Title:

An Expert System For Material Handling Equipment Selection

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Summary

Manufacturing Systems are subject to increasingly frequent changes in demand in terms of number and type of products they produce. It is impractical to continually re-configure the facilities, but it is possible to modify the material handling arrangements so that the selected equipment is the most appropriate for the current requirements. The number of decisions that need to be made coupled with the rate at which decisions must be taken adds significant difficulty to the problem of equipment selection.

Furthermore there are relatively few experts who have the necessary range of knowledge coupled with the ability to use this knowledge to select the most appropriate material handling solution in any situation. Access to such experts is therefore greatly restricted and decisions are more commonly made by less experienced people, who depend on equipment vendors for information, often resulting in poor equipment selection.

This research first examines the significance of appropriate material handling equipment choice in dynamic environments. The objective is to construct a computer based expert system utilising knowledge from the best available sources in addition to a systematic procedure for selection of material handling equipment. A new system has been produced, based on the Flex language, which elicits from the inexperienced user details of the handling requirements in order to build an equipment specification. It then selects from among 11 handling solution groups and provides the user with information supporting the selection.

Original features of the system are the way in which the knowledge is grouped, the ability of the procedure to deal with quantifiable and non-quantifiable equipment and selection factors, selection of decision analysis method and the validation of the final choice to establish confidence in the results. The system has been tested using real industrial data and has been found in 81% of cases to produce results which are acceptable to the experts who provided the information.

Declaration

The author declares that the contents of this thesis are the result of his work except where acknowledged sources have been used.

Acknowledgements

I wish to express my deepest appreciation to my research supervisor Dr. Tim C. Goodhead for his support, guidance and advice during this work. His criticism, and suggestions as well as his overall friendly style contributed enormously to the development of this research and it provided a comfortable environment in which to conduct such a task.

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CHAPTER ONE General Introduction

1.1 Introduction

A manufacturing enterprise strives to be competitive through its ability to adapt swiftly to any sudden changes in the global manufacturing climate by applying new methods and advanced technologies. Black [1] referred to Sir John Harvey-Jones's message that "for a production organisation to survive in the long term it must aim to be the best in the world at its chosen activity. If it does not, some other competing organisation in the world having the same aim will eventually win the customers for the product or services. To meet this aim, organisations have continuously to review their designs, manufacturing processes, and various procedures within the organisations."

Gould [2] was more specific by addressing the issue of manufacturing paradigms and the need to move away from cultures that have existed for around 100 years to updated ones to gain competitiveness in the global market. A major factor now is that the rate of change that is required of an enterprise is reaching the limits at which the enterprise can respond. It is the contention of this thesis that material handling could become either the bottleneck that restricts change or the means to enable change within the production environment. Which ever is the case, the belief is that selection of the most appropriate material handling method may occupy a position of far greater significance in the future than it does at present.

The aim of this research is to develop an improved method for material handling equipment selection. This method will tackle the complexity of selecting handling equipment in view of the rapid changes occurring in the new manufacturing era. Also it will aid the decision maker in selecting the best equipment which suits their production requirements.

1.2 Evolution Of Manufacturing Trends

The world of manufacturing is complex because of the diversity and the number of issues involved. According to Sule [4], manufacturing organisations are especially challenging, since they involve the performance of multiple activities (e.g. production process, inventory control, material flow, labour ....etc.). Kidd [3] echoed the same message remarking that the past four decades in particular have witnessed applications of many manufacturing trends which have influenced industry to varying degrees.

Ford pioneered 'mass production' in the 1920s as a manufacturing trend in the US. As the production process became more complex, the total process was analysed and subdivided into a number of simpler production functions. Workers were carefully but rather narrowly trained to operate their own tools and specialised machines with much improved efficiency. 'Mechanisation' became a key word in manufacturing [5], but although it was extremely well suited to certain types of production, it was not appropriate for all.

The concept of mass production was characterised by certain factors such as:

1. A stable and 'monochromatic' market.

2. Long product life cycles and production runs.

3. Stabilised engineering design

4. Industrial engineering based on breaking a job down into its parts.

5. Repetitive operations carried out by each worker.

The mass production concept fulfilled the mass market needs slowly and steadily. However, mass production was so focused on production that the personal link between the manufacturer and customer was far removed [6].

Mass production has been a dominating influence in manufacturing industries since the 1950s. Factories in the US and Europe geared up to producing large volumes of low variety and low cost products. They were however inflexible and lost capability to respond to rapid shifts in market conditions [3].

By the late 1960s to the mid 1970 the manufacturing industries were in the midst of a new technological revolution. This revolution was characterised by the increasing application of computers for both information processing and automatic control. Also, it contributed significant changes in the techniques of manufacturing which lead to some improvements (shorter lead time, added flexibility, and managing inventory ...etc.) in mass production efficiency [5]. During the same period Japanese manufacturers realised other limitations of the mass production concept (e.g. excessive inventory, inflexibly ...etc.) and they took the initiative to develop their own manufacturing paradigm, nowadays called 'lean manufacturing'.

Lean manufacturing is concerned with manufacturing products with less of everything, i.e. less time to design, less inventory, less lead time, less activities, less defects.

By the late 1970s many Japanese enterprises were starting to out-perform US and European competitors. As the lean manufacturing paradigm became established in Japan, generating a competitive edge for Japanese companies who were using it, in contrast the mass production paradigm was contributing to loss of market share for US and European Industry [3]. As the markets became more diverse and product variety was needed to satisfy more discerning customers.

The development of advanced manufacturing technology (AMT) in the 1970s- and 1980s was the necessary boost for the lean manufacturing paradigm to flourish. In an attempt to improve production efficiency AMT has focused upon the development and application of new manufacturing techniques in both hardwired and softwired form.

a) Among hardwired equipment are:

1. Computer-Controlled work centres (CNC, etc.);
2. Robotics and other automation schemes (Manipulators, etc.); and,
3. Automatic inspection equipment (Probes, Sensing transducers, etc.).

b) Softwired equipment include:

1. Computer-Aided Design (CAD);
2. Computer-Aided Manufacturing (CAM);
3. Computer-Aided Production Management (CAPM);

4. Flexible Manufacturing Systems (FMS);
5. Computer Integrated Manufacturing (CIM); and,
6. Artificial Intelligence (AI) in manufacturing, etc..

The hardwired equipment is concerned with the actual handling and processing of production materials on the shop floor, while the softwired equipment is concerned with the handling and processing of manufacturing and management information, and thus the planning and control of the manufacturing system.

Furthermore, the application of other methods like Just-In-Time (JIT), Material Requirement Planning (MRP), Manufacturing Resource Planning (MRP II), and Total Quality Management (TQM)...etc. all contributed enormously to the efficiency and the flexibility of the production operation [5].

Flexible and computer aided manufacturing has steadily grown to dominate manufacturing since the early 1980s till the present time. 'Automation' or 'Factory Automation' was the key word. Software such as MRP II, CAD, CAPM has automated much work involving repetitive calculations and many administrative processes. But it reached a limit where the changes are introduced only in softwired equipment to bring flexibility into production processes. Wu [5] argued that the latest revolution in manufacturing has been brought about by advances in computer and information technologies which put more emphasis on information and control than on hardware refinement. The question now is "whether future advancement can rely purely on software developments?".

Computer controlled hardware has reached a plateau where more advances in software is providing little or no change to existing manufacturing equipment. Although the development and applications of new manufacturing technologies are said to hold great promise for improving the performance of various manufacturing processes and auxiliary operations, it is very difficult to establish just how much they can achieve [5].

In other words, the capability to provide flexibility through features built into software is almost unlimited, but the ability to provide hardware which can be reconfigured in endless ways at a speed to match the software changes is problematical. Also, the advances in software have resulted in more complexity because of the constraints of the hardware (hardware might not be compatible with the software advanced features or changes in software didn't match the changes in hardware).

In an attempt to regain the competitive edge, a concept was originated in 1991 by the Iacocca Institute in US which was called 'agile manufacturing' [7].

Agile manufacturing means '*the ability of an enterprise to manage the changing unpredictable world of commerce and industry and survive in markets that demand rapid response to unexpected changes in customer demands, competitive challenges and technological breakthroughs*' [8].

The new paradigm for manufacturing in the 21st century presents an enormous challenge to industry because of the shift from mass, lean, flexible, and computer aided production (co-ordinating and enhancing production processes) to a highly rapid and dynamic manufacturing climate (speed and time constraints) with a variety of products produced. Products need to be tailored to particular customer requirements at little more than mass production costs - the '*mass customisation*' concept [2].

According to Allred [13], the competition, at the present time, between different enterprises is focusing on customer satisfaction because customers are demanding smaller batch sizes, shorter lead times, and higher product quality. Therefore speed, flexibility, and zero errors are considered the main objectives between competitors.

To meet this challenge and achieve the necessary agility (co-ordinated speed) in a manufacturing enterprise it must adapt to the new structure. The agile manufacturing structure should be considered and co-ordinated within every company's business strategies and products. The structure is supported by three primary resources [3, 9]:

1. Innovative management structures and organisation.
2. A skill base of knowledgeable and empowered people.
3. Flexible and intelligent technologies.

These three resources must be carefully integrated to achieve agility in manufacturing. This integration indicates that all parts of an enterprise are working toward a common goal.

In applying the agile manufacturing paradigm, the manufacturing enterprise is expected to respond rapidly to any changes in market demand by reducing product lead time. It is also expected to be highly flexible and adaptable to meet any changes in product variety to satisfy customer requirements. Currently, one of the requirements said to be important for agile manufacturing is plant layout configuration [14]. The layout configuration should be highly flexible and easy to change to accommodate sudden changes in production.

