers cycle time requirements.

- Output rate

Output rate is a measure that is sometimes known as productivity. It is defined as the number of products produced in a single operation or run. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers output requirements.

- Set-up time

Set-up time is a measure that is sometimes known as changeover time. It is defined as the time required to change a machine from making one product to making another (Krajewski and Ritzman, 2001). Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers set-up time requirements.

- Effectiveness

Effectiveness rate represents the degree to which an operation unit is able to accomplish its objective (Krajewski and Ritzman, 2001). Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers effectiveness rate requirements.

- Efficiency

Efficiency stands for different interpretations in the manufacturing industry and represents the capacity of performing a given task within the specified standard time (Hitomi, 1996). According to Zimmerman (2001), it is the machine uptime divided by the total of uptime and downtime. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers efficiency rate requirements.

Flexibility

Today flexibility plays an important role in manufacturing, as it enables organisations to simultaneously produce multiple and diverse products, upgrade and redesign their products in short life cycles (Abdel-Malek et al., 2000). In addition, organisations that consider flexibility to give them a competitive edge design their manufacturing strategies to seek the benefits of flexibility. Slagmulder and Bruggeman (1992) presented a case that involves an organisation which invested in design flexibility without knowing whether this type of flexibility could really create a competitive advantage, which resulted in machines losing capacity and causing a bottleneck. Furthermore, according to Kara et al. (2002), despite the number of flexibility definitions and classifications in the literature, flexibility remains poorly understood and poorly utilised in practice.

Crowe (1992) defines flexibility as the ability to make substantial changes in schedules and volumes for existing products and to handle frequent product revisions and introductions. The relevant literature related to flexibility in manufacturing can be classified in two categories: flexibility types and flexibility measurement. The flexibility types represent different elements and attributes of a production facility, and various flexibility types are discussed in the literature. The most important flexibility types are: machine flexibility, routing flexibility, process flexibility, product flexibility, and volume flexibility. However, flexibility measurement represents the gauge upon which each flexibility type is to be measured (Abdel-Malek et al., 2000).

Consequently, to ensure that the automation investment option satisfies the flexibility technical issues, and to keep the evaluation process within reasonable applications, the aforementioned flexibility types will be used to measure the extent to which the automation option satisfies the manufacturing systems designers flexibility requirements.

- Machine flexibility

Machine flexibility represents the number and variety of operations a machine can execute without incurring high transition penalties or large changes in performance outcomes (Crowe, 1992). Therefore, the compatibility of the automation option will be determined by the number of various types of operations that it can perform.

- Routing flexibility

Routing flexibility represents the ability to produce parts through alternative workstation sequences in response to equipment breakdowns (Crowe, 1992). Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired routing flexibility of the manufacturing system.

- Process flexibility

Process flexibility represents the set of product types that the system can produce without major setups. It is also referred to as mix flexibility (Crowe, 1992). Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired process flexibility of the manufacturing system.

- Product flexibility

Product flexibility represents the ability to change over to produce new products quickly and economically (Crowe, 1992). Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired product flexibility of the manufacturing system.

- Volume flexibility

Volume flexibility represents the ability to produce parts economically in high and low total quantities (Crowe, 1992). Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired volume flexibility of the manufacturing system.

Quality

Quality now plays a critical role in corporate strategy (Groover, 2001). According to Oakland (1995, p.19), "the reputation enjoyed by an organisation is built by quality, reliability, delivery and price. Quality is the most important of these competitive weapons." Moreover, in an effort to improve quality companies are turning to automated manufacturing processes (Sandlberg, 1992).

The term quality has different interpretations and definitions from the producer's or user's point of view. For example, Crosby (1979) defines quality as "conformance to requirements", where as Juran (1999) defines it as "fitness for use."

Consequently, to bring quality into context and enable the manufacturing systems designers to address this sub-element, the compatibility of the automation option will be determined based on the extent to which the following elements match the manufacturing systems designer's quality requirements (Groover, 2001):

-Conformance to specification (Process Capability Index - C_{pk}).

-Software reliability.

-Technology reliability.

-Inspection system (offline/online).

-Scrap.

7.3.1.2 Ancillary technical sub-elements

In addition to the main aspects of the technical element that are essential for technology evaluation, there are ancillary issues in automated manufacturing systems that could influence the acquisition of a particular technology, such as tooling requirements, maintenance complexity, and vendor support. Therefore, to enable the manufacturing systems designers address these secondary issues, ancillary technical sub-elements were incorporated into the technical evaluation. The ancillary technical sub-elements are:

Support and test equipment

Support and test equipment of manufacturing technology represents an important issue to consider in automated machining centres, interfacing with robotic, welding stations, and other applications. According to Greenwood (1988), tool carousels and automatic tool changes play an important part in nearly all flexible manufacturing systems. The need for special tooling, fixtures, automatic test equipment, etc. can affect the selection of different automated manufacturing technology. Therefore, to ensure that the automation investment option has acceptable support and to test equipment specifications, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the automation option support and test equipment requirements.

Maintainability

Maintainability refers to the ease with which maintenance work can be done (BSI Handbook, 1992). The justification of equipment maintainability is considered to be of importance in the evaluation of automated manufacturing technology as it involves repairs and service issues (Zimmerman, 2001). Equipment of whatever type, complexity, and cost is liable to break down, and maximum productivity is dependent upon quick restart after a failure. In addition, the importance of adequate machinery access allows easier house keeping and serviceability (Shafer, 1999). Therefore, the degree of complexity in repair and access can improve or hinder downtime and serviceability. A common index that is used to measure maintainability is known as Mean Time To Repair (MTTR) (Jones, 1995; BSI, 1992). It represents the average time required to perform maintenance over a specified operating period (Jones, 1995). Consequently, to ensure that the automation investment option has acceptable maintainability specifications, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the automation option mean time to repair (MTTR).

Technology supplier

Vendor support is considered to be an important element in the success and ease of technology design and implementation. The research in decision attributes involving advanced manufacturing technologies has confirmed the criticality of vendor support in evaluating capital decisions for advanced manufacturing (Saleh et al., 2001). Therefore, to enable the manufacturing systems designers to address supplier capability and support to determine the feasibility of the technology supplier, the supplier has been added as a sub-element in the evolution element.

The investigation undertaken by Saleh et al. (2001) into factors affecting capital investment has revealed that the sub-elements that are considered important by the manufacturing systems designer's in capital investment are: timeliness for vendor, responsiveness of vendor, proven reliability, and extensiveness and timing of training.

Consequently, to enable the manufacturing systems designers to address the technology supplier and to keep the evaluation process within reasonable applications, the following sub-evaluation elements will be used for evaluating the automation options in this decision tool:

- Technology and technical capability

Technology and technical capability refers to the availability of expert knowledge by the vendor's staff on its technology and achievements (Zimmerman, 2001). The compatibility of the automation option will be determined by how satisfied the manufacturing systems designers are with the vendor's staff's technical professionalism and credibility references.

- Vendor support

Vendor support refers to technical support that is received before and after purchasing a machine or piece of equipment. It includes both vendor services and after-sales service. Vendor services represent issues such as training, assembly, repair, replacement, etc. After-sales service, on the other hand, stands for under-warranty and/or out of warranty services (Saleh et al., 2001). Therefore, the compatibility of the automation option will be determined by how satisfied the manufacturing systems designers are with the pre- and after-sales services offered.

- Delivery lead time

Delivery lead time is used to indicate to the date on which the equipment will be received from the supplier or to the date on which the equipment begins to run production. It is normally expressed in weeks after receipt of the order (Zimmerman, 2001). Therefore, the compatibility of the automation option will be determined by how satisfied the manufacturing systems designers are with the delivery lead time.

- Longevity

Lifespan represents the machinery's life cycle and it is an issue that affects long-term manufacturing utilisation and unit cost evaluation (Zimmerman, 2001; Dahlen and Bolmsjo, 1996). Therefore, to ensure that the automation investment option has an acceptable lifespan, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the automation option life cycle.

7.3.2 Systems Integration

The application of automated manufacturing systems will necessitate the adaptation and integration of its hardware and software systems with the existing technologies and information systems (Vonderembse et al., 1997). Frohlich and Dixon. (1999) conducted an investigation into the types of advanced manufacturing technology adaptations and concluded that information systems adaptation is critical for successful implementation. Moreover, compatibility was found to be one of the important attributes in capital decisions involving advanced manufacturing technologies (Saleh et al., 2001). It corresponded to the ability of an advanced manufacturing system to ensure that the new technology will be compatible with the existing (or future) software, hardware, and people in the manufacturing system. Therefore, addressing hardware and software systems integration at the acquisition stage will enable the manufacturing systems designers to understand the impact and suitability of the manufacturing automation option, which in turn will lead to better selection and adaptation.

However, as manufacturing technology consists of hardware and software systems, the sub-elements will therefore represent the two sections to enable adequate consideration of both hardware and software integration. Table 7.3 lists three references that indicate the importance of the system integration sub-elements.

Systems integration sub-elements	Reference
Hardware systems	Saleh et al. (2001), O'Brien (2000), Vonderembse et al. (1997)
Software systems	Saleh et al. (2001), O'Brien (2000), Frohlich and Dixon (1999)

Table 7.3: References of the System Integration Sub-Elements

7.3.2.1 Systems integration technical sub-elements

Hardware systems

Integration of the physical and electronic parts of a computer and the machinery itself is required to make a manufacturing systems work. Hardware integration is responsible for ensuring that the hardware component, manufacturing cells, transfer lines, material handling systems, etc. are compatible and effectively linked. Therefore, to ensure the integration feasibility of the automation investment option with the existing manufacturing hardware systems, the compatibility of the automation option will be measured by the degree to which the new technology is (Saleh et al., 2001; O'Brien, 2000):

-Able to operate with existing hardware components.

-Able to operate with existing machine tools and inspection equipment.

-Able to be configured and upgraded.

Software systems

Maximum integration requires not only the hardware to be properly integrated, but also the computer programs. Software integration is responsible for ensuring that activities such as programming, communication, controlling, networking, etc. function quickly, smoothly and economically. Consequently, to ensure the integration feasibility of the automation investment option with the existing manufacturing software systems, the compatibility of the automation option will be measured by the degree to which the new technology is (Saleh et al., 2001; O'Brien, 2000):

-Able to operate on existing software platform.

-Able to operate in collaboration with existing software.

-Able to be configured and updated.

7.3.3 Safety Justification

The results from the industrial study revealed that safety was considered to be an important driver for automation and it was one of the most important factors in their decision-making process (Section 4.6.5). In addition, organisations follow the regulations set out by the British Standards and the Occupational Health and Safety Act in the design of manufacturing systems. There are specific requirements of health and safety laws which manufacturers need to comply with when they are buying new machinery. One deals with what manufacturers and suppliers of new machinery have to do (e.g. Supply of Machinery Regulations 1992). The other deals with what the users of machinery and other equipment have to do (e.g. Provision and Use of Work Equipment Regulations 1992) (Health and Safety Executive, 2004).

The application of automation can improve certain safety issues; however, it can also cause hazards and injuries (Gabriel, 2003; Yokamizo et al., 1985). Furthermore, Vannas and Mattila (1996) demonstrated in a study on the development of flexible manufacturing systems that if safety has not been taken into consideration in the system design, flexible manufacturing may cause unexpected occupational safety and health problems. Therefore, it is important to incorporate safety evaluation to determine the impact of different automation levels on the work environment and safety systems, which will enable better selection. However, it is difficult to encapsulate the health and safety regulations and guidelines in a single category. As a result, the sub-elements will be divided into two sections to sustain an organised and practical approach to address the safety issues. Table 7.4 lists three references that indicate the importance of the safety sub-elements.

Safety justification sub-elements	**Reference**
Machinery	Health & Safety Executive (2004), Noyes (2001), Vannas and Mattila (1996)
Work environment	Health & Safety Executive (2004), Gabriel (2003), Noyes (2001)

Table 7.4: References of the Safety Sub-Elements

7.3.3.1 Safety justification sub-elements

Machinery

Machinery addresses the machinery safety guidelines that are important to consider in the evaluation of manufacturing automation. Essentially the assessment is on satisfying the requirements that relate to the Buying New Machinery regulations and the European Machinery Directive. This covers safeguards, emergency controls, warning devices, safety distance, clearance, etc (Health & Safety Executive, 2004). Consequently, to ensure that the automation investment option complies with health and safety guidelines, the compatibility of the automation option will be measured by the extent to which the automation option complies with the machinery health and safety regulations.

Work environment

The work environment addresses the work environment safety guidelines that are important to consider in the evaluation of manufacturing automation. According to Noyes (2001), the list of standards relating to the workplace is endless and there are EU (European Union) standards relating to the supply of machinery and environmental aspects of workplace, which machinery must comply with. The environmental factors cover noise levels, vibration, lighting, radiation, temperature, humidity, air quality, pollution (Heath and safety, 2003). Therefore, to ensure that the automation investment option complies with health and safety guidelines, the compatibility of the automation option will be measured by the extent to which the automation option complies with work environment health and safety regulations.

7.3.4 Strategic Justification

Strategic evaluation is now considered to play an important role in technology investment as the traditional financial justification procedures that are based on financial measures, such as internal rate of return or payback period are said to constitute a barrier to the adoption of new manufacturing technologies (Badiru, 1990). They have been criticised for not being able to address the long-range multidimensional issues of the advanced manufacturing technologies, because they tend to focus on short-term measures of profitability (Badiru, 1990).

In addition, according to Slagmulder and Bruggeman (1992), "several authors argue that good investment appraisal considers all the relevant factors, in other words they are convinced that there is a need to integrate strategic with financial considerations." They conducted an investigation into the justification of strategic investments in flexible manufacturing technology, and one of their findings is that a good strategic analysis is a prerequisite for effective investment decision-making for flexible manufacturing technology. Furthermore, Noble (1989) argues that the strategic dimension is one of the issues that must be considered during the justification process. He describes how the strategic justification should determine the feasibility of computer integrated manufacturing in meeting corporate goals, strategic plans, market share, and functional improvements. Therefore, enabling the manufacturing systems designers to determine how compatible the reviewed automation options with their corporate strategy will enable them to assess the extent to which the selected automation option is consistent with the business directions and competitive environment.

Corporate strategy represents management tactics that attempt to optimise the match between the organisation's mission and the organisation's internal operations. It includes setting short- and long-term business objectives, setting courses of action, and allocating resources (Blanchard and Thacker, 2003).

According to Johnson and Scholes (2003), strategies will exist at a number of levels of an organisation, and the authors have distinguished three different levels of strategy:

1. Corporate strategy: relates to the overall scope of the organisation and is concerned with financial markets.
2. Competitive or business strategy: relates to a unit within the organisation and is concerned with how to compete in a market.
3. Operational strategy: is at the operating end of the organisation and is concerned with how the different functions of the enterprise - marketing, finance, manufacturing and so on - contribute to the other levels of strategy.

In addition, Blanchard and Thacker (2003) point out that four levels of strategy are present within the overall context of an organisation. These are:

1. Industrial level strategy: deals with issues that relate to an industrial sector or reflect the level and nature of government intervention.
2. Corporate level strategy: deals with issues that relate to the market sectors in which the company as a whole competes.
3. Business level strategy: deals with issues that relate to identifying the markets in which each of the company's businesses compete.

4. Functional level strategy: deals with issues that relate to investing in and developing the necessary capabilities to support the business market.

From the above it is clear that corporate strategy is developed in line with the mission of the company, and that the activity of investment is associated with the strategy of functional level. Therefore, to enable the manufacturing systems designers to link organisation mission and strategy with the automation investment decision, the sub-strategy elements are designed to represent the elements of manufacturing function strategy. Table 7.5 lists three references that indicate the importance of the strategic sub-elements.

Strategic justification sub-elements	**Reference**
Short-term strategic manufacturing objectives	Kakati (1997), Naik and Chakravarty (1992), Slagmulder and Bruggeman (1992)
Long-term strategic manufacturing objectives	Kakati (1997), Naik and Chakravarty (1992), Slagmulder and Bruggeman (1992)

Table 7.5: References of the Strategic Sub-Elements

7.3.4.1 Strategic justification sub-elements

Short-term strategic manufacturing objectives

Short-term objectives are milestones that are set to be achieved in approximately one year (Blanchard and Thacker, 2003). They could be anywhere from a three month goal to an eighteen month goal. The short-term instructional objectives are measurable intermediate steps between the present level of performance and the annual goals. Therefore, to ensure that the automation investment option is aligned with the short-term manufacturing strategy directions, the compatibility of the automation option will be measured by the degree to which it supports the short-term strategic manufacturing objectives.

Long-term strategic manufacturing objectives

Long-term objectives are specific enough to elicit action but broad enough to allow the goals to be achieved in five years (Blanchard and Thacker, 2003). They could be anywhere from a three year goal to a five year goal. Therefore, to ensure that the automation investment option is aligned with the long-term manufacturing strategy directions, the compatibility of the automation option will be measured by the degree to which it supports the long-term strategic manufacturing objectives.

7.3.5 Financial Justification

Economic justification has a strong influence on the approval of automation investment. 16 of the interviewed respondents reported that this was the dominant factor in the selection of automation level (Section 4.6.5). In addition, Moerman (1998) states that "The evaluation of complex investment alternatives asks for an in-depth analysis of the economic and strategic issues." There are three categories of financial justification: economic, analytical, and strategic (Kolli et al, 1994; Soni et al, 1992; Meredith and Suresh, 1986). Accordingly, the financial justification criterion in this tool represents the economic justification, which is the traditional financial evaluation method. It is based on comparing the potential return from a particular project with the return that could be gained from other investments, and it is more suited to the assessment of short-term profitability goals (Noble, 1989).

The cost justification approach represents a single objective deterministic method, which evaluates a single economic objective associated with the justification of investment (Soni et al., 1992). The most common cost justification methods available for assessing manufacturing investments for the confident evaluation of any project involving the purchase of long-life engineering plant are: payback period, return on investment, internal rate of return, and net present value.

Moreover, an important step in planning the economic justification is to develop initial cost estimates. According to Dorf (1983, p.153) "A critical factor to be recognized in purchasing automated manufacturing systems and robots is the fact that the total cost of installing and operating such an installation is many times the cost of the parts and equipment". The importance of addressing installation and operation costs was also highlighted by Primrose (1991), as well as the need to incorporate unit cost and investment cost in the financial justification process.

Consequently, to enable the manufacturing systems designers to arrive at a sound financial evaluation, the sub-financial elements are economic justification, investment cost, unit cost, instillation cost, and operation costs. Each automation option will be assessed against them to determine its degree of compatibility. Table 7.6 lists three references that indicate the importance of the financial sub-elements.

Financial justification sub-elements	**Reference**
Economic justification	Atrill and McLaney (1999), Soni et al, (1992), Noble (1989)
Investment cost	Saleh et al. (2001), Randhawa and West (1992), Primose (1991),
Unit cost	Hopp and Spearman (2000), Mital (1992), Primrose (1991)
Installation cost	Krar and Gill (2003), Martin (2002), Saleh et al. (2001)
Operation cost	Krar and Gill (2003), Martin (2002), Zimmerman (2001)

Table 7.6: References of the Financial Sub-Elements

7.3.5.2 Financial justification sub-elements

Economic justification

Economic justification approaches include discounted and non-discounted cash flow approaches to cost valuation and investment justification (Meredith and Suresh, 1986). The discounted cash flow is a discount of future cash flows in order to express their present values to properly determine the value of an investment under consideration as a whole. However, the non-discounted cash flow focuses on just recovering the initial investment cost with out consideration to time value of money. Both of these approaches are widely used to decide which investments to undertake and which investments not to make.

The most common methods of discounted and non-discounted cash flow are return on investment, internal rate of return, net present value, and payback period (Randhawa and West, 1992; Meredith and Suresh, 1986). Consequently, to ensure that the automation investment option is economically justified, and to keep the evaluation process within reasonable application the aforementioned important methods will be used to measure the extent to which the automation option satisfies the manufacturing systems designers financial requirements:

- Return on investment

This financial measure represents the rate of interest required to make future savings equal to the investment cost. It calculates the average annual profit in future years resulting from the investment and expresses it as a percentage of the capital investment (Primrose, 1991). Consequently, to ensure that the automation investment option has acceptable return on investment, the compatibility of the automation option will be measured by the extent to which the automation option exceeds the organisation's set rate.

- Internal rate of return

This financial measure represents a percentage figure that indicates the relative yield on the use of capital (Noble, 1989). It is the discount rate which makes the net present value of the cash-flows from an investment equal zero. Therefore, to ensure that the automation investment option has acceptable internal rate of return, the compatibility of automation option will be measured by the extent to which the automation option exceeds the organisation's set rate.

- Net present value

This financial measure represents the discounted cash flow to time zero. It converts the entire set of positive and negative cash flows projected to occur over the life service of the equipment to a single equivalent value discounted to the present time (Noble, 1989). Thus, to ensure that the automation investment option has acceptable net present value, the compatibility of automation option will be measured based on the level of positive return that the automation option provides.

- Payback period

This financial measure represents the minimum length of time required to recover the initial investment without taking into account the time value of money. It divides investment cost by net annual savings to determine the time required to recoup the investment (Noble, 1989). Thus, to ensure that the automation investment option has acceptable payback period, the compatibility of automation option will be measured by the extent to which it satisfies the organisation's target payback period.

Investment cost

Investment cost is the money paid to purchase the manufacturing automation option. Primrose (1991) points out that cost of capital is one of the factors that have to be considered in evaluating any project. Therefore, to ensure that the automation investment option has an acceptable investment cost, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the purchase cost.

Unit cost

Unit cost is the total cost of producing one unit of output. It is calculated by dividing the total cost of production by the total number of units of output produced (Hopp and Spearman, 2000). The result is the cost per unit of that output. Therefore, to ensure that the automation investment option has an acceptable unit cost, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the unit cost.

Installation cost

The installation cost represents the initial cost estimation that relates to the implementation of the investment (Dahlen and Bolmsjo, 1996). Costs that are considered under this sub-financial element will be those such as (Dahlen and Bolmsjo, 1996; Primrose, 1991):

-Implementation costs.

-Utilities costs.

-Software and hardware integration costs.

-Support and test equipment costs.

-Training costs.

Therefore, to ensure that the automation investment option has an acceptable installation cost, the compatibility of the automation option will be measured by the extent to which the automation option satisfies the organisation's budget for such expenditures.

Operation cost

The operation cost represents the operating cost estimation during the entire investment's life-cycle (Dahlen and Bolmsjo, 1996). Costs that are considered under this sub-financial element will be those such as (Dahlen and Bolmsjo, 1996; Mital, 1991):

-Labour costs.

-Depreciation costs.

-Maintenance, overhaul, and repair costs.

-Phase-out cost (disposition cost (-)/salvage value (+)).

Consequently, to ensure that the automation investment option has an acceptable operation cost, the compatibility of the automation option will be measured by the extent to which the automation option satisfies the organisation's budget for such expenditures.

7.3.6 Technology and People Integration

As mentioned in Section 2.3.1, authors place emphasis on the design of human-centred systems as opposed to technology-centred systems, known as "technocentric" (Hendrick, 2002; Uden, 1995; Kidd, 1994; Bohnhoff; 1992; Wobbe, 1992). They call for managers and designers to ensure appropriate consideration of both technical and human aspects in the design and evaluation of human-machine systems.

The domain of ergonomics is concerned with the design of human-machine interfaces, and plays an important role in ensuring that certain conditions are fulfilled before a workplace can be called human-centred (Medsker and Campion, 1997). In addition, Neumann et al. (2002) conclude that decisions relating to the technical sub-system can have unanticipated downstream consequences for ergonomics, raising the need to incorporate human factors into the decision-making process at the earliest phases of the design process. Therefore, addressing technology and people will support the manufacturing systems designers to align their automation decision with the design of a human-centred system and ensure appropriate consideration of the human sub-systems.

The technology and people elements will represent the human factors that relate to micro-ergonomics. Micro-ergonomics refers to the human-machine interface, human-environment interface, and user-system interface (Hendrick, 1995). Section 7.3.3 addressed the human-environment interface. However, to address the rest of the components that fall within this domain, the technology and people integration element was categorised into the following sub-elements: workstation design, physical workload, mental workload, and user/machine interaction. Table 7.7 lists three references that indicate the importance of the technology and people integration sub-elements.

Technology and people integration sub-Elements	Reference
Workstation design	Das (2001); Burns and Vicente (2000), Das and Grady (1983)
Physical workload	Noyes (2001), Coury et al. (2000), Sanders and McCormick (1993)
Mental workload	Gabriel (2003), Endsley and Kaber (1999), Parasuraman, (1997)
User/machine interaction	Oborski (2004), Gabriel (2003), Wilson (1991)

Table 7.7: References of the Technology and People Integration Sub-Elements

7.3.6.1 People and technology integration sub-elements

Workstation design

The workstation design deals with the three-dimensional work-space envelop within which an individual works and the dimensions of the people who are going to operate within those spaces. It takes into account the population size, gender, and age, in order to ensure the compatibility of the workplace with the worker (Sanders, 1992). According to Das and Grady (1983, p. 103), "Workplace dimensions should be compatible with anthropometric characteristics of the anticipated user." Consequently, to ensure that the workstation design of the automation investment option is in accordance with human factors guidelines (Sanders and McCormick, 1993; Clark and Corlett, 1984; Das and Grady, 1983), the compatibility of automation option will be measured by the extent to which the workstation specifications (e.g. work height, work posture, online line maintenance, set-up, and house-keeping) matches the user's physical characteristics (e.g. weight, height, age, gender, and reach).

Physical workload

Physical workload deals with the strength and endurance of the body and relates to the acceptable levels of physical characteristics of the job. It concerns the work activities that require physical effort and the manual handling of materials, supplies, and tools (Sanders and McCormick, 1993). The degree of automation has to be assessed against the user's physical workload capabilities as it can lead to favouring or restricting automation due to certain physical and repetitive movements that are causes of musculoskeletal disorders and physical stress and strain (Coury et al., 2000). Therefore, to ensure that the physical workload requirements of the automation investment option are in accordance with operator's physical abilities (Viikari-Juntura, 1997; Sanders and McCormick, 1993; Singleton, 1972), the compatibility of automation option will be measured by the extent to which the physical workload specifications (e.g. material handling, force, feed rate, and cycle time) matches the user's physical capabilities (e.g. strength, motion, and endurance).

Mental workload

Mental workload deals with the human cognitive ability and relates to information-processing and adaptive responses. It takes into account the psychological aspects of work, both in terms of how work affects the mind and how the mind affects the work (Hollnagel, 1997). Therefore, to ensure that the mental workload requirements of the automation investment option are in accordance with operator's mental abilities (Noyes, 2001; Hollnagel, 1997; Sanders and McCormick, 1993), the compatibility of automation option will be measured by the extent to which the mental workload requirements (e.g., training, decision making, attention, and situation awareness) match the user's mental capabilities (e.g. memory, learning, processing information, and perception).

User/machine interaction

User/machine interaction deals with interface design and relates to display and controls design (Noyes, 2001). It utilises physical and cognitive ergonomics to take into account human-machine interface and information exchange (Singleton, 1972). It addresses the following issues (Sanders and McCormick, 1993):

-encoding (degree of match between display and perceptual model of operator).

-psycho-physics (degree of match between display and user senses).

-dynamics (degree of match between control system and motor skills and timing of operator).

-functional anatomy (degree of match between control and physical ability).

The significance of addressing these issues may vary across manufacturing industries. It is more likely that they would be of importance during the evaluation of highly automated manufacturing systems that incorporate control rooms. Subsequently, to ensure that the user/machine interaction of the automation investment option is in accordance with human factors guidelines (Sanders, 1992; Oborne, 1982; Singleton, 1972), the compatibility of automation option will be measured by the extent to which the user/machine interaction specification (e.g. information input/output devices, and information processing requirements) match the user's physical and mental capabilities (e.g. force, speed, accuracy, and senses).

7.3.7 Technology and Organisation Integration

Organisational issues are affected by introducing automation into an organisation. Majchrzak and Klein (1987) examined the effects of introducing computerised office and factory automation into an organisation. The findings support the notion that there are certain organisational issues that are affected by introducing technology, and addressing them will provide a better understanding of the impact and challenges of introducing different automation levels. They point out that it is misleading to examine the direct effects of computerised technology on organisational outcomes such as profits and satisfaction, and the key to achieving success with computerised technology is matching changes in organisational processes to each other.

In addition, according to Pasmore (1988, p. 61), "technological choices at the organisational level may influence relationships among different units or departments, organisational structures, reward systems, organisational flexibility and overall performance." Further, Noyes (2001) emphasises the fact that the human factors/ergonomics approach is to consider the 'whole', and that it would be unwise to focus solely on the design of human-machine interactions without reference to the larger picture, i.e. organisational issues. Therefore, addressing technology and organisation integration will aid the manufacturing systems designers in assessing these issues and align their automation decision with socio-technical principles consideration.

The technology and organisation element will represent the human factors that relate to macro-ergonomics. As mentioned in Section 2.3.1, macro-ergonomics refers to the organisation-machine interface. It is the subsequent part of the traditional ergonomics profession, because it deals with the overall structure of the work system as it interfaces with the system's technology (Hendrick, 1995). In addition to tackling organisational issues, it also involves human resources issues. Accordingly, to address the components that fall within this domain the technology and organisation integration element was categorised into the following sub-elements: organisational work procedure, organisation structure, work group, personnel polices, and job design. Table 7.8 lists three references that indicate the importance of the technology and organisation integration sub-elements.

Technology and organisation integration sub-elements	Reference
Organisational work procedure	Das (2001), Kid (1990), Majchrzak and Klein (1987)
Organisation structure	Majchrzak and Meshkati (2001), Fallik (1988), Parsons (1985)
Work group	Hendrik and Kleiner (2001), Tschan and Cranach (1996), Wild (1975)
Personnel polices	Mital and Pennathur (2002), Endsley (1994), Majchrzak (1988)

Table 7.8: References of the Technology and Organisation Integration Sub-Elements

7.3.7.1 Technology and organisation integration sub-elements

Organisational work procedure

The pattern and nature of organisational work procedure will be affected by the degree of change in automation level applied to process and assembly work. The integration of new technologies and group-work may lead to new concepts of reorganisation and supervision reduction. Work organisation refers to how work can be optimally organised to ensure that the workforce performs well. It includes consideration of issues such as shift work, work breaks, work policies, reporting lines, and work standards and procedures (Noyes, 2001; Wild, 1975). Consequently, to ensure that the work procedure requirements of the automation investment option are applicable with the current organisational work procedure, the compatibility of the automation option will be measured by the degree of change required in organisational work procedures.

Organisation structure

In macro-ergonomics the concept of organisation structure refers to the division of labour and hierarchy of authority in an organisation (Hendrickk, 1986). It deals with the structural mechanisms the organisation adopts to organise and control employee behaviour and organisational functions. In addition, in an open systems orientation the influence of technology change on an organisation affects four components: the task, the individuals, the formal organisation, and the informal organisation (Majchrzak and Klein, 1987). The formal organisational structure and the informal organisational structure outlined in the open systems framework represent issues such as degree of centralisation, organisation orientation, organisation culture, inter-group relations, and future vision. The examination undertaken by Majchrzak and Klein (1987) elaborates on how all these areas were found to be affected by the introduction of new technology one way or another.

Therefore, to ensure that the impact of the automation investment option on the organisation structure is acceptable, the compatibility of the automation option will be measured by the degree of change required in (Hendrick, 2002; Majchrzak and Klein, 1987):

-degree of bureaucracy (hierarchy system or project oriented system).

-management role (discretion, authorisation, and supervision).

-degree of centralisation (constraint to exercise decision-making).

-organisation orientation (salary-based or skill-based).

-operation structure (process flow and assembly flow).

-organisation culture (values, statues, goals, and cultural barriers).

Work group

A work group is any number of workers sharing certain characteristics and relating one to another in such a way as to differentiate them. It constitutes formal and informal groups that constrain the degree of collective working and relationships. The formal groups represent groups that are created to achieve specific goals and to carry out specified tasks that are clearly related to the overall organisation mission. However, the informal group represents groups that are developed between members of the organisation that extend beyond functional objectives (Wild, 1975).

The group working environment and gain share could be influenced by the division of labour and responsibilities imposed by different levels of automation. Das (2001) points out that outputs within an open systems framework (group and inter-group behaviour) are affected by technical change. He states that "new technology may minimise the interaction among workers by reducing their numbers and increasing the distances between their workstations."

Therefore, to ensure that the impact of the automation investment option on the work group structure is acceptable, the compatibility of automation option will be measured by the degree of change required in (Tschan and Cranach 1996; Wild, 1975):

-group structure (group size, responsibilities, autonomy, and supervision).

-group incentive compensation (profit sharing and team reward).

-group communication (information need and information share).

Personnel policies

Most organisational activities are based on human resources management, and the function of organising and controlling the human infrastructure plays a major role in personnel management. It mainly involves recruitment and selection, policy and procedure development, classification and compensation analysis, employee training and development, labour relations, and safety (Legge, 1997).