A case reported by Owen et al [8] emphasises that a key element of agility is re-configurability of assembly cells. In this case the product demand mix was highly unpredictable, and cells, once formed did not have the right balance of capability and capacity for any long period ahead. The decision was to make all assembly benches and handling equipment mobile. This allowed the whole of the assembly shop to be rapidly reconfigured.

This case highlights three points. Firstly, it showed that handling equipment was part of the process as well as the assembly benches. Secondly, it showed the flexibility needed in handling equipment as well as the rest of the layout configuration. Thirdly, the layout configuration can be changed in order to achieve an efficient operation.

The last point emphasises the fact that in an agile manufacturing environment a change in layout can be thought of as unavoidable if efficiency is to be maintained. If this is the case, a business must be expected to change its existing layout frequently and rapidly to respond quickly and efficiently to market demand. This results in decreasing production cost, shortening lead time, suppressing work in progress (WIP), streamlining material flow and avoiding bottlenecks, minimising handling of material, properly utilising manufacturing resources, providing smoothly sequenced operation, achieving line balancing, and increasing quality by closely monitoring processes.

There is no problem if a business has a relatively simple operation like assembly with mobile benches and equipment to achieve agility. But this is rarely the case, and changing the layout configuration causes many problems for manufacturing plants employing cells of heavy and complex machinery when trying to move the hardware all the time to achieve an efficient manufacturing operation.

There are many reasons why it might not be possible or desirable to change the layout. It might be because of building restrictions, lack of space, inflexibility of the layout, machines are heavy to move, need special foundations or require a long period of time for set-up to regain its performance prior to shutdown. Moving machines frequently can cause reliability problems and is likely to affect quality as well as the general disruption to the production schedule, which needs adjusting every time the layout is changed.

Other major factors are cost of moving machines, cost of planning the new layout configuration, and cost of machine down time while changing to the new configuration. All these additional costs will eventually accumulate and may increase the manufacturing cost to a point where the layout change is not cost effective, particularly if each new arrangement only remains in place for a short time.

As an alternative to changing the layout, the material handling system becomes the sole means to manage the situation. Instead of reconfiguring the layout it may be better to reconfigure the handling system because this can be performed faster and with less impact on the manufacturing equipment. Whether this reconfiguration of the handling system can itself be accommodated by its own flexibility, or whether it may need to be changed from one type to another depends on the nature of the equipment employed within the manufacturing enterprise.

1.3 Material Handling In Agile Manufacturing Environments

Manufacturing industries are on the verge of a new approach to manufacturing which is expected to accompany them into the 21st century. The agile manufacturing concept is predicted to replace the old manufacturing concepts (mass production, lean manufacturing, just-in-time and flexible manufacturing). The agile manufacturing concept has not appeared overnight. Section (1.2) described how the new concept evolved over time as a result of the development of many previous manufacturing cultures with the aid of advanced manufacturing methods and technologies just like the lean manufacturing concept. The lean manufacturing paradigm addressed some limitations of the mass production concept like long lead time and inflexibility. Agile manufacturing aims to achieve quick response to global market changes and produce a variety of products with mass production prices (mass customisation) which the lean manufacturing concept lacks.

The aim is to create a manufacturing business which is able not only to produce in volume but to deliver into a wide variety of market niches simultaneously [10]. The fast pace of this type of manufacturing to rapidly meet market and customer demand in the shortest possible lead time in order to maintain competitiveness is producing great pressures on manufacturing enterprises. One of the major problems is developing organisational structures that support the rapid changes needed in administrative procedures. This is largely being addressed by software solutions. However software alone cannot deal with hardware changes that are needed to deal with physical differences in the types of products and the quantities to be produced and handled. Therefore some physical changes need to be made and the ones which present a potentially large problem relate to plant layout and material handling. As has already been stated, frequent and rapid changes to plant layout are difficult and undesirable, so this work will focus on reconfiguring material handling to enable agility in manufacturing.

What is covered by the term "material handling"? There are many definitions for material handling. Apple [11] defines material handling rather simplistically as '*handling material*'. But Meyers's definition [12] is " *material handling uses the right method to provide the right amount of the right material at the right place, at the right time, in the right sequence, in the right position, in the right condition, and at the right cost*".

The material handling system within the manufacturing enterprise should be changed to fulfil the requirements of the new manufacturing paradigm. However, it is important that the handling system is well co-ordinated with the introduction of any new manufacturing processes or many problems (e.g. long lead time, too much WIP, and bottlenecks) will be created. Therefore, it is vital that the handling system can accommodate the output rates of previous processes and deals with processes bottleneck without creating too much inventory. Allred [13] argued that to automate individual production processes without managing the work flow between those processes means manufacturing processes are done faster and more accurately but the way material moves through the factory has not been optimised. Bottlenecks still remain which hamper productivity and negate the promised benefits of automation.

The practical solution is either to replace the old material handling system which is causing the previously mentioned problems, or to have a handling system that can be reconfigured to enable the necessary degree of flexibility and adaptability to absorb any rapid changes in the market. All this has to be considered as a part of selecting appropriate material handling equipment. Choosing appropriate material handling equipment is an essential part of the material handling system design. Nevertheless, it is a complex aspect, because of the diversity and the number of issues involved in the selection process (e.g. many equipment models and sub-models, the variety of equipment's features and characteristics).

1.4 Selection Of Material Handling Equipment

Selecting appropriate material handling equipment plays an important part in the design of material handling system. This is because the selection process requires careful and thorough analysis of various issues (e.g. flexibility, equipment features and characteristics, facility constraints) or else the handling equipment will impose a limits on the system's performance.

The expected manufacturing 'metamorphosis' for the next century places greater responsibilities on the material handling system. This is because agile manufacturing means that we must either have amazingly flexible systems that can make anything we want it to efficiently, or be able to reconfigure our systems very quickly to create different arrangements of cells to meet the new requirements.

The latter approach could be achieved by making all the facilities mobile. But this is only feasible for assembly because of the cost and time of performing the movements. The alternative is to accept that layouts could be very poor in terms of excessive material flow and material handling cost will rise to save the cost of continual reconfiguration. As the proportion of manufacturing cost arising from material handling rises, the importance of selecting the right handling equipment increases. There is a clear distinction between selecting the best equipment for the forthcoming period and the decision as to whether it is cost effective to make the change. Unless it is known what the "ideal" equipment is, the penalty associated with not changing cannot be established. There is therefore a requirement to select handling equipment for perpetually changing production requirements on a frequent basis.

Gould [2], Booth [10], and Allred [13] stated that in the future, manufacturing companies will have to achieve both objectives, that is compressed lead times and handle a wide variety of product without undue cost. So, the task of selecting appropriate material handling equipment in increasingly dynamic environments must be clearly focused on the objectives behind the shifting of manufacturing toward the agility concept.

1.5 Thesis Objectives

It is the contention of this research that one of the major elements in an agile enterprise is the material handling system (MHS) or the factory's material flow pipeline [13]. Choosing handling equipment which best suits continually changing production operations represents a major source of difficulty in the process of defining and designing the MHS. This is due to the tangible and non-tangible issues involved particularly in this dynamic manufacturing environment and because of the need for frequent decision making.

It is proposed to use an expert system as a decision tool when production conditions are changed to tell us what is the "ideal" equipment and whether this happens to be the equipment presently in use. If it is not, then there is a need to decide whether to change, or to remain with the existing, less than ideal, equipment. The decision process on whether or not to change will be largely a financial decision, depending on the business strategy employed by individual enterprises and is not part of this research.

Therefore the thesis objectives are:

1. To develop a systematic approach for the selection process of material handling equipment.
2. To analyse different material handling equipment selection techniques to establish their suitability for this type of analysis.
3. To determine the best technique which lends itself to implementation within an expert system.

1.6 The Structure Of The Thesis

The thesis guides the reader through the development of the new expert system and it demonstrates a systematic approach to achieve the research objectives defined in section (1.5).

The foundation of the research work is established in the first three chapters (1, 2, and 3) which represent the problem definition part of the research. A general overview of the evolution of manufacturing paradigms with the emphasis on material handling issues, and the importance of selecting appropriate handling equipment in a dynamic manufacturing environment have been introduced in this chapter. A closer focus on material handling and especially the approaches to tackle the difficulties associated with material handling equipment are addressed in chapter 2 where an original method of forming handling equipment into groups is presented. A discussion is provided in chapter 3 of the complexity of the selection process, and the diversity of the issues involved in such situations. Furthermore an evaluation of decision analysis methods is produced.

Chapters 4, 5, 6, and 7 cover the development of a new approach to tackle the complexity of the material handling equipment selection problem. Chapter 4 examines the role of computerisation and evaluates expert system applications within the artificial intelligence context as well as providing an overview of the current selection systems available through a literature review.

An investigation conducted on the available selection systems generated original development issues regarding building an expert system for material handling equipment selection and is contained in chapter 5. Next is the development methodology for equipment evaluation technique within an expert system application. The implementation process of the new system is described in chapter 7.

The final part of the research work is presented in chapters 8, 9, and 10. This part is concerned with the results produced by experiments conducted on the new expert system to evaluate its selection performance.

Chapter 8 is concerned with original element of this research which is an objective comparison between different multi-criteria decision analysis techniques related to the selection of material handling equipment. They are then applied in a single software package (expert system software) to test their selection performance in order to distinguish which is the best for the final implementation process. Although work published by other authors in this field involved experiments which used other multi-criteria techniques for specific data and a specific selection criteria, nevertheless they did not provide an evaluation of why these particular multi-criteria decision techniques are used. Therefore this new approach is considered to enhance the decision making process regarding the selection of handling equipment.

The expert system produced was modified by employing different decision analysis techniques and each version was first tested using random data. The analysis of decisions based on the previous results by the testing investigation stage is used to explain if there is an effect of different multi-criteria decision analysis techniques on the systems' final choice of best equipment. By changing from one multi-criteria technique to another, tests are performed to establish which one produces more accurate and effective results for the decision maker and which multi-criteria technique lends itself to an expert system application.

An evaluation process of the final expert system using real examples from manufacturing industry for the purpose of validating this system are contained in chapter 9. This evaluation process of the new system's performance establishes the circumstances in which it produces results that are in agreement with the opinions of practising engineers working with existing handling situations. It also establishes the confidence that can be placed in the decision produced by the system. Finally chapter 10 concludes the research, and presents recommendations for further and future work.

CHAPTER TWO Material Handling Equipment

2.1 Introduction

Handling of materials and products is an important aspect of international trading. There are many means of handling ranging from lorries, trains, ships, aircraft etc. to trolleys, conveyors and cranes which are used universally to perform materials handling. They belong to what we will call the total global set of handling methods. The range of methods is vast and the number of industrial pieces of equipment is huge so it is impractical to try to search and analyse this total global population without some guidelines.

2.2 Defining Problem Guidelines

An important issue in the analysis of the global set is the type of handling activities and the requirements which influence the business decision for selecting particular handling methods. A business decision contains two parts. Firstly, the strategy, financial situation, equipment company selection etc. Secondly, purely technical information on the handling activity, particular problem, equipment selection specifications etc.

2.2.1 Non-Cost Equipment Evaluation

The selection analysis of material handling equipment will be based on a non-cost evaluation of alternatives because the factors used for business decision making may vary from company to company or for a given company may even vary at different times in its business cycle. In contrast, the technical issues do not change over a short period of time like the business factors. The following are matters influencing business decisions :

1) Long-term corporate and business strategy

2) Short-term business and manufacturing tactics

3) Uncertainty and instability in business environment

These complex matters should be dealt with at top management level where there is the knowledge and the expertise to handle business decisions of this type. It is very difficult to build an expert system capable of incorporating all of the economic factors because of difficulty in constantly updating the knowledge and agreeing on the decision criteria etc.

But it may be possible to establish the best technical solution and then use relatively simple economic decision tools to see if it can be afforded. It is only if the optimal solution is known that it can be determined how much it is worth compared with cheaper solutions. Therefore these business matters which affect the selection decision are considered to be beyond the scope of this work.

An important point which supports this intention is the fact that cost is really hidden within the technical performance of equipment even though it is a non-cost selection investigation. By defining and considering appropriate equipment selection factors and criteria, an appropriate selection result for a particular situation will be made. The assumption is that in the long term the most suitable equipment will minimise total costs. Therefore the emphasis at this stage is to focus on the other important issues which constitute this problem in an attempt to produce an effective selection decision tool.

2.2.2 Technical Issues Of This Problem

Even when neglecting the non-technical factors associated with equipment selection, the problem is vast. In an attempt to narrow down the scope of selecting from the global set to find an appropriate handling method for a particular situation, the total global population can be divided into sets each containing a number of handling methods (see figure 2.1) which are considered suitable for particular situation. For the purpose of this research, the situations will be restricted to movement of discrete manufactured parts (see figure 2.2) within the confines of a single manufacturing plant. Although this excludes all long distance transportation methods and movement of 'continuous products' (chemicals, papers, textiles etc.), these situations are considered to cover the cases when the selection problem is greatest.

In other words the scope of the research is defined as follows:

1. Restricted to the technical part of a business decision
2. Selection decision analysis based on technical issues
3. Movement within a manufacturing plant
4. Discrete manufactured parts

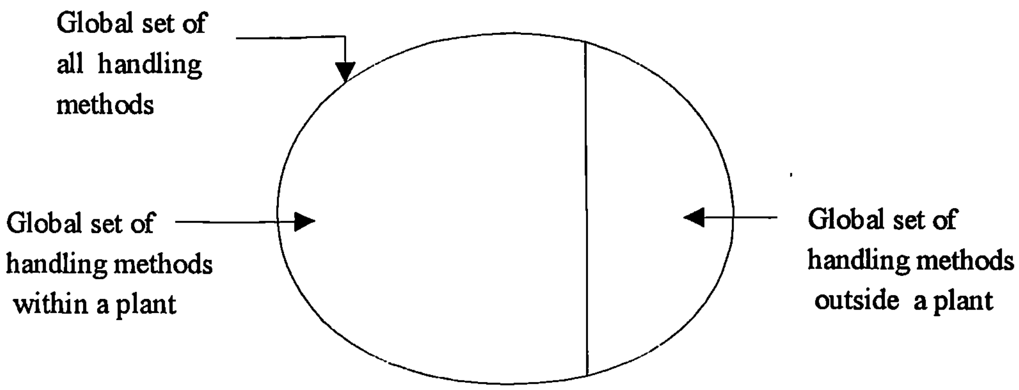

Figure 2.1- Divisions within the global set of all handling methods

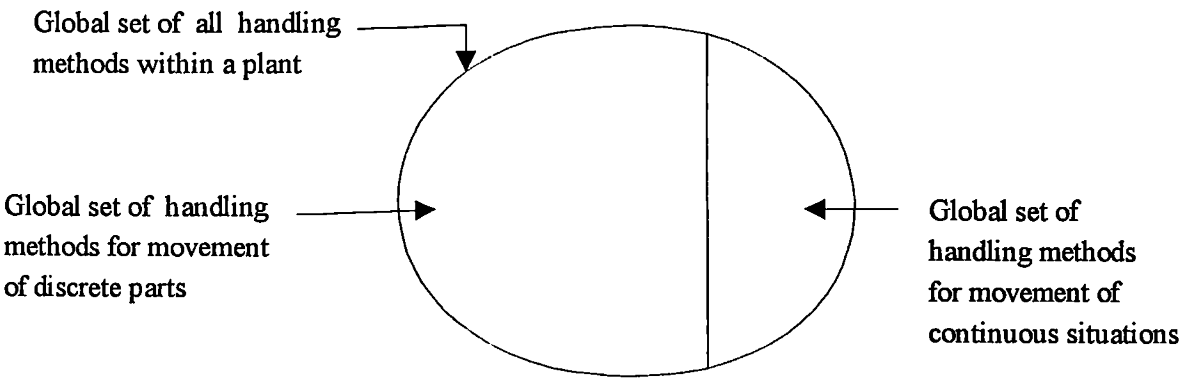

Figure 2.2- Divisions of the global set of all handling methods within a plant

2.3 The Material Handling Selection Problem

The previous chapter has suggested that the material handling system and equipment will occupy a position of far greater importance in achieving higher production operation efficiency if the agile manufacturing concept is widely adopted. Apple [11] stated that one of the few general conclusions we can draw about material handling is that its scope is expanding and its importance is becoming more widely recognised.

Material handling itself is not complex, since it is merely concerned with moving material from one location to another (A ==> B). This primary function can be achieved in a huge number of ways because there are a variety of basic methods, each of which can use a range of different types of handling equipment and it is partly this that makes the selection task complex. The other thing that makes it complex is that there are many secondary attributes (flexibility, speed, safety, cost, reliability, space efficiency, environmental friendliness etc.) that ideally need to be satisfied, but for a given task there is no easy way either to rate the relative importance of these functions, or to rate how well different handling methods compare with one another based on the same attributes.

Paradoxically therefore, it is the simplicity of the task that makes selection of handling method so difficult for the following reasons:

a) There are a vast number of handling equipment alternatives that satisfy the primary function.

b) There are poor means of matching available options to particular tasks due to:

1. Many secondary criteria
2. Difficulty of rating the importance of each criteria against the others
3. Difficulty of rating any piece of equipment against particular criteria

The main problem is that there are a huge number of possibilities and no easy way to rank them properly. Therefore the remainder of this chapter is intended to review the characteristics of material handling activity and handling equipment to provide a clear understanding of the complexity associated with the analysis of selecting handling alternatives.

2.4 Ways Of Simplifying The Problem

The main priority in the analysis of material handling situations is finding the best material handling equipment which most nearly satisfies the business requirements. Ultimately an enterprise must select equipment of a specific make, type, and model number. But the question is "which is the best equipment to be selected?" To be able to find an answer for this question it is necessary to search thoroughly for the right equipment among a spectrum of handling equipment makes and models. The range of all equipment models of all types available from all manufacturers in all countries of the world is vast. The number of products advertised in trade magazines, reflect the size of the market and quotes such as "In what is already a crowded marketplace, another fork lift truck manufacturer has arrived. The new arrival from Korea, Halla." [15] are indicative of an expanding market place with new suppliers continually adding new products.