The impact of change in automation level on personnel policies and job design will cause a knock-on effect on job satisfaction and participation levels (Zikiye and Rebecca, 1992). In addition, the threat and fear of change will cause, to some extent, resistance among the workforce (Wild, 1975). Furthermore, according to Majchrzak (1988, p. 6), "ignoring human resource issues until the technology arrives or until human resource problems present themselves creates problems off the shopfloor as well as on."

The personnel polices will influence the selection of automation level, while others will be affected by the selected automation level. The personal policies that may influence automation level selection are: wages, layoffs and compensation, employee turnover, availability, skills, and attitude. However, the issues that might be affected by the selected automation level are: career development opportunities, selection and training, job qualifications, pay systems, job satisfaction, and social behaviour (Wild, 1975).

Therefore, to ensure that the impact of the automation investment option on the personnel policies is acceptable, the compatibility of the automation option will be measured by the degree of change required in (Endsley, 1994; Wild, 1975):

-appraisal policies for both individuals and teams (reward and control system).

-development system (career path).

-job security.

-training requirements.

Job design

The impact of introducing new technology may necessitate modifications to the job meaning, task variety, discretion, accountability, and knowledge (electric, electronic, and technical) (Zikiye and Rebecca, 1992). According to Wild (1975) mechanisation adversely affects jobs by increasing the division of labour, rendering certain skills obsolete, and removing control of the work-pace. Furthermore, in the modification of the work system it is important to address Hackman and Oldham's five job characteristics; task variety, identity, significance, autonomy, and feedback (Hendrick et al., 2002).

Therefore, to ensure that the impact of the automation investment option on the job design is acceptable, the compatibility of automation option will be measured by the degree of change required in (Hendrick et al., 2002):

-job structure (classification and standardisation).

-job rotation (shift/single/multiple).

-job autonomy (responsibilities and span of control).

-job perception (meaning and feedback on performance).

-job demand (skills, education, experience, and coordination).

7.4 Chapter Summary

This chapter has presented the manufacturing automation evaluation issues pertaining to technology, organisation, and human factors that were extracted from the literature review process. It is important to state that these elements and sub-elements are unlikely to be conclusive. However, as they represent the crucial evaluation ingredients within the literature, they will be deployed in forming the decision tool's evaluation elements and sub-elements.

CHAPTER 8

MANUFACTURING AUTOMATION DECISION TOOL

8.1 Introduction

This chapter describes the design and development of the research solution. It outlines the main components of the decision tool framework, and provides a detailed description of the implementation procedure. Chapter 6 and 7 resemble the source of input upon which the methodology is built and the evaluation elements are defined. The decision tool's structure and implementation steps are mostly derived from chapter 6, whereas the evaluation elements and sub-elements are derived from chapter 7.

8.2 Manufacturing Automation Decision Tool Formulation

This section describes the method of incorporating human factors into the earliest stages of manufacturing systems design. The approach is based on a concept that links QFD with FMEA to support the manufacturing systems designer in alternative selection and risk assessment process. The elements and sub-elements utilised in the selection and assessment process addresses the macro- and micro-ergonomics, thereby ensuring early awareness and consideration.

8.2.1 Manufacturing Automation Decision Tool Concept

The consideration of human factors in manufacturing automation investment is an activity that requires the evaluation of both tangible and intangible elements. The QFD method not only allows the consideration of both tangible and intangible elements, but also the identification of the importance of each of these elements in the decision. However, there are situations when taking a decision could result in accepting some trade-offs, and it becomes an obstacle for manufacturing systems designers to revisit and plan for them in the implementation stage. Therefore, an extra technique was appended to highlight any related trade-offs or areas of concern for implementation review.

Rather than the primitive traditional investment justification process, the proposed model uses the QFD technique as the prime method to link the automation investment objectives with technology, organisation, and people evaluation for the selection of the best alternative. Subsequently, the decision is fed into the FMEA technique to highlight the related potential problems associated with it. The combination of the QFD and FMEA techniques shown in Figure 8.1 represents an outline of the proposed concept.

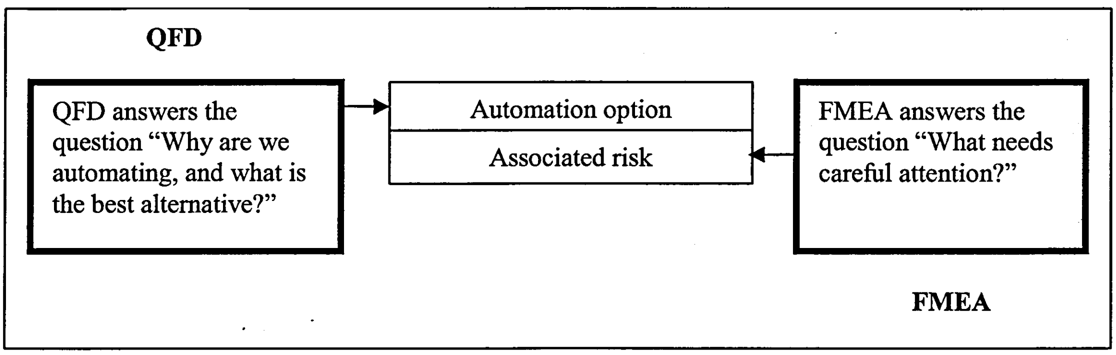


Figure 8.1: Manufacturing Automation Decision Tool Concept

Even though this concept involves constructing a joint QFD and FMEA approach, both techniques will be used to support manufacturing systems decision-making process. Thus, they need to be incorporated into a framework, developed specifically for this purpose. In this framework the QFD process involves constructing two interlinked matrices. The first matrix starts with the management and their needs and converts them into system evaluation elements. The second matrix follows through the evaluation elements (inputs) and magnifies them into sub-evaluation elements for selection of the best alternative (outputs). The best alternative data is then fed into the FMEA to conduct a risk assessment, as shown in Figure 8.2.

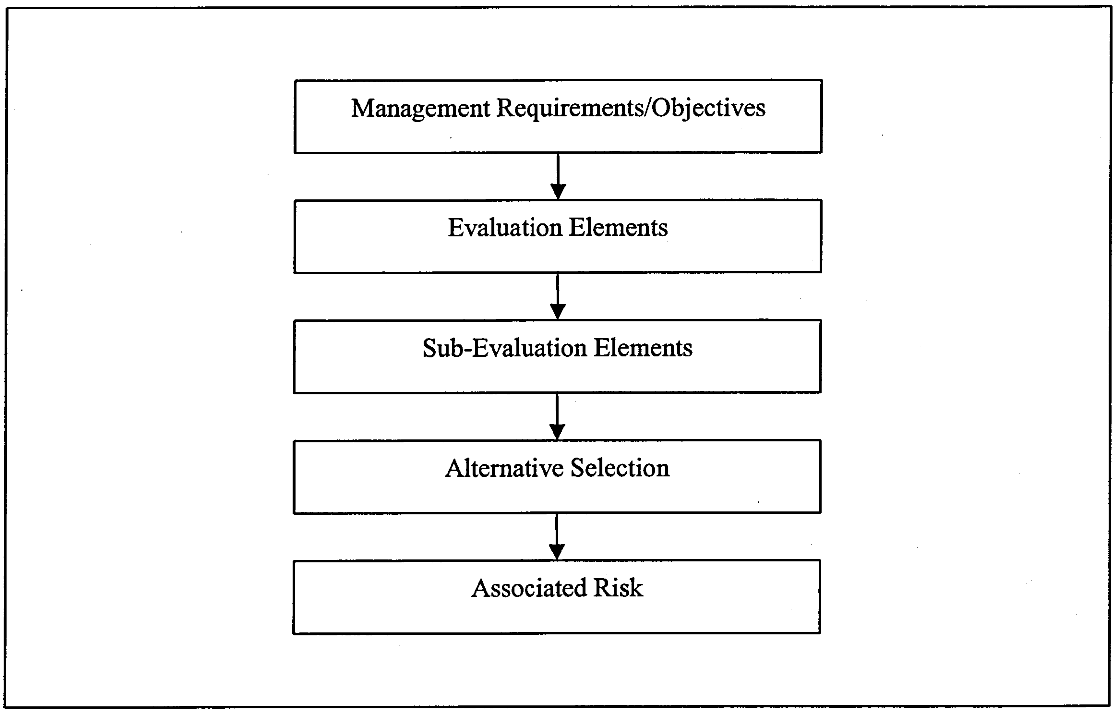


Figure 8.2: Manufacturing Automation Decision Tool Framework

This process enhances the decision outcome as the flow in which the sequence is constructed enables the manufacturing systems designer not only to link the selection process with the core automation investment objectives, but also to be prepared for future shortcomings. In addition, it is a formalised process that allows a traceable decision process for future reference and continuous improvement.

8.2.2 Manufacturing Automation Decision Tool Structure

The decision tool process is depicted in Figure 8.3. The sequential flow is hierarchically categorised into four stages. Each stage consists of the people involved, relevant tools, activities, and outcome.

Stage 1

The purpose of the first stage is to determine the importance of the evaluation elements. The project team gathers and prioritises the automation investment objectives from the stakeholders involved in the investment. Then, they feed the data into the QFD matrix to establish relationships between the objectives and the evaluation elements. The matrix computation will enable the team to realise how much influence each evaluation criterion will have on the decision-making process.

Stage 2

The aim of the second stage is to identify the best alternative. It involves the participation of both the project team and the operations manager. In this stage the results are transformed from the first QFD matrix to the second matrix to represent the sub-evaluation elements importance ranking. The second matrix computation will enable the team to evaluate the alternative options against the sub-evaluation elements to identify the most suitable option.

Stage 3

The purpose of the third stage is to identify the risks associated with the best alternative. In this stage the best alternative data from the second QFD matrix is transferred to the FMEA worksheet to indicate any potential problems. The negative scores within the best alternative data highlight the potentially troublesome areas for review and recommendations for action. The outcome from this stage is represented in a risk assessment diagram to provide a complete picture of the areas and degree of associated risk.

Stage 4

This is the final stage in the manufacturing automation decision tool process, and represents the decision assessment review. It involves the preparation of a feasibility study report to be viewed by the operations manager and board members. The report justifies the decision outcome, indicating the associated risks and future recommended action.

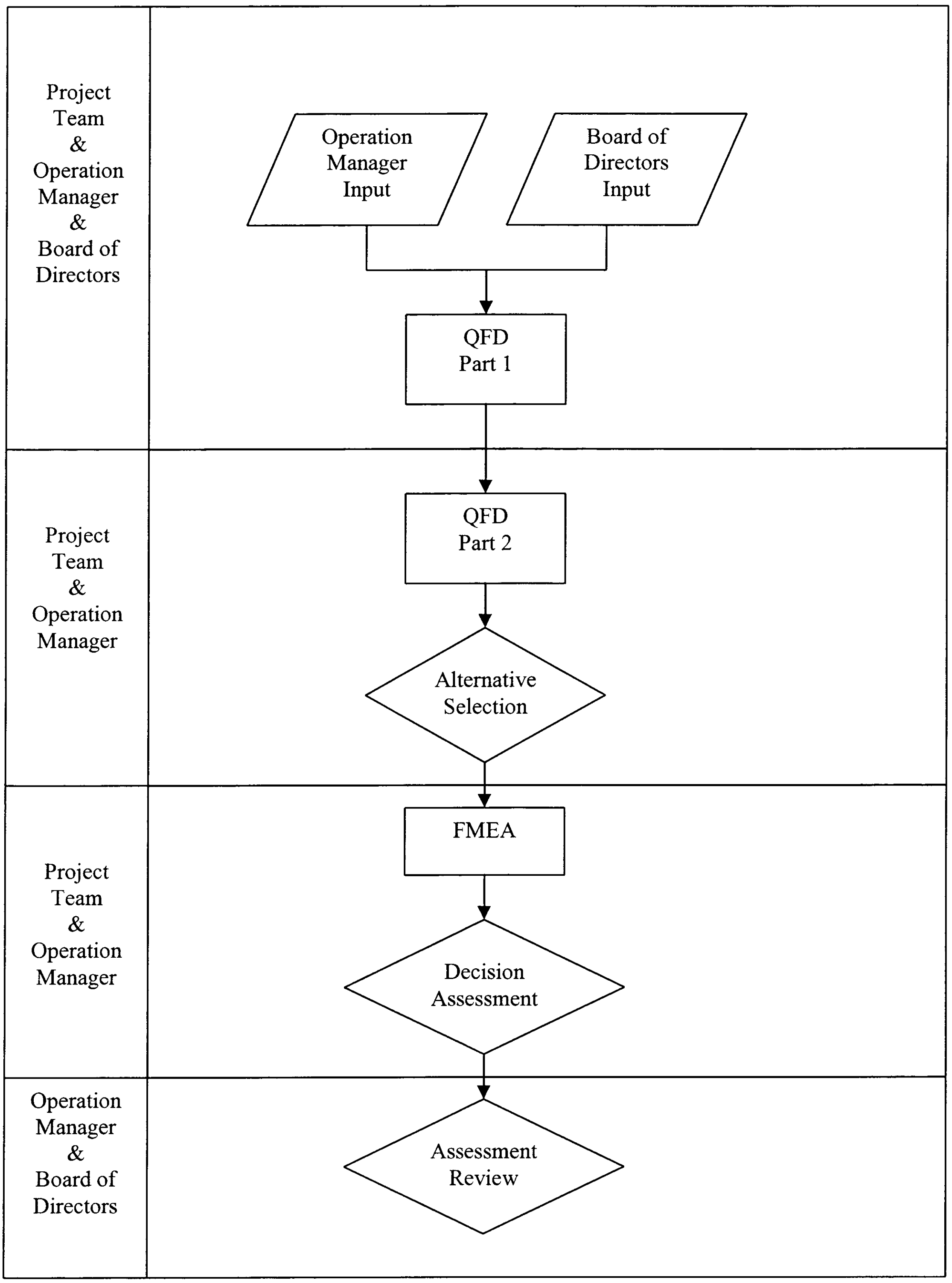


Figure 8.3: Manufacturing Automation Decision Tool Structure

8.2.3 QFD and FMEA Techniques Modifications

In order to deploy the QFD and FMEA techniques in the proposed structure, certain modification were necessary. The techniques are deployed in non-product application, specifically, in automated manufacturing systems selection and risk assessment process. Therefore, certain parts from the basic structure; described in Chapter 6; had to be either renamed or omitted. The omitted sections include:

QFD Technique Modifications

The 'Roof' of the House of Quality that consists of the correlations between the features themselves is not deployed in QFD phase one and two (step 6, section 6.2.3). The main benefit of the correlation study is to identify conflicting design requirements. Therefore, as the proposed application involves evaluation elements and the focus is on linking the investment objectives with the evaluation elements; it was realised that the inclusion of this part would be unrelated to the evaluation elements and outcome.

Furthermore, the same situation was encountered with the matrix planning and technical & target analysis parts (step 5, section 6.2.3). The matrix planning is conducted to enable the user to incorporate additional information that aids him to decide what aspects of the planned product will be emphasised during the development project. It relates to market competitive analysis and customer feedback analysis. Consequently, such investigations are not feasible to be applied for investment decision-making.

Whereas, the technical & target analysis parts are used to support the user in developing technical benchmarks and goal setting. It relates to competitive performance and own performance analysis to enable target setting. Therefore, such examinations are not applicable and had to be left out.

FMEA Technique Modifications

Two major steps were removed from the basic FMEA application to enable technique adoption in non-product context. Assigning detection ratings and calculating the resulting RPN as the failure modes are reduced (step 6 and step 10, section 6.3.3).

The deployment adopted in this framework involves intangible risk assessment process. Consequently, a detection rate, which is nominated for chance of design control detecting failure, is difficult to perform in non-product risk assessment situation. In addition, the process of calculating new risk priority numbers, which are based on taken corrective actions, is found to be additional work that does not support the main purpose of this risk assessment deployment.

Furthermore, two additional sections were added to the standard FMEA procedure; namely Risk Priority Number for the evaluation elements; to enable diagram representation of the associated risk in each evaluated area; and decision assessment diagram.

The mentioned modifications were conducted after a literature review; in both QFD and FMEA non-product applications; demonstrated feasibility of carrying out these alterations. In addition, some of the examples in Section 6.2.5 and 6.3.4 undertook similar alterations, in order to permit deployment in their new settings.

8.3 The Manufacturing Automation Decision-Making Tool Implementation Process

This section outlines the manufacturing automation decision tool implementation process that has been formulated to guide the manufacturing systems designer implement the developed research solution. Details of the steps, activities, and techniques involved are described in the workbook format in Appendix B.1. The following represent a summary of the decision tool implementation process:

Step 1- Determining the automation investment drivers

The starting point is to identify and define the automation investment objectives. This involves the analysis of the core purpose of the investment. It requires the review of strategic, technical, organisational, people, and financial gains/requirements.

Step 2- QFD phase 1 deployment

The first part of the QFD application takes place here. This step involves constructing the House of Quality matrix; Figure 8.4 presents a proforma of this worksheet. The focus of this application is to link the investment objectives with the main evaluation elements, in order to determine how much influence each evaluation criterion will have on the decision-making process.

Step 3- Categorising and prioritising the automation investment objectives list

This step involves completing the rooms in the House of Quality known as 'automation investment drivers' and 'ranking of importance'. The automation investment objectives are categorised into the following sections: strategic requirements, tactical requirements, and operational requirements, and prioritised according to a rating scale of 1 to 5.

Step 4- Determining the relationship between investment objectives and evaluation elements

This step involves completing the central part of the house matrix. The investment objectives are assessed against the established main evaluation elements (section 7.3). A score is inserted in the appropriate matrix location according to the scale of relationship; one for a weak relationship, three for a moderate relationship, and nine for a strong relationship.

Step 5- Determining the evaluation elements importance

This step involves the computation of the relationship scores on each evaluation criterion to determine importance. The calculation process is conducted by multiplying the scores of relationship with the weights of objectives.

Objectives/Requirements		Automation Investment Drivers	Strategic Justification	Financial Justification	Systems Integration	Technology & Organisation Integration	Technical Justification	Technology & People Integration	Safety Justification	Ranking of Importance
	Strategic									
	Tactical									
	Operational									
		Total								
		Normalised								

Project Details		
	Project Title:	
	Project Official:	
	Remarks:	
	Options:	

Figure 8.4: QFD Worksheet - Part 1

This procedure is repeated for all the objectives. Thereafter, the summation of each evaluation criterion takes place to establish the total score. Finally, the total score of each criterion is normalised.

Step 6- QFD phase 2 deployment

The second part of the QFD application takes place here. This step involves constructing the second QFD matrix; Figure 8.5 shows a proforma of this worksheet. In addition, the evaluation elements importance values are transferred from step five and are located in the table called "rank of importance". The focus of this application is to decompose the main evaluation elements, in order to facilitate the evaluation of the alternative automation investments.

Step 7- Evaluating the alternative automation options

This step involves completing the central part of the matrix. The alternative automation investments are assessed against the established sub-evaluation elements (section 7.3). It refers to completing the central part of the matrix. A score is inserted in the appropriate matrix location according to the scale of acceptance; 9 for strongly acceptable, 3 for moderately acceptable, and 1 for slightly acceptable. However, as there is a possibility of disapproval, a negative scoring is utilised; -1 for slightly unacceptable, -3 for moderately unacceptable, and -9 for strongly unacceptable.

Step 8- Determining the best alternative

This step is similar to step five. It involves the computation of the assessment scores on each alternative to determine best alternative. The calculation process is conducted by multiplying the scores of assessment with the weights of evaluation elements. This procedure is repeated for all the sub-evaluation elements. Thereafter, the summation of each alternative takes place to establish the total score. The alternative with the highest total score represents the best automation option.

			Manufacturing Automation Options					
	Elements	Sub-Elements	OPT 1	OPT 2	OPT 3	OPT 4	OPT 5	Ranking of Importance
Evaluation Elements	Strategic	Support short- term strategic manufacturing objectives						
		Support long- term strategic manufacturing objectives						
	Financial	Acceptable economic justification results						
		Acceptable investment cost						
		Acceptable unit cost						
		Acceptable instillation cost						
		Acceptable operation cost						
	Systems Integration	Feasible to integrate with existing manufacturing hardware systems						
		Feasible to integrate with existing manufacturing software systems						
	Technology & Organisation Integration	Compatible with organisation work procedure						
		Compatible with organisation structure						
		Compatible with work group						
		Compatible with personnel polices						
		Compatible with current job design						
	Technical	Acceptable productivity specifications						
		Acceptable flexibility specifications						
		Acceptable quality specifications						
		Acceptable support and test equipment						
		Acceptable maintainability specifications						
		Acceptable technology supplier						
		Acceptable longevity						
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics						
		Machine physical workload specification compatible with user's physical characteristics						
		Machine mental workload specification compatible with user's mental capabilities						
		User/machine interface specification compatible with user's physical and mental capabilities						
	Safety	Comply with machinery safety regulations						
		Comply with work environment safety regulations						
		Total						

Figure 8.5: QFD Worksheet - Part 2

Step 9- FMEA deployment

In this step the FMEA application is deployed. It involves constructing an FMEA table; Figure 8.6 shows a proforma of this worksheet. In addition, the selected alternative data are transferred from step seven and are located in the table called 'selected option. The focus of this application is to identify the risk associated with the selected alternative.

Step 10- Determining the potential problem modes and their effects

Unlike conventional FMEA applications, this technique is deployed to specify the potential problems with selecting this alternative. Therefore, the QFD evaluation analysis is utilised to facilitate this process. The data with negative values indicate where the problem modes and their effects should be identified.

Step 11- Assigning severity and likelihood ratings

This step involves determining the severity and likelihood rating. The severity rating is an estimation of how serious the effects would be, should a problem arise, whereas the likelihood rating is an estimation of how likely a problem mode is to occur. Both ratings are based on a 5-point scale, with 1 being the lowest rating and 5 being the highest.

Step 12- Determining the recommended action

This step involves recommending future actions to eliminate or reduce these problems. In addition, the recommendation will also be accompanied by a description of the body responsible for implementation.

Step 13- Calculating the Risk Priority Number (RPN)

The potential problem Risk Priority Number within the sub-element is calculated first, by multiplying the severity rating by the likelihood rating, as in a standard FMEA procedure. Then it is tallied and divided by the number of sub-elements reviewed, to preserve equal representation and obtain the element Risk Priority Number. Thereafter, they are normalised, to facilitate determining the significance of the areas that need reviewing during project planning and implementation.

	Elements	Sub-Elements	Potential Problem	Potential Effect(s) of Problem	Selected Option [ ]	Severity	Potential Cause(s) of Problem	Likelihood of Problem	Recommended Action & Responsibility	RPN (sub-element)	RNP (element)	Normalised RPN
Evaluation Elements	Strategic	Support short- term strategic manufacturing objectives										
		Support long- term strategic manufacturing objectives										
	Financial	Acceptable economic justification results										
		Acceptable investment cost										
		Acceptable unit cost										
		Acceptable instillation cost										
		Acceptable operation cost										
	Systems Integration	Feasible to integrate with existing manufacturing hardware systems										
		Feasible to integrate with existing manufacturing software systems										
	Technology & Organisation Integration	Compatible with organisation work procedure										
		Compatible with organisation structure										
		Compatible with work group										
		Compatible with personnel polices										
		Compatible with current job design										
	Technical	Acceptable productivity specifications										
		Acceptable flexibility specifications										
		Acceptable quality specifications										
		Acceptable support and test equipment										
		Acceptable maintainability specifications										
		Acceptable technology supplier										
		Acceptable longevity										
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics										
		Machine physical workload specification compatible with user's physical characteristics										
		Machine mental workload specification compatible with user's mental capabilities										
		User/machine interface specification compatible with user's physical and mental capabilities										
	Safety	Comply with machinery safety regulations										
		Comply with work environment safety regulations										

Figure 8.6: FMEA Worksheet

Step 14- Decision assessment diagram deployment

This step represents the outcome from the decision assessment process. It is an overview of the main evaluation areas and status. Figure 8.7 shows an example of this proforma. The FMEA normalised risk priority numbers are utilised to depict those areas which are potentially troublesome.

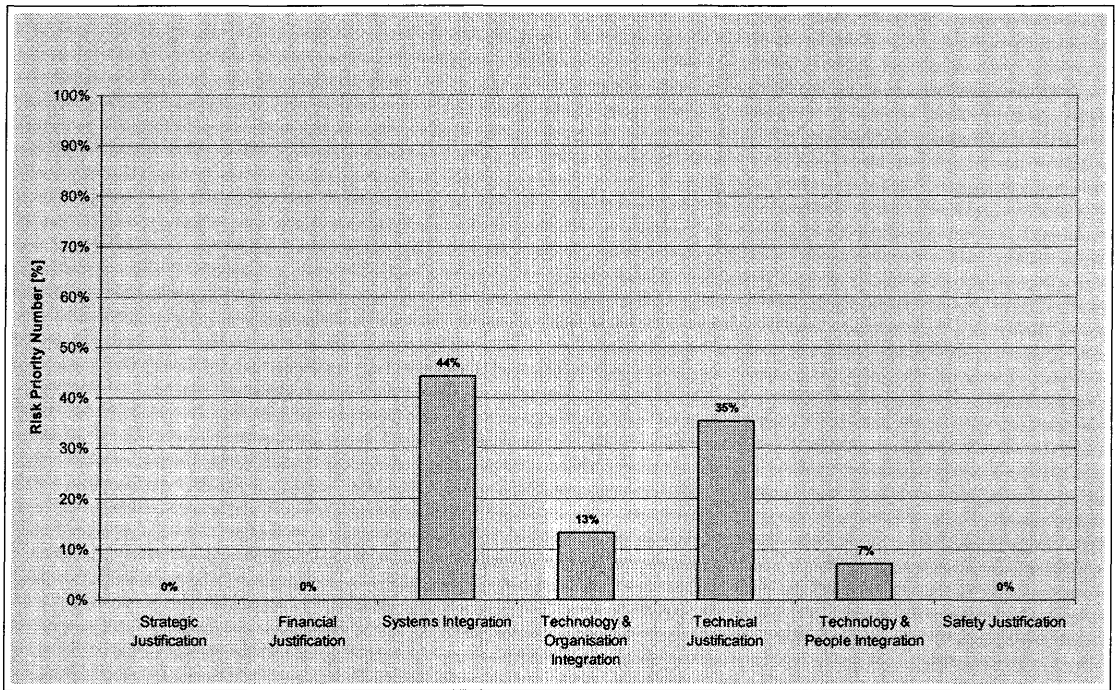


Figure 8.7: Decision Assessment Diagram

8.4 Manufacturing Automation Decision Tool Presentation Format

The proposed manufacturing automation decision tool needs to be presented in a format that is comprehensible and user-friendly. Therefore, the literature on suitable methods for QFD and FMEA generation was reviewed. The means of delivery available were either in paper-based form or computer technology (Cohen, 1995; Teng and Ho, 1996). Consequently, a decision needed to be made as to the format in which the tool would be produced.

In order to ensure the usability of the tool by the intended users, it was seen important to incorporate an industrial perspective as well. Accordingly, as the survey participants were promised a copy of the research outcome, a letter was sent to the survey participants updating them on the situation and asking for preference of decision tool application (see Appendix B.2). The letter puts forward the possibility of presenting the decision tool as either a workbook or a software package, and includes a list of advantages and disadvantages of both approaches to support analysis.

From the 19 participants the correspondence resulted in eight requesting the software package, five requesting the workbook format, and six did not reply. Consequently, based on the feedback it was decided to prepare the tool in the software format and accompany it with a mini workbook in order to satisfy both needs.

8.4.1 Software Application

Several QFD and FMEA commercial shells are available, such as Capture© for the QFD application, and Pathmaker© for the FMEA application. These software packages are designed to support the user in building and deploying these applications. The user-friendly and interactive function allows the user to save time and effort in implementation and computation. However, none of the available software could be deployed to develop the proposed decision tool, due to the complexity in customising and linking the QFD and FMEA together. Therefore, it was necessary to develop a software application for executing the proposed decision tool.

As the aim of this research is not to produce a commercial package but to investigate a technique for decision-making, the user interface was built by using the standard Excel programming component of Visual Basic for Applications (VBA). This decision was based on finding a programming application that would ensure user's ease of access and consume minimum time and effort in learning. In addition, the user interface was designed in accordance with the principles of software ergonomics and screen display guidelines mentioned by Shneiderman and Plaisant (2005), Mayhew (1992), and Shackel and Richardson (1991). The developed software application is annexed to this thesis.

8.4.2 Workbook

The participants who requested to have a workbook as a medium of application were interested in having a structured procedure that promotes understanding and learning by doing. Some of them reported that the reason for opting to use a workbook was that they would like to know clearly how the outcome will be derived, in addition to the benefit of ability to customise. According to this feedback, the design and creation of the decision tool workbook had to be produced in a similar style as the existing workbooks available to support organisations in implementing new methodologies.

A number of workbooks published by the Department of Trade and Industry (DTI., 1998; DTI., 1996; DTI., 1992) were used as source of information to guide the design of the decision tool workbook. The workbook produced described the decision tool's framework and methodology in greater details and disclosed the computation involved. The developed workbook is presented in Appendix B.1.

8.5 Chapter Summary

This chapter described the proposed manufacturing automation decision tool for this research study. It provided a clear picture of the mechanism involved. In addition it explained the manner in which the QFD and FMEA techniques were linked to support the manufacturing systems designers, not only in reaching a decision, but also in understanding what influenced their decision, and which issues need further consideration.

Furthermore, the decision tool implementation procedure was presented and means of delivery. The methodology was delivered in a software application and a workbook format.

CHAPTER 9

DECISION TOOL EVALUATION

9.1 Introduction

Field tests play an important role in eliciting the end user's views and opinions of the decision tool that has been developed. This chapter describes the industrial assessment and the case study performed to evaluate the feasibility, usability, and usefulness of the developed decision tool. In addition, it includes a preview of the evaluation process and an overall discussion of the results.

9.2 Evaluation Technique

This section further describes the evaluation study outlined in section 3.4.1. It defines the evaluation technique chosen to assess the developed manufacturing automation decision tool in industry.

An evaluation study is considered to be a process of applying scientific procedures to build up reliable and valid evidence on the manner and extent to which specified activities produce particular effects or outcomes (Rutman, 1977). In addition, Robson (2002) identifies that there are different purposes for conducting an evaluation, which are used to look at different questions and aspects. He indicates that there are two main categories that cover the types of evaluation models; the formative evaluation, which is intended to help in the development of the programme, and the summative evaluation, which concentrates on assessing the effects and effectiveness of the programme.

Patton (1987) describes how formative evaluations are particularly valuable in the early stages of a programme, and how they are aimed at improving the programme quality, whereas summative evaluations are conducted after a particular 'run' of a programme to make basic decisions about whether a programme is effective and whether it should be continued.

Accordingly, with the stage and intention of this evaluation it was appropriate to specify this study as a summative evaluation. In addition, what reinforces the selection was the way that Robson (2002) clearly states how the summative evaluation is likely to cover the total impact of the programme; not simply the extent to which stated goals are achieved, but all the consequences that can be detected. This point is crucial to the objective of this research as the evaluation focus is not only directed towards evaluating the developed solution, but also to identifying the aspects that need further attention to improve the solution and support the continuation of this research.

9.2.1 Evaluation Design

In an evaluation process it is important to pay attention to the design of the evaluation test, as well as the goals or problems which the test is intended to meet or solve (Rutman, 1977). According to Patton (1987), considering the evaluation design alternative leads directly to consideration of the relative strengths and weaknesses of qualitative and quantitative data. This described in Section 3.4. A decision was made to employ a qualitative evaluation, as qualitative data will facilitate the obtaining of direct quotations and careful descriptions of user interaction with the decision tool (Patton, 1987).

However, with regard to the goals of the evaluation, they relate to the validation of the developed decision tool and contribution of this thesis. The two typical approaches appropriate for this type of evaluation are industrial assessment and case studies (Patton, 1987; Robson, 2002; Yin, 2003). Accordingly, the evaluation programme was designed to allow the researcher to perform an industrial assessment process followed by a case study process.

The industrial assessment process includes conducting an evaluation by comparison and an evaluation by demonstration. The intention of the evaluation by comparison was to establish the unique similarities and differences between the existing and the newly developed approach. The method involves the researcher comparing the proposed solution against industrial practice. However, the intention of the evaluation by demonstration was to seek expert opinions and to identify any problems and difficulties with the developed decision tool prior to direct application in the case study. The method involves the researcher demonstrating the decision tool to experts in industry.

The case study process was an example of evaluation by application. The intention was to evaluate whether the proposed research solution is workable, gives a useful output, and is practical and relevant to the real world. The method involves the researcher applying the decision tool to a real case, alongside an expert from industry.

9.3 Evaluation by Comparison

The survey participants were willing to support the development of the decision tool. Accordingly, two participants were randomly selected from the survey list and contacted by phone to assist in the industrial practice assessment. This number was considered to be sufficient to facilitate a comparison of the developed approach with leading industry practice. These organisations provided information on their automation decision-making process, which included a breakdown of the issues that have to be reviewed to reach a decision. Nevertheless, due to a request for confidentiality from the aerospace systems manufacturer, only information from the automotive company will be disclosed in this thesis (the automotive company's decision-making process is included as Appendix C.1).