The words “a crowded marketplace” from the previous quote indicates the state of material handling equipment field at present. Furthermore the ‘global marketplace’ offers an estimated 3,500,000 makes, types, and models of industrial handling equipment [Appendix A]. In other words, this industry is a huge business which deals with a large variety of equipment models and each model has it own features and characteristics. It is not reasonable to attempt to select from this total global population of equipment for the following reasons:

1. Too many makes and models
2. Perpetually changing
3. Practicalities of supply/maintenance/legalities etc. if selecting from manufacturers anywhere in the world
4. Different levels of sophistication (manual to fully automated)
5. Long search period
6. Complex task
7. Tedious, and slow process
8. Not cost effective

Therefore it is necessary for purely practical reasons to *classify* this total global population into a number of groups based on features and characteristics of the equipment. There are two possible ways to perform this task:

a) Restrict the set in which to search to a small number of local equipment suppliers then choose from the ‘best’ available (see figure- 2.3).

b) Reduce the total number of options by classifying equipment into groups. Reject equipment in all inappropriate groups and restrict further search to one group only (see figure 2.4).

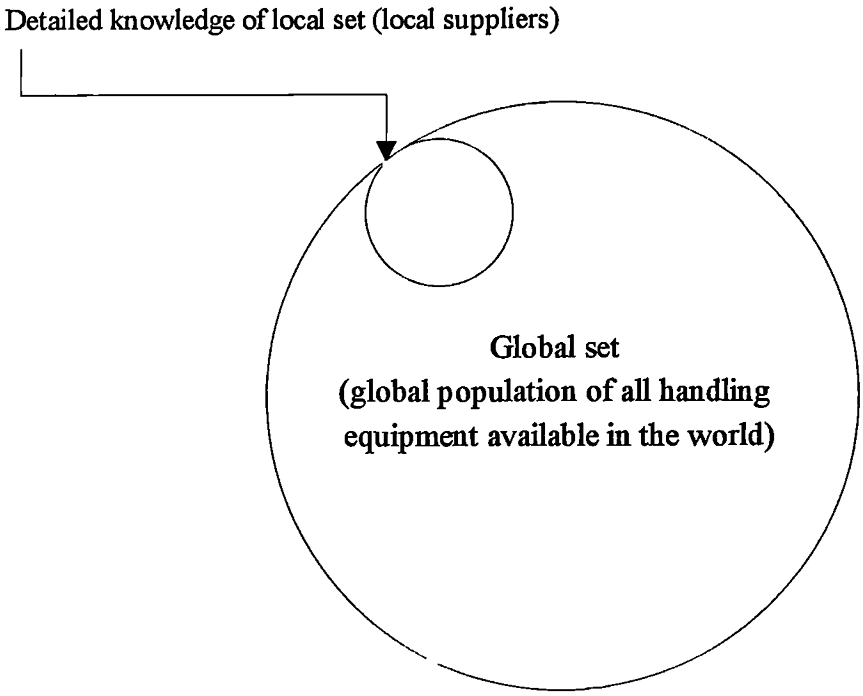

Figure 2.3- Search area restricted to a local set

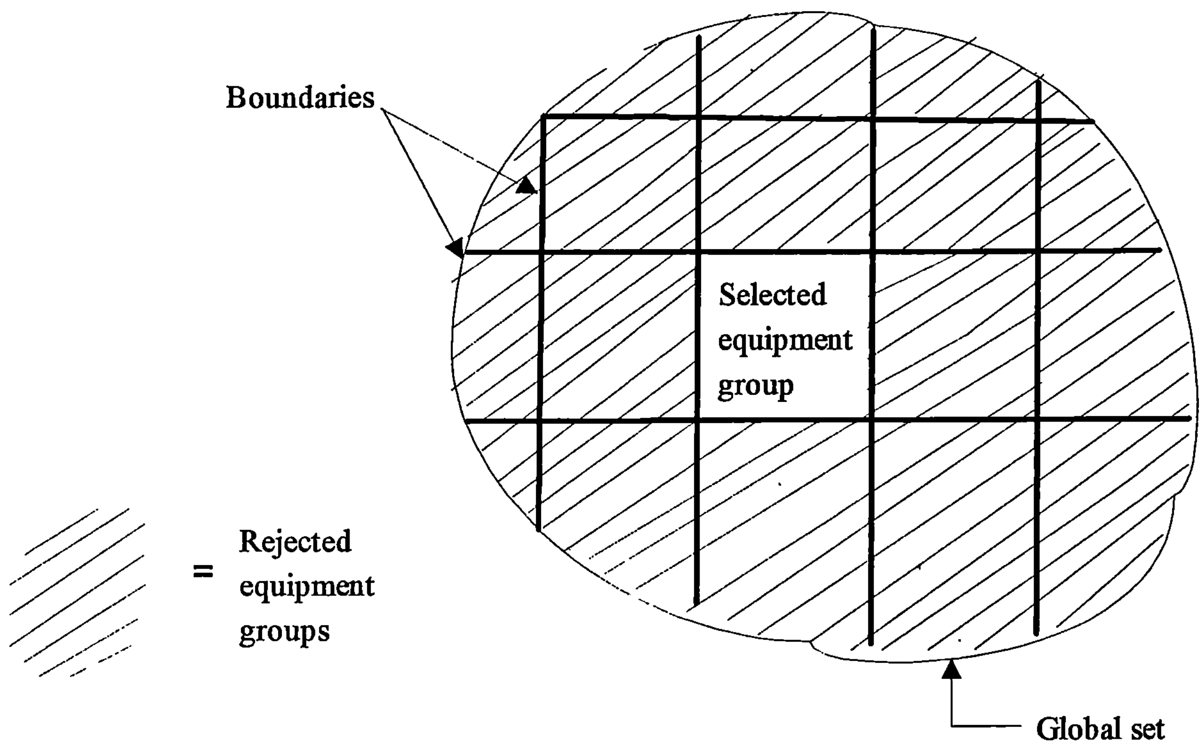

Figure 2.4- Global population divided into groups

2.4.1 Selecting Equipment From A Restricted Supplier

A company which requires a solution to a material handling problem must ultimately identify specific makes and models of equipment from particular suppliers. The supplier may be the equipment manufacturers or may be a selling agent for a number of equipment manufacturers. It is possible for a company to restrict itself to dealing with one supplier or a limited number of suppliers. To do so minimises the scale of the selection problem and it may not be too difficult to identify the equipment which most readily satisfies the handling requirements from among the limited number of makes and models of equipment available from the restricted number of suppliers. It is however highly unlikely that a limited sub-set (local supplier - see figure 2.3) of all available equipment will contain the 'best' equipment and so the selected equipment will be sub-optimal.

In other words, restricting the search area in this way makes the selection process achievable manually and it is possible for an individual to become an 'expert' within their own limited range of makes and models. Also, it will reduce search time, speed up the selection process and minimise the cost associated with this process.

However the chance of the optimum equipment solution (see figure-2.5) falling within the local set are small, even assuming that there is a universally recognised 'optimum' solution. In other words it is not known whether the optimum is inside or outside the local set, but it is far more likely to be outside.

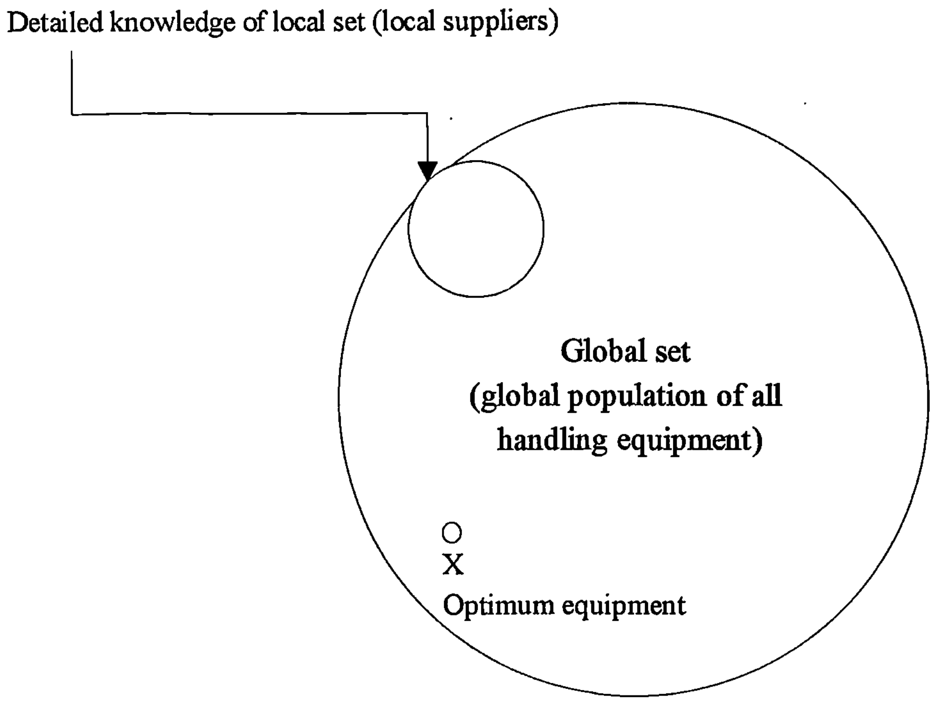

Figure 2.5- Optimum equipment outside the local set

The probability of the optimum being inside a local set is =

$$\left(\frac{\text{No. in local set}}{\text{No. in global set}} \times 100 \right) \%$$

For example if the global set is roughly 3,500,000 models of handling equipment [Appendix A], we might assume that a local supplier offers 1000 different pieces of equipment so the local set has 1000 models. Substituting these values into the above formula gives a probability of 0.029 %. This is a very low probability which means that there is a very high chance, almost guaranteed, that the optimum equipment will be excluded from the local set.

Also by missing the optimum and disregarding so much equipment which falls outside the restricted or local set, there is a risk that the solution to a handling problem may yield much lower performance than a competitor who used the same strategy but whose local set happened, by chance, to contain the optimum equipment. Therefore this method is not suitable to attempt to find the best handling equipment.

2.4.2 Classifying Equipment Into Groups

The other possibility is to attempt to divide the global equipment population (global set, see figure- 2.4) into 'groups'. Investigating and establishing boundaries for all groups is a preliminary selection step. This must be followed by an analysis to establish which is the one 'group' that contains the optimal equipment solution. All other 'groups' are then rejected and the search is limited to the selected group.

By referring to figure 2.4 the optimum solution now falls within the selected equipment group, which will increase the chance to select the optimal equipment by restricting the analysis to a specified group and minimise the effects of missing the best handling solution. This second approach means that we must identify a way to classify equipment into groups. To do this the following two steps aid the classification process:

1. Use generic types of equipment by eliminating individual manufacturers makes, types, and model numbers. Most equipment in the same generic group usually performs similar handling tasks with minor differences. Manufacturers often compete 'head-on' with similar specifications and sell not on capabilities of equipment alone but

on price, service before and after sale, labour training and support, and the strong financial situation of its enterprise for further and future technical support.

2. Draw boundaries between generic types to produce a "manageable" number of equipment groups. For instance handling equipment can be characterised as being "manually operated" or "unmanned" or it can operate "on" or "off the ground" etc. These common characteristics can be used as a boundaries to classify similar groups.

To consider drawing boundaries to produce a number of groups for selection analysis, there are some points which must be established. If the number of groups is small, e.g. 4 or less, there will inevitably be a very large range of equipment in each group which still presents a significant selection complexity due to the diversity of the equipment in a particular group. Therefore having very few groups does not necessarily make the search easy.

The boundaries established between them will not be sufficient and explicit enough to clearly differentiate one particular group from another. This is because some equipment can be considered to lie in more than one group. The probability is high that this approach will create a significant area of boundary fuzziness between adjacent groups. To clearly distinguish between adjacent groups an imaginary boundary called the 'ideal' boundary should be defined. Then it is necessary to establish the best explicit boundary definition as close as possible to the 'ideal' in an attempt to reduce fuzziness of boundaries between different groups (see figure 2.6). So there are two functions of the ideal boundary:

1. Eliminates fuzziness of boundaries between groups

2. Acts as a reference (mark) for drawing boundaries

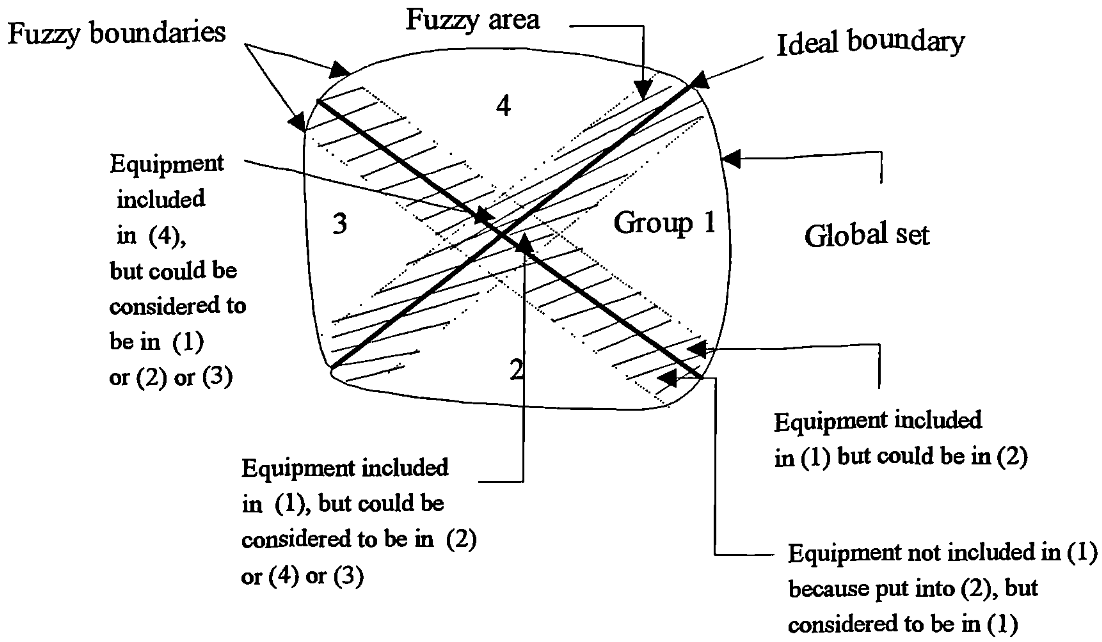

Figure 2.6- Fuzzy areas between larger equipment groups

Figure (2.6) displays many gray areas between the dotted lines which contain much equipment that needs to be classified further into groups of equipment according to other characteristics. Ultimately, following this approach produces a high risk of missing important equipment which greatly affects the result of any selection analysis process because of the fuzziness of boundaries between different groups of equipment. Therefore establishing where 'ideal' boundaries must be set aids the process of drawing boundaries which will minimise the fuzziness between groups. But this is a complex task due to the huge amount of equipment, their diverse characteristics, and the existence of uncertainty in defining equipment capability.

It should be observed in figure (2.6) that the fuzzy area is small compared to the area of each group, but all fuzzy areas are a significant proportion of the total area of the total global set. It should also be observed that some fuzzy areas are shared between two or more groups. Therefore if the fuzzy area is too large in contrast to the size of the group itself (see figure 2.7), then the search area is not restricted enough. Also the validity of the search analysis will be reduced by the amount of fuzziness, because the risk of missing too many alternatives, one of which could be the optimum choice, is too high.

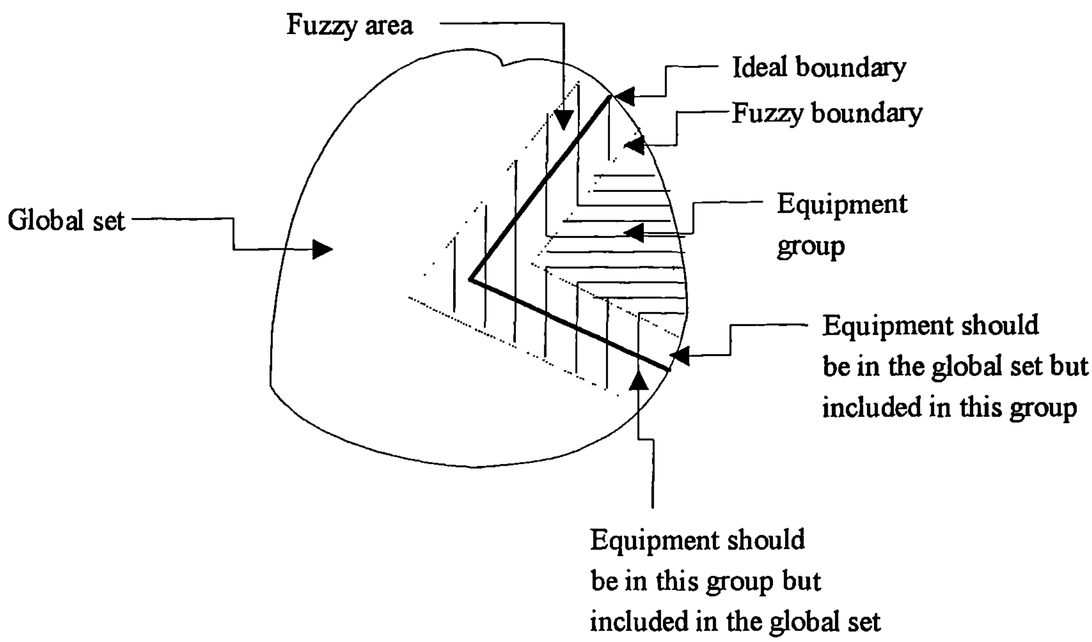

Figure 2.7- Fuzzy areas between one equipment group and the global set

Figure (2.7) depicts one equipment group, as an example, to illustrate that even though there is one group, there is a significant area of fuzziness compared to the actual group area. Furthermore the approach using few boundaries has three types of complexity:

1. Within equipment of the ideal group due to diversity of characteristics.
2. Within equipment of the fuzzy area because of difficulty of defining many equipment types and which group they belong to.
3. Where to draw the boundary between specific equipment groups and the fuzzy area between any 2 equipment groups.

In contrast, attempting to use a larger number of boundaries to establish many smaller equipment groups, e.g. 100 (see Figure-2.8) results in a much more detailed specification of the equipment in each group. It might be thought that this more detailed specification allows a much more precise division of equipment with more clearly defined boundaries but there is now a greater similarity between equipment in adjacent groups and there remains an area of fuzziness between groups. In this situation the fuzzy area will be much smaller than that between larger groups, but as a proportion of the size of the groups, it may be highly significant.

Figure (2.8) illustrates that an approach employing many equipment groups has clear and better defined equipment groups. Although the fuzzy area is actually quite small, because equipment group areas are also small, the fuzzy area is relatively large as a proportion of the equipment group area which makes the chance that the optimum equipment falls within a specific group relatively small.

To summarise both approaches, Table-2.1 highlights a comparison and the main differences between the "few boundaries larger equipment groups" and "the many boundaries with less equipment groups" approaches.