The evaluation was based on the approach and the contents of the decision-making process in each organisation. Regarding the comparison of their respective approaches, it was clearly apparent that none of the decision-making processes had a structured approach to link the automation objectives with the evaluation process, nor had they conducted a decision risk assessment at the initial stages of the evaluation. However, concerning the content comparison, the following is a summary of the comparative analysis:

Company 'A'

Company 'A' is an international company engaged in the development and support of advanced defence and aerospace systems. The manufacturing automation decision-making process in company 'A' represents eight steps in an eighteen step process. The eighteen steps are used as a structured approached from the initial project launch to the stage of operation. Therefore, the comparison is conducted against the contents of the first nine stages, as the ninth stage is the business case proposal.

The aspects outlines from the project launch to generating a business case are as follows: technical specifications, capital investment, vendor feasibility, and timescale. Accordingly, it can be deduced that company 'A' addresses only two areas; technical and financial, from the developed tool, thereby, lacking the macro and micro-ergonomics consideration outlined in the developed decision tool.

Company 'B'

Company 'B' is a leading car manufacturer that produces commercial vehicles. The manufacturing automation decision and implementation process in company 'B' is administrated by complying with the manufacturing technology acceptance process. The eight phases are used as a structured approached to guide the engineers from product design and evaluation up to operation. Accordingly, the comparison is conducted against the contents of the second phase, which represents the manufacturing technology sourcing phase. The manufacturing technology sourcing phase resembles the process of identifying and selecting the manufacturing technology that meets the needs of the product design and productivity requirements.

The manufacturing technology sourcing phase addresses the following issues: technical specifications, technology supplier feasibility, and financial feasibility. These issues were examined against the developed contents of the approach to outline the major differences. The examination revealed that up to the stage of technology selection the macro- and micro-ergonomic issues were not present. In addition, it was realised that at the phase of vendor tryout the organisation considers occupational safety and health administration guidelines.

9.3.1 Evaluation by Comparison Discussion

The industrial practice examination pointed out the proposed solution uniqueness in addressing the human factors issues at the initial stages of technology evaluation and selection. In addition, it highlighted the approach's individuality in formally integrating the selection process with the risk assessment process.

Furthermore, regarding the consideration of occupational safety and health administration guidelines pertaining to micro-ergonomics, in company 'B', this is conducted at the vendor tryout phase prior to installation, which is at a stage where the manufacturing technology and supplier have already been selected. This could be the case with other organisations too. Nonetheless, the intention of this research is to incorporate the elements of both macro- and micro-ergonomics at the earliest stage of alternative technology evaluation, in order to support manufacturing systems designers' better incorporate human factors in the planning and designing of manufacturing system. Consequently, this will help in avoiding the pitfalls of over-automation and will reduce the risk of insufficient human-automation corporation, which leads to the failure of manufacturing systems to deliver cost effective and flexible organisation.

9.4 Evaluation by Demonstration

The purpose of the trial evaluation is to discover any problems and difficulties with the developed decision tool prior to the direct application in industry settings. In addition, it is considered as a mean for identifying the potential user opinion on the proposed solution appropriateness and worthiness. The following sub-sections will describe the involved preparation activities, execution process, and the outcome from the field tests.

9.4.1 Evaluation by Demonstration Preparation

The industrial trial evaluation process was arranged into four stages: five minute briefing, fifteen minute user trial, thirty minute questionnaire completion, and five minute debriefing. However, prior to performing the evaluation the following activities had to be performed (Rubin, 1994):

- Selecting and acquiring participants.
- Preparing evaluation material.
- Ensuring evaluation questionnaire validity and reliability.
- Ensuring decision tool validity and functionality.
- Conducting pilot test.

9.4.1.1 Participants selection

The participants targeted for an evaluation study should be representative of the intended users of the system or programme being tested (Neilsen, 1993). Rubin (1994) clearly states that the test results will only be valid if the people selected are typical end users of the product. In addition, Patton (1987) differentiates between the logic of general probabilistic sampling methods and the purposeful sampling used in evaluation studies. Describing how the power of purposeful sampling lies in selecting information-rich cases for in-depth study, he points out that there are no guidelines for determining the size of purposeful samples.

Following these propositions led to targeting the survey participants for this industrial evaluation study. The survey participants were willing to support the development of the decision tool and were aware of the research. Therefore, targeting them for the industrial trial evaluation would save time as well as ensure that the people who are approached are typical end users of the decision tool. Accordingly, three participants were contacted to perform the industrial evaluation. This number was considered to be sufficient for gathering the required feedback to extract expert opinion and determine the research solution appropriateness.

The three candidates were randomly selected from the survey participants list. The selection process resulted in the inclusion of two organisations from the aerospace industry; a leading commercial aircraft manufacturer and a military aircraft component manufacturer, and one from the automotive industry; an automotive component manufacturer.

9.4.1.2 Evaluation material

The test materials are used to communicate with the participants for collecting data. They are considered to be aids to the testing process, and commonly include questionnaires and task scenarios (Rubin, 1994). In the case of this evaluation, the test material was a questionnaire, as it was not feasible to provide realistic scenarios or use actual cases in the preparation of a task scenario.
A semi-structured questionnaire was created to be used in the interview to enable data collection and analysis. The questions were designed in accordance with the evaluation design, using a qualitative data collation style. In addition, they were developed and arranged in a manner that aligns with the usability testing and evaluation questions reported in Patton (1987), Ravden and Johnson (1989), Nielsen (1993), and Rubin (1994).

The developed evaluation questionnaire was categorised into three sections to address the following assessment criteria: feasibility, usability, and usefulness. The evaluation assessment criteria were based on Platts (1990) and Adesola (2002) suggestions for testing any particular methodology. In addition, Nielsen (1993) outlines these criteria for assessment during computer interface evaluation for developed software programmes and packages. The feasibility questions were formed to assess the user's ability in realising the developed methodology. The usability questions, however, were generated to assess the convenience and practicality of application. Finally, the usefulness questions were designed to assess the significance of the incorporated human factors elements and the developed decision tool. A copy of the evaluation questionnaire is included in Appendix C.2.

Furthermore, within these three sections specific questions were included to address the following: the familiarity with the deployed techniques, the ability to measure the added human factors elements, the appropriateness of the evaluation elements and sub-elements, the extent to which the decision tool allows better consideration of human factors, the willingness to apply it, and the interviewee's existing decision-making processes. These questions were incorporated as they answer important queries regarding the outcome of this research and contribution to knowledge.

The style and wording of the questions for the evaluation test were chosen and based on the works by Patton (1987), Rubin (1994), Adesola (2002), and Wilkinson and Birmingham (2003). In addition, the ranking scale chosen to scale responses was the Likert scale. However, in contrast to the typical five-point scale, a four-point scale was used. The main reason for using a four-point scale was to restrict the number of choices provided, thereby avoiding the neutral ground. This technique is used to prevent 'questionnaire drift' (Wilkinson and Birmingham (2003).

9.4.1.3 Evaluation questionnaire validity and reliability

The developed evaluation instrument (questionnaire) had to be both valid and reliable (Patton, 1987). Validity refers to the degree to which the evaluation instrument measures what it purports to measure, whereas reliability represents the degree to which the measure can be depended upon to secure consistent and stable results (Rutman, 1997). Therefore, to ensure the validity of the questionnaire, it was assessed against the intentions of this evaluation study. The questions were found to address the proposed approach, execution format, contents, and research contribution to knowledge, which corresponds with the purpose of this evaluation study.

Reliability, on the other hand, was enforced by designing the questions and their measures in accordance with the guidelines mentioned by Patton (1987) and Wilkinson and Birmingham (2003).

9.4.1.4 Decision tool validity and functionality

Before the industrial trial evaluation could take place it was crucial to test the validity of the proposed decision tool with those who are knowledgeable about the techniques deployed, and to verify the functionality of the software application.

Accordingly, the proposed decision tool was reviewed by a QFD expert from Cranfield University, and an aerospace industry auditor who is experienced in both QFD and FMEA applications. The examination included the verification of the following issues: computation formulae, scale selection, added modifications, omitted sections, and deployment in a different context. The outcome of this examination was very valuable as it ensured face validity and led to constructive alterations. Face validity is a method used in model validation (Stewart, 1994).

On the other hand, the software application functionality was verified by performing a hypothetical selection of a manufacturing automation technology. The test involved a demonstration run and a manual computation of the entire process. The purpose of this test was to ensure the prevention of any uncontrollable problems that might occur during the process of formal evaluation, and to verify the degree of consistency in obtaining the same results when deploying either the software application or the workbook.

9.4.1.5 Pilot test

Piloting and iterating the evaluation test is a primary stage in the development of evaluation programmes, as it is the last opportunity to modify the evaluation programme (Ravden and Johnson, 1989). In addition, pilot testing the interview questions is a perfect method of eliminating ambiguous questions and correcting imperfections, as well as improving the validity and reliability of the questionnaire (Wilkinson and Birmingham, 2003). Therefore, a pre-test was performed at Cranfield University with a number of staff from the Manufacturing Systems Department. Each test took approximately one hour to complete. The tests produced useful feedback on the structure and flow of the interview, as a result of which the questionnaire was modified.

Once the evaluation questionnaire was pre-tested and amended, it was ready to be piloted. The first interview conducted was used as a pilot study, with the aim of ascertaining how closely the questions addressed the evaluation aim. The answers indicated that the questions did not require modifications, and consequently the pilot responses were included in the main study frame.

9.4.2 Evaluation by Demonstration Process

The industrial trial evaluation test was conducted with three participants who have been involved with the earlier survey. A letter was sent to each candidate to obtain permission for an interview to conduct the evaluation study. The letter included a briefing on the research progress and a request for participation in the evaluation (for more details, see Appendix C.3). Once approval was received the evaluation test was conducted, and was performed in the following order (Nielsen, 1993):

Briefing

The briefing started with an overview of the research progress and an explanation of the purpose of the evaluation study. Confidentiality was assured, and the evaluation process was outlined. The briefing was administered using an evaluation protocol document developed for the evaluation study, which was created to sustain consistency of evaluation process. The evaluation protocol document for the evaluation study was developed in accordance with guidelines proposed by Robson (2002) and Patton (1987) (see Appendix C.4).

User trial

Each participant was asked to have a trial interaction with the decision tool. The intention was to enable the users to try out the decision tool for themselves and to explore the stages and steps of the decision and assessment process. They were provided with both the workbook and the software application. Thereafter, a demonstration run was performed, during which they were encouraged to ask any questions about the process or contents.

Administering the questionnaire

Following the user trial, the questionnaire sections were briefly outlined to offer the participant an overview of the content and structure of the questionnaire. Thereafter, the participant was asked the questions in each section. As mentioned earlier, the questionnaire is in a semi-structured format, therefore, where convenient, additional probing and clarification questions were raised. In addition, during the questionnaire process, a tape recorder was deployed to increase the accuracy of data collected.

Debriefing

The debriefing was conducted at the end of the questionnaire. It incorporated a free discussion to focus on understanding any areas of difficulty and to allow additional comments or suggestions.

9.4.3 Qualitative Data Processing

The process of transforming the qualitative data into organised and presentable data was an essential task for interpreting and analysing the qualitative questionnaire feedback into a rational description. Patton (1987) states that the analysis of qualitative data is a creative process and there is no one right way to go about organising, analysing, and interpreting qualitative data. However, he suggests four basic directions for qualitative analysis; namely qualitative description, case analysis, content analysis, and inductive analysis.

After reviewing the four methods it was decided to follow the content analysis procedure, as it was similar to the coding procedure used in the survey analysis process, in addition to offering simplicity of execution.

Content analysis is a process of organising and simplifying the complexity of data into meaningful and manageable themes or categories. It basically involves identifying coherent and important patterns in the data (Patton, 1987). Accordingly, the evaluation questionnaire content was analysed after the evaluation test took place. The content of the qualitative questions was labelled first, and then a data index was established. Following this process the content was classified to enable pattern identification.

9.4.4 Evaluation by Demonstration Results

The results of the field test and the comments of participants are presented in this section. After coding the qualitative responses, the results from the three companies were grouped to facilitate the presentation of feasibility, usability, and usefulness evaluation outcomes. This was seen as being more appropriate than a percentile representation as the number of participants was low. In addition, examples of some qualitative results obtained in the form of descriptive comments to the questionnaire are presented in Appendix C.5.

<u>9.4.4.1 Evaluation by demonstration feasibility outcome</u>

The feasibility section assessed the participants' familiarity with the deployed techniques, comprehension of the mechanism involved, and feasibility to measure the incorporated human factors elements. The feedback on the feasibility of the developed approach is presented in Table 9.1. The table results indicate that the participants were familiar with the selected techniques for this methodology and were able to comprehend the mechanism involved. In addition, they all declared capability in measuring the incorporated human factors elements. However, regarding simplicity in following the approach, the second participant did not find it as easy as the rest. The complication he pointed out was associated with the amount of data involved.

Furthermore, the participants' suggestions towards making the approach more workable, responses from question five; included inserting additional steps to enhance the impact or clarity of certain processes. The following describes the recommendations suggested:

-Risk assessment process: include a clear-by date area and comment area for personal definitions of severity and likelihood levels.

-Workbook check points: include a sign-off area.

Question number	Commercial Aircraft Manufacturer	Aircraft Component Manufacturer	Automotive Component Manufacturer
1. Familiarity with approach	Very familiar	Very familiar	Very familiar
2. Simplicity in understanding approach	Very easy	Quite easy	Very easy
3. Simplicity in following approach	Very easy	Not very easy	Very easy
4. Ability to measure the human factors sub-elements	Yes	Yes	Yes

Table 9.1: Evaluation by Demonstration Feasibility Responses

9.4.4.2 Evaluation by demonstration usability outcome

The usability section assessed the contents, usability, and future application of the developed decision tool; the responses are presented in Table 9.2. The results demonstrate that the participants found the content of both the main evaluation elements and sub-elements to appropriately address the issues involved in a manufacturing automation decision-making process, and the usability of both the workbook and software application as satisfactory.

Furthermore, the participants' main concern regarding application and deployment (responses from question 11) was associated with the fact that the decision tool was not tested in real life. Other concerns reported were feasibility to use the decision tool in a different environment (to assess process selection and manufacturing organisation acquisition), and method of assigning weights to the sub-elements measures.

However, the participants responded positively when asked whether they would be considering adopting this approach to support future decisions (responses from question 12 a). According to them the following issues created the interest for future deployment (responses to question 12 b):

-Enables the analyst to address people issues more appropriately.

-Provides a complete process of selection and risk assessment.

-Simple and quick decision-making process.

Question number	Commercial Aircraft Manufacturer	Aircraft Component Manufacturer	Automotive Component Manufacturer
6. Evaluation elements appropriateness	Yes	Yes	Yes
7. Evaluation sub-elements appropriateness	Yes	Yes	Yes
8. Clear workbook steps	Yes	Yes	Yes
9. Easy to use the workbook	Yes	Quite easy	Yes
10. Easy to use the software	Yes	Quite easy	Yes
12. Future application	Yes	Yes	Yes

Table 9.2: Evaluation by Demonstration Usability Responses

9.4.4.3 Evaluation by demonstration usefulness outcome

The usefulness section assessed the perceived value of the incorporated human factors elements and the developed decision tool. The feedback on the perceived value of the incorporated human factors elements was positive, as presented in Table 9.3. The descriptive responses demonstrate how the participants acknowledged the value added by the additional human factors issues addressed.

Question number	Commercial Aircraft Manufacturer	Aircraft Component Manufacturer	Automotive Component Manufacturer
13. Incorporate appropriate technology, organisation, and people issues	Yes	Yes	Yes
14. Allows addressing human factors better	Yes	Yes	Yes

Table 9.3: Evaluation by Demonstration Usefulness Responses

Moreover, regarding the feedback on the perceived value of the developed decision tool in comparison with their current decision making process, the strengths were:

-Addresses people issues.

-Formally addressing human factors.

-A formalised, rigorous, and integrated decision-making process.

-In a software application format.

-A selection tool in addition to risk assessment capability.

-Weighting assignment for each category.

-Can be deployed in different environments.

However, the weaknesses reported in comparison to their current decision-making process related to the complication in decision-making when unexpected outcomes result from considering the incorporated human factors elements.

9.4.4.4 Debriefing session outcome

The debriefing session was conducted to elicit further discussion and comments from the participants on the issues raised during the trial and questionnaire sessions. However, what was particularly useful was the set of comments received when the participants were informed of the recommendations made by other participants (keeping anonymity intact).

When pointing out the suggestions noted, the responses were neither in favour nor against them, except for the sign-off suggestion. Two participants were not interested in including sign-offs. One commented that this is an evaluation tool used at the stage between initiating the idea and the acquisition of technology, therefore, no sign-offs would be necessary. Another participant pointed out that in his organisation, decisions are decentralised and the organisation has a flat structure. Therefore, the automation decisions are made by the same person throughout the process.

9.4.5 Evaluation by Demonstration Discussion

Having given an overview of the industrial trial evaluation results, the responses and their meanings are critically analysed in order to elicit the findings from the results. The following represents the findings extracted from the questionnaire feedback.

9.4.5.1 Evaluation by demonstration feasibility outcome analysis

Question one and two results positively support the selection of the techniques for this research decision tool. All of the participants were comfortable with the selected techniques deployed in the decision tool. Their background knowledge on both techniques reflected on their ability to grasp the mechanisms involved. In addition, they were able to swiftly understand and learn the purpose of using each technique and how they were integrated to pursue the anticipated benefits from the proposed decision tool.

Moreover, the decision tool was developed to support users in identifying the most suitable manufacturing automation option according to their investment drivers, as well as conducting a risk assessment analysis. Therefore, it was expected that there would be a certain degree of difficulty in following the steps throughout the three stages. However, after reviewing question three responses, it was quite clear that the participants were able to follow the steps and stages involved without complications. This finding pointed out that the manner in which the stages and steps progressed were acceptable and comprehensible.

Another important issue to discuss before moving on to the suggestions made to make the decision tool more workable is the ability to measure the incorporated human factors issues. The ability to understand and follow a structured approach is considered to be a positive outcome, but without the capability to investigate and measure the evaluation elements included, the benefits, and even the deployment of the application would be hindered. Now as the technical and financial issues addressed are more or less conventional, the focus was directed to determining the ability of the anticipated users to review and evaluate the micro and macro-ergonomics issues introduced. The feedback from question four revealed that all participants approved their ability in investigating and measuring the additional issues pertaining to micro and macro-ergonomics. This positively reflects the appropriateness of the chosen level of depth and detail required to address these issues.

Finally, analysing the suggestions made towards making the approach more workable. The recommendations made by the participants were not consistent and were not regarded as very significant. Therefore, no change is needed at present, and the tool can be regarded as feasible. In addition, it was decided to preserve these recommendations for future work, in order to be further investigated prior to implementation.

Overall, the feasibility analysis confirms the capability of the participants to understand and follow the proposed approach, as well as their ability to address the introduced human factors issues. This positive finding is considered to be of importance to the outcome of this research, as the main intention of this study was to develop an approach that management are familiar with, and at the same time, one that is able to address human factors issues.

9.4.5.2 Evaluation by demonstration usability outcome analysis

In response to question six and seven all participants stated approval that both the main evaluation elements and sub-elements appropriately address the issues involved in a manufacturing automation decision making process. This indicates that the evaluation elements and sub-elements established from the literature survey were appropriate. In addition, according to the positive results received from question eight, nine and ten, it is apparent that the participants saw the interaction with both the workbook and software application to be relatively easy to learn and use.

The participants' concerns regarding application and deployment, in response to question eleven, focused mainly on the lack of valid deployment. This matter also affects the concern towards its capability to perform in a different environment, and the reported weaknesses, which are difficult to determine without operating the decision tool in a live situation. However, at this point the purpose of the evaluation test was to create a reliable base from which to further initiate any developments or application trials.

In addition, the query regarding assigning weights to the sub-elements measures was actually thought of during the development of the decision tool. The idea was to develop questions associated with a ranking scale that would enable the user to weight the sub-elements measures. However, it was strongly believed that providing the measure as an example to follow and leaving the measuring technique to be self customised would keep the decision-making process less complicated and would enable the user to add additional measures. Furthermore, this concern was raised by one participant only; the other two appreciated the fact that they could model the measures according to the patterns of their existing measures.

Finally, the results from question twelve revealed the participants positive attitude towards future adoption. The feedback provided illustrates the uniqueness of this approach in exposing vital issues that are overlooked in their decision-making process. Another point that appealed to them was the decision tool's quick selection and risk assessment capability. Both aspects had a strong impact on their decision, and even stimulated one participant's eagerness to apply it in a decision he is currently undertaking.

Overall, the usability analysis confirms the suitability of the decision-making elements addressed, the usability of the application formats, and the interest in application. This positive finding encourages the continuation of this research study beyond this thesis.

9.4.5.3 Evaluation by demonstration usefulness outcome analysis

The usefulness assessment was conducted to specifically address the participants' level of awareness and appreciation of the incorporated human factors elements. Even though the usability evaluation analysis revealed the participants awareness of additional issues addressed in this decision tool, it is appropriate to analyse how significant they perceive theses issues to be in terms of added value. This was the purpose of asking them the appropriateness of addressing technological, organisational, and people issues, and then following it with a more specific question on whether the decision tool will allow them to address human factors better (question 13 and 14). According to the results the participants were satisfied with the issues addressed and convincingly, were aware of the significant value contributed by this decision tool, which was also confirmed in the strength comparison outcome.

Finally, the results from question fifteen revealed that the developed approach surpasses decision-making process in two vital aspects; firstly, that it allows the user to consider and address people issues appropriately, and secondly, that it formally combines the selection process with the risk assessment process. This positively demonstrates that the decision tool was able to complement existing decision-making process.

Overall, the usefulness analysis confirms the participants' awareness and appreciation of the incorporated human factors elements. For them to acknowledge the importance of addressing people issues and realising the approach's capability in bridging this gap is considered to be a very important finding for this research study.

9.5 Evaluation by Application

The purpose of the evaluation by application is to validate the developed decision tool by direct application in industry settings and understand carefully where refinements and improvements are needed. In addition, to identifying if the result is worth the effort and whether the methodology gives useful output to the organisation. The following sub-sections will describe the involved preparation activities, execution process, and the outcome from the evaluation by application.

9.5.1 Evaluation by Application Preparation

The nature of the research programme outlined in section 3.4.1 suggests case study technique to be adopted as the appropriate research method to carry out the evaluation by application. However, prior to performing the case study the following activities had to be performed (Yin 2003):

- Selecting the test site.
- Preparing evaluation material.
- Ensuring evaluation questionnaire validity and reliability.

9.5.1.1 Test site selection

A single case study was used for the evaluation by application. The following pre-defined criteria were set to guide the researcher in what to look for in a test-site:

- The test site is considered as a representative of the manufacturing industry.
- The test site is in the initial phase of redesign or has recently been redesigned.
- The scope of the project had to be big enough to test the validity of the proposed decision tool, but small enough to be carried out completely in a feasible time frame.

Through the collaboration with Cranfield University staff it was possible to find a test site that would meet these criteria. A member of staff in the School of Manufacturing Systems had arranged for a case study to take place at Rolls-Royce compression systems plant in Inchinnan. Accordingly, the researcher contacted by phone the senior manufacturing engineer responsible for the equipment acquisition and design of the newly developed facility, to set up the case study.

The senior engineer provided a case study for testing the produced research solution, which was conducted within the Rolls-Royce project team for a period of six months. Details of the project can be found in Section 9.5.3.

9.5.1.2 Evaluation material

Interviews are one of the most important sources of information collection in a case study (Yin, 1989). Although Yin (2003) describes the structure for conducting this case study, it was difficult to determine the sort of data to be collected. Therefore, in order to evaluate the effectiveness and success of the developed decision tool in practice, an assessment methodology was necessary (Platts, 1990). Platts (1990) describes an assessment methodology as a structured process that involves people in a participative manner, both in basic data collection and joint discovery through its subsequent analysis, leading to creatively identifying improvement opportunities.
Accordingly, an assessment methodology involving the participant was developed based on four stages; three assessments to be administered during the case study and a final assessment at the end of the case study. Again, as in Section 9.4.1.2, the assessment criteria were based on feasibility, usability and usefulness (Platts, 1990; Adesola, 2002).

Moreover, interviewing is one of the most important sources of case study information (Yin, 1989). Consequently, a semi-structured questionnaire was developed to guide the assessment process during and after the case study. The questionnaire was categorised into four sections to reflect the assessment methodology. The first three sections are designed to assess the feasibility and usability at the end of each stage in the decision tool, and the final section is designed to assess the feasibility, usability and usefulness of the overall process and methodology. A copy of the evaluation by application questionnaire is included in Appendix C.6.

The questions were designed using a qualitative data collection style, to ensure in-depth assessment (Patton, 1987). The process of designing the questionnaire was based on three steps, of the five step approach by Brown (1997): clearly outline what is to be measured, generate an item pool, and review item pool. Furthermore, the wording and questions arrangement were developed in accordance with the work of Oppenheim (1996) and Wilkinson and Birmingham (2003).

9.5.1.3 Evaluation questionnaire validity and reliability

The developed case study evaluation instrument (questionnaire) has to produce constant data and measure what it is supposed to (Black, 1993). Yin (2003) warns of the bias inherent within leading questions, as biased questions distort the objectivity of data. In addition, Davis (1996) warns of a questionnaire that fails to measure what it is suppose to, as it will be of little help to the researcher and will be considered invalid. This indicates that the evaluation questionnaire used in the case study should measure exactly what the researcher aims to measure, and can be repeated with the same result.

Accordingly, the entire assessment methodology was pre-tested with a number of researchers at Cranfield University. Following the pre-test, modifications were made to the draft questionnaire to ensure that the questions focused on the goal of this case study and to avoid misunderstanding caused by poorly worded questions.

9.5.3 Evaluation by Application Process

A case study was conducted at the Rolls-Royce compression systems plant in Inchinnan. A half day meeting was held to introduce the proposed solution to the senior engineer, and discuss the project's scope and time frame for executing the case study. Accordingly, arrangements were made to conduct a case study based on chip forming machine selection in two days.

9.5.3.1 Background of case study

The Rolls-Royce Compression Systems facility in Scotland has just been relocated and redesigned. The old facility was in Hillington and relocated to Inchinnan at a cost of 85 million pounds.

The old site was built in 1939 for the duration of the Second World War to support the Durby facility. However, in 2002 a three year investment plan was made to relocate and redesign the Hamilton facility to overcome the high operating and infrastructure costs, in addition to the need for extra forging machines. The redesigning process was conducted with the TYODA consultancy and was based on four businesses - forging, rotors, compression stators, and seals. The factory was built around these four businesses, taking an inside out design approach.

The selection and installation of equipment began in April 2003. The investment projects were conducted using Rolls-Royce's contract buyer sign-off process (Appendix C.7). The contract buyer sign-off process is applied in projects that exceed one million pounds, and involves four stages: Contract Review Board 1 (Pre-RFQ), Contract Review Board 2 (Pre-negotiation), Contract Review Board 3 (Post Negotiation Review), and Contract Review Board 4 (Post Implementation Review).

Initially the project team begins with identifying the need for the acquisition of the new machines/processes. Thereafter, the technical specifications and commercial requirements (e.g. budget, terms of business, split of payment, etc.) are defined. The technical specifications and commercial requirements are then matched and compounded. Once agreement is achieved the sourcing for suppliers starts and a Request For Quotation (RFQ) is sent out. At this point the first Contract Review (Pre-RFQ) is conducted to confirm who is involved in the project and to source suppliers. Then the designers conduct the technical assessment and the financial personnel conduct the commercial assessment to perform the second stage in the Contract Review (Pre-negotiation).

The assessment is conducted by evaluating the attributes against the targets using a scale of 1 to 10; less than 5 rating represents an unacceptable outcome, 6 to 8 rating represents the least acceptable outcome, and above 8 rating represents the most desirable outcome. The supplier with the highest total score is considered to be the best option.

Once the second contract review is over, the technical and commercial personnel initiate the negotiation strategy with the supplier to conduct the third Contract Review Board (Post Negotiation Review). The Contract Review Board examines the technical assessment outcome, the commercial assessment outcome, the negotiation results, and the implementation plan, finally closing the loop with the fourth Contract Review (Post Implementation Review) to promote continuous improvement and learning initiatives.

The case study adopted for the evaluation by application was based on the latest equipment selection and acquisition process performed at the seals division; the selection and acquisition of eight chip forming machines. The investment project was conducted within a period of six months using the Rolls-Royce contract buyer sign-off process. Appendix C.7 includes the decision-making process conducted in the project.
The technical assessment covered the following attributes: equipment technical specifications, supplier capability, support equipment, reliability and maintenance, service response time, and hardware integration.

The commercial assessment covered the following attributes: warranty, terms of business, lead time, software integration, life cycle cost, installation costs, equipment cost, and financial appraisal.

The historical outcome of the Rolls-Royce decision-making process indicated suppler A as the most desirable option for this project. However, Rolls-Royce ended up awarding supplier B the contract. Suppler B offered a better discount in the re-negotiation phase prior to the third Contract Review (Post Negotiation Review), whereas supplier A did not re-negotiate the business terms. Therefore, as the price was lower and the technical differences were not very great, Rolls-Royce ended up awarding the contract to supplier B.

9.5.3.2 Overview of decision tool application in case study

The practical application was conducted in two days at the Rolls-Royce Compression Systems facility in Inchinnan, during which the researcher was directly involved in observing the application and evaluating the tool. Together with a semi-structured questionnaire, a diary was used to gather any additional qualitative data and note observations. The objectives of applying and testing the decision tool were to:

1. Validate the proposed research solution using real data.
2. Carefully consider the way the tool is applied to understand what and where modifications are needed.
3. Determine whether the methodology gives a useful output.
4. Determine the value of the research solution to the organisation.

The first day began with a brief discussion outlining the application and evaluation process to the senior engineer. The application plan was structured as follows: on the first day to conduct the first and second stage of the decision process (linking automation investment drives with evaluation elements, and automation alternative selection), and on the second day to conduct the third stage (decision risk assessment). However, the evaluation plan was structured to be conducted at the end of each stage.

Once the briefing discussion was over the senior engineer was offered the choice of performing the case study either through the workbook or the software application. He preferred to use the software application for performing the case study. Thereafter, he began to follow the steps of the first stage and eventually filled in the required data. At the end of the first stage the first section of the semi-structured questionnaire was administered. Then he proceeded to the second stage and filled in the required data.

At the end of the second stage, the second section of the semi-structured questionnaire was administered.

On the second day the results from the second stage were reviewed before performing the final stage of the decision tool. Once the final stage was completed the third section and fourth sections of the semi-structured questionnaire were administered. The application and evaluation process was swiftly conducted within the scheduled time frame, which allowed for extra discussions to take place at the end of each day.

9.5.4 Evaluation by Application Results

The decision tool produced the same outcome as the Rolls-Royce historical assessment outcome; the best option was supplier A. Appendix C.8 depicts the results obtained from the practical application. In addition, the qualitative data gathered from the evaluation and observation were analysed in accordance with Patton's (1987) content analysis method. The results are presented and categorised in accordance with the evaluation process.

9.5.4.1 Evaluation by application first phase outcome

The first part of the evaluation questionnaire was aimed at assessing the feasibility and usability of the steps and processes involved in stage one of the decision tool; linking automation investment drivers with evaluation elements. The participant was able to execute the first stage without difficulty and found it easy to follow the steps. The feedback of the feasibility and usability from this assessment is presented in Table 9.4.

Question number	Response
1. Easy to follow this stage of the methodology	Yes
2. Labour intensive	No
3. Anything unnecessary or redundant	No
4. Difficult instructions	No
5. Confusion during execution	No
6. Unfamiliar or unacceptable terms/issues	No
7. Any recommendation for improving this stage	No

Table 9.4: Evaluation by Application First Phase Responses

9.5.4.2 Evaluation by application second phase outcome

The second part of the evaluation questionnaire was aimed at assessing the feasibility and usability of the steps and processes involved in stage two of the decision tool; automation alternative selection. The participant was able to execute the second stage without difficulty and found it easy to follow the steps. The feedback of the feasibility and usability from this assessment is presented in Table 9.5.

Question number	Response
8. Easy to follow this stage of the methodology	Yes
9. Labour intensive	No
10. Anything unnecessary or redundant	Yes
11. Difficult instructions	No
12. Confusion during execution	No
13. Unfamiliar or unacceptable terms/issues	No
14. Any recommendation for improving this stage	Yes

Table 9.5: Evaluation by Application Second Phase Responses

9.5.4.3 Evaluation by application third phase outcome

The third part of the evaluation questionnaire was aimed at assessing the feasibility and usability of the steps and processes involved in stage three of the decision tool; decision risk assessment. The participant was able to execute the third stage without difficulty and found it easy to follow the steps. The feedback of the feasibility and usability from this assessment is presented in Table 9.6.