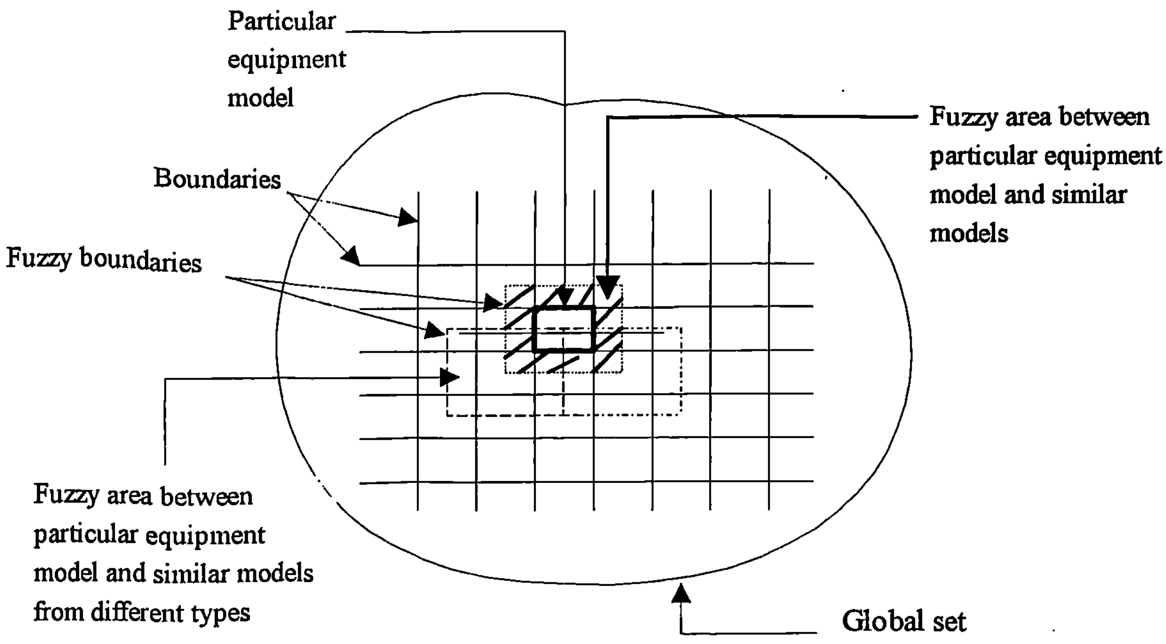

Figure 2.8- Fuzzy areas between smaller equipment group

Few Boundaries	Many Boundaries
Large equipment groups	Small equipment groups
Boundary is not explicit	Boundary is relatively explicit
Similarity is low between groups	Similarity is high between groups
Less details about specific type	Much detail about specific model
Relatively small fuzzy area with significant number of equipment	Large fuzzy area with few equipment
Probability is relatively high that optimum lies inside fuzzy areas	Probability is high that optimum lies outside selected group
Difficulty with many features and characteristics in same group	Difficulty with similarity between adjacent groups

Table-2.1

The above Table, (2.1), reveals limitations arising from approaches involving very few and very many boundaries. It is clear that neither approach has obvious superiority. The problem is one of finding the number of boundaries that gives groups which have the minimum amount of fuzziness associated with them as this will maximise the chances of selecting a group containing the optimum solution.

Ultimately, an investigator should select carefully the number of groups to successfully satisfy the analysis process. Therefore it is logical to choose a 'compromised' number of groups to overcome the difficulties of the previous two cases, recognising that precisely where to draw boundaries is a difficult task.

2.5 Difficulties With The Boundaries Approach

It is possible to choose any number of equipment groups for the purpose of selection analysis. But the difficulty lies with the separation process and establishing where to draw boundaries between selected groups. The ideal is to draw boundaries where groups are totally unambiguous and it is universally accepted which equipment falls into which group. But the ideal is difficult to attain and there is no universally established 'protocol' for this task.

There are so many features and characteristics presented by the total population of equipment types, makes and models. Defining precisely where to draw a boundary is complex, because of the diversity of characteristics encountered during the grouping process. This can be tedious when attempted manually. In reality boundaries between different types of equipment are overlapped (see figure- 2.9).

So attempting to draw boundaries might be described as determining the shared characteristics (e.g. manually operated, fully automated .etc.) between many groups of equipment to produce clear divisions and a number of groups which minimises the fuzziness for appropriate selection investigation.

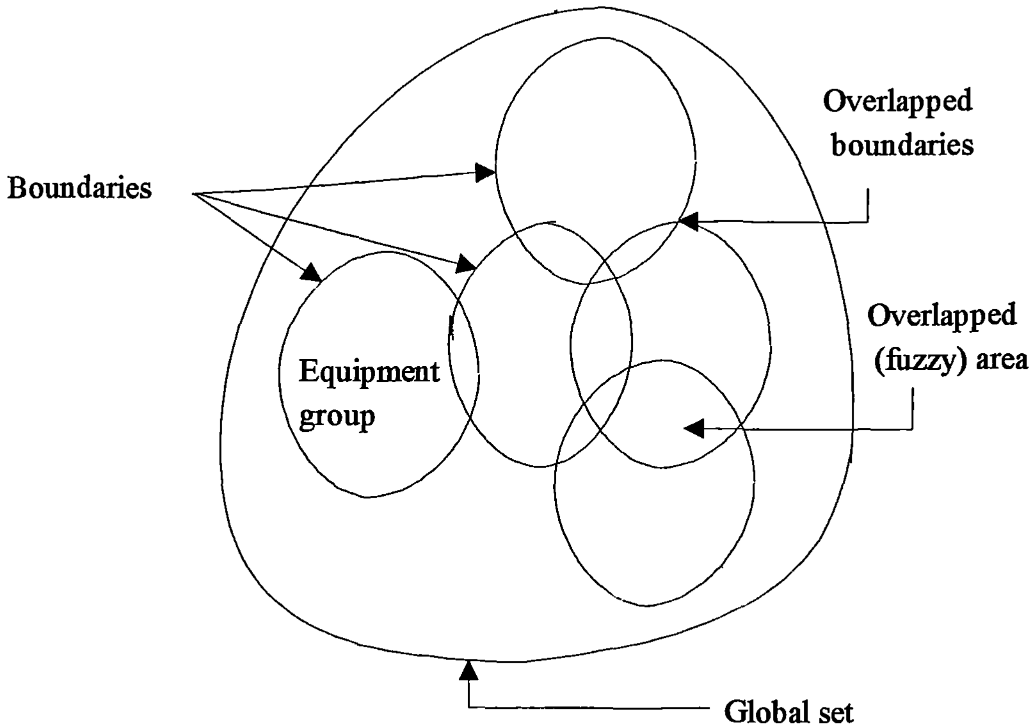

Figure 2.9- Groups boundaries overlapped

For example within forklift trucks are some models which use two types of power source, electric for inside tasks and liquid fuel to generate electric power while working outside the plant. Also, there are fixed path and mobile conveyors which overlap with forklift trucks when compared by power source characteristic. Conveyors fitted with automatic identification and turn tables to direct materials in different paths, can overlap with a forklift truck when using variable path criteria. The towline handling method is another good example. This equipment consists of a series of trucks attached to a fixed path chain conveyor, so this handling method operates in a similar manner to a continuous conveyor on a fixed path movement, but it utilises trucks to handle materials. The combination of trucks and conveyor in one handling method creates complexity of grouping equipment because it can be grouped with either conveyors, or trucks, or both.

The previous examples demonstrate that there are many handling methods which are difficult to categorise into generic types (e.g. conveyors, trucks .etc.) producing overlapped situations and creating fuzzy areas. Fuzziness negates the explicitness of the boundaries between adjacent groups and causes difficulty in selection. Therefore it is essential to determine where it is best to draw the boundaries to minimise the number of such situations.

Boundary definition is directly related to the number of groups. It has been stated in section 2.4.2 that if we choose to introduce less boundaries which creates fewer groups with correspondingly larger amounts of equipment in each, then we will have significant fuzzy or gray areas between groups, the group is not restricted, and the boundary is not explicit. In contrast, many boundaries produce more groups with smaller amounts of equipment then complexity arises from the amount of detail produced on particular types which might complicate the analysis procedure. Also the great similarity between groups brings about a problem of distinguishing to which group a piece of equipment belongs. Ultimately, both extremes fail to attain the optimum solution.

In other words we can express the problems with the boundary approach as follows:

1. Universal boundaries do not exist
2. Too many equipment types produce boundary fuzziness
3. Too few boundaries do not give explicit divisions
4. Too many boundaries give too much similarity between groups
5. The same equipment may fall into different groups depending on the shared characteristics between many groups.
6. Difficulty of selecting the optimum

The solution is to try to choose reasonably clear boundaries which will produce a manageable number of equipment groups to decrease the situation complexity, i.e. to define boundaries in a way to minimise the fuzziness between boundaries and reduce overlaps to distinguish clearly between groups. This means a compromised number of groups which represent all the generic groups and covers all aspects of industrial handling for the specified task.

To analyse the problem of selecting the right handling equipment many researchers in the field of material handling have introduced approaches to separate and group similar handling equipment into categories (e.g. industrial trucks, conveyors). These approaches will be discussed in the next section.

2.6 Different Approaches For Grouping Handling Equipment

Even when individual makes and models of handling equipment are eliminated by only considering generic types, there is so much equipment available in today's market with different characteristics such as power source (e.g. petrol, gas, and electric), operating features (manned, and unmanned), and capability (e.g. fixed route, flexible route) etc. A universally accepted grouping system for this equipment does not exist at present due to the many possible alternatives and the difficulty of establishing or drawing an exact boundary which separates and distinguishes one group or type from another. For example conveyors are commonly used for continuous production, with fixed path materials movement. But now a days it is possible to modify the conveyor system with a turn table and a scanner to read material's bar codes then switch between many variable paths. Also, there are flexible and expandable conveyors which have mobility as well as flexibility to be configured to perform unloading and loading tasks, for instance, and then be reconfigured and moved to another location. There are many other examples like those previously mentioned which make the task of grouping of handling equipment difficult.