Question number	Response
15. Easy to follow this stage of the methodology	Yes
16. Labour intensive	Yes
17. Anything unnecessary or redundant	No
18. Difficult instructions	No
19. Confusion during execution	No
20. Unfamiliar or unacceptable terms/issues	No
21. Any recommendation for improving this stage	No

Table 9.6: Evaluation by Application Third Phase Responses

9.5.4.4 Evaluation by application final phase outcome

The fourth part of the evaluation questionnaire was aimed at assessing the overall feasibility, usability, and usefulness of the proposed research solution. The participant found the tool to be overall feasible, usable, and useful. The feedback of the feasibility, usability, and usefulness from this assessment is presented in Table 9.7.

Question number	Response
22. Easy to follow the methodology	Yes
23. User friendly and clear tool	Yes
24. Produced valid output	Yes
25. Worth time invested	Yes
26. Improve your decision	No
27. Influences preparation and implementation process	Yes
28. Incorporate Technology, Organisation, and People issues	Yes
29. Allow you to address human factors issues better	Yes

Table 9.7: Evaluation by Application Final Phase Responses

In addition, regarding the feedback to question 30, the participant stated the following strengths in comparison to Rolls-Royce decision-making process:

-Gives overall presentation and better view.

-Gives in one document a lot of points of what you should consider.

-Provides weighting criteria that takes into consideration the importance of the issues.

-Brings out Human factors issues.

However, the pointed out weakness was:

-More time consuming.

9.5.5 Evaluation by Application Discussion

Having given an overview of the evaluation by application results, the responses and their meanings are critically analysed in order to elicit the findings from the results. The following represents the findings extracted from the questionnaire feedback and observation.

9.5.5.1 Evaluation by application first phase analysis

The participant was able to follow the instructions and determine the weighting of the evaluation elements with ease. He realised the importance of utilising the investment drivers to determine the weighting of the evaluation elements. Whereas, with the Rolls-Royce decision-making process (Appendix C.7) the technical and commercial evaluation attributes are considered as equal, which is questionable.

In addition, the participant did not recommend any improvements for this stage. His reply for question seven was "I am quite happy with what I have seen and done." However, it was observed that the technical, financial, and safety elements were linked and scored faster than the rest of the evaluation elements. The researcher believes that the reason for the delay in linking and scoring the other evaluation elements with the investment drivers is that the Rolls-Royce decision-making process concentrates mainly on meeting technical and financial requirements. Therefore, taking into account organisational and people issues was a new encounter and had to be thought of carefully.

Overall the feedback gathered from assessing the linking of automation investment drivers with the evaluation elements stage demonstrates the feasibility and usability of the first part of the methodology. Furthermore, regarding the observations made, the participant was eventually able to complete the stage and was content with the weighting of the evaluation elements.

9.5.5.2 Evaluation by application second phase outcome analysis

The participant was able to follow the instructions and determine the weighting of the sub-evaluation elements without any difficulty. The process involved in this stage is similar to the Rolls-Royces decision-making process, which enhanced execution time. The Rolls-Royce decision-making process included technical and commercial evaluation attributes that are rated according to a scale. Consequently, when asked whether this stage was labour intensive (question 9), he replied "it might take longer if the data was not available."

In addition, in question ten, the participant pointed out that a couple of the sub-evaluation elements were not related to this project. Therefore, he considered them to be redundant and replied with "Yes". However, when informed in the discussion period at the end of the day about the capability of the user to not consider the irrelevant issues in the assessment, he showed awareness of this but wanted to test the tool out. Furthermore, the recommend improvement (question 14) for this stage was that there should be a pop-up message asking to confirm data deletion when a different option is selected for comparison, in order to avoid accidental data loss.

Overall the feedback gathered from assessing automation alternative selection stage demonstrates the feasibility and usability of the second part of the methodology. Moreover, the automation alternative selection stage provided the same output as the historical outcome of the Rolls-Royce decision-making process. Both methodologies indicated supplier A's machines as the most appropriate option for this project.

9.5.5.3 Evaluation by application third phase analysis

The participant was able to follow the instructions and determine the associated risks with the selected automation alternative easily. The participant analysed the risk associated with the issues that were negatively rated during the evaluation. In addition, he carefully examined the issues that had raised concern in the evaluation but were not negatively rated, and reported the risk that could be associated. To the researcher this was a promising sign, demonstrating the participant's involvement and interest in the proposed solution, as not only were the negatively scored sub-evaluation elements analysed, but also the issues that did not receive the highest rate of acceptance.

The participant did not recommend any improvements for this stage. However, in question 16 the participant pointed out that this stage needed more time to execute compared to the other two stages. He stated that "the nature of this sheet demands you to actually take extra time to think and record the reasons behind the risk associated."

Overall the feedback gathered from the decision risk assessment stage demonstrates the feasibility and usability of the final part of the methodology. Moreover, regarding the observations made, it was noted that the participant realised the importance of this stage, as in the Rolls-Royce decision-making process there was no formal decision risk assessment approach.

9.5.5.4 Evaluation by application final phase outcome analysis

The participant found the proposed methodology easy to follow and the decision tool to be user friendly and clear (question 22 and 23). He stated in response to question 23 "I like the fact you have all the help buttons behind and the description and the sheets." In addition, he found the tool capable of producing valid output (question 24). He stated "Compared to the assessment I did the overall result found was the same." This was also mentioned in his response to question 25 regarding his perception of the results obtained from undertaking the case project using this methodology being worth the time invested; he replied "Yes, I think it is a valid tool, in the categorisation it gives a good guide to look at other areas you might not necessarily consider."

He did not think that using the tool would result in a better decision (question 26), and replied "Overall I think we have got the same result." However, he indicated extra benefits of the new decision tool. He noted that the preparation and implementation would have been different. His reply for question 27 was "Ultimately it lays out the risk areas and therefore starts making your project plan. It makes you think how to mitigate the risk associated."
Regarding the tool's ability to address human factors issues, the participant confirmed its appropriateness in incorporating the technical, organisation, and people issues (question 29) outcome from question 28, and 29 verified it. His reply for question 29 was "It certainly brought human factors issues out, especially when you are a more technically oriented person." He also indicated that in this case study the difference between the levels of automation was not very large, pointing out that with greater differences the human-machine interface issues scoring would vary between alternatives and more negative signs would appear.

In addition, question 30 feedback concurs with the outcome achieved from the findings discussed in the evaluation by comparison and evaluation by demonstration. The comments confirm the decision tool's ability to support human factors incorporation at the initial stages of technology selection, and the unique ability of the developed approach in formally integrating the selection process with the risk assessment process in one document.
Furthermore, the weakness indicated cannot be considered a drawback. Even though the participant stated that the tool consumes more time than the existing process, he commented "but it is a false view, because you have to do such assessment for such decision."

Overall the feedback gathered from the evaluation by application demonstrates the feasibility, usability, and usefulness of the proposed research solution. The developed research solution was tested using real data and gave a valid output. The usefulness of the solution was realised by the participant as the decision tool enabled him to incorporate the human factors issues and enhanced his preparation and implementation consideration. In addition, the participant asked for a copy of the decision tool once the research study was completed.

9.6 Discussion of Key Findings

A number of key findings have emerged from the evaluation by comparison, evaluation by demonstration, and evaluation by application. Theses findings are presented as discussion points below.

Finding 1: The methodology supports addressing human factors alongside other considerations at the earliest stages of manufacturing systems design

The results from the industrial practice evaluation, industrial trial evaluation, and case study evaluation all demonstrate the decision tool's capability in assisting human factors incorporation alongside technical, organisational, and economic factors at the initial stages of technology selection. The results of the industrial practice evaluation revealed that none of the industrial methodologies were taking into consideration both macro- and micro-ergonomics at the technology selection phase. This finding was also discovered in the three organisations visited for the trial evaluation and in the firm where the practical application took place. In addition, both the trial evaluation and the practical application feedback demonstrated the participants' appreciation of the incorporation of the human factors elements and approval of greater assistance in addressing human factors.

Finding 2: The methodology distinctively integrates technology selection process with risk assessment process

The proposed approach has been able to surpass the decision-making processes examined in this entire evaluation study by formally combining the manufacturing automation selection process with the risk assessment process. This finding was reported in the industrial practice comparison and was acknowledged by the participants who took part in this evaluation study. Positive comments were made, emphasising the importance of having the assessment formally undertaken and recorded. Moreover, even though the decision tool gave the same outcome as the Rolls-Royce decision-making process in the evaluation by application, the participant confirmed that the implementation and preparation would have differed as a result of the risk assessment being incorporated in this methodology. This demonstrates the added value of this step and how it complemented the existing decision-making process.

Finding 3: The methodology was feasible and usable

According to Platts (1990), if the steps of a methodology have been followed, then the methodology is proved feasible. Throughout the evaluations by demonstration the participants were able to comprehend the proposed methodology and state their ability to follow it. Furthermore, the evaluation by application gave a good indication of this in practice, as the testing showed that the methodology can work and was followed perfectly.

Positive reaction and feedback was also obtained regarding usability. The evaluation by demonstration participants rated the decision tool's usability as very user-friendly and clear. In addition, in the evaluation by application the participant was satisfied overall with the instructions and help provided, and the user-friendly interaction.

Finding 4: The methodology produced a useful output

Even though the evaluation by demonstration findings indicated that the developed methodology is useful, the usability evaluation outcome analysis (Section 9.4.5.2) showed that the main issue raised was the lack of valid deployment in a real life setting. However, with the outcome from the evaluation by application it was demonstrated that the methodology was capable of producing credible and useful results. In addition, the participant found it worthwhile and was looking forward to receiving a copy of the developed methodology.

Overall these key findings can be considered as a measure of success. The key findings have proved that the methodology is feasible, usable, useful, and able to address the gap identified in the literature.

9.7 Chapter Summary

This chapter has reported the results of an evaluation study conducted to assess the feasibility, usability, and usefulness of the developed approach. The results from the industrial assessment and practical application formed the basis for drawing the main findings reported in the discussion. The size and extent of the evaluation programme restricts the ability to generalise on the reported findings. However, the results analysis has clearly demonstrated the degree to which the proposed research solution is positively feasible, usable, and useful.

CHAPTER 10

DISCUSSION AND CONCLUSIONS

10.1 Summary

This chapter concludes the research presented in this thesis. It describes and discusses what has been studied, how it has progressed, and what has been achieved (objectives, approach, and solution). This chapter also evaluates the main findings, together with a discussion of the strengths and weaknesses of the research. Recommendations for further research that could continue the work of this study are also outlined.

10.2 Principal Research Findings Against Research Aim

This section recalls the aim and objectives of the research, along with the findings from each phase of the research programme in order to conclude the principal research findings.

10.1.2 Summary of Research Aim and Objectives

The aim of the research was defined in Section 3.2 as follows:

> "To assist manufacturing systems designers to better incorporate human factors in automated manufacturing systems design."

The research aim was addressed by completing a set of objectives, namely to:

1. Determine from an industrial perspective how human factors are incorporated in automated manufacturing systems design, and the need for improvement.
2. Create a decision tool to support the design of automated manufacturing systems by incorporating human factors alongside technical, organisational, and economical factors.
3. Evaluate the decision tool.

10.2.2 Research Findings

To ensure fulfilment of these objectives, a research programme was established. The programme consisted of an industrial survey, the design and operation of a decision tool, and an industrial evaluation.
Based on the objectives of the research together with findings from the programme the principal research findings are summarised as follows:

Objective One: To determine from an industrial perspective how human factors are incorporated in automated manufacturing systems design, and the need for improvement.

It is not sufficient to rely on literature only to determine and justify the need for better incorporation of human factors in manufacturing systems design. It is also important to consider what the industry perceives as significant, and how this issue is tackled in industry. Therefore, an industrial survey was conducted to highlight the methodologies deployed and to identify the improvements that are required regarding human factors incorporation in automated manufacturing systems design (Chapter 4).

Based on the industrial feedback it was realised that there was no specific approach deployed to incorporate human factors in the decision making process. In addition, there was sufficient feedback to illustrate the need to design a decision tool that promotes the addressing of human factors issues within the automated manufacturing systems selection criteria, in order to ensure that human factors are incorporated at the earliest stage of automated manufacturing systems design, and to highlight the shortcomings in implementation.

The key findings that were revealed from the survey include the following (section 4.7):

1. More than half of the respondents did not follow a formalised approach in selecting and designing their manufacturing systems.
2. More than half of the respondents were dissatisfied with the design process due to: informality in the design procedure, insufficient time to go through all the design phases, and insufficient consideration of implementation.
3. The respondents who were not satisfied with their decision making process reported dissatisfaction due to insufficiency in incorporating all the influential elements from the beginning.
4. Consideration of human factors in the selection and design of the manufacturing systems were actually interpreted as compliance with health and safety requirements. In addition, the macro-ergonomics issues were the least important factor in the decision making process.
5. More than half of the respondents had encountered a situation where they automated a process and then had to go back and rely on manual operation. In addition, it was during the design and implementation phases that unanticipated issues became apparent and had to be dealt with.

Objective Two: To create a decision tool to support the design of automated manufacturing systems by incorporating human factors alongside technical, organisational, and economical factors.

Based on the industrial survey results and the review of the literature (Chapter 4, 5, 6, and 7), A decision tool to support manufacturing systems designers better incorporate human factors in the design of automated manufacturing systems was created (Chapter 8).

The existing decision tools revealed from the survey were considered along with the decision tools in literature to facilitate mechanism selection. They were examined against a set of criteria. The outcome from this procedure resulted in the selection of both Quality Function Deployment and Failure Mode and Effect Analysis techniques for the mechanism of the research solution (Section 5.3). The Quality Function Deployment method was selected as an approach to determine the most appropriate alternative, and the Failure Mode and Effect Analysis method was selected to highlight the issues to be considered during design and implementation.

Furthermore, the influential elements in manufacturing systems selection, as identified from literature, were amalgamated with the industrial feedback to define the decision tool's evaluation elements and sub-elements. These evaluation elements and sub-elements addressed both human factors issues and automated manufacturing selection issues (Section 7.3). The human factors issues represented macro- and micro-ergonomic aspects whereas the automated manufacturing issues were strategic, financial, technical, integration, and safety aspects.

Accordingly, when the chosen techniques and the influential elements identified were combined, it was possible to design a decision tool that determines the appropriate automated manufacturing systems design, and identifies the human-automation interaction requirements to be embraced during implementation (Chapter 8).

Once the decision tool framework was designed, it was necessary to produce the tool in a user-friendly and comprehensible format. The outcome from this process was a decision tool that is executable in a workbook and a software application format (Section 8.5).

Objective Three: To evaluate the decision tool.

Presenting the decision tool in an operational format constituted part of the final phase of the research programme; thus, to complete the research programme and conclude this study, an industrial evaluation had to be conducted (Chapter 9). The purpose of this evaluation was to gain industrial feedback on the decision tool developed. The evaluation study involved industrial assessment and practical application.

The evaluation by comparison was performed to thoroughly evaluate the decision tool's methodology and content against leading industry practice, and this resulted in a positive outcome (Section 9.3.1). Thereafter, the evaluation by demonstration and evaluation by application was performed to assess the feasibility, usability, and usefulness of the workbook and software application which had been developed, and this also resulted in a positive outcome (Section 9.4.5 and 9.5.5).

The key findings that were revealed from the entire evaluation study include the following (Section 9.6):

1. The methodology supports addressing human factors alongside other considerations at the earliest stages of manufacturing systems design.
2. The methodology distinctively integrates the technology selection process with the risk assessment process.
3. The methodology was feasible and usable.
4. The methodology produced a useful output.

The positive outcomes and key findings from this phase demonstrate the success in completing the research programme. In addition, what has been presented in this section demonstrates that the objectives of this research study have been met.

10.3 Contribution to Knowledge

The research study presented in this thesis makes a major contribution to the subject of human factors in manufacturing systems design and a minor contribution to the subject of operations research. This section summarises both the primary and secondary contributions of this research.

10.3.1 Primary Contribution

The literature review revealed that human factors play an important part in modern manufacturing systems design, in addition to the increasing importance of addressing both macro- and micro-ergonomics in order to meet future challenges. However, there was found to be insufficient consideration of human factors early in manufacturing systems design process to enable manufacturing systems managers and designers to achieve the anticipated significant benefits.

The main outcome of this research is the creation of a decision support tool for the design of automated manufacturing systems by incorporating human factors alongside technical, organisational, and economical factors. The purpose of the developed decision tool is to assist manufacturing systems designers, through a structured approach, to better address human factors (both macro- and micro-ergonomics) and to determine their influence at the earliest stages of manufacturing systems design. This structured approach, and the content embraced within it, forms the principal research contribution of this thesis.

The principal contribution that this thesis makes to knowledge is an approach that embraces a new concept; one which brings forward human factors (macro- and micro-ergonomics) incorporation to a very early stage of manufacturing systems design, as early as the feasibility study stage, concurrently allowing further design and implementation consideration.

10.3.2 Secondary Contribution

The other contribution is the integration of both the Quality Function Deployment and Failure Mode and Effect Analysis methods in the decision-making process of the design of automated manufacturing systems. The area of application and method of integration is considered a new approach in the decision-making research domain. The high degree of industrial interest shown in the integration of these methods in a single methodology indicates the importance of this contribution.

The methodology produced uses the Quality Function Deployment method to determine the most appropriate automation alternative, and thereafter, the Failure Mode and Effect Analysis method to highlight the issues requiring attention during design and implementation. It allows the user to link the automation investment objectives with the evaluation elements and thereafter facilitate alternative selection and risk assessment. In addition, the computation procedure involved enables the user to make a rigorous assessment of the issues considered, and to gain a better understanding of their influence on the decision outcome.

10.4 Limitations of the Research

The manner in which the decision tool was designed and evaluated suggests some limitations that could affect the findings of this research. This section discusses the limitations related to the research methodology and the generaliseability of the research findings.

10.4.1 Limitations of Research Methodology

The decision tool developed was based on the findings from the literature and the information acquired from various organisations in the manufacturing industry. The research methodology used for acquiring the industrial information was a survey (face-to-face interview). This method could have been reinforced by conducting a case study to obtain greater detail and further data. This might have produced a more robust decision tool, along with addition validation of the evaluation sub-elements. However, due to limitations of access to the relevant individuals for such a case study this was considered impractical.

In addition, the evaluation programme designed for this study was able to provide a broad assessment of feasibility, usability, and usefulness. The evaluation programme could have been further enhanced by expanding the assessment criteria to allow a deeper analysis of the issues requiring further attention and a thorough testing of feasibility and usability.

10.4.2 Limitations of Research Findings

As in any research, the more cases that are used for the testing of the developed solution, the more precise the conclusion will be. In addition, the three organisations which were invited to take part in the evaluation trial could only offer a limited amount of time to conduct it. This had an influence on the scope and extent of the issues covered. Furthermore, the evaluation by application was based on one case study. Therefore, the level of generalisability of the research findings can be said to be limited due to the limited number and depth of tests. However, the evaluation feedback suggests a promising indication of industrial acceptance and potential application.

10.4.3 Limitations of Decision Tool Application

The researcher is conscious that the evaluation by application was performed in a single case study. The evaluation by demonstration pointed out weaknesses and included recommendations which were not highlighted in the evaluation by application, and this demonstrates the importance of further applications. The ideal situation would have been to conduct couple of case studies to enable a comprehensive elicitation of strengths and/or weaknesses of the proposed research solution.

Having recognised the limitations of this research, its principal findings and contribution to knowledge still stand. The evaluation results and findings demonstrate that the approach adopted is a successful step towards providing a structured methodology to assist manufacturing systems designers to incorporate human factors into automated manufacturing systems design more effectively. In addition, some of the limitations discussed provide opportunities for future research. The next section considers possible future research work.

10.5 Recommendations for Further Research

During the course of addressing the research aim and objectives, a number of areas have been identified where further research would increase the knowledge and understanding of the developed application and evaluation. This section describes the directions for further research.

10.5.1 Opportunities for Enhancing the Decision Tool Application

In Section 9.4.5.1 it was decided to preserve the reported recommendations for future work to be further investigated prior to industrial implementation. The suggestions for making the approach more workable were:

-Risk assessment process: include a clear-by date area and comment area for personal definitions of severity and likelihood levels.

-Workbook check points: include a sign-off area.

These recommended improvements are not considered to be essential from the point of view of the researcher, and they are considered minor refinements. These changes can be easily applied to the workbook format, however would need extra time and effort with the software application. Incorporating these changes in the software application would necessitate minor reprogramming of the application.

However, it is advisable to not make any changes to the tool until further evaluations have been conducted to confirm the need for the change, as these issues caused a certain amount of debate as to whether or not they should be included (Section 9.4.4.4). In addition, they were not raised in the practical application.

Another opportunity for enhancing the solution developed would be to extend the software application to include a database for future reference and analysis, thereby allowing the user to have a live document that permits amendments during project execution as well as keeping records of the actual decisions taken and issues highlighted.

10.5.2 Verification of Findings

The evaluation findings reported in this thesis provided positive evidence to demonstrate the value of continuing this study (Section 9.6). However, the findings need to be verified to provide a better understanding of the reported strengths, weakness, and concerns (Section 9.4.4 and 9.5.4). Therefore, this solution needs to be tested through more case studies and action research to verify findings and extend its generalisability.

Performing a comprehensive evaluation study through more industrial applications would permit an investigation of the feasibility and usability of the application in greater depth, as well as obtaining a greater understanding of the decision tool's strengths and weaknesses in terms of execution and performance.

10.5.3 Application in Different Environment

During the trial evaluations process two comments were made which indicate the possibility of the application of this methodology in other areas of the manufacturing decision-making process. Even though the decision tool produced in this thesis assists in the incorporation of human factors in manufacturing systems design, it is built within the setting of workstation/cell selection and assessment. However, the comments that were made concerned the use of this approach for assessing process selection as well as manufacturing organisation acquisition (Section 9.4.4.2).

These concerns can be seen as opportunities to further extend the solution's application in new settings. The methodology would remain the same; however the issues involved would require investigation and validation. This would also apply if there was interest in shifting the deployment of the decision tool from discrete manufacturing industries to process industries.

10.6 Concluding Remarks

As this research is considered to be the start rather than the end of an investigation, this chapter has concluded the research findings by describing the research programme's accomplishments with regard to the research aim and objectives. In addition, it has presented the major contributions to knowledge as well as discussing the research limitations, in order to guide and facilitate future work.

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APPENDIX A

Appendix A.1: Industrial Survey Questionnaire

Section A: General information about the establishment

This part of the interview tries to gather information on the organisation and your position.

1. Name of establishment:

....

2. Position:

....

3. Number of Employees:

A 100-499 B 500-999
C 1000-4999 D 5000-10,000
E Over 10,000

4. State the approximate annual turnover of the establishment:

....

Section B: Automation level

This section refers to the level and drivers of automation in the organisation.

5. What is your definition of automation?

....
....
....

6. What are your drivers for automation?

A. Production cost [ ]
B. Product quality [ ]
C. Flexibility [ ]
D. Productivity [ ]
E. Health & Safety [ ]
F. Agility [ ]
Others: ....

7. At which level of automation do you consider your plant?

A. High B. Medium C. Low

8. How did you judge the level of automation?

....
....
....

9. Is there a risk of over automation? **If Yes** how do you avoid over automation?
....
....
....

10. Is identifying the ideal level of automation an area of concern to your organisation? **If Yes** could you indicate why?
....
....
....

Section C: Manufacturing system design

This section refers to the main methods and tools used in the formulation of the manufacturing system

11. Do you follow a structured methodology (e.g IDEFO) when designing your manufacturing system? **If Yes** could you state the method?
....
....

12. Who was involved in the design?
....
....

13. Was an external party used to support the design of the manufacturing system? **If Yes** could you state the name of the organisation?
....

14. What factors were concentrated on in the design?
....
....
....

15. Is the current efficiency and productivity as expected from the investment? **If No** could you state why not?
....
....
....

16. Are you satisfied with the current manufacturing design procedure? **If No** could you state why not?
....
....
....

Section D: Human factors issues

This section refers to the amount of human consideration in the plant.

17. How many operators work in the production floor?
....

18. What is the ratio between automated work station and manual work station?

A. More than 5:1 [ ]
B. Between 5:1 and 2:1 [ ]
C. Between 2:1 and 1:2 [ ]
D. Between 1:2 and 1:5 [ ]
E. Below 1:5 [ ]

19. Did you consider Human factors and Ergonomics in the decision and design of manufacturing system? **If Yes** could you state how?
....
....
....

20. Do you think that this is enough? **If No** could you state why not?
....
....
....

21. Are you satisfied with the existing human interaction and integration in your manufacturing plant? **If No** could you state why not?
....
....
....

Section E: Automation decision making

This section refers to the decision making process and influential elements.

22. What is the decision making process in your organisation towards manufacturing systems selection? And is it a formalised process?
....
....
....
....

23. Who is involved in the decision?
....
....

24. Could you select **and** state the degree of importance of the following criteria used in the decision making? *On a scale from 1 to 5 (with 5 meaning very important)*

A. Organisation vision and mission [ ]
B. Technical implications [ ]
C. Quantitative financial measures [ ]
D. Qualitative strategic objectives [ ]
E. Safety implications [ ]
F. Social factors [ ]
G. Market environment [ ]
H. Production demand [ ]
I. Government laws and regulations [ ]
Others:...

25. What type of financial justification is used in the decision making process?

A. NPV (Net Present Value) [ ]
B. IRR (Internal Rate of Return) [ ]
C. B/C Ratio (Benefit-Cost Ratio) [ ]
D. Payback Period [ ]
E. MMARR (Modified Minimum Annual Revenue Requirement) [ ]
Others:...

26. Did you use support tools/models in the decision making (e.g AHP)? **<u>If Yes</u>** could you state them?
....
....
....

27. Are you satisfied with the existing decision making process? **<u>If No</u>** could you state why not?
....
....
....

28. Have you encountered a situation where you automated a process and it did not match with the operator's skills or work pattern? **<u>If YES</u>** could you state what happened?
....
....
....

29. If a formalised Decision Making process that incorporated Financial, Technical, and Human issues was developed would you use it? **<u>If YES</u>** could you state why?
....
....
....

Appendix A.2: Ethics Committee Consent Letter

ax to 01234 750192 F.A.O Tricia Jolly

Human Factors PhD Research
Ethics Proposal

dent: Bader Al-Mannai
ervisor: Professor J Kay
te: 20 November 2003
le of Project Design of Manufacturing System Model

e the following ethical issues been satisfied?

	Yes	No	N/A	Comments
Consent	✓			
Deception	✓			
Debriefing	✓			
Withdrawal	✓			
onfidentiality	✓			
rotection	✓			
Observational			✓	
ther			✓	

rall comments/feedback:

~~e de~~lete as appropriate:
ept/Reject/Accept, subject to the following changes

ics Committee Member

e DR KEITH MASON **Signature** [signature] **Date** 25/11/03

Appendix A.3: Industrial Survey Participation Letter

School of Industrial & Manufacturing Science

Cranfield UNIVERSITY

Cranfield University
Cranfield
Bedfordshire MK43 0AL
England
Tel +44 (0) 1234 750111
Fax +44 (0) 1234 750875
http://www.cranfield.ac.uk/sims

Name/Operation Manager,
Comp. addr.

22nd Oct 2003

Dear [ ],

I am a PhD research student at Cranfield University in the Department of Manufacturing Systems.

My research deals with the level of automation used in manufacturing. I am to produce a methodology that will aid managers when planning a manufacturing facility to identify the optimum level of automation. This area is currently receiving a lot of attention in manufacturing automation organisations. The results of this work will help in improving productivity and cost effectiveness. Consequently, I would greatly appreciate your co-operation and participation.

I would be grateful for the opportunity to meet you to discuss issues such as: the number of operators working on a machine, the total number of manual and automated machines and the decision making criteria that you use when planning automation. The interview should not take more than an hour of your time.

I will contact you in ten days time to see if you are able to participate in the interview. Alternatively you may contact me via the contact details below.

Thank you very much for your time and I look forward to hearing from you.

Yours Faithfully,

Bader Mannai

Mr. Bader Mannai,
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Appendix A.4: Interview Protocol Document

Intro:

- First of all I would like to thank you for giving me this opportunity to interview you and take some of your time.

- To introduce my self my name is Bader Mannai. I am a PhD student at Cranfield University, prior to this I did my master in quality management and my bachelor's degree was in manufacturing management.

Warm up:

- I am researching in automation decision making to investigate human factors influence to enable organisations understand how much to automate.
- As an initial stage of this research I am conducting interviews with officials who are involved in the operations and manufacturing systems decision making process.
- My aim from this interview is to gain an overview and understanding of the process and influential issues related to your automation decision making.
- Before we start I would like to assure you that the interviewee and the information collected shall be treated strictly confidential and shall not be used for any purpose other than that of this research.
- I would like to assure you the participant's anonymity and right to withdraw from the interview at anytime.
- It is important to indicate to you that I am interested in your opinion and personal experience, thus there is no right and wrong answer.
- Can I have your permission to tape-record the interview; this will help increase the reliability of data analysis.

Main interview

- Quick indication of the sections.
- Start interview

Closure

- Your kind participation in this research will help me in identify and documenting the current practice and issues to focus on in automation decision making.
- I would like to ask you whether or not you would like to be contacted to in the future to get feedback and assist in this research.
- Again, thank you very much.

APPENDIX B

Appendix B.1: Manufacturing Automation Decision-Making Workbook

Manufacturing Automation Decision-Making Workbook

A Practical Approach to Address
Technology, Organisation, and People

Foreword

This Manufacturing Automation Decision-Making Workbook has been produced as part of a PhD programme, which offers manufacturing organisations a new approach to improve the automation decision by addressing the right proportions of technical, organisational, and human factor issues at the earliest stages of manufacturing automation decision-making.

Manufacturing automation investments are critical decisions that can result in great financial gains or losses. Thus, the manufacturing systems designers need frameworks not only for supporting decision-making, but also for understanding how their decisions affect the organisation as a whole.

The assessment process is built on the fundamental concept that technology is seen as only one aspect of an interdisciplinary strategy in which people and organisation are key elements. Consequently, improving the balance between the relative importance of technology, organisation and people in the decision-making process will have a knock-on effect in improving manufacturing systems selection and design process.

The framework outlined in this workbook has been designed with the intention of meeting this need. It is a step-by-step guideline that allows the decision maker to conduct a sound feasibility study of the automation alternatives and pinpoint obstacles for consideration during planning and implementation.

The workbook is not a technical manual, so it does not include a detailed analysis of the decision-making and assessment criteria incorporated. In addition it can be used by all sizes of businesses, to aid them in making the right decision and be prepared for implementation.

Contents

Introduction

Today's manufacturing environment is vulnerable to disturbance and is increasingly shaped by technology. The way in which people and organisations are considered can shape either excellence in such an environment, or the diminishment of opportunities.
Therefore, in association with the ongoing research to bridge the gap between technology, organisation, and people in manufacturing systems design to adapt to new challenges, a manufacturing automation decision-making aid workbook has been developed.

The structure in which the workbook is synchronised allows the user to link management's automation investment objectives with technology, organisation, and human factors evaluation to determine the best alternative, and thereafter, to conduct a risk assessment to draw attention to any problems that might be associated with that option in terms of design and implementation.

The techniques deployed in this workbook are generic and are intended to consist of managerial parameters that are strategically valuable to many organisations, allowing the technology selection and evaluation process to be aligned with the human-centred concept and performed by either novice or veteran technology evaluation personnel.

Who is this workbook for?

This workbook is aimed at manufacturing systems designers in manufacturing companies. It is for those who wish to ensure that their automation decisions and actions are consistent with their business needs and organisational infrastructure. In short, this workbook is designed to provide a framework to guide, inform and support the user through the decision-making process for manufacturing automation acquisition.

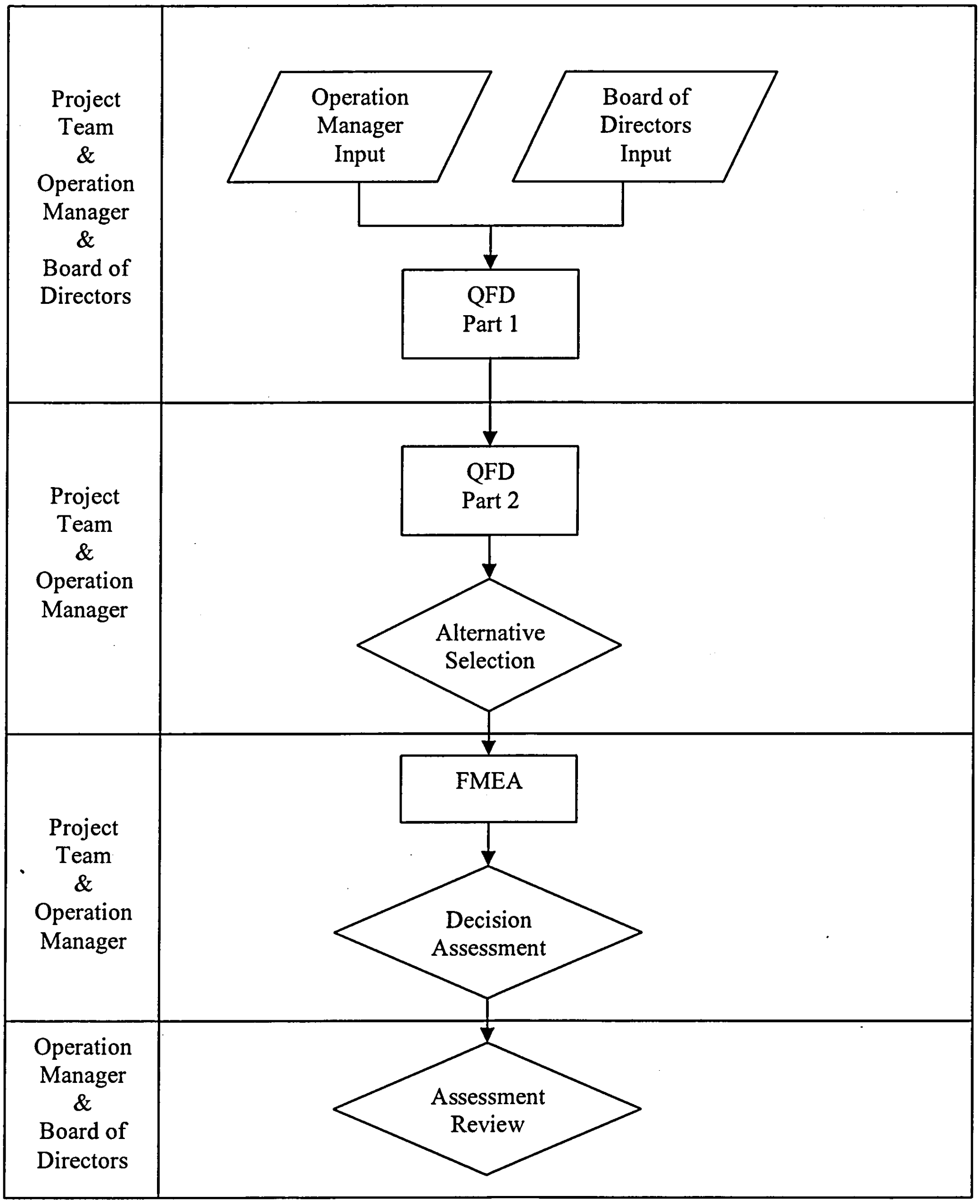
Benefits of using this workbook

The main benefits will be:

- A coherent decision-making process that addresses strategic, financial, technical, organisational, and people issues.
- Linking automation investment drivers with technology, organisation, and people evaluation elements for the selection of the best alternative.
- A decision-making process that pays equal attention to human factors as to technical factors.
- A rapid way of determining the most suitable automation alternative and its associated risks.

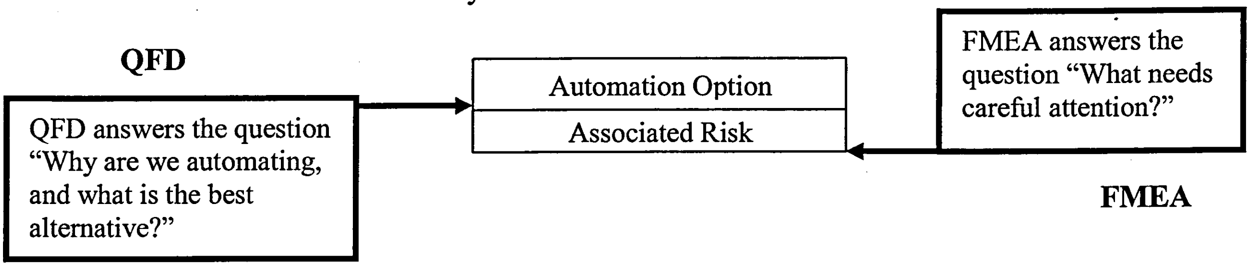
Workbook Structure

The process described in the workbook is designed to be carried out as an individual task. However, some of the activities within the workbook are best executed with the aid of a project team, as shown below. The workbook structure compromises four phases. Each phase consists of the activities, outcomes, people involved, and relevant techniques. The workbook describes how to carry out each phase and what is expected as a result. In addition, it provides all the materials that the user will need to guide and shape his/her decision.



Tools Deployed

QFD: Quality Function Deployment
FMEA: Failure Mode Effects Analysis



Workbook Tips

This symbol suggests ways to carry out a particular task.

This symbol will refer you on to the annex at the back of the workbook. These will refer you to other sources of information, as well as providing more details on various topics.

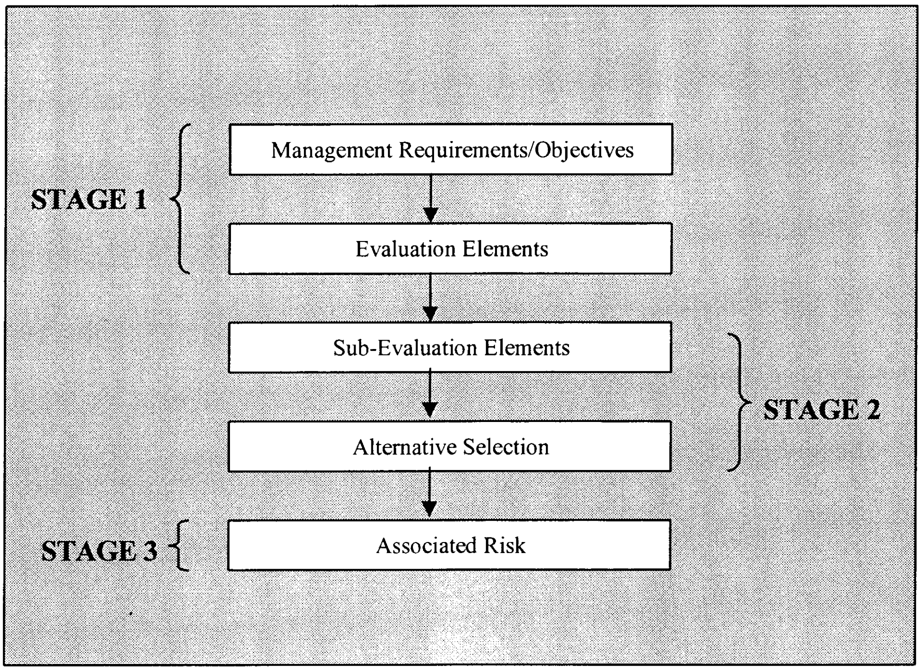
Starting Points

The process as described in the workbook structure follows a logical, simple, incremental sequence in which most parts build on input in the form of decisions made and information acquired in a previous part.

The sequential flow for this framework can be hierarchically categorised into three stages as follows:

- Stage 1: Linking automation investment drivers with evaluation elements.
- Stage 2: Automation alternative selection.
- Stage 3: Decision risk assessment.

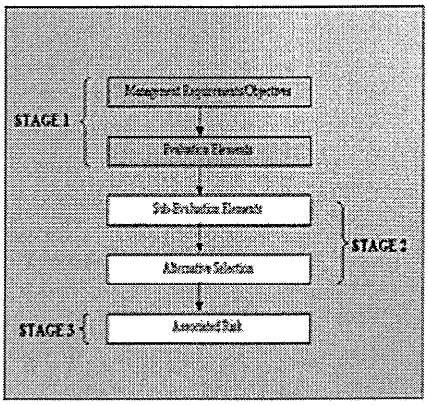
The first stage starts with the operation manger/directors and their needs and relates their needs to system evaluation elements. The second stage follows through the evaluation elements and magnifies them into sub-evaluation elements for selection of the best alternative. The third stage deploys the selected alternative evaluation data for facilitating associated risk investigation, as shown below.



At the end of each stage, space is provided to check that all actions have been carried out and to record personal and team reflection of activities, achievements, and future actions. The captured knowledge is useful for cross-referencing and future decisions. In addition, a simple example is presented to support the user's comprehension.

STAGE 1

Linking Automation Investment Drivers with Evaluation Elements



The purpose of the first stage is to determine the relevance of the evaluation elements in relation to management's needs. The user gathers and prioritises the automation investment objectives from the stakeholders involved in the investment, and then places the data into the QFD (Quality Function Deployment) matrix to establish relationships between the needs and the evaluation elements. The matrix computation will enable the user to see how much influence each evaluation criterion will have on the decision-making process.

<u>STEP 1</u>

What are your automation investment drivers?

The starting point is to identify and define the automation investment drivers. Such a process will involve the analysis of the core purpose of this investment. In addition, it will require the review of strategic, financial, technical, organisational, and people gains/requirements.

<u>Actions</u>

- Identify and define the quantitative and qualitative automation investment objectives/requirements.

<u>Source of Input</u>

- Board of Directors
- Operation Manager

In addition, the people who will be affected by the decision can be perceived as valuable sources who can contribute to determining the automation investment objectives/requirements. The following is a list of potential people to consult.

- Clients
- Suppliers
- Cross functional departments
- Employees

To facilitate this activity a brainstorming session is recommended. More information on brainstorming is given in the Annex.

STEP 2

Deploy the first part of QFD

The first part of the QFD application takes place here. This step involves constructing the House of Quality matrix.

Actions

- Use Profile 1 to construct a House of Quality matrix.

Profile 1

			Evaluation Elements							
		Automation Investment Drivers	Strategic Justification	Financial Justification	Systems Integration	Technology & Organisation Integration	Technical Justification	Technology & People Integration	Safety Justification	Ranking of Importance
Objectives/Requirements	Strategic									
	Tactical									
	Operational									
		Total								
		Normalised								

Project Details	Project Title:	
	Project Official:	
	Remarks:	
	Options:	

QFD Worksheet – Part 1

Objectives/Requirements	Automation Investment Drivers	Strategic Justification	Financial Justification	Systems Integration	Technology & Organisation Integration	Technical Justification	Technology & People Integration	Safety Justification	Ranking of Importance
		Evaluation Elements							
Strategic	Quality reputation	9				9			5
	Aspirational products	9		1	1	9			4
Tactical	Reduce time to market	9		3	1	9	1		3
	Reduce unit cost	9	3	3		9	3		5
	Quick payback period	3	9						5
	(1)				(3)				(2)
Operational	Advanced CAD/CAM system			3		9			3
	Precision mouldings					9			4
	Hybrid automation in assembly			9	3	9	9		4
	Improve working conditions					1	9	9	2
	Total	168	60	73	19	254	72	18	(4)
	Normalised	25%	9%	11%	3%	38%	11%	3%	(5)

Project Details		
	Project Title:	Aluminume detail machining cell selection
	Project Official:	Kevin M.
	Remarks:	Three options avialable
	Options	OPT 1: Semi-Auto Type A, OPT 2: Fully Auto, OPT 3: Semi-Auto Type B

Example of QFD Worksheet – Part 1

STEP 3

Categorise and prioritise your automation investment drivers list

This step involves categorising and prioritising the list to ease the data input into the QFD matrix. The investment objectives/requirements will include a jumbled combination of qualitative and quantitative needs that belong to different organisation levels. Consequently, the user should categorise these objectives into the following sections: strategic, tactical, and operational. However, as for prioritising these objectives a simple rating scale of 5 to 1, 5 being extremely important, is to be used.

Actions

- State the automation investment requirements/objectives at strategic, tactical, and operational levels in the automation investment drivers table (cell 1) (text format).
- Evaluate the importance of each automation investment driver. Insert the importance scale (5 to 1) in the ranking table (cell 2) (numeric value).

Source of Input

- Brainstorming outcome

To facilitate the weighting process a written description of the rating is given in the Annex.

STEP 4

Identify relationships between investment drivers and evaluation elements

This step involves completing the central part of the house matrix. The investment drivers are matched against the evaluation elements, to determine the relevance of the evaluation elements in relation to management's needs. The user inserts a score in the appropriate matrix location according to the scale of relationship, 9 for a strong relationship, 3 for a moderate relationship, and 1 for a weak relationship.

Actions

- Determine the strength of the relationships between drivers and evaluation elements. Insert the relationship strength value (9 to 1) in the relationship matrix (cell 3) (numeric value).

The evaluation elements and scale of evaluation description is given in the Annex.

STEP 5

Determine the importance of the evaluation elements

This step involves the computation of the relationship scores on each evaluation element to determine importance. The user starts the calculation process by multiplying the scores of the relationship with the weights of the drivers. Thereafter, the summation of each evaluation element takes place to establish the total score. Finally, the total score of each element is normalised.

Actions

- Evaluate the importance of the evaluation element. Insert the row weight (numeric value) in the total table (cell 4). The importance can be expressed by the following equation:

$$\text{Row Weight} = \Sigma\ (\text{Rank of Importance})\ X\ (\text{Strength of Match})$$

E.g. Row Weight (System Integration) = (1 X 4) + (1X 3) + (3X 4) = 19

- Normalise the evaluation element importance value. Insert the normalised weight (numeric value) in the normalised row (cell 5). The normalisation can be expressed by the following equation:

$$\text{Normalised Weight} = \frac{(\text{Evaluation Element Importance})\ X\ 100}{(\text{Total Evaluation Element Importance})}$$

E.g. Normalised Weight (System Integration) = $\frac{19\ X\ 100}{667}$ = 3%

Stage 1 Checklist

Tick

Tick	
Yes ○	❖ If you were able to link the automation investment objectives with the evaluation elements and determine their importance.
No ○	❖ If you feel you were not able to link the objectives with the evaluation elements and determine their importance. You will need to re-examine the relationships between the objectives and evaluation elements more thoroughly.

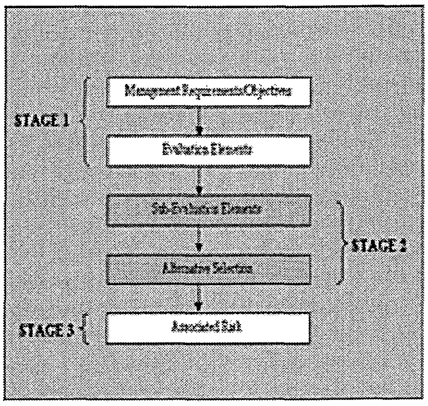
Stage 1 Hints

- ❈ Aim to ensure that the main automation objectives are addressed.
- ❈ Be very broad minded when linking automation objectives with evaluation elements.

Comments:

STAGE 2

Automation Alternative Selection



The aim of the second stage is to identify the best alternative. In this stage the results are transformed from the first QFD matrix to the second matrix to represent the sub-evaluation elements importance ranking. The second matrix computation will enable the user to evaluate the alternative options against the sub-evaluation elements, in order to identify the most suitable option.

STEP 1

Deploy the second part of QFD

The succeeding part of the QFD application takes place here. This step involves constructing the second QFD matrix. In this step the main evaluation elements are decomposed and rephrased to facilitate the evaluation of the alternative automation investments.

In addition, this step involves transferring the evaluation elements importance values from the first QFD worksheet, and are located in the table called "rank of importance" in the second QFD worksheet.

Actions

- Use Profile 2 to construct the second part of the QFD application.
- Transfer the normalised weight (numeric value) from the first QFD worksheet to the ranking of importance table (cell 1) (Numeric value).

Source of Input

- The normalised evaluation elements importance from Stage 1 (outcome of step five).

Profile 2

	Elements	Sub-Elements	Manufacturing Automation Options					
			OPT 1	OPT 2	OPT 3	OPT 4	OPT 5	Ranking of Importance
Evaluation Elements	Strategic	Support short- term strategic manufacturing objectives						
		Support long- term strategic manufacturing objectives						
	Financial	Acceptable economic justification results						
		Acceptable investment cost						
		Acceptable unit cost						
		Acceptable instillation cost						
		Acceptable operation cost						
	Systems Integration	Feasible to integrate with existing manufacturing hardware systems						
		Feasible to integrate with existing manufacturing software systems						
	Technology & Organisation Integration	Compatible with organisation work procedure						
		Compatible with organisation structure						
		Compatible with work group						
		Compatible with personnel polices						
		Compatible with current job design						
	Technical	Acceptable productivity specifications						
		Acceptable flexibility specifications						
		Acceptable quality specifications						
		Acceptable support and test equipment						
		Acceptable maintainability specifications						
		Acceptable technology supplier						
		Acceptable longevity						
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics						
		Machine physical workload specification compatible with user's physical characteristics						
		Machine mental workload specification compatible with user's mental capabilities						
		User/machine interface specification compatible with user's physical and mental capabilities						
	Safety	Comply with machinery safety regulations						
		Comply with work environment safety regulations						
		Total						

QFD Worksheet - Part 2

			Manufacturing Automation Options					
	Elements	Sub-Elements	OPT 1	OPT 2	OPT 3	OPT 4	OPT 5	Ranking of Importance
Evaluation Elements	Strategic	Support short- term strategic manufacturing objectives	9	3	3			25%
		Support long- term strategic manufacturing objectives	9	3	9			
	Financial	Acceptable economic justification results	3	-3	3			9%
		Acceptable investment cost	9	1	3			
		Acceptable unit cost	9	9	9			
		Acceptable instillation cost	3	-3	3			
		Acceptable operation cost	3	-1	3			
	Systems Integration	Feasible to integrate with existing manufacturing hardware systems	-1	9	1			11%
		Feasible to integrate with existing manufacturing software systems	3	9	1			
	Technology & Organisation Integration	Compatible with organisation work procedure	3	3	3			3%
		Compatible with organisation structure	3	-3	-3			
		Compatible with work group	-3	-3	-1			
		Compatible with personnel polices	-1	-1	1			
		Compatible with current job design	3	9	-3			
	Technical	Acceptable productivity specifications	9	9	9			38%
		Acceptable flexibility specifications	-9	9	-1			
		Acceptable quality specifications	9	-1	9			
		Acceptable support and test equipment	3	-3	-3			
		Acceptable maintainability specifications	9	3	3			
		Acceptable technology supplier	9	-1	3			
		Acceptable longevity	3	9	3			
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics	9	3	3			11%
		Machine physical workload specification compatible with user's physical characteristics	3	3	3			
		Machine mental workload specification compatible with user's mental capabilities	-1	-3	-3			
		User/machine interface specification compatible with user's physical and mental capabilities	3	3	3			
	Safety	Comply with machinery safety regulations	3	1	3			3%
		Comply with work environment safety regulations	3	1	1			
		Total	21.56	14.12	14.54			

1 2 3

Example of QFD Worksheet - Part 2

STEP 2

Evaluate the alternative automation options

This step involves evaluating the alternative automation investments against the sub-evaluation elements. It refers to completing the central part of the matrix. The user inserts a score in the appropriate matrix location according to the scale of acceptance; 9 for strongly acceptable, 3 for moderately acceptable, and 1 for slightly acceptable. However, as there is a possibility of disapproval, a negative scoring is utilised; -1 for slightly unacceptable, -3 for moderately unacceptable, and -9 for strongly unacceptable.

Actions

- Evaluate each investment option against the sub-evaluation elements. Insert the satisfaction strength value (9 to -9) in the relationship matrix (cell 2) (numeric value).

To facilitate the evaluation process a written description of the sub-evaluation elements and scale of evaluation description is given in the Annex.

STEP 3

Determine the best alternative

This step is similar to step five in Stage 1. It involves the computation of the evaluation scores on each alternative to determine the best alternative. The user starts the calculation process by multiplying the scores of the evaluation with the weights of evaluation elements. Thereafter, the summation of each alternative takes place to establish the total score. The alternative with the highest total score represents the best automation option.

Actions

- Determine the most suitable automation investment alternative. Insert the row weight (numeric value) in the total table (cell 3). The computation process is expressed by the following equation:

  Row Weight = Σ (Rank of Importance) x (Strength of Satisfaction)

  E.g. Row Weight (Alternative 1) = (0.25 X 9) + (0.25 X 9) + (0.09 X 3) + (0.09 X 9) + (0.09 X 9) + (0.09 X 3) + (0.09 X 3) + (0.11 X -1) + (0.11 X -3) + (0.03 X 3) + (0.03 X 3) + (0.03 X -3) + (0.03 X -1) + (0.03 X 3) + (0.38 X 9) + (0.38 X -9) + (0.38 X 9) + (0.38 X 3) + (0.38 X 9) + (0.38 X 9) + (0.38 X 3) + (0.11 X 9) + (0.11 X 3) + (0.11 X -1) + (0.11 X 3) (0.03 X 3) + (0.03 X 3) = 21.56

Stage 2 Checklist

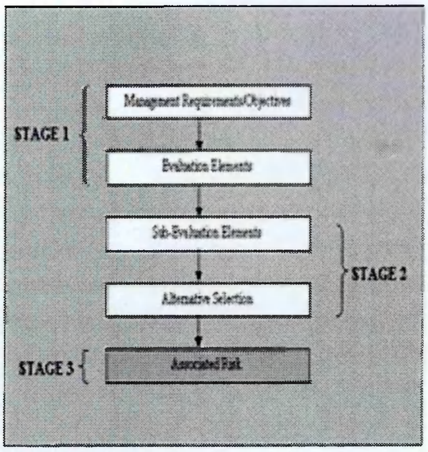
Tick	
Yes ○	❖ If you were able to determine the most suitable automation alternative.
No ○	❖ If you feel you were not able to determine the best automation alternative. You will need to review the evaluation scoring of the alternatives using the written description of the sub-evaluation elements in the Annex.

Stage 2 Hints

- ❋ Each alternative has benefits and drawbacks, so avoid rushing the evaluation process.
- ❋ To ensure equal treatment, try to address each issue at the same time for each automation option.
- ❋ Refer to the outlined evaluation measures in the Annex to assist you in the scoring.
- ❋ Keep a list of trade-offs.

It is important to record any personal or team comments regarding the alternatives evaluation outcome as it can be useful for future cross-referencing and decisions.

Comments:



STAGE 3

Decision Assessment

The purpose of the third stage is to identify the risks associated with the selected alternative. In this stage the selected alternative evaluation data from the second QFD worksheet is transferred to the FMEA (Failure Mode Effects Analysis) worksheet to indicate any potential problems. Any negative scores within the data are used to pinpoint the potentially troublesome areas for special attention. The outcomes from this final stage are the potential problems and degrees of associated risk for future action.

STEP 1

FMEA deployment

In this step the FMEA technique is deployed to identify the risks associated with the selected alternative. It involves constructing a Failure Mode Effects and Analysis table. In this table the main and sub-evaluation elements are utilised to facilitate the assessment of the best alternative.

In addition, this step involves transferring the chosen alternative data from the second QFD worksheet to the FMEA table column called 'selected option [ ]'.

Actions

- Use Profile 3 to construct the FMEA table.
- Transfer the selected alternative row data (numeric value) from the second QFD worksheet to the selected option data column (cell 1) (numeric value).

Source of Input

- The row data of the selected alternative from Stage 2 (outcome of step 2).

Profile 3

	Elements	Sub-Elements	Potential Problem	Potential Effect(s) of Problem	Selected Option [ ]	Severity	Potential Cause(s) of Problem	Likelihood of Problem	Recommended Action & Responsibility	RPN (sub-element)	RNP (element)	Normalised RPN
Evaluation Elements	Strategic	Support short- term strategic manufacturing objectives										
		Support long- term strategic manufacturing objectives										
	Financial	Acceptable economic justification results										
		Acceptable investment cost										
		Acceptable unit cost										
		Acceptable instillation cost										
		Acceptable operation cost										
	Systems Integration	Feasible to integrate with existing manufacturing hardware systems										
		Feasible to integrate with existing manufacturing software systems										
	Technology & Organisation Integration	Compatible with organisation work procedure										
		Compatible with organisation structure										
		Compatible with work group										
		Compatible with personnel polices										
		Compatible with current job design										
	Technical	Acceptable productivity specifications										
		Acceptable flexibility specifications										
		Acceptable quality specifications										
		Acceptable support and test equipment										
		Acceptable maintainability specifications										
		Acceptable technology supplier										
		Acceptable longevity										
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics										
		Machine physical workload specification compatible with user's physical characteristics										
		Machine mental workload specification compatible with user's mental capabilities										
		User/machine interface specification compatible with user's physical and mental capabilities										
	Safety	Comply with machinery safety regulations										
		Comply with work environment safety regulations										

FMEA Table

	Elements	Sub-Elements	Potential Problem	Potential Effect(s) of Problem	Selected Option |1|	Severity	Potential Cause(s) of Problem	Likelihood of Problem	Recommended Action & Responsibility	RPN (sub-element)	RNP (element)	Normalised RPN
Evaluation Elements	Strategic	Support short- term strategic manufacturing objectives			9							0
		Support long- term strategic manufacturing objectives			9							
	Financial	Acceptable economic justification results			3							0
		Acceptable investment cost			9	(1)						
		Acceptable unit cost			9							
		Acceptable instillation cost	(2)	(3)	3			(4)				
		Acceptable operation cost			3							
	Systems Integration	Feasible to integrate with existing manufacturing hardware systems	Require changes in feed rate settings	Flow obstruction	-3	5	Higher output rate specifications	5	Add feed magazine, Operation Dept. (John Tate)	25	25	44%
		Feasible to integrate with existing manufacturing software systems			3							
	Technology & Organisation Integration	Compatible with organisation work procedure			3		(5)		(6)	(7)	7.5	13%
		Compatible with organisation structure			3							
		Compatible with work group	Require changes in work group number	Resistance to new technology	-3	3	Less operators required	2	Relocate excess staff, Personnel Dept. (Peter Mathew)	6		
		Compatible with personnel polices	Additional skills	Lower quality consistency and resistance	-1	3	Job rotation, labour turnover	3	Additional training and re-grading , Personnel Dept. (Steve Shore)	9		
		Compatible with current job design			3							
	Technical	Acceptable productivity specifications			9						20	35%
		Acceptable flexibility specifications	Low volume flexibility	Difficulty in meeting market demand	-9	4	Not economical for low quantity	5	Part grouping , Industrial Engineering Dept. (Paul Wisker)	20		
		Acceptable quality specifications			9							
		Acceptable support and test equipment			3							
		Acceptable maintainability specifications			9						(8)	
		Acceptable technology supplier			9							(9)
		Acceptable longevity			3							
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics			9						4	7%
		Machine physical workload specification compatible with user's physical characteristics			3							
		Machine mental workload specification compatible with user's mental capabilities	Extra time to learn and adapt to new software	Increase operation time and lower consistency	-1	2	Steep learning curve	2	Additional job training, Personnel Dept. (Steve Shore)	4		
		User/machine interface specification compatible with user's physical and mental capabilities			3							
	Safety	Comply with machinery safety regulations			3							0
		Comply with work environment safety regulations			3							

Example of FMEA Table

STEP 2

Determine the potential problems with the selected alternative

Unlike conventional FMEA applications, this technique is deployed to specify the potential problems with selecting this alternative. Therefore, the QFD evaluation analysis is utilised to facilitate this process. The data with negative values are indicators of where the user should start identifying the problem modes and their effects.

Actions

- Using the selected alternative negative data as indicators for potential problems, state the problem modes, their effects, and their causes. State the problem mode in the potential problem column (cell 2), the effects in the potential effects of problem column (cell 3), and the causes in the potential causes of problem column (cell 4) (text format).

STEP 3

Specify the severity of the potential problems and the likelihood of occurrence

This step involves determining the severity and likelihood rating. The severity rating is an estimation of how serious the effects would be should a problem arise, whereas the likelihood rating is an estimation of how likely a problem mode is to occur. Both ratings are based on a 5-point scale, with 5 being the highest and 1 being the lowest rating. A combination of expertise and knowing the potential cause is used to estimate the values.

Actions

- Assess potential problem severity. Insert the severity rate (5 to 1) in the severity column (cell 5) (numeric value).
- Assess the likelihood of the potential problem. Insert the likelihood rate (5 to 1) in the likelihood of problem column (cell 6) (numeric value).

To facilitate the rating process a written description of the severity and likelihood scale is given in the Annex.

STEP 4

Determine recommended action

This step involves recommending future actions to eliminate or reduce these problems. In addition, the recommendation will also be accompanied by a description of the body responsible for implementation.

Actions

- State future actions and responsibility for implementation in the recommended actions and responsibility column (cell 7) (text format).

STEP 5

Calculate the Risk Priority Number (RPN)

The potential problem Risk Priority Number within the sub-evaluation elements is calculated first, by multiplying the severity rating by the likelihood rating, as in a standard FMEA procedure. Then it is tallied and divided by the number of sub-evaluation elements reviewed, to preserve equal representation and obtain the elements Risk Priority Number. Thereafter, they are normalised, to aid the user in determining the significance of the areas that need reviewing during project planning and implementation.