In the literature there have been many attempts to group material handling equipment on the basis of a variety of criteria. Apple [11] proposed division into four basic or common types of equipment as follows (see figure 2.10):

1. Conveyors.

   Conveyors are defined as gravity or powered devices commonly used for moving uniform loads continuously from point-to-point over fixed paths, where the primary function is *conveying*.

2. Industrial trucks.

   These are described as hand or powered vehicles used for the movement of mixed or uniform loads intermittently over various paths having suitable running surfaces and clearance, where the primary function is manoeuvring or *transporting.*

3. Cranes and hoists

   These are defined as overhead devices used for moving varying loads intermittently between points within an area, fixed by the supporting and guiding rails, where the primary function is *transferring.*

4. Auxiliary equipment

   This is a category consisting of devices or attachments used with handling equipment to make its use more efficient (e.g. pallets, containers, lift truck attachments, and weighing equipment).

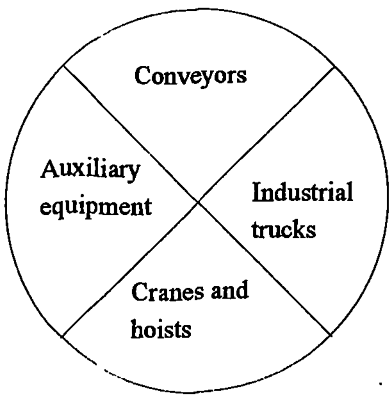

Figure 2.10- Apple's [11] four basic types of equipment

In this grouping system the first three are basic types of equipment and the fourth category is just attachments and accessories used to enhance equipment performance or to broaden the application of basic equipment.

This approach depends on the handling function only to distinguish and separate equipment. But the handling functions alone are not sufficient to clearly define a unique group. This is because the differences between the three functions (transferring, transporting and conveying) are not obvious and different people may interpret them differently. We need to be able to define exactly the differences between the three functions. The difficulty in defining these differences creates great fuzziness and ambiguity. A particular problem is that Apple does not provided enough information on how he arrived at this grouping system and what technical criteria have been used to define groups.

The lack of explicit definition of groups means that some equipment types which can perform several handling functions might fit in all three groups. For example a towline system can be considered to be operating as a conveying, transporting, and transferring handling system at the same time due to its continuous movement of a series of pallet trucks attached to a chain conveyor. Also, a mono-rail conveyor is a conveying and transferring system. So there is ambiguity in terms of which group particular equipment belongs to. Therefore significant fuzzy areas are developed between adjacent groups which make the boundaries not clear enough to restrict groups (see Figure 2.11).

Figure (2.11) displays the fuzziness between adjacent groups based on Apple's division. Towline can be considered to represent all the fuzzy areas between conveyors, trucks, and cranes and hoists. A monorail conveyor can perform by transferring and transporting which causes it to fall in the fuzzy area between trucks and cranes. Group 4 contains the auxiliary equipment which could be suitable for use with all three groups. So the boundaries are not confined enough to clearly distinguish between groups.

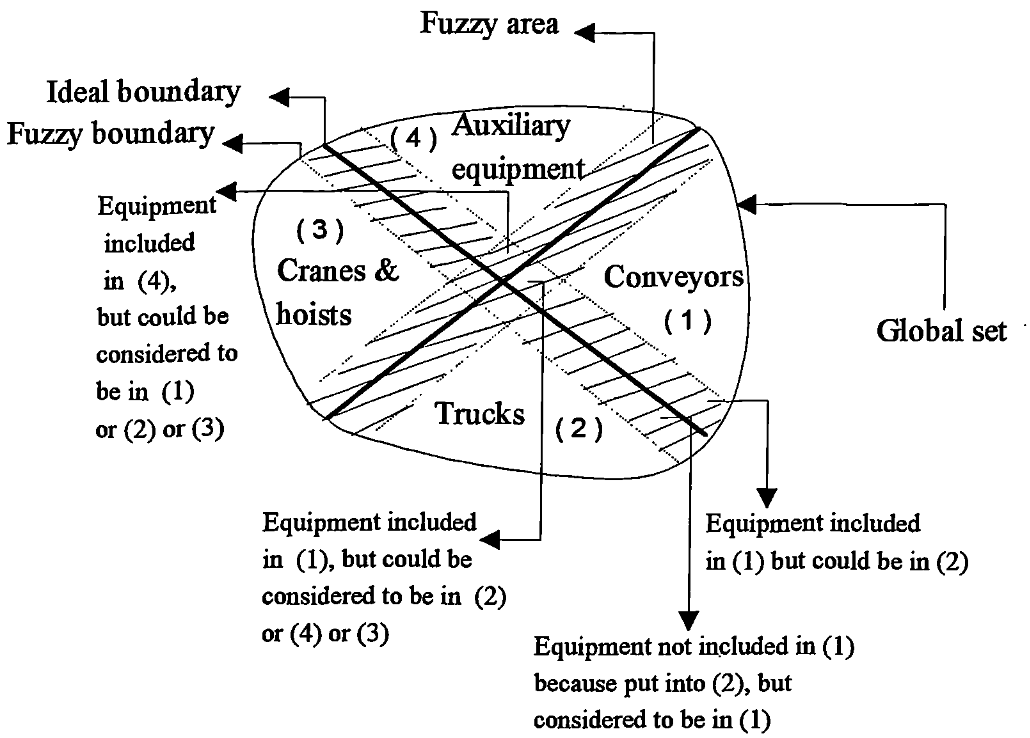

Figure 2.11- Fuzzy areas between larger equipment groups, Apple's method

Apple's method of equipment classification is a good example of the previous case in section 2.4.2 of drawing few boundaries producing large equipment groups resulting in significant areas of overlap between groups due to their large number and the wide range of characteristics in each group. It was shown previously that this type of approach is unlikely to lead to selection of the optimum solution because of the high probability that the optimum will lie in the fuzzy area outside a particular boundary.

If we reconsider Apple's grouping system and particularly the first three definitions of basic equipment types, it can be seen that they contain several characteristics which can be used as boundaries to produce alternative ways of dividing Apple's basic groups. The following are examples of characteristics mentioned in the previous definitions :

1. Power source: almost all conveyors use electricity, some models of industrial trucks use electricity, and electricity also drives cranes and hoists. It is therefore possible to combine these three categories into one group (see figure 2.12).

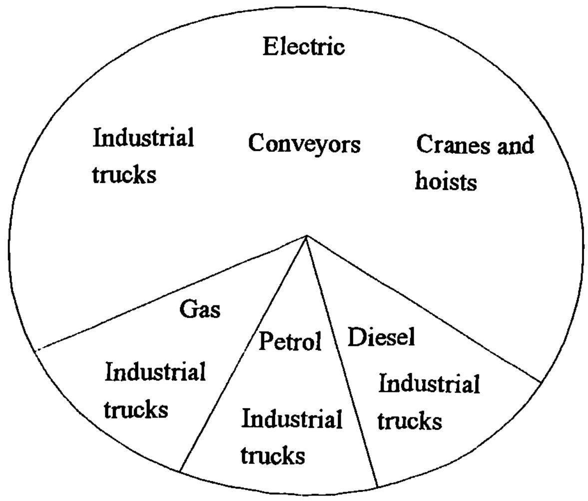

Figure 2.12- Apple's three basic types of equipment in different categories according to power source criteria

Figure (2.12) shows that by using the power source criteria we can have another arrangement of Apple's basic equipment types. Also this grouping results in less duplication between groups except for dual fuel equipment. The main problem here is that the electric powered group has large amount of equipment which still produces difficulty. This is because of diversity of characteristics which makes selection from within that group a further problem.

2. Type of load: individual items, unit load, or a mix of these two are handled by industrial trucks and cranes and hoists. Conveyors handle the same type of loads but instead of mixed (individual items, and unit load) they are preferred for bulk handling. This selection factor can be used to group equipment (see figure 2.13).

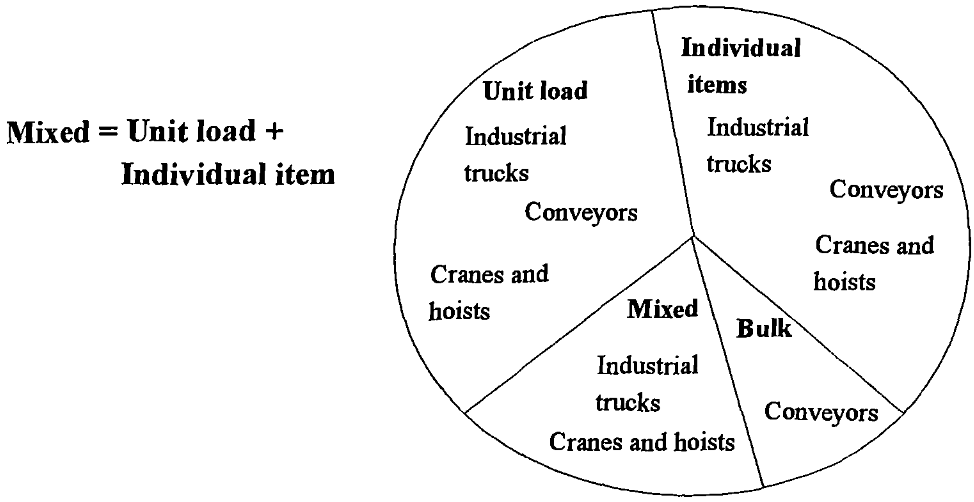

Figure 2.13- Apple's three basic types of equipment in different categories according to type of load criteria

Figure (2.13) depicts the main problem of extensive duplication of equipment between groups which in turn leads to a large amount of equipment in most groups. Therefore the explicitness of boundaries is reduced.