Actions

- Calculate the potential problem Risk Priority Number within the sub-evaluation elements. Insert the sub-evaluation element risk priority number (numeric value) in the RPN (sub-evaluation element) column (cell 8). The prioritisation can be expressed by the following equation:

  Risk Priority Number (sub-evaluation element) = (Severity Weight) x (Likelihood Weight)

  E.g. Risk Priority Number (Work group) = 3 X 2 = 6

- Sum the sub-criterion Risk Priority Numbers in each criterion and divide by the number of sub-evaluation elements reviewed. Insert the criterion Risk Priority Number (numeric value) in the RPN (evaluation element) column (cell 9). The prioritisation can be expressed by the following equation:

$$\text{RPN (Criterion)} = \frac{\Sigma\,\text{(Sub-evaluation element RPN)}}{\text{Number of Sub-Evaluation Elements Reviewed}}$$

E.g. RPN (Technology & Organisation Integration) $= \frac{6+9}{2} = 7.5$

- Normalise the Risk Priority Number for each evaluation element. Insert the normalised criterion Risk Priority Numbers (numeric value) in the normalised RPN column (cell 10). The normalisation can be expressed by the following equation:

$$\text{Normalised RPN (Criterion)} = \frac{\text{RPN (Evaluation Element)} \times 100}{\Sigma \text{ RPN (Evaluation Element)}}$$

E.g. Normalised RPN (Technology & Organisation Integration) $= \frac{7.5 \times 100}{56.5} = 13\%$

STEP 6

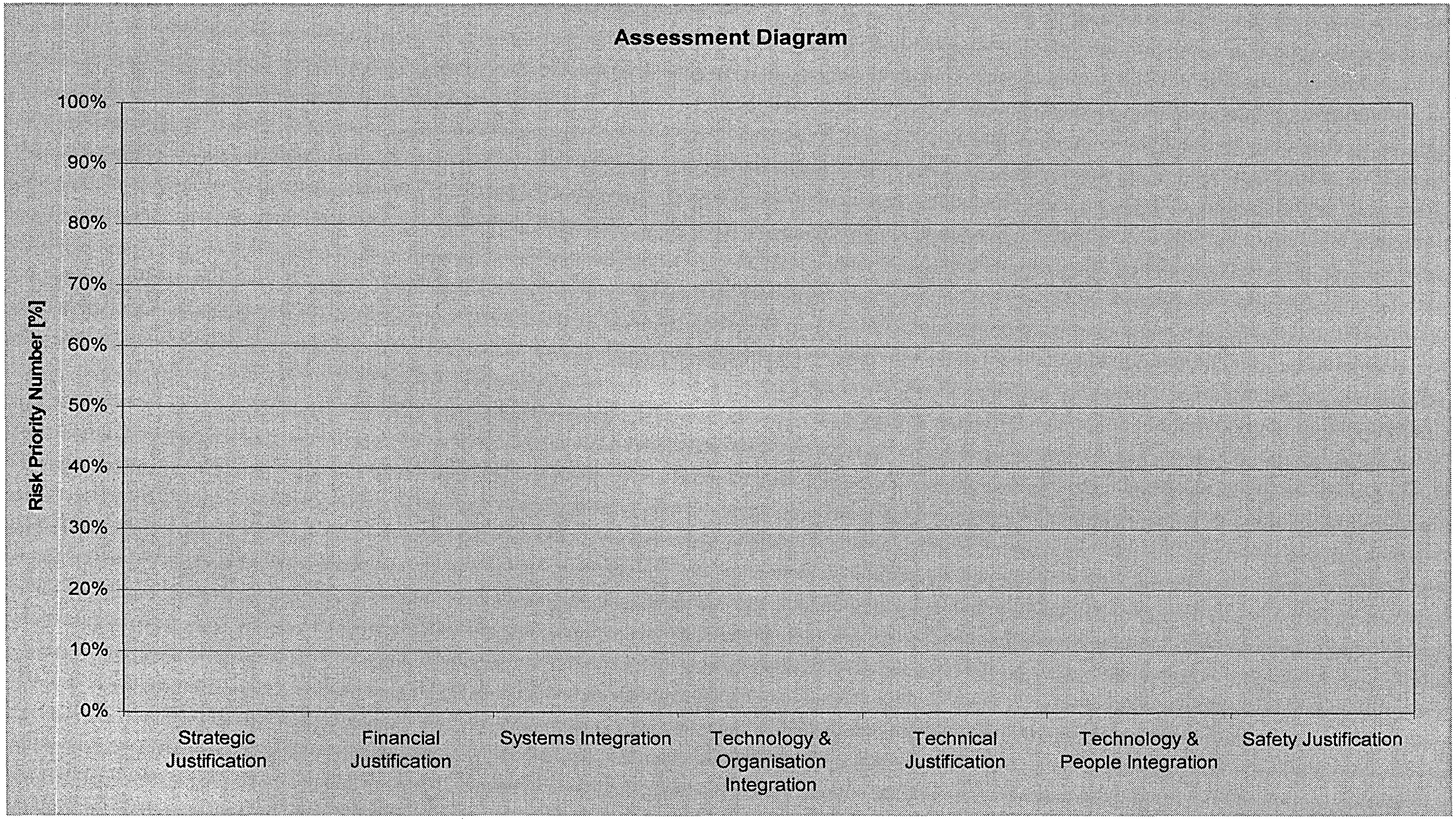
Draw the decision assessment diagram

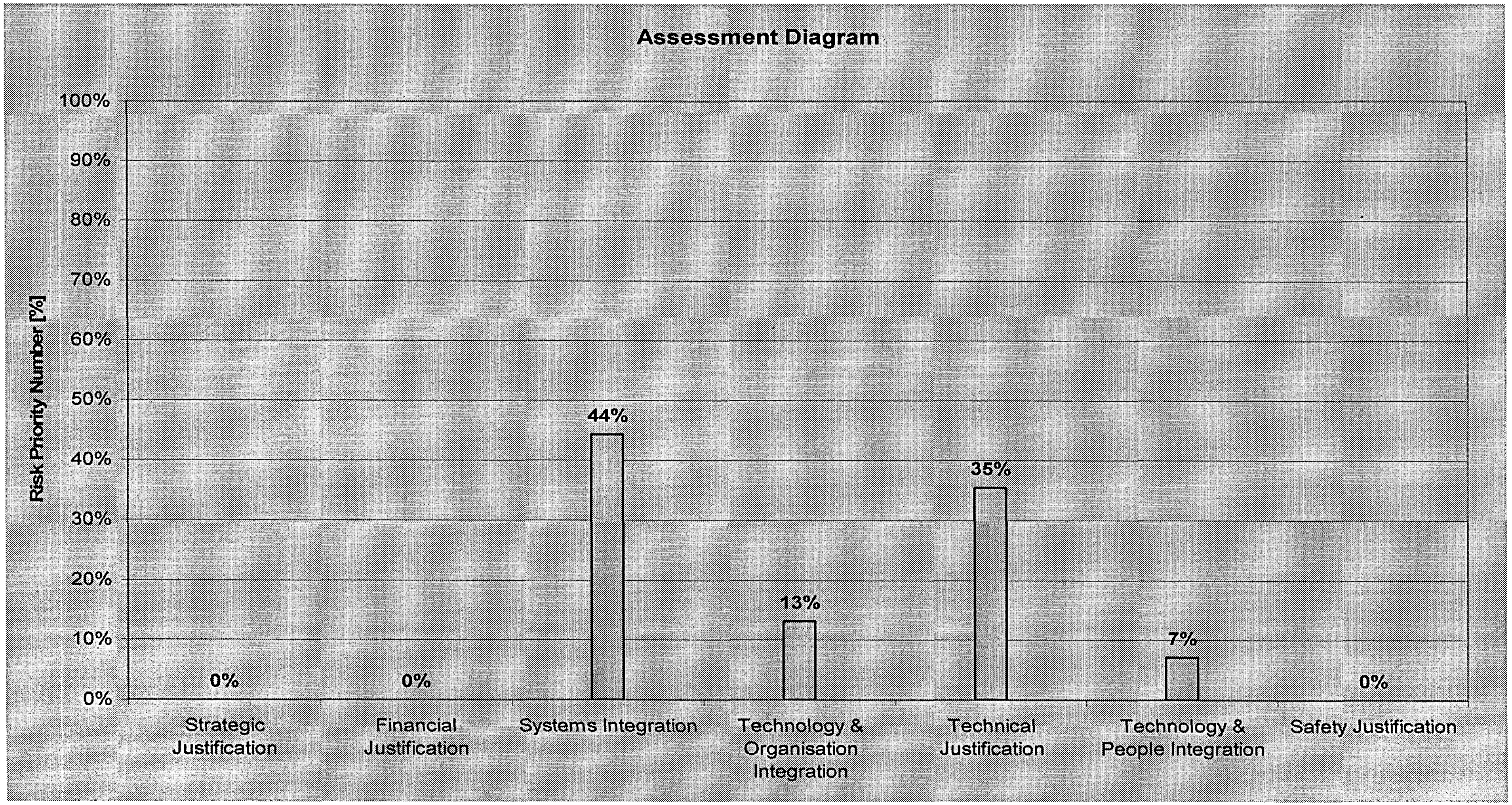
This step is an outline representation of the outcome from the decision assessment process. It is an overview of the main assessment areas and status. The normalised Risk Priority Numbers are utilised to depict those areas which are potentially troublesome.

Actions

- Use Profile 4 to construct the assessment diagram.
- Use the normalised RNP values (numeric value) from the FMEA table to draw the assessment results.

Profile 4


Assessment Diagram
Risk Priority Number [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Strategic Justification
Financial Justification
Systems Integration
Technology & Organisation Integration
Technical Justification
Technology & People Integration
Safety Justification



Example of Assessment Diagram

Stage 3 Checklist

Tick

Tick	
Yes ○	❖ If you were satisfied with the decision assessment outcome.
No ○	❖ If you feel you were not satisfied with the decision assessment outcome. You will need to review Stages 2 and 3, and perform any modifications where appropriate.

Stage 3 Hints

- ❋ Use the risk assessment process to define the worst downsides and scenarios.
- ❋ Try to be creative while providing recommendations to minimise the risk.
- ❋ You will not be able to eliminate associated risk altogether, so focus on ensuring that the main issues are carefully attended to.

It is important to record any personal or team comments regarding the decision assessment outcome as it can be useful for future decisions.

Comments:

Assessment Review

This is the final phase in the decision-making process, and by reaching this point indicates that you have been able to identify the most suitable automation alternative and explored the associated risk.

Consequently, the decision outcome and information gained from the assessment process should be used to facilitate the preparation of the feasibility study for management review. The potential benefit of utilising this information in the report improves the justification process, as it points out the associated risks and future recommended action.

In addition, the assessment review outcome and future action observations can offer an excellent feedback loop, upon which the decision-making process is continuously improved and updated.

Annex

Brainstorming

Brainstorming is technique that initiates and encourages a team's creativity. It is a formal approach for assisting a team in generating as many ideas as possible in a short time. The maximum benefit from brainstorming can be gained by adopting the following rules:

Always define the central issues and make sure everyone agrees upon them.

- Everyone should be allowed and encouraged to contribute. No-one should be allowed to dominate the session.
- Every idea should be recorded in the words of the speaker.
- Use a visual display to record ideas.
- Never criticise ideas.
- Make no attempt to evaluate the ideas, just generate them.
- Do not develop idea at length or get involved in detailed discussions.
- The session should run for a set time or until all the ideas have been exhausted.
- Avoid getting sidetracked by constraints.

Many people feel that they contribute more fully to a discussion when using brainstorming. Often ideas are generated that would not have come from an individual member of the team alone. The underlying goal of brainstorming is to generate a number of ideas regardless of the quality. Theses ideas can then be prioritised, developed or deleted as appropriate.

Rank of Importance Scale

To support the rating of the automation investment objective/requirement; a description of the importance scale (5 to 1) is presented below.

Ranking	Description
5	Very high importance
4	High importance
3	Moderate importance
2	Low importance
1	Very low importance
Blank	Not applicable

Relationship Scale

To support the scoring process of relationships between investment objectives and evaluation criteria; a description of the relationships strength (9 to 1) is presented below.

Ranking	Description
9	Strong relationship
3	Moderate relationship
1	Weak relationship
Blank	No relationship

Evaluation Scale

To support the scoring process of investment options against sub-evaluation elements; a description of the evaluation scale (9 to -9) is presented below.

Ranking	Description
9	Strongly acceptable
3	Moderately acceptable
1	Slightly acceptable
-1	Slightly unacceptable
-3	Moderately unacceptable
-9	Strongly unacceptable
Blank	Not applicable

Severity Scale

To support the rating of potential problem severity; a description of the severity scale (5 to 1) is presented below.

Ranking	Description
5	High disruption
4	Moderate disruption
3	Low disruption
2	Very low disruption
1	Unnoticeable
Blank	Not applicable

Likelihood Scale

To support the rating of potential problem likelihood; a description of the likelihood scale (5 to 1) is presented below.

Ranking	Description
5	High chance of occurrence
4	Moderate chance of occurrence
3	Low chance of occurrence
2	Very low chance of occurrence
1	Remote chance of occurrence
Blank	Not applicable

Decision-Making Evaluation Elements

This is a description of the main evaluation elements and sub-evaluation elements used in the decision-making process to evaluate an automation option. It provides a comprehensive overview of the areas and issues involved. In addition, it outlines examples of the types of measurement that might be appropriate to facilitate the evaluation process. Therefore, it is expected that the user will tailor the evaluation measures outlined to fit his/her evaluation needs.

Strategic justification

Corporate strategy is developed in line with the mission of the company, and the activity of investment is associated with manufacturing strategy. The strategic justification takes into account the investment drivers that are associated with:

- Short- term manufacturing strategy objectives.
- Long- term manufacturing strategy objectives.

<u>Strategic sub-evaluation elements</u>

The strategic sub-evaluation elements represent the elements of manufacturing function strategy, to enable the manufacturing systems designers to link organisation mission and strategy with the automation investment decision. The benefit of enabling the manufacturing systems designers to determine how compatible the reviewed automation options are with their corporate strategy will support them in assessing the extent to which the selected automation investment is consistent with their business direction and competitive environment.

- Short-term strategic manufacturing objectives

Short-term objectives are milestones that are set to be achieved in approximately one year. They could be anywhere from a three month goal to an eighteen month goal. The short-term instructional objectives are measurable intermediate steps between the present level of performance and the annual goals. Therefore, to ensure that the automation investment option is aligned with the short-term manufacturing strategy directions the compatibility of the automation option will be measured by the degree to which it supports the short-term strategic manufacturing objectives.

- Long-term strategic manufacturing objectives

Long-term objectives are specific enough to elicit action but broad enough to allow the goals to be achieved in five years. They could be anywhere from a three year goal to a five year goal. Therefore, to ensure that the automation investment option is aligned with the long-term manufacturing strategy directions, the compatibility of the automation option will be measured by the degree to which it supports the long-term strategic manufacturing objectives.

Financial justification

The financial justification has a strong influence on the approval of automation investment. It addresses the investment drivers that are associated with:

- Economic justification.
- Investment cost.
- Unit cost.
- Installation cost.
- Operation cost.

<u>Financial sub-evaluation elements</u>

The financial sub-evaluation elements are designed to represent the most dominant economic issues, to enable the manufacturing systems designers to arrive at a sound financial evaluation.

- Economic justification

The economical justification approaches include discounted and non-discounted cash flow approaches to cost valuation and investment justification. To ensure that the automation investment option is economically justified, the following methods will be used to measure the extent to which the automation option satisfies the manufacturing systems designers financial requirements:

-Return on investment (ROI)

This financial measure represents the rate of interest required to make future savings equal to the investment cost. Consequently, to ensure that the automation investment option has acceptable return on investment, the compatibility of automation option will be measured by the extent to which the automation option exceeds the organisation's set rate.

-Internal rate of return (IRR)

This financial measure represents the discount rate which makes the net present value of the cash-flows from an investment equal zero. Therefore, to ensure that the automation investment option has acceptable internal rate of return, the compatibility of automation option will be measured by the extent to which the automation option exceeds the organisation's set rate.

-Net present value
This financial measure converts the entire set of positive and negative cash flows projected to occur over the life service of the equipment to a single equivalent value discounted to the present time. Thus, to ensure that the automation investment option has acceptable net present value, the compatibility of automation option will be measured based on the level of positive return that the automation option provides.

-Payback period
This financial measure represents the minimum length of time required to recover the initial investment without taking into account the time value of money. Thus, to ensure that the automation investment option has acceptable payback period, the compatibility of automation option will be measured by the extent to which it satisfies the organisation's target payback period.

- Investment cost

Investment cost is the money paid to purchase the manufacturing automation option. Therefore, to ensure that the automation investment option has an acceptable investment cost, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the purchase cost.

- Unit cost

Unit cost is the total cost of producing one unit of output. Therefore, to ensure that the automation investment option has an acceptable unit cost, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the unit cost.

- Installation cost

The installation cost represents the initial cost estimation that relates to the implementation of the investment. Costs that are considered under this sub-financial element will be those such as:

-Implementation costs.
-Utilities costs.
-Software and hardware integration costs.
-Support and test equipment costs.
-Training costs.

Therefore, to ensure that the automation investment option has an acceptable installation cost, the compatibility of the automation option will be measured by the extent to which the automation option satisfies the organisation's budget for such expenditures.

- Operation cost

The operation cost represents the operating cost estimation during the entire investment's life-cycle. Costs that are considered under this sub-financial element will be those such as:

-Labour costs.
-Depreciation costs.
-Maintenance, overhaul, and repair costs.
-Phase-out cost (disposition cost (-)/salvage value (+)).

Consequently, to ensure that the automation investment option has an acceptable operation cost, the compatibility of the automation option will be measured by the extent to which the automation option satisfies the organisation's budget for such expenditures.

Systems Integration

The application of automated manufacturing systems will necessitate the adaptation and integration of its hardware and software systems with the existing technologies and information systems.

Systems integration assessment takes into account the investment drivers that relate to machinery and database integration, such as improving material and information flow, obtaining real-time information, improving adaptation and upgrade capabilities, etc. Overall it addresses the investment drivers that are associated with:

- Hardware systems integration.
- Software systems integration.

Systems integration sub- evaluation elements
The systems integration sub-evaluation elements address hardware and software integration at the acquisition stage, to enable the manufacturing systems designers to assess the impact and complexity in adaptation with existing manufacturing systems.

- Hardware systems

Integration of the physical and electronic parts of a computer and the machinery itself is required to make a manufacturing system work. Hardware integration is responsible for ensuring that the hardware component, manufacturing cells, transfer lines, material handling systems, etc. are compatible and effectively linked. Therefore, to ensure the integration feasibility of the automation investment option with the existing manufacturing hardware systems, the compatibility of the automation option will be measured by the degree to which the new technology is:

-Able to operate with existing hardware components.
-Able to operate with existing machine tools and inspection equipment.
-Able to be configured and upgraded.

- Software systems

Maximum integration requires not only the hardware, but also the computer programs to be properly integrated. Software integration is responsible for ensuring that activities such as programming, communication, controlling, networking, etc. function quickly, smoothly and economically. Consequently, to ensure the integration feasibility of the automation investment option with the existing manufacturing software systems, the compatibility of the automation option will be measured by the degree to which the new technology is:

-Able to operate on existing software platform.
-Able to operate in collaboration with existing software.
-Able to be configured and updated.

Organisation and technology integration

This element represents the human factors that relate to the organisation-machine interface. It takes into account the investment drivers that address organisation and technology integration, such as improving harmonisation of the work system's elements, aligning organisational structure with new technology, minimising resistance to change, etc. Overall it addresses the investment drivers that are associated with:

- Organisational work procedure.
- Organisation structure.
- Work group.
- Personnel policies.
- Job design.

Organisation and technology integration sub-criteria

There are certain organisational issues that are affected by introducing technology, and addressing them will provide a better understanding of the impact and challenges of introducing different automation levels. The organisation and technology sub-evaluation elements aid the manufacturing systems designers in assessing these issues.

- Organisational work procedure

The pattern and nature of organisational work procedures will be affected by the degree of change in automation levels applied to process and assembly work. The integration of new technologies and group-work may lead to new concepts of reorganisation and supervision reduction. Work organisation refers to how work can be optimally organised to ensure that the workforce performs well. It involves issues such as shift work, work breaks, work polices, reporting lines, work standards, etc. Consequently, to ensure that the work procedure requirements of the automation investment option are in line with the current organisational work procedure, the compatibility of the automation option will be measured by the degree of change required in organisational work procedures.

- Organisation structure

Organisation structure refers to the division of labour and hierarchy of authority in an organisation. It deals with the structural mechanisms the organisation adopts to organise and control employee behaviour and organisational functions. Therefore, to ensure that the impact of the automation investment option on the organisation structure is acceptable, the compatibility of the automation option will be measured by the degree of change required in:

-Degree of bureaucracy (hierarchy system or project oriented system).
-Management role (discretion, authorisation, and supervision).
-Degree of centralisation (constraint to exercise decision-making).
-Organisation orientation (salary-based or skill-based).
-Operation structure (process flow and assembly flow).
-Organisation culture (values, statues, goals, and cultural barriers).

- Work group

A work group constitutes formal and informal groups that constrain the degree of collective working and relationships. The group working environment and gain share could be influenced by the division of labour and responsibilities imposed by different levels of automation. Therefore, to ensure that the impact of the automation investment option on the work group structure is acceptable, the compatibility of the automation option will be measured by the degree of change required in:

-Group structure (group size, responsibilities, autonomy, and supervision).
-Group incentive compensation (profit sharing and team rewards).
-Group communication (information needs and information sharing).

- Personnel policies

Personnel policies mainly involve recruitment and selection, policy and procedure development, classification and compensation analysis, employee training and development, labour relations, and safety. These polices will influence the selection of the automation option, while others will be affected by the selected automation option. Therefore, to ensure that the impact of the automation investment option on the personnel policies is acceptable, the compatibility of the automation option will be measured by the degree of change required in:

-appraisal policies for both individuals and teams (reward and control system).
-development system (career path).
-job security.
-training requirements.

- Job design

The impact of introducing new technology may necessitate modifications to the job value, task variety, discretion, accountability, and knowledge (electric, electronic, and technical). Therefore, to ensure that the impact of the automation investment option on the job design is acceptable, the compatibility of the automation option will be measured by the degree of change required in:

-Job structure (classification and standardisation).
-Job rotation (shift/single/multiple).
-Job autonomy (responsibilities and span of control).
-Job perception (meaning and feedback on performance).
-Job demand (skills, education, experience, and coordination).

Technical justification

The aspects of strategic and financial issues are essential for automated technology evaluation; however, there are technical elements that influence the acquisition of automated manufacturing systems which are necessary to address.

The technical justification takes into account the investment drivers that are associated with:

- Productivity.
- Flexibility.
- Quality.
- Support and test equipment.
- Maintainability.
- Technology supplier.
- Longevity.

Technical justification sub-evaluation elements

The technical justification sub-evaluation elements represent both the primary and the ancillary technical issues, to enable the manufacturing systems designers to address the impact of technical implications on their decision.

- Productivity

Productivity plays an important part in the technical justification of manufacturing technology. Therefore, to ensure that the automation investment option satisfies the productivity technical issues, the compatibility of the automation option will be measured based on the extent to which the following elements results match the manufacturing systems designers operation requirements:

-Capacity

Capacity is the maximum output of a system in a given period under ideal conditions. Therefore, the compatibility of automation option will be determined by the extent to which it satisfies the manufacturing systems designers maximum output rate requirements.

-Throughput

Throughput is a measure that is defined as the average output of a production process (machine, workstation, line, plant) per unit time (e.g., parts per hour). Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers throughput rate requirements.

-Cycle time

Cycle time is a measure that is defined as the average time between completion of two discrete units of production. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers cycle time requirements.

-Output rate

Output rate is a measure that is defined as the number of products produced in a single operation or run. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies management output requirements.

-Set-up time

Set-up time is a measure that is defined as the time required to change a machine from making one product to making another. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers set-up time requirements.

-Effectiveness

Effectiveness rate represents the degree to which an operation unit is able to accomplish its objective. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers effectiveness rate requirements.

-Efficiency

Efficiency stands for the capacity for performing a given task within the specified standard time. Therefore, the compatibility of the automation option will be determined by the extent to which it satisfies the manufacturing systems designers efficiency rate requirements.

- Flexibility

To ensure that the automation investment option satisfies the flexibility technical issues, and to keep the evaluation process within reasonable applications, the following flexibility types will be used to measure the extent to which the automation option satisfies the manufacturing systems designers flexibility requirements.

-Machine flexibility

Machine flexibility represents the number and variety of operations a machine can execute without incurring high transition penalties or significant changes in performance outcomes. Therefore, the compatibility of the automation option will be determined by the number of various types of operations that it can perform.

-Routing flexibility

Routing flexibility represents the ability to produce parts through alternative workstation sequences in response to equipment breakdowns. Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired routing flexibility of the manufacturing system.

-Process flexibility

Process flexibility represents the set of product types that the system can produce without major setups. Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired process flexibility of the manufacturing system.

-Product flexibility

Product flexibility represents the ability to change over to produce new products quickly and economically. Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired product flexibility of the manufacturing system.

-Volume flexibility

Volume flexibility represents the ability to produce parts economically in high and low total quantities. Therefore, the compatibility of the automation option will be determined by the extent to which it can support the desired volume flexibility of the manufacturing system.

- Quality

To enable the manufacturing systems designers to address quality in their decision-making and determine how well the selected option meets their quality objectives, the compatibility of the automation option will be based on the extent to which the following elements match the manufacturing systems designer's quality requirements:

-Conformance to specification
(Process Capability Index – Cpk).
-Software reliability.
-Technology reliability.
-Inspection system (offline/online).
-Scrap.

- Support and test equipment

Support and test equipment of manufacturing technology represents an important issue as the need for special tooling, fixtures, automatic test equipment, etc. can affect the selection of different automated manufacturing technology.

Therefore, to ensure that the automation investment option has acceptable support and test equipment specifications, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the automation option support and test equipment requirements.

- Maintainability

Maintainability refers to the ease with which maintenance work can be done. Equipment of whatever type, complexity, and cost is liable to break down, and maximum productivity is dependent upon quick restart after a failure. In addition, the importance of adequate machinery access allows easier house keeping and serviceability. Consequently, to ensure that the automation investment option has acceptable maintainability specifications, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the automation option Mean Time To Repair (MTTR).

- Technology supplier

Vendor support is considered to be an important element in the success and ease of technology design and implementation. Therefore, to enable the manufacturing systems designers to address the technology supplier and to keep the evaluation process within reasonable applications, the following sub-evaluation elements will be used for evaluating the automation options:

-Technology and technical capability

Technology and technical capability refers to the availability of expert knowledge by the vendor's staff of its technology and achievements. The compatibility of the automation option will be determined by how satisfied the manufacturing systems designers are with the vendor's staff's technical professionalism and credibility references.

-Vendor support

Vendor support refers to technical support that is received before and after purchasing a machine or piece of equipment. It includes both vendor services and after-sales service. Therefore, the compatibility of the automation option will be determined by how satisfied the manufacturing systems designers are with the pre- and after-sales services offered.

-Delivery lead time

Delivery lead time is used to indicate to the date on which the equipment will be received from the supplier or to the date on which the equipment begins to run production. It is normally expressed in weeks after receipt of the order. Therefore, the compatibility of the automation option will be determined by how satisfied the manufacturing systems designers are with the delivery lead time.

- Longevity

Longevity represents the machinery's life cycle, and it affects long-term manufacturing utilisation and unit cost evaluation. Therefore, to ensure that the automation investment option has an acceptable lifespan, the compatibility of the automation option will be measured by the extent to which the manufacturing systems designers are satisfied with the automation option life cycle.

People and technology integration

This element represents the human factors that relate to the human-machine interface and user-system interface. It takes into account the investment drivers that relate to user-machine integration such as capabilities, interface design, employee welfare, etc.

Overall it addresses the investment drivers that are associated with:

- Workstation design.
- Physical workload.
- Mental workload.
- User/machine interaction.

<u>People and technology integration sub-evaluation elements</u>

The people and technology integration sub-evaluation elements assesses both human and technical sub-systems at the acquisition stage, to ensure aligning the automation decision with appropriate consideration of both technical and human aspects.

Note: To address this element appropriately will require the assistance and consensus of the technology designer.

- Workstation design

The workstation design deals with the three-dimensional work-space envelope within which an individual works and the dimensions of the people who are going to operate within those spaces. It takes into account the population size, gender, and age, in order to ensure the compatibility of the workplace with the worker. Consequently, to ensure that the workstation design of the automation investment option is in accordance with human factors guidelines, the compatibility of automation option will be measured by the extent to which the workstation specifications (e.g. work height, work posture, online maintenance, set-up, and house-keeping) matches the user's physical characteristics (e.g. weight, height, age, and reach). The means of measuring this will be through the technology designer confirmation in taking account of these issues.

- Physical workload

Physical workload deals with the strength and endurance of the body and relates to the acceptable levels of physical characteristics of the job. The degree of automation has to be assessed against the user's physical workload capabilities as it can lead to favouring or restricting automation, due to certain physical and repetitive movements that are causes of physical stress and strain. Therefore, to ensure that the physical workload requirements of the automation investment option are in accordance with the operator's physical abilities, the compatibility of the automation option will be measured by the extent to which the physical workload specifications (e.g. material handling, force, feed rate, and cycle time) matches the user's physical capabilities (e.g. strength, motion, and endurance). The means of measuring this will be through the technology designer confirmation in taking account of these issues.

- Mental workload

Mental workload deals with the human cognitive ability and relates to information-processing and adaptive responses. It takes into account the psychological aspects of work, both in terms of how the work affects the mind and how the mind affects the work. Therefore, to ensure that the mental workload requirements of the automation investment option are in accordance with the operator's mental abilities, the compatibility of the automation option will be measured by the extent to which the mental workload requirements (e.g., training, decision making, attention, and situation awareness) match the user's mental capabilities (e.g. memory, learning, processing information, and perception). The means of measuring this will be through the technology designer confirmation in taking account of these issues.

- User/machine interaction

User/machine interaction deals with interface design and relates to display and control design. It addresses the following issues:

-Degree of match between display and perceptual model of operator.
-Degree of match between display and user senses.
-Degree of match between control system and motor skills and timing of operator.
-Degree of match between control and physical ability.

The significance of addressing these issues may vary across manufacturing industries. It is more likely that they would be of importance during the evaluation of highly automated manufacturing systems that incorporate control rooms. Subsequently, the compatibility of the automation option will be measured by the extent to which the user/machine interaction specification (e.g. information input/output devices, and information processing requirements) match the user's physical and mental capabilities (e.g. force, speed, accuracy, and senses). The means of measuring this will be through the technology designer confirmation in taking account of these issues.

Safety justification

There are specific requirements of health and safety laws which manufacturers need to comply with when they are buying new machinery. Safety justification takes into account the investment drivers that relate to health and safety issues, such as improving work conditions, eliminating hazard tasks, reducing injury and accident reports, etc.

Overall it addresses the investment drivers that are associated with:

- Machinery safety.
- Work environment safety.

<u>Systems integration sub-evaluation elements</u>
The application of automation can improve certain safety issues; however, it can also cause hazards and injuries. Therefore, the safety justification sub-evaluation elements are incorporated, to enable the manufacturing systems designers to determine the impact of different automation options on their work environment and safety systems.

- Machinery

Machinery addresses the machinery safety guidelines that are important to consider in the acquisition of manufacturing automation. This covers safeguards, emergency controls, warning devices, safety distance, clearance, etc. Consequently, to ensure that the automation investment option complies with health and safety guidelines, the compatibility of the automation option will be measured by the extent to which it complies with the machinery health and safety regulations.

- Work environment

The work environment addresses the work environment safety guidelines that are important to consider in the evaluation of manufacturing automation. The environmental factors cover noise levels, vibration, lighting, radiation, temperature, humidity, air quality, pollution, etc. Therefore, to ensure that the automation investment option complies with health and safety guidelines, the compatibility of the automation option will be measured by the extent to which it complies with work environment health and safety regulations.

Further Reading

- Cohen, L. (1995). Quality Function Deployment: How to Make QFD Work For You. Publisher: Addison Wesley Longman, USA.

- Franceschini, F. (2001). Advanced Quality Function Deployment. Publisher: St. Lucie Press, London.

These books provide the user the opportunity to further understand how the QFD technique works. It explains the overall concept of the technique and includes an in depth computation procedure with examples.

- Mcdermott, R., Mikulak, R., and Beauregard, M., (1996). The Basics of FMEA. Publisher: Productivity, USA.

This book is designed to be used for engineering application. However, it can be useful to the user in further understanding how the FMEA technique works, as it provides detailed description of the application process with examples.

Appendix B.2: Decision Tool Presentation Format Preference Letter

School of Industrial & Manufacturing Science

Cranfield UNIVERSITY

Cranfield University
Cranfield
Bedfordshire MK43 0AL
England
Tel +44 (0) 1234 750111
Fax +44 (0) 1234 750875
http://www.cranfield.ac.uk/sims

Name,
Comp. addr.

5th October 2004

Dear [ ]

I would like to thank you for participating in my research study and providing me with information which further progressed the research. I am delighted to inform you that based on the outcome of the interviews and academic literature; I have created a method for supporting managers when conducting a feasibility study, to identify the most appropriate automation level.

The method can be presented to users as a workbook or a software package; however, before going further, I would like to know your preference. I am including a list of advantages and disadvantages of both approaches.

Workbook		Software Package	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Detailed step-by-step procedures manual	User undertakes computation	All computation done by software	Brief accompanying step-by-step guide
Deep insight into the decision-making criteria/sub-criteria	Consumes more time for execution	Fast to execute	little insight into the decision-making criteria/sub-criteria
Easy to modify	Tedious to run trials	Easy to run trials	Difficult to modify

Based on the responses, I will be able to deliver the method in a format that suits industry preference. A copy of the decision tool will be sent to you on completion of this research, as promised.

Your response can be sent via any contact means you desire – see contact details below.

Thank you very much for your time and I look forward to hearing from you.

Yours sincerely

Bader Mannai
Building 52
Mobile: 07881880810
Office: 01234 750111 Ext 5506
Fax: 01234752159
Email: b.al-mannai.2002@Cranfield.ac.uk

APPENDIX C

Appendix C.1: Automotive Company Decision-Making Process

Introduction

The steps of the manufacturing technology acceptance process shown in Figure 1 occur at different times within the Product Development System (?DS), shown in Figure 2. The table on page 5 links the checkpoints of this generic programme timing chart with the corresponding steps of the manufacturing technology acceptance process.

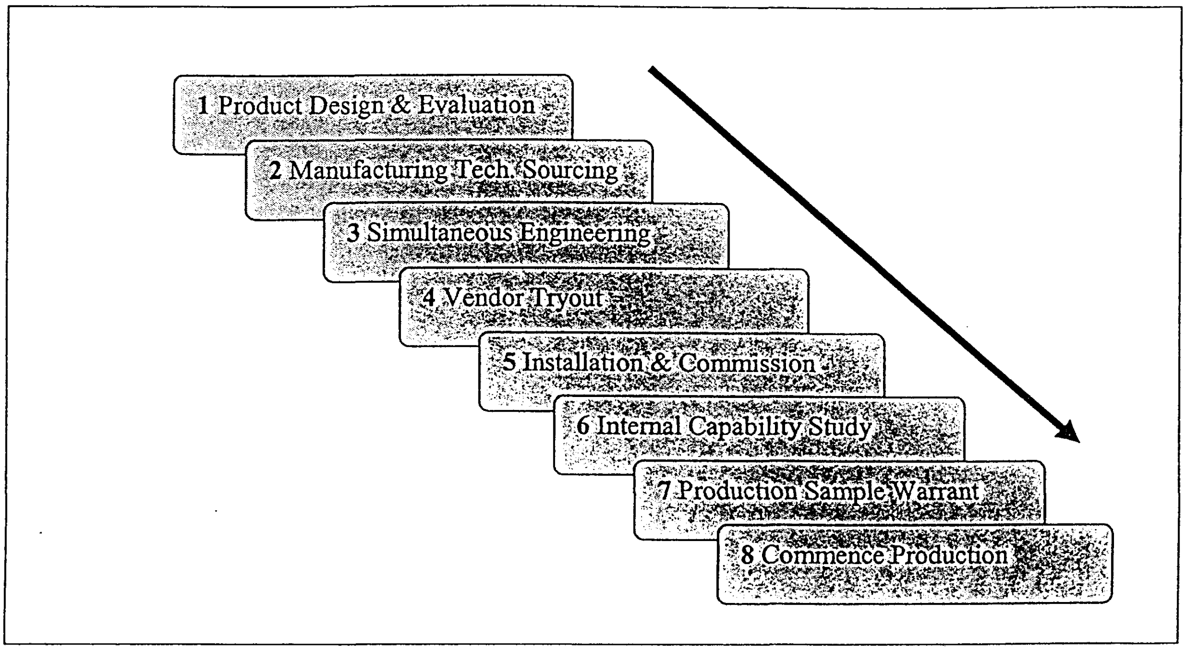


Figure 1 – Manufacturing Technology Acceptance Process

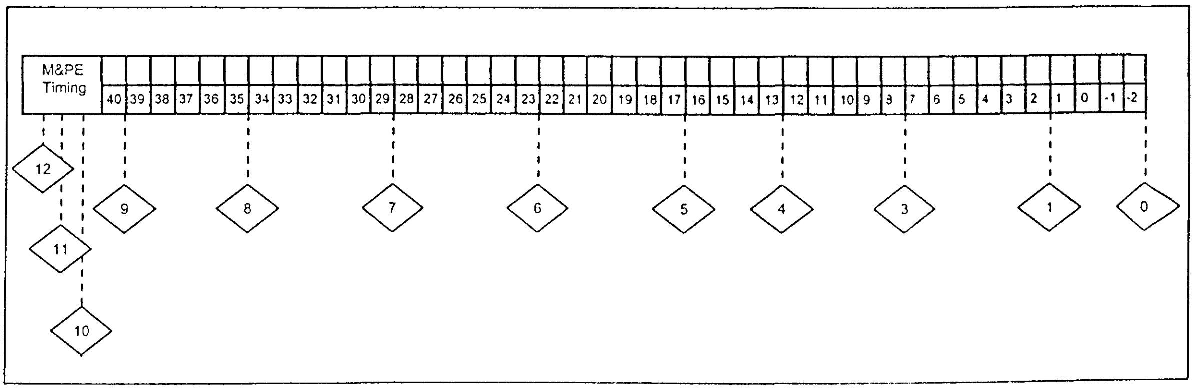


Figure 2 – PDS Generic Timing Chart

Powertrain Manufacturing and Plant Engineering

Title: Machinery and Equipment Procurement
Revision Date: Oct. 27, 1999
Administrator: Core & Commonization / Production Engineering

Document Number: PTP02-038ME
Revision Number: Initial
Retention Period: S

1. Purpose
This procedure describes the process for procuring machinery and equipment within Powertrain Manufacturing and Plant Engineering (PTO M&PE).

. Scope/Activities Affected
All PTO M&PE Functional Areas who procure machinery and equipment.

. Related Attachments or Forms
PTF02-005ME Recap Summary and Recommendation Form

. Related References or Procedures
PTG02-021ME Process Verification Manual
PTP02-029ME Study / Appropriation Request (Project) Reusability Procedure
PTP02-031ME Transition Agreement

Definitions
None

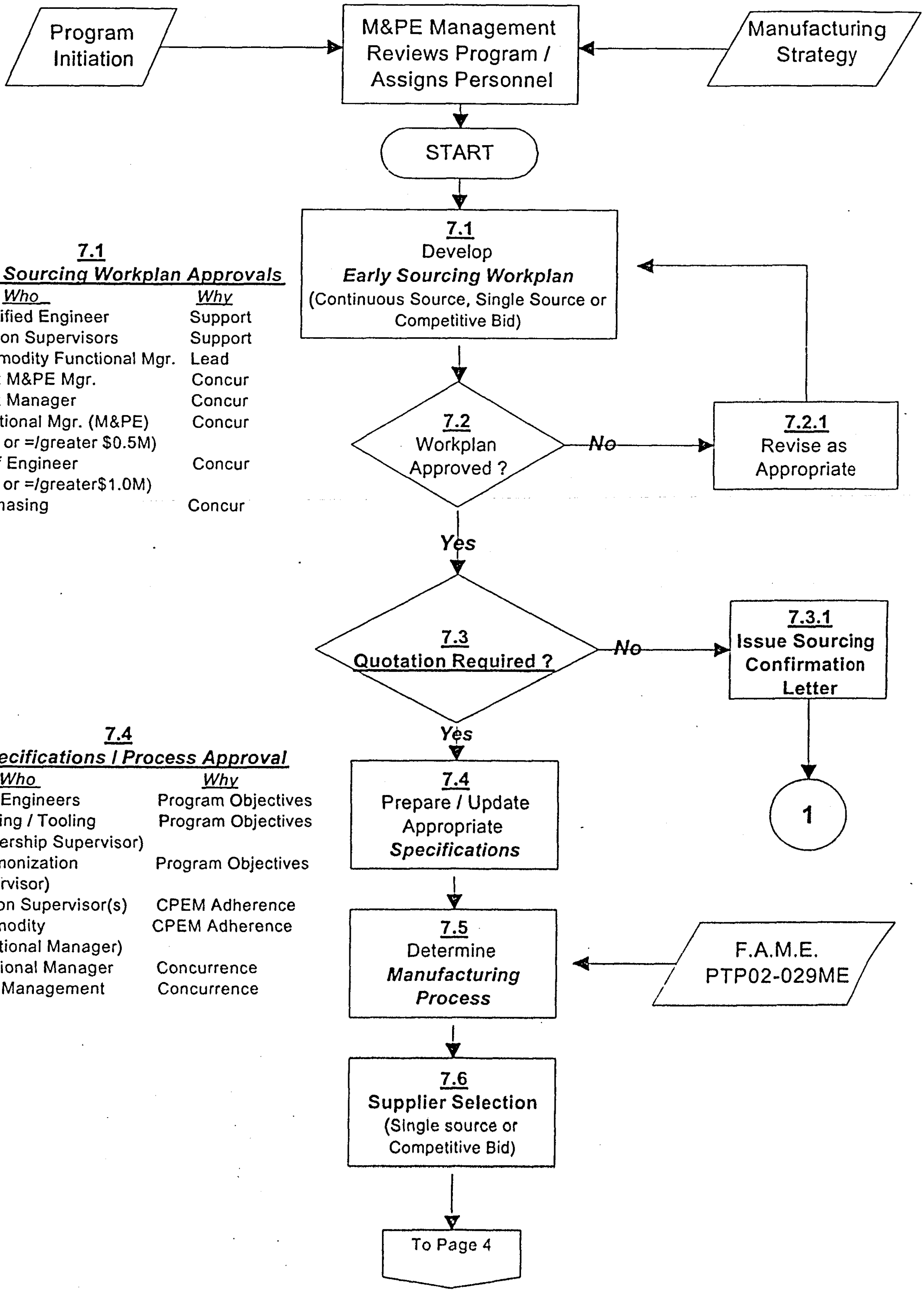
Exclusions
None

Procedure
See attached Machinery and Equipment Procurement Flowchart.

General Rules
8.1 All contact with Suppliers shall be through PTO M&PE functional engineers.
8.2 Purchasing shall be notified of all requested clarifications which may result in a cost change.

Quality / Environmental Records
All completed forms, notes and reports generated in conformance to this procedure are maintained by the PTO M&PE organization in compliance with the Global Information Standard 1 (GIS1) Schedule.

Machine and Equipment Procurement Flowchart



7.1
Early Sourcing Workplan Approvals

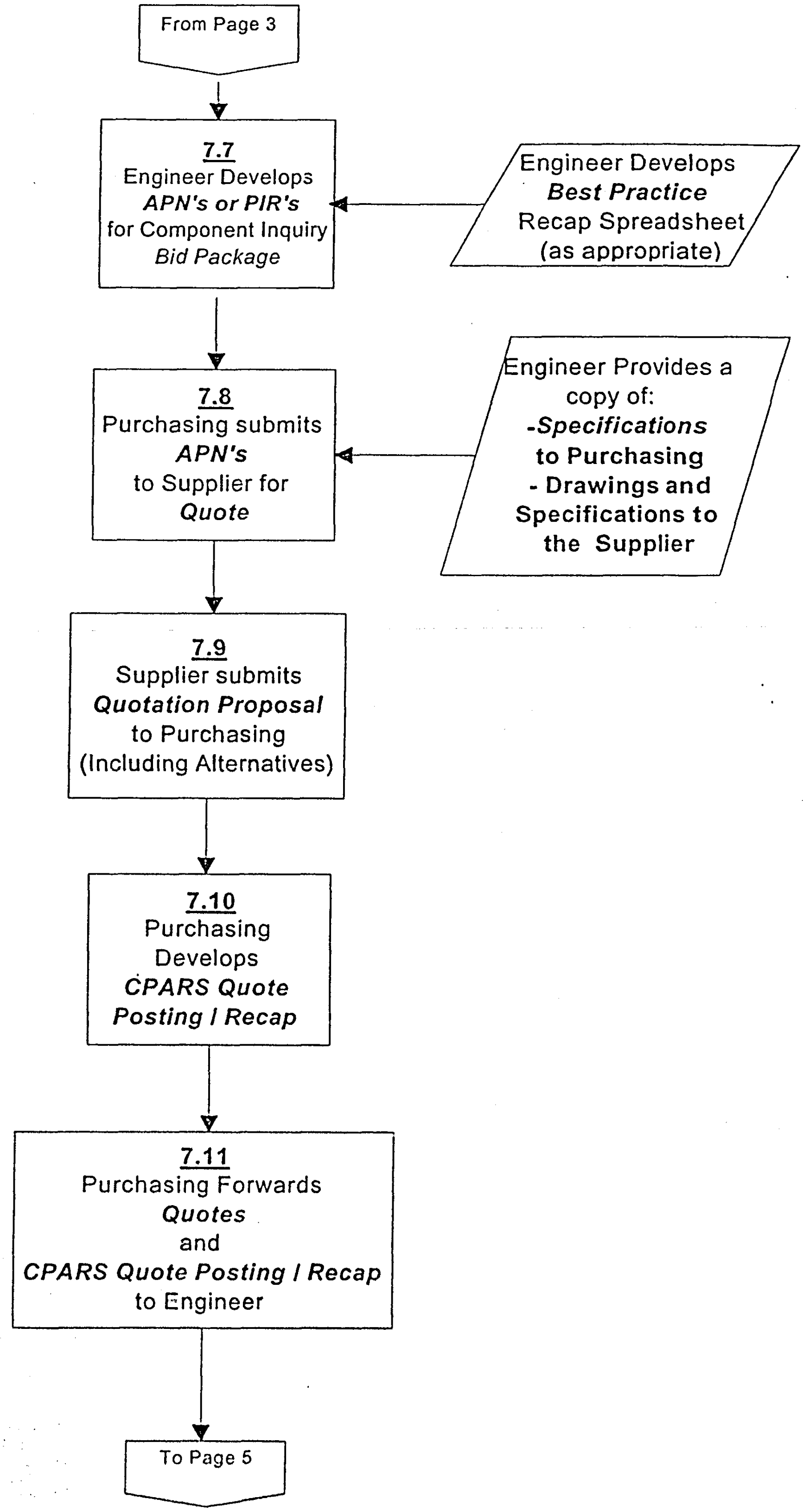
Who	*Why*
* Identified Engineer	Support
* Section Supervisors	Support
* Commodity Functional Mgr.	Lead
* Plant M&PE Mgr.	Concur
* Plant Manager	Concur
* Functional Mgr. (M&PE) (New or =/greater $0.5M)	Concur
* Chief Engineer (New or =/greater$1.0M)	Concur
* Purchasing	Concur

7.4
Specifications / Process Approval

Who	*Why*
* Lead Engineers	Program Objectives
* Gauging / Tooling (Leadership Supervisor)	Program Objectives
* Commonization (Supervisor)	Program Objectives
* Section Supervisor(s)	CPEM Adherence
* Commodity (Functional Manager)	CPEM Adherence
* Functional Manager	Concurrence
* Plant Management	Concurrence

7.7APN / PIR Approvals

Who	*Why*
* Requestor	Originator
* Section Supervisor	Concurrence



From Page 4

7.12
Supplier(s) / Purchasing
Formal Quote Presentation
(as appropriate)

7.13
Quote Price Clarifications ?

Yes →

7.13.1
Engineer identifies the quote clarifications required to the supplier(s) through Purchasing and the supplier(s) submit their response to Purchasing and the Engineer

No ↓

7.14
Engineer Prepares
Recap Summary & Recommendation Form (PTF02-005ME)
With Purchasing input/ support as appropriate

7.14

Recap Summary - Content (PTF02-005ME)

* Recap Summaries must contain the following:
  1- Unit Pricing
  2- Why Supplier was Selected
  3- Are Costs Reasonable / Competitive
  4- Plant Issues with the Supplier
  5- R&M Performance Sheet (New Equipment)

Recap Summary - Approvals

Who	*Funds*	*Why*
* Lead Engineer		Originator
* Tooling / Gauging (Supervisors)	All	CPEM Adherence
* New Programs (Program Leaders)	All	Budget & Timing
* Components (Section Supervisors)	All	CPEM Adherence
* Purchasing	All	Concurrence
* Plant M&PE Mgr.	All	Concurrence
* Commodity (Functional Mgr.)	All	Concurrence
* Plant Manager	TBD	Concurrence
* Functional Mgr.	>/=$500K or New	Concurrence
* Chief Engineer	>/=$1.0M or New	Concurrence

Note: TBD is agreed upon with each Plant Mgr.

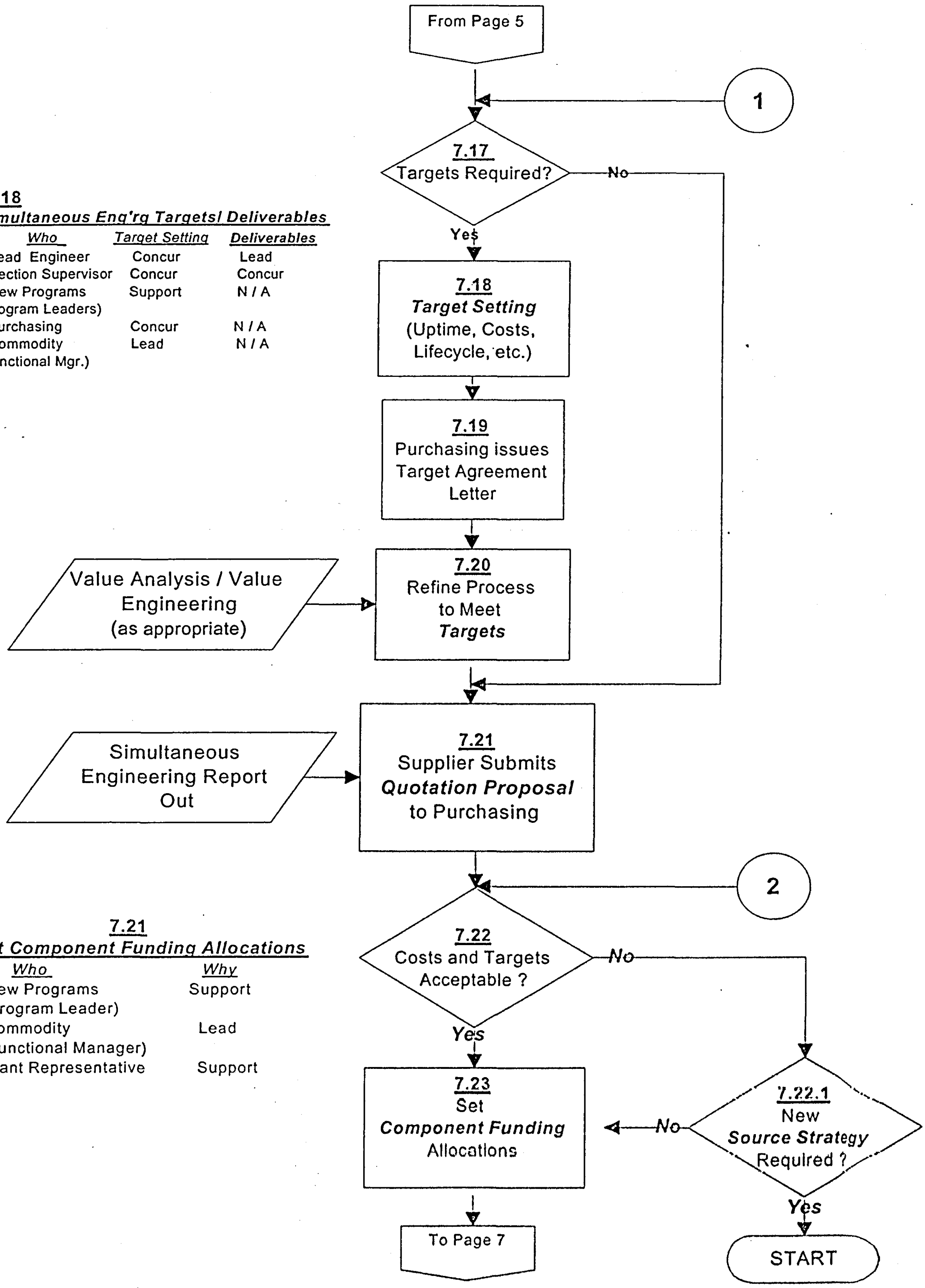
7.15
Simultaneous Engineering Letter Required ?

No → 2

Yes ↓

7.16
Purchasing Issues
Simultaneous Engineering Letter

To Page 6

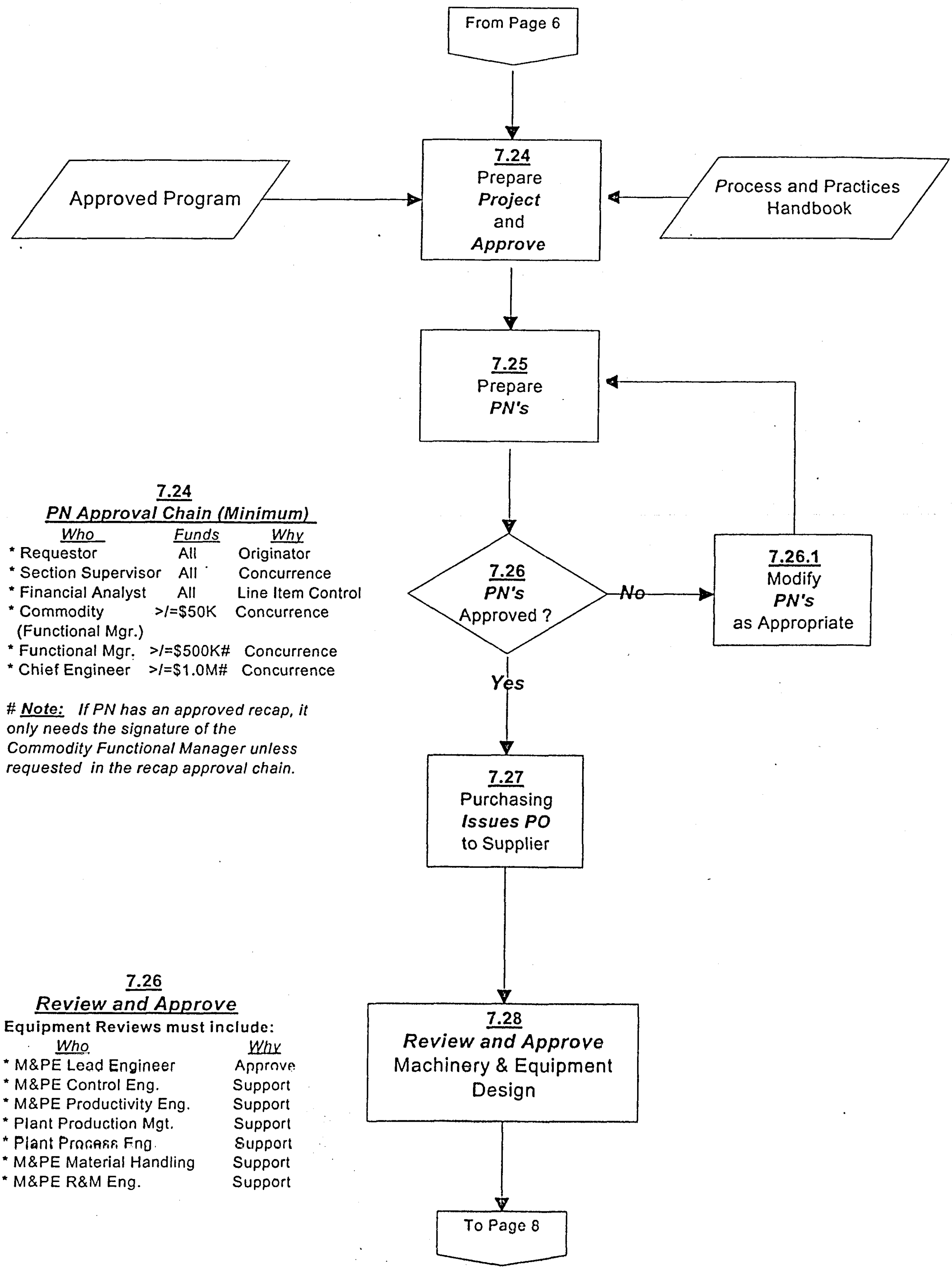


7.18
Simultaneous Eng'rg Targets/ Deliverables

Who	*Target Setting*	*Deliverables*
* Lead Engineer	Concur	Lead
* Section Supervisor	Concur	Concur
* New Programs (Program Leaders)	Support	N / A
* Purchasing	Concur	N / A
* Commodity (Functional Mgr.)	Lead	N / A

7.21
Set Component Funding Allocations

Who	*Why*
* New Programs (Program Leader)	Support
* Commodity (Functional Manager)	Lead
* Plant Representative	Support



7.24
PN Approval Chain (Minimum)

Who	*Funds*	*Why*
* Requestor	All	Originator
* Section Supervisor	All	Concurrence
* Financial Analyst	All	Line Item Control
* Commodity (Functional Mgr.)	>/=$50K	Concurrence
* Functional Mgr.	>/=$500K#	Concurrence
* Chief Engineer	>/=$1.0M#	Concurrence

Note: *If PN has an approved recap, it only needs the signature of the Commodity Functional Manager unless requested in the recap approval chain.*

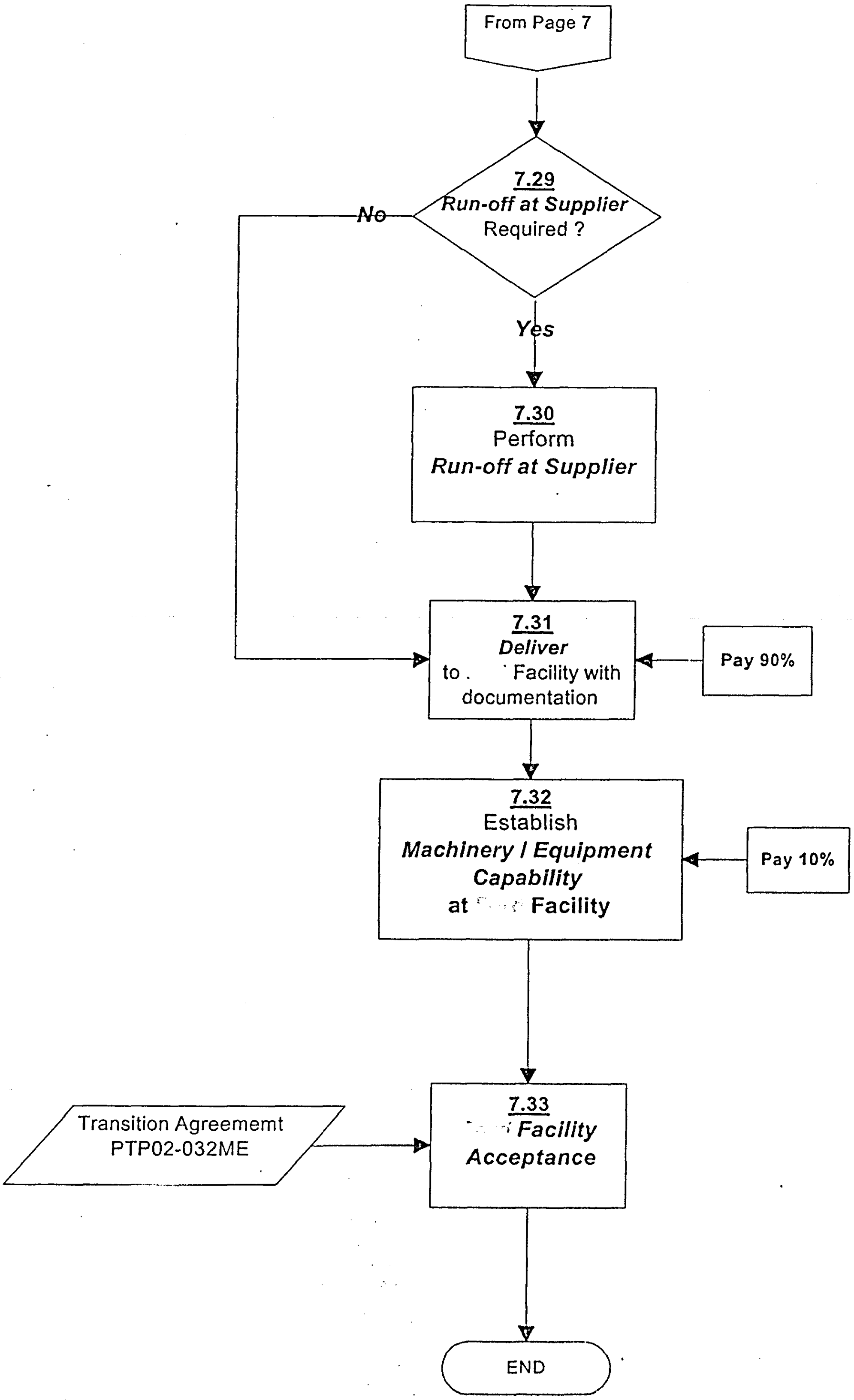
7.26
Review and Approve

Equipment Reviews must include:

Who	*Why*
* M&PE Lead Engineer	Approve
* M&PE Control Eng.	Support
* M&PE Productivity Eng.	Support
* Plant Production Mgt.	Support
* Plant Process Eng.	Support
* M&PE Material Handling	Support
* M&PE R&M Eng.	Support

Title: Machinery and Equipment Procurement
Revision Date: Oct. 27, 1999
Administrator: Core & Commonization / Production Engineering

Document Number: PTP02-038ME
Revision Number: Initial
Retention Period: S



ATO MANUFACTURING SPECIFICATIONS CHECK-SHEET

APN/PN/CPARS

(By Requesting Manufacturing Activity)

A. PROCESS INFORMATION:

B. STANDARDS AND SPECIFICATIONS:

_ - Machinery and Equipment Guidelines
_ - ATO "General Machine Specification and Procurement Handbook
_ - _Local_ Plant Addendum
_ - Powertrain Operations AutoCad Specifications for Facilities and tooling
_ - ECPL Placarding Guidelines
_ - Electrical Equipment Data Form #2630
_ - Safety Procedures (See local plant requirements)
_ - Technical Training Specifications and Vendor/Supplier Requirements
_ - Motor Company and Michigan OSHA Safety Standards
_ - Reliability and Maintainability Guidelines (M-110)
_ - Measurement System Analysis
_ - Process Verification Plan & Report Job Aid
_ - Ford Continuing Process Control & Capability Improvement

NOTE: Please refer to ATEO ISO 9000 Quality System "Document Master List" for latest published dates.

C. SPECIAL CONDITIONS:

_ - UTILITIES:
_ .See General Machine Specification and Procurement Handbook
_ - ENVIRONMENT:
_ .See Machinery and Equipment Guideline (pages 31 & 32)
_ - INSTALLATION

D. ACCEPTANCE PROCEDURE:

_ - SAFETY DEMONSTRATION:
_ .Verify requirements with local Safety Engineer
_ - RELIABILITY DEMONSTRATION:
_ .Per Reliability & Maintainability Guidelines
_ - TRYOUT BEFORE DELIVERY:
_ .Written instruction from Manufacturing Engineer
_ - TRYOUT AFTER DELIVERY:
_ .Written instruction from Manufacturing Engineer

E. SPECIAL WARRANTY REQUIREMENTS:

_ .Per terms of Purchase Order

F. SUPPLIER TECHNICAL SUPPORT:

_ - TRAINING:
_ .Powertrain Operations Technical Training Specs.
_ - MANUALS:
_ - DRAWINGS:
_ .Powertrain Operations AutoCad Specs.
_ - PM SCHEDULES:
_ . Total Productive Maintenance (TPM)
_ - SPARE PARTS:
_ .Supplier recommended
_ - TECHNICAL CONSULTING:

G. OPTIONS:

_ - PROCESS ALTERNATIVES:
_ - CONTRACT MAINTENANCE:

MANUFACTURING ADMINISTRATION
SEPTEMBER 25, 1996

Appendix C.2: Industrial Trial Evaluation Questionnaire

Section A: Feasibility evaluation

This part of the interview involves assessing the feasibility of the developed support tool.

1. Are you familiar with both Quality Function Deployment and Failure Mode Effects Analysis methods?

No/Not at all   Not very familiar   Quite familiar   Yes/Very familiar

2. Do you feel the approach is reasonably easy to understand?

No/Not at all   Not very easy   Quite easy   Yes/Very easy

3. Do you feel the approach is reasonably easy to follow?

No/Not at all   Not very easy   Quite easy   Yes/Very easy

4. In your opinion will you be able to measure both organisation & technology and people & technology sub-elements? **If** No could you state why not?

____

____

____

____

5. Is there anything in the approach that you would like to change to make it more workable?

____

____

____

____

Section B: Usability evaluation

This part of the interview involves assessing the content and usability of the developed support tool.

6. Do you feel the evaluation elements in the approach address the main issues of an automation decision-making process? **If** No could you state why not?

7. Do you feel the choice of evaluation sub-elements in the approach is appropriate? **If** No could you state why not?

8. Overall do you feel the workbook steps are clear?

Not at all clear   Not very clear   Quite clear   Very clear

9. Overall do you find the workbook easy to use?

No/Not at all   Not very easy   Quite easy   Yes/Very easy

10. Overall do you find the software application easy to use?

No/Not at all   Not very easy   Quite easy   Yes/Very easy

11. What are your concerns regarding the application of this support tool?

12 a. If you were to carry out a manufacturing automation investment in the future, would you consider adopting this approach to support your decision?

No/Not at all   Not likely   Quite likely   Yes/definitely

12 b. Can you please explain why?

Section C: Usefulness evaluation

This part of the interview involves assessing the usefulness of the developed support tool

13. In your opinion does this approach incorporate the appropriate Technology, Organisation, and People issues in the selection and assessment process? **If** No could you state why not?

14. Overall do you feel that this approach will allow you to address Human Factors issues better? **If** No could you state why not?

15. In comparison to your current decision-making process, please state what you consider to be the major strengths and weakness of the suggested approach?

Appendix C.3: Industrial Trial Evaluation Participation Letter

School of Industrial & Manufacturing Science

Cranfield UNIVERSITY

Name,
Comp. addr.

Cranfield University
Cranfield
Bedfordshire MK43 0AL
England
Tel +44 (0) 1234 750111
Fax +44 (0) 1234 750875
http://www.cranfield.ac.uk/sims

8th May 2005

Dear [ ]

It has been a while since I contacted you regarding the research progress. However, I would like to inform you that in accordance with your feedback, a workbook and a software package have been produced. Both applications are designed to aid managers when conducting a feasibility study, to identify the most appropriate automation alternative.

Nonetheless, I wonder whether I could arrange a brief meeting with you next month, to evaluate the manufacturing automation decision tool. The evaluation study will permit me to elicit the aspects that need further attention or amendments before the final version is dispatched to you.

Your response can be sent via any contact means you desire – see contact details below.

Thank you very much for your time and I look forward to hearing from you.

Yours sincerely

Bader Mannai
Building 52
Mobile: 07881880810
Office: 01234 750111 Ext 5506
Fax: 01234752159
Email: b.al-mannai.2002@Cranfield.ac.uk

Appendix C.4: Evaluation Trial Interview Protocol Document

Intro:

- First of all I would like to thank you for giving me this opportunity to evaluate the decision tool with you and take some of your time.

- To bring you up to date with my research progress the proposed manufacturing automation decision tool has been developed in both workbook and software format.

Briefing:

- As a final stage of this research I am conducting evaluation tests with officials who are involved in the operations and manufacturing systems decision making process.
- My aim from this evaluation is to evaluate the developed decision tool and to capture the aspects that need further attention or improvements.
- Before we start I would like to assure you that the interviewee and the information collected shall be treated strictly confidential and shall not be used for any purpose other than that of this research.
- I would like to assure you the participant's anonymity and right to withdraw from the interview at anytime.
- It is important to indicate to you that I am interested in your opinion and personal experience, thus there is no right and wrong answer.
- Can I have your permission to tape-record the interview; this will help increase the reliability of data analysis.

User Trial:

- Present the workbook followed by the software application for review.
- Demonstration trial for interacting with the decision tool.

Administrate Questionnaire:

- Quick indication of the questionnaire sections.
- Start the questionnaire.

Debriefing:

- Allow free discussion

Closure

- Your kind participation in this evaluation study will assist me in identifying necessary modifications and the validation of the research outcome.
- I would like to inform you that once the research has been completed you will be receiving the final version of the decision tool.
- Again, thank you very much.

Appendix C.5: Evaluation Trial Questionnaire Qualitative Response

Question Number	Descriptive Comments
5. Recommendations on approach	"The ability to have a dynamic risk register, in order to maintain in progress file document" "Including gate back as sign offs, to ensure people buy in the process and acquisition's objectives consistency throughout the evaluation"
11. Concerns regarding application and deployment	"That it has never been tested, but I think it will be very interesting to actually apply this support tool to a live circumstance" "This might be good for machine shop but what about business buying off' "How to mange the sub categories measures and the weighting and what they will do to the final score"
12,b. Reasons for willingness to future deployment	"It converts the soft issues into hard data; I would rather see hard data than see none at all" "We have element of this tool, but it doesn't put things together they are not integrated together, we might have a risk assessment process, but the QFD and FMEA is done separately. It brings everything together" "The ability to evaluate options quicker, and have a number at the end of it; because people like dealing with numbers"
14. Allows addressing human factors better	"It is nice to see that it raises these issues" "It is a big step to move forward as it looks at people, which are becoming more and more important now" "It makes the first step to make a link which could be further expanded later on"
15. Strengths in comparison to the participants decision making process	"It addresses the soft issues" "It integrates people, we don't do that" "Human factors issues are considered in our process, but it is based on experience not as formal as in your process and not in all the issues" "It covers all the essential aspects and it has got a good understanding of the key elements used in making a decision" "Not as detailed as this approach and no so much background information for anybody to criticise" "I like the integration; I like the fact that it is a one stop shot that's a strong selling point" "Making the tool beyond that into risk assessment. Risk assessment tool all built together very clever, risk assessment tool as well as selection tool, that is very powerful way gathered under one software"
15.Weakness in comparison to the participants decision making process	"we are trying to include ownership name" "Weakness, no, only if you consider it forces you to think more careful of these sensitive issues and about the justification. If the results don't match the gut felling, then it puts you in an awkward situation, which one to follow"

Appendix C.6: Evaluation by Application Questionnaire

Stage 1: Linking automation investment drivers with evaluation elements

1. Did you find this stage of the methodology easy to follow? **<u>If</u>** No could you state why not?

2. Did you find this stage labour intensive? **<u>If</u>** Yes could you state why?

3. Was anything in this stage unnecessary or redundant? **<u>If</u>** Yes could you state why?

4. Which of the instructions you found difficult to follow?

5. Were you confused at any point during the execution of this stage? **<u>If</u>** Yes could you state why?

6. Were there any terms/issues unfamiliar or unacceptable to you? **If** Yes could you state them?

7. What modifications would you recommend to improve this stage of the methodology?

Stage 2: Automation alternative selection

8. Did you find this stage of the methodology easy to follow? **If** No could you state why not?

9. Did you find this stage labour intensive? **If** Yes could you state why?

10. Was anything in this stage unnecessary or redundant? **If** Yes could you state why?

11. Which of the instructions you found difficult to follow?

12. Were you confused at any point during the execution of this stage? **If** Yes could you state why?

13. Were there any terms/issues unfamiliar or unacceptable to you? **If** Yes could you state them?

14. What modifications would you recommend to improve this stage of the methodology?

Stage 3: Decision risk assessment

15. Did you find this stage of the methodology easy to follow? **If** No could you state why not?

16. Did you find this stage labour intensive? **If** Yes could you state why not?

17. Was anything in this stage unnecessary or redundant? **If** Yes could you state why not?

18. Which of the instructions you found difficult to follow?

19. Were you confused at any point during the execution of this stage? **If** Yes could you state why not?

20. Were there any terms/issues unfamiliar or unacceptable to you? **If** Yes could you state them?

21. What modifications would you recommend to improve this stage of the methodology?

On completion: Feasibility, usability, and usefulness evaluation

22. Overall did you find the methodology easy to follow? **If** No could you state why not?

23. Did you find the tool to be user friendly and clear? **If** No could you state why not?

24. Did the methodology produce a valid output? **If** No could you state why not?

25. Do you think the results obtained from undertaking the case project using this methodology are worth the time invested? **If** No could you state why not?

26. Would you have made a better decision if this methodology had been used?

27. Would preparation and implementation have been different if this methodology was used? **If** Yes could you state why?

28. In your opinion does this methodology incorporate the appropriate Technology, Organisation, and People issues? **If** No could you state why not?

29. Overall do you feel that this methodology allowed you to address Human Factors issues better? **If** No could you state why not?

___

___

___

___

30. In comparison to your current decision-making process, please state what you consider to be the major strengths and weakness of the suggested methodology?

___

___

___

___

Appendix C.7: Rolls-Royce Decision-Making Process

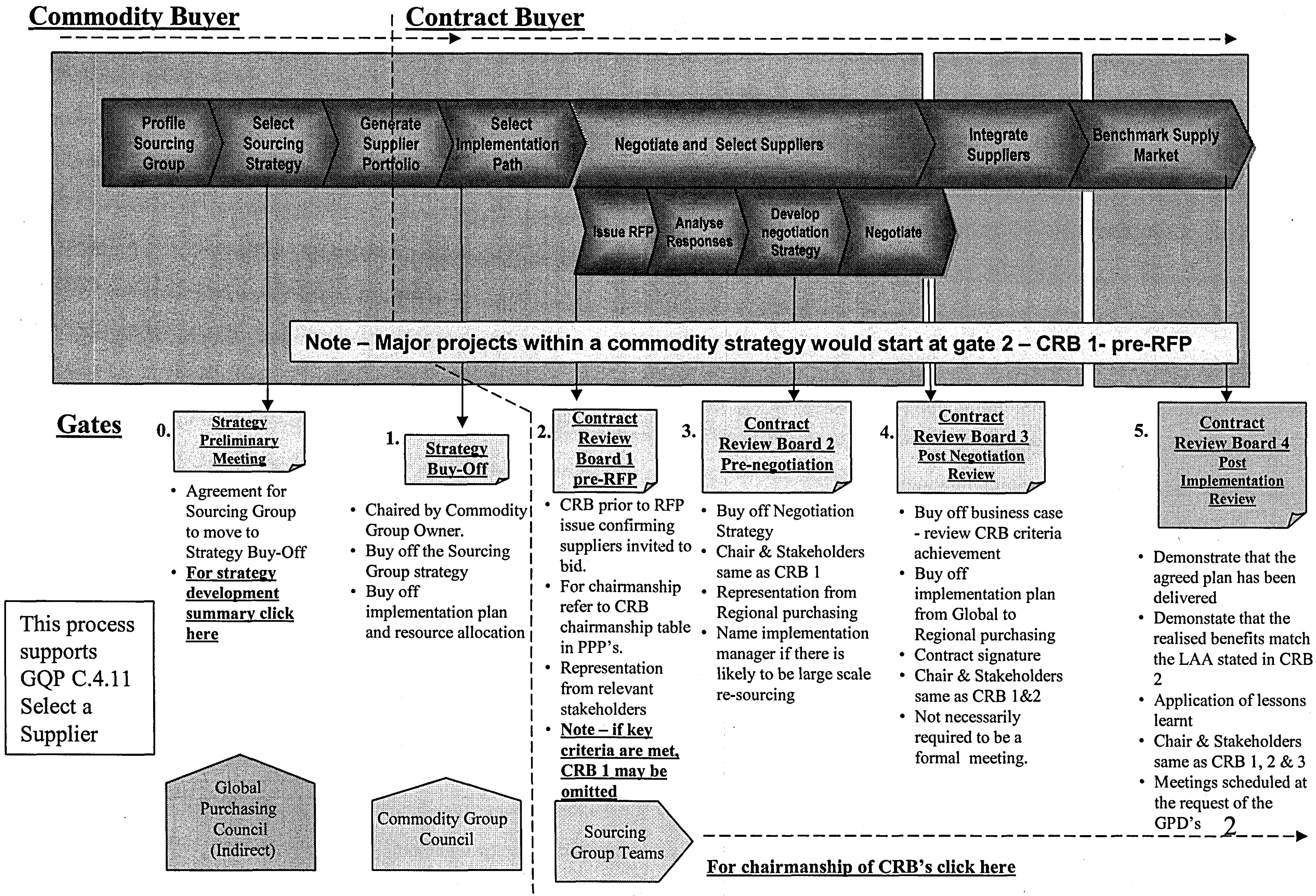
(Global Indirect) Contract Review Board 3
Post final negotiations review

Manufacturing Systems
Chip Forming Machines (WMA)
CRB Chairman :
Project Sponsor:
Seals 016 requirement 8 x M/Cs
Purchase Executive:
Project Owner:
27.04.2004

As project owner I am committed to operate within the parameters agreed within this document, any deviation from this will be re-submitted to the CRB

Signed………… …………Project owner

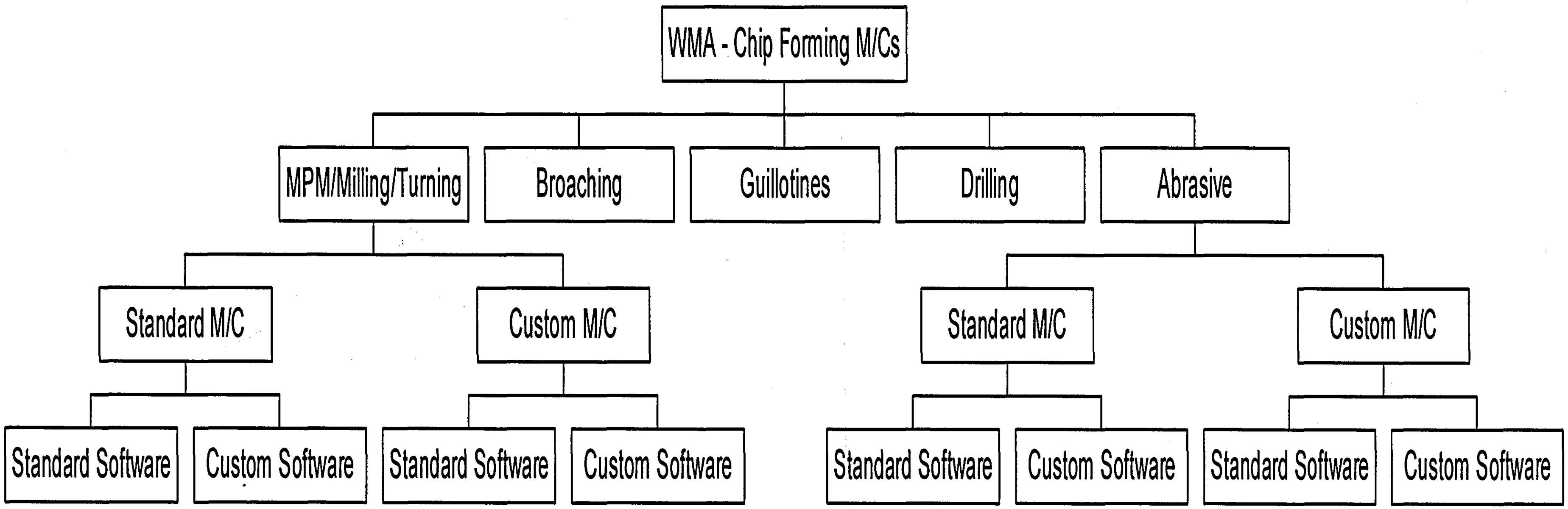
The Rolls-Royce Indirect gated sign-off process covering both strategy development and implementation



2

Sourcing Group Tree - Chip Forming Machines

ACE PROJECT – CHIP FORMING WMA



ACE WMA Requirements technical

Is Supplier Capable of Providing Equipment to Specification?

Package	Criteria	Supplier A	Supplier B	Supplier C
Seals Replacement Lathes	Proven Machine Tool Technology	Y	Y	Y
Seals Replacement Lathes	Machine Swing and Capacity	Y	Y	Y
Seals Replacement Lathes	Tool Probing	Y	Y	Y
Seals Replacement Lathes	Parts Catcher	Y	Y	Y
Seals Replacement Lathes	2 Axis Machine	Y	Y	Y
Seals Replacement Lathes	Compatability With Existing Tooling	Y	Y	Y
Seals Replacement Lathes	Machine Software	Own Control	Fanuc 18iT	Seimens 810D
Seals Replacement Lathes	Post Processor	N	Y	N
Seals Replacement Lathes	Chip Conveyor	Y	Y	Y
Seals Replacement Lathes	Feed Rate	12m/min	16m/min	12m/min
Seals Replacement Lathes	Number of Tool positions	15	12	12
Seals Replacement Lathes	Lead Time	12 weeks	12 weeks	20 weeks

ACE WMA Requirements technical

Is Supplier Capable of Providing Package to Specification?

Package	Supplier A	Supplier B	Supplier C
SEALS 016	Y	Y	?

ACE WMA Requirements technical

Ace Project – Chip Forming WMA

Bid Assessment Template

Attribute	Target (Seals Lathes)	Supplier A SCORE /10	Supplier B SCORE /10	Supplier C SCORE /10	Comments
Equipment size	Equipment should fit within the footprint area designated in the cell 5.5m x 4m	7	8	7	Supplier B 5.76m x 3.14m. Supplier A 7.6m x 4.2m Supplier C 6.81m x 4.1
Swing & Capacity	Does machine accommodate full range of fixtures and components	10	10	10	
Maximum Turning Dia	Does machine accommodate full range of components	8	8	10	Supplier B m/c has a max dia of 900mm, tool overhangs have to be kept under 50mm to maintain this dimension. Supplier C offer max. dia of 1000. Supplier A max dia of 910
Future Growth	Can machine accommodate future increases in component diameter,	8	8	9	Richard Booth (design) has confirmed that there will be no increase in compressor core over the next 5 years. Only one engine planned (Trent E7) core about t500 size. Moreover, he has suggested that core dias may actually decrease
Post Processor	Is a post processor available	7	8		Post processor available for Supplier B
Tool Holding Capacity	Max tools tool capacity	8	7	7	Supplier B & Supplier C have fixed 12 position turret turrets. Supplier A has 15 position, 10 od/id 5 dedicated id
Parts catcher	Does machine have a CNC driven Parts catcher	8	8	8	All 3 Supplier's machines will have an automatic tail mounted parts catcher
Coolant	Does machine have high pressure coolant	8	8		Supplier B has high pressure coolant - 70 bar Supplier A options upto 70 bar Supplier C max 7 bar - no future growth to take advantage of cutting tech
Fixture quick release	Does machine have fixture quick release system and suitability for purpose	8	8	6	Supplier A & B - Wixroyd system is backed by 30 years experience Supplier C offering a 1 off system built as part of turnkey - unproven
Build Quality	Is the build quality of all the suppliers the same	9	8	6	Build quality on Supplier A & B machines looks neat and robust for a machine in this price range. Larger turret on Supplier A
Slide accuracy	Comparison of slide accuracy and repeatability same	8	9	6	Supplier B - accuracy +/- 0.005mm; repeatability +/- 0.002mm Supplier C m/c - accuracy +/- 0.016mm, repeatability +/- 0.009mm Supplier A - accuracy +/- 0.01mm; repeatability +/- 0.003mm
Technical Competence	Our Impression of the technical competence of each supplier	8	8		Supplier C have had problems with swarf entrapment in spindle. Slow to responed to technical questions Supplier A & B have demonstrated greater competence with overall package offered
Proven technology	Has the offered equipment been proven in the field	8	8	6	Supplier A & B are offering Wixroyd quick release system for fixtures. This is a proven modular Design Wixroyd has 30years experience in this field. Supplier C offered a bespoke system not proven for this application
Service response times	How are the response times per company Based on R-R experience (if no previous equipment 5 will be given)	9	8		Supplier A & B have service engineers based in Scotland. Supplier C nearest is Wakefield
Reliability & maintainability	MTM opinion on maintainability of the machines	8	8		MTN have preference for Supplier A machine with Supplier B a close 2nd, access, feedback, motors & control system all good OEM equipment.
Previous Equipment Internal	How previous equipment has performed Based on R-R experience (if no previous equipment 5 will be given)	8	8		Supplier B have machines in Main Works and Sunderland good reports on operation and reliability. Mazak has machines in Hillington and other parts of the company
Previous Equipment External	How previous equipment has performed Based on other external UK installations (if no pr (if no previous equipment 5 will be given	8	8	6	Supplier A & B have a good UK customer base with many examples of repeat business. Supplier C has some examples of their lathes in UK but not the offered model
	Total Score	139	138	110	
	Max Possible	170	170	170	
	Percentage	82%	81%	65%	

MDA (8 or above)	(grey)
LAA (6 to 8)	(white)
Less than 5	(black)

ACE WMA Requirements commercial

ACE PROJECT – CHIP FORMING WMA

Commercial Bid Assessment Template prior to negotiations Seals 016 Lathes					
	Seals 8 off Lathes				
Attribute	**Target**	**Supplier B**	**Supplier A**	**Supplier C**	**Comments**
5 year warranty	RR will not incur any maint / costs during				2 Years min plus 3 year option
	the first five years of operation inc	7	7	7	
Terms of Business	GCP2001 and Appendix 11 to be adhered to	10	7	7	As minimum requirement
L/Ds,	2% per week max 10 weeks	7	7	7	As minimum requirement
Price	To meet the allocated budget				After 2 rounds of negotiations none of the suppliers are within budget
Delivery	To meet the required delivery date		7		9th Sept 04
Retrospective discount	Once the order is placed, future orders create				Agreed further discount if other modules are won for ACE
	retrospective discount on these machines				
Training	Included	10	10	10	As per R-R specification
Colour	As per specification inc	7	7	7	As per R-R specification
Life Cycle Costs	Included	7	10	10	As requested by R-R
Floor Slab	Aware of R-R requirements	10	10	10	All suppliers are aware of requirements
Software compatability	First in, last in across the board	7	7	7	Minimum requirement
	Total Score	72	74	72	
	Max Possible	110	110	110	
	Percentage	65%	67%	65%	
MDA 7 to 8					
LAA (6 to7)					
Less than 5					

CRB 3 Post Negotiation

Commercial selection criteria

	Supp B	Supp A	Supp C
Seals 016 Lathes 1 off	£222,979	£198,000	£196,145
Total Cost 8 off	£1,783,832	£1,584,000	£1,569,160
Total Budget	£1,056,000	£1,056,000	£1,056,000
Cost v Budget	-£727,832	-£528,000	-£513,160
Percentage over budget	-68.92%	-50.00%	-48.59%
Negotiated cost per unit	£175,000		
Tot negotiated cost	£1,400,000		
Total Saving	£383,832		
% Saving total	-21.50%		
Financial Appraisal		✓	✓
Terms of Business agreed	✓	✓	

CRB 3 Post Negotiation

Supplier selection criteria technical & commercial

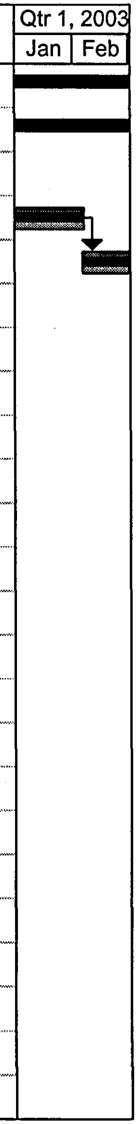
Seals 016 lathes 8 off required

Technical / Commercial Checklist			
Seals	Supp B	Supp C	Supp A
Machine Type	LATHE	LATHE	LATHE
Service/Response	✓	✗	✓
Program Compat (Exist)	✗	✗	✗
Fixt Compat (Exist)	✓	✓	✓
Technical Compat (App)	✓	✗	✗
Previous Equipment	✓	✗	✓
Build Quality	✓	✗	✓
Cycle Time	✓	✓	✓
Budget	✗	✗	✗
Delivery - 8	✗	✗	✗
Installation	✓	✓	✓
Commissioning	✓	✓	✓
Warranty	✓	✓	✓
Training	✓	✓	✓
Basic Price	£153,250	£149,550	£198,000
Options Price	£69,729	£46,595	inc
T.O.B	✗	✗	✓
OEE	✓	✓	✓
Con/Stock	✓	✗	✓
Spare Parts	✓	✓	✓
W.L.C	✓	✓	✓
Total	£1,783,832	£1,569,160	£1,584,000
No of Machines	8	8	8
Req Total	8	8	8
Over/Under Budget	£727,832	£513,160	£528,000

Action plan

ACE PROJECT – CHIP FORMING WMA

ID		% Complete	Task Name	Task Owner	Start	Finish	Predecessors	CELL
1		**35%**	**Seals 016 LATHES X 8 CUSTOMER W. ALLAN**		**Fri 15/11/02**	**Tue 26/07/05**		
2		**78%**	**RFP**	**BS**	**Fri 15/11/02**	**Mon 15/03/04**		
3	✓	100%	Create and send out RFP	BS	Fri 15/11/02	Tue 17/12/02		
4	✓	100%	RFP at suppliers and technical validation	SUPPLIE	Thu 19/12/02	Wed 05/02/03	3	
5		73%	RFP assessment and selection of suppliers	BS / WA	Wed 05/02/03	Fri 27/02/04	4	
6	✓	100%	CRB/Mini CRB preparation (RFP) complete	BS / WA	Mon 01/03/04	Mon 15/03/04		
7		0%	**CRB/MINI CRB 2**	BS / WA	Mon 15/03/04	Mon 15/03/04	6	
8		**0%**	**Negotiations**	**BS / WA**	**Tue 16/03/04**	**Mon 29/03/04**	**7**	
9		0%	Negotiation prep	BS / WA	Tue 16/03/04	Tue 16/03/04		
10		0%	Round 1	BS / WA	Mon 22/03/04	Mon 22/03/04	9	
11		0%	Round 2	BS / WA	Tue 23/03/04	Tue 23/03/04	10	
12		0%	CRB/MINI CRB 3	BS / WA	Fri 26/03/04	Fri 26/03/04	11	
13		0%	Select supplier	BS / WA	Mon 29/03/04	Mon 29/03/04	12	
14		0%	**RAISE ORDER**	BS	Mon 29/03/04	Mon 29/03/04	13	
15		**0%**	**Supply of the equipment**	**SUPPLIEF**	**Tue 30/03/04**	**Tue 26/07/05**	**14**	
16		0%	Delivery of m/c 1, Hillington Tay RRPS Project	SUPPLIE	Tue 30/03/04	Fri 25/06/04		
17		0%	Completion of acceptance	/ WA / SUPPLIE	Wed 28/07/04	Wed 28/07/04	16	
18		0%	Delivery m/c 2, 3 Hillington Shroud RRPS Project	SUPPLIE	Mon 02/08/04	Mon 02/08/04		
19		0%	Completion of acceptance	/ WA / SUPPLIE	Thu 02/09/04	Thu 02/09/04		
20		0%	Delivery of m/c 4 Casings cell Tay cell	SUPPLIE	Mon 17/01/05	Mon 17/01/05		
21		0%	Completion of acceptance	/ WA / SUPPLIE	Thu 17/02/05	Thu 17/02/05	20	
22		0%	Delivery of m/c 5, 6 Shroud Cell	SUPPLIE	Mon 14/03/05	Mon 14/03/05		
23		0%	Completion of acceptance	/ WA / SUPPLIE	Thu 14/04/05	Thu 14/04/05		
24		0%	Delivery of m/c 7, 8 Casings cell	SUPPLIE	Mon 20/06/05	Mon 20/06/05		



CRB 3 Post Negotiation

Appendix C.8: Practical Application Results

Requirements / Objectives		Automation Investment drivers	Strategic Justification	Financial Justification	Systems Integration	Technology & Organisation Integration	Technical Justification	Technology & People Integration	Safety Justification	Ranking of Importance
			Evaluation Elements							
Requirements / Objectives	Strategic	Replace existing obsolete technology	9				9			5
		Meet overall budget		9						5
		Making the new plant more cost effective	9	9						4
		Maintain organisational structure and work practise				9				4
		Improve health and safety aspects and employee welfare	9					3	9	4
	Tactical	Reduce set-up time					9			4
		Improve cycle time					9			3
		Improve cutting time					9			3
		Achieve hardware integration			9					4
		Improve overall cost of running machine		9						3
		Improve reliability					9	1		5
	Operational	Feed rate minimum 12m/min					9			3
		2 Axis machine					9			5
		Parts catcher					9			5
		Tool probing					9			5
		E C safety compliant							9	5
		Machinery safety compliant							9	5
		Total	117	108	36	36	342	17	126	
		Normalised	14.96%	13.81%	4.60%	4.60%	43.73%	2.17%	16.11%	

Project Details		
Project Details	Project Title:	Inchinnan plant, chip forming machines selection
	Project Official:	Walter Allen and (Technical and Commercial Personnel)
	Remarks:	Chip forming machines (MPM/Milling/Turning - Standard M/C - Standard Software)
	Options:	Three options: Option one (WMA machine by supplier A), Option two (WMA machine by supplier B), Option three (WMA machine by supplier C)

	Elements	Sub-Elements	Option 1	Option 2	Option 3	Option 4	Option 5	Ranking of Importance
			Manufacturing Automation Options					
Evaluation Elements	Strategic Justification	Support short-term strategic manufacturing objectives	9	9	3			14.96%
		Support long-term strategic manufacturing objectives	9	9	9			
	Financial Justification	Acceptable economic justification results	-3	-9	-3			13.81%
		Accepable investment cost	-3	-9	-3			
		Acceptable unit cost	9	9	3			
		Acceptable installation cost	3	3	3			
		Acceptable operation cost	9	9	9			
	Systems Integration	Feasable to integrate with existing manufacturing hardware systems	9	9	9			4.60%
		Feasable to integrate with existing manufacturing software systems	3	9	3			
	Technology & Organisation Integration	Compatible with organisation work procedure	9	9	9			4.60%
		Compatible with organisation structure	9	9	9			
		Compatible with work group	9	9	9			
		Compatible with personnel policies	9	9	9			
		Compatible with current job design	-1	-1	-1			
	Technical Justification	Acceptable productivity specifications	9	9	-1			43.73%
		Acceptable flexibility specifications	9	9	9			
		Acceptable quality specifications	9	9	1			
		Acceptable support and test equipment	9	9	9			
		Acceptable maintainability specifications	9	9	-3			
		Acceptable technology supplier	9	9	-3			
		Acceptable longevity	9	9	9			
	Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics	9	9	9			2.17%
		Machine physical workload specification compatible with user's physical characteristics	9	9	9			
		Machine mental workload specification compatible with user's mental characteristics	3	3	3			
		User/machine interface specification compatible with user's physical and mental characteristics	9	9	9			
	Safety Justification	Comply with machinery safety regulations	9	9	9			16.11%
		Comply with work environment safety regulations	9	9	9			
		Total	35.34	33.96	19.16	0.00	0.00	

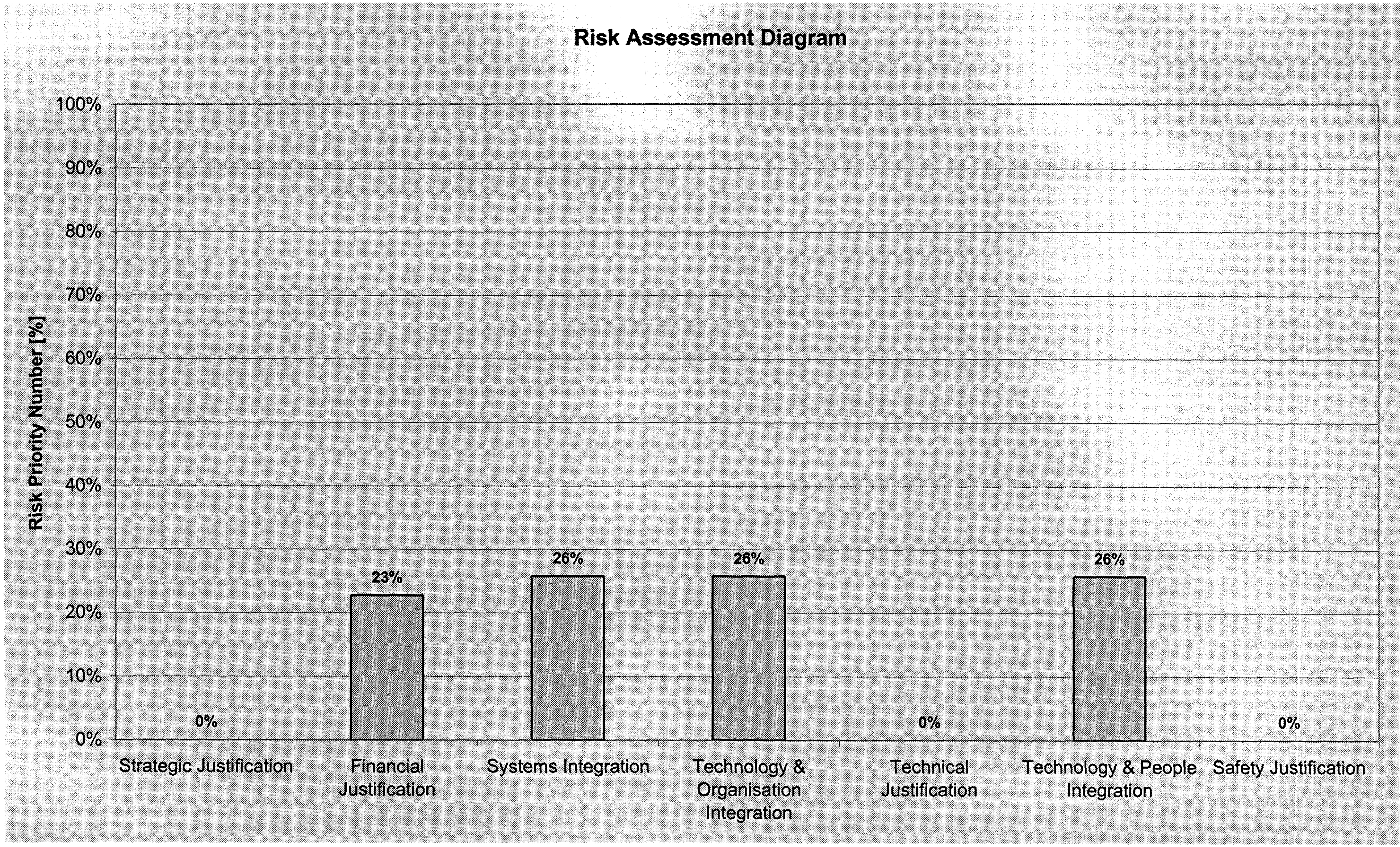
Evaluation Elements

Elements	Sub-Elements	Potential Problem
Strategic Justification	Support short-term strategic manufacturing objectives	
	Support long-term strategic manufacturing objectives	
Financial Justification	Acceptable economic justification results	Budget wont cover investment cost
	Accepable investment cost	Investment cost too high
	Acceptable unit cost	
	Acceptable installation cost	Required services out of scope of supply
	Acceptable operation cost	
Systems Integration	Feasable to integrate with existing manufacturing hardware systems	
	Feasable to integrate with existing manufacturing software systems	Post processor required
Technology & Organisation Integration	Compatible with organisation work procedure	
	Compatible with organisation structure	
	Compatible with work group	
	Compatible with personnel policies	
	Compatible with current job design	Employees need training to operate new machine package
Technical Justification	Acceptable productivity specifications	
	Acceptable flexibility specifications	
	Acceptable quality specifications	
	Acceptable support and test equipment	
	Acceptable maintainability specifications	
	Acceptable technology supplier	
	Acceptable longevity	
Technology & People Integration	Machine workstation design specification compatible with user's physical characteristics	
	Machine physical workload specification compatible with user's physical characteristics	
	Machine mental workload specification compatible with user's mental characteristics	Employees need to adapt to new programme
	User/machine interface specification compatible with user's physical and mental characteristics	
Safety Justification	Comply with machinery safety regulations	
	Comply with work environment safety regulations	

Evaluation Elements	Elements	Potential Effect(s) of Problem	Selected Option 1	Severity	Potential Cause(s) of Problem
	Strategic Justification		9		
			9		
	Financial Justification	Could stop investment	-3	5	Original budget was based on refurbishment not replacement
		Could stop investment	-3	5	Supplier quotation/specification cost is too high
			9		
		Increase the installation cost	3	3	Unforeseen service requirements
			9		
	Systems Integration		9		
		Part programme would have to be written in manual code	3	4	Will require resources to write post processor
	Technology & Organisation Integration		9		
			9		
			9		
			9		
		Effects overall operation efficiency and health and safety	-1	5	New skills required to operate new machine
	Technical Justification		9		
			9		
			9		
			9		
			9		
			9		
			9		
	Technology & People Integration		9		
			9		
		Require extra time to adapt and run operation effectively	3	5	Low learning curve to adapt to new programme
			9		
	Safety Justification		9		
			9		

Evaluation Elements

Elements	Likelihood of Problem	Recommended Action and Responsibility	RPN Sub-Element	RPN Element	Normalised RPN
Strategic Justification				0.0	0%
Financial Justification	5	Secure funding and reduce investment cost (Commercial personnel)	25	17.7	23%
	5	Renegotiate with supplier to reduce investment cost (Commercial personne	25		
	1	Raise contract variation (Commercial personnel)	3		
Systems Integration				20.0	26%
	5	Post processor would have to be written (Technical IT personnel)	20		
Technology & Organisation Integration				20.0	26%
	4	Include training in specification and investment cost, (Technical personnel)	20		
Technical Justification				0.0	0%
Technology & People Integration				20.0	26%
	4	Provide adequate training and adaptation time, (Technical personnel)	20		
Safety Justification				0.0	0%


Risk Assessment Diagram
Risk Priority Number [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
23%
26%
26%
0%
26%
0%
Strategic Justification
Financial Justification
Systems Integration
Technology & Organisation Integration
Technical Justification
Technology & People Integration
Safety Justification