3. Direction of movement: usually conveyors and industrial trucks are used for horizontal movement. Again type of movement can be used to form other groups and the direction of movement criteria produces the same result as the power source criteria in terms of grouping of equipment (see figure 2.14).

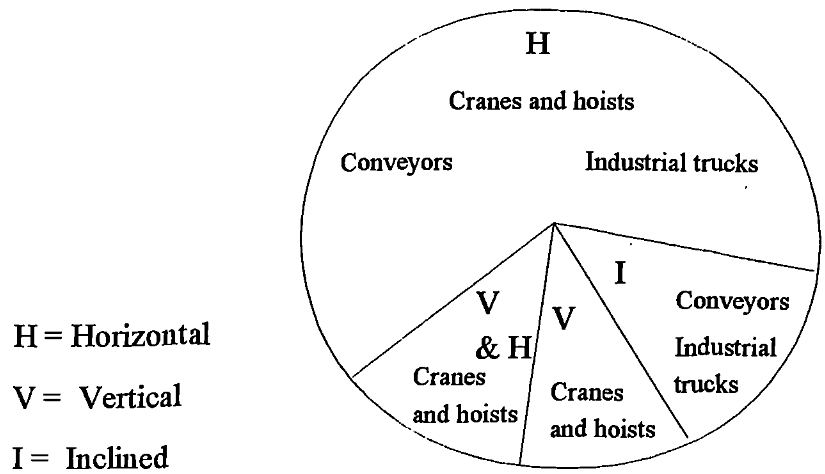

Figure 2.14- Apple's three basic types of equipment in different categories according to movement criteria

4. Level of automation: cranes and hoist as well as industrial trucks can be operated as totally autonomous equipment. Pallet trucks and trolleys without power sources must be used manually. Some conveyors, and cranes and hoist are commonly semi-automated operations because of manual loading/unloading or involvement. Some types of trucks are fully automated (e.g. AGV) (see Figure 2.15). We should, also, observe that figure (2.15) illustrates similar conclusions as with examples (1), and (3) which were mentioned earlier.

5. Speed: fixed speed is usually associated with conveyors, cranes and hoists, but variable speed is available with trucks. Some types of trucks offer fixed and variable speeds to accommodate particular tasks. Speed criteria tends to produce less duplication between equipment groups, but is not normally a sufficiently important factor on its own on which to select equipment.

TA = Totally autonomous

MO = Manually operated

SA = Semi-automated

FA = Fully automated

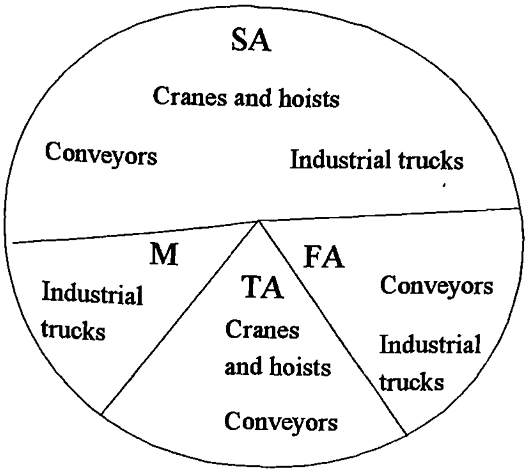

Figure 2.15- Apple's three basic types of equipment in different categories according to level of automation criteria)

6. Continuous: conveyors are used for continuous movement of material. Trucks, and cranes and hoist are used for handling discrete loads at particular intervals. This criteria has the same effect as the speed criteria with respect to equipment division.

7. Route: conveyors, and cranes and hoists are usually operated on a fixed route. In contrast trucks work on a variable route. In the same manner the route criteria produces less duplication between equipment groups.

8. Production volume: Industrial trucks can be designed to handle low, medium, and relatively high volumes. Cranes and hoists are for low and medium volumes. Conveyors are mainly for high volume production operations.

There are several points highlighted by the previous examples which should be discussed. Firstly, they show that the division of equipment should not be based on one criteria because it tends produce large equipment groups which affects boundary explicitness and creates diversity of characteristics. Secondly, they introduce the possibility of investigating the combination of more than one criteria to produce the best division of equipment groups. Thirdly, these eight criteria tend to separate into two divisions:

1. Preferred characteristics of the solution, i.e. examples (1) and (4).
2. Definite characteristics of the problem, i.e. examples (2) and (3)

These different characteristics show that it is possible to divide Apple's equipment groups in a variety of ways in order to produce groups of similar equipment. Therefore the possibility of combining many criteria to distinguish between groups should be attempted. But we have to observe that by introducing too many boundaries leads to difficulty of distinguishing due to too many overlaps between groups. Also this case is likely to lead to the missing of the optimum solution because of high similarity between groups. Furthermore Apple's grouping system did not clarify how manual handling would be dealt with and what type of function would suit it. His method also requires another handling group to cover handling methods which are completely missing from his categorisation (e.g. towline, scissors tables, lifting elevators, vacuum hose and tubes, gravity chute etc.).

Therefore it appears that equipment function criteria can be used as a grouping approach, but alone cannot produce a grouping system which all equipment selection depends on due to difficulty of the boundaries explicitly and the complexity of equipment characteristics. So Apple's approach needs to be reconsidered as a grouping system. This opens other 'avenues' to develop other approaches.

In one of the most recent equipment selection approaches by Liang et al [16] a classification of 9 categories of material handling equipment was based on that most widely used by manufacturing industry in the US and they are as follows:

1. Forklift truck
2. Tractor trailer
3. AGV tugger with trailers
4. Unit-load AGV
5. Monorail conveyor
6. Power and free conveyor
7. Roller conveyor
8. Chain conveyor
9. Towline

These 9 equipment categories range from a broad group which contains several different models like forklift trucks employing different power sources (e.g. electric, diesel, gas) and different capabilities (e.g. reach truck, side loader, mast stacker, counter balance), and a small group like the chain conveyor as a handling method.

Although these 9 categories cover the most widely used in the US industry with a variety of equipment covering a large spectrum of handling activities, nevertheless in the author's opinion they require two more categories to complete the total global set. These are '*manual handling*', and '*other equipment*'. The 'manual handling' category is necessary because in selecting a handling method there must always be the possibility that no equipment is necessary or justified. The 'other equipment' category is necessary because all other categories are quite specific in terms of content, and although they represent the most popular equipment, there will always be situations in which more specialised equipment is needed.

It must also be noted that the 9 categories are derived from an analysis of US manufacturing industry and will be biased towards the particular handling situations most common in the US. It is particularly noticeable that cranes and hoists do not feature in the 9 categories and this is probably because the plentiful availability of land in the US makes single storey building with wide aisles for handling economically attractive.

In contrast, many Pacific Rim countries have very high land costs and the use of overhead space and vertical material movement in general is more appropriate. The 'other equipment' category will therefore contain "cranes and hoists" as well as any less common equipment not included in other categories.

In the closing statement of section 2.4.2 it was suggested that a number of equipment groups lying somewhere between "few" and "many" was needed to minimise the fuzziness occurring among different groups. Therefore it was considered necessary to determine the optimum number of groups to fulfil this task.

2.6.1 Evaluating Material Handling Equipment Groups

Analysis was performed to establish a classification of equipment into groups which provides the minimum amount of fuzziness between groups. It should be recognised that it is impossible to have a set of equipment groups which achieve zero fuzziness because of the huge number of possible equipment groups and the variety of overlapping equipment characteristics which make it difficult to draw well defined (crisp) boundaries between groups of equipment. The result of this investigation is to be implemented in the forthcoming decision analysis tool.

Analysis was undertaken to test several sets of groups of the total global population of handling equipment. The Microsoft™ EXCEL package was used because of its ability to organise data and provide the necessary analysis with appropriate figures and graphs. The examination of these sets was performed to derive the percentage area of fuzziness in each set of groups.

The estimation procedure for each of these sets contains 2 phases. Phase-1, is concerned with obtaining a reasonable estimate of the number of pieces of equipment in each group of the sets. These values are derived as a proportion of the total amount of material handling equipment available globally. The estimated percentage for the market share of different groups of equipment was based on figures provided from industrial suppliers and manufacturers sales catalogues obtained through the internet:

1) WD Matthews (www.wdmatthews.com/catalog.html)

2) Carolina Tractor (www.carolinatractor.com)

3) Maybury On-line Catalogue (www.maybury.com)

4) Meyers Material Handling, Inc. (www.meyermat.com/products)

5) SJF Material Handling Inc., On-line Catalogue (www.sjf.com)

6) Yahoo Business and Economy, Industrial Supplier; Material Handling (www.yahoo.co.uk/Business_and_Economy/Companies/industrial_Suppliers)

7) American Material Handling (www.amer-material-handling.com)

8) Yale Material Handling (www.yale.com)

9) Promat 99-Material Handling Of America (www.mhia.org/pr99)

10) Industrial Equipment Manufacturing (www.industrial-connection.com)

11) Farnell Industrial Catalogue (www.farnell.com)

12) EQ Net- Product Catalogue (www.eqnet.com)

13) Material Handling On Line (www.materialhandling.com)

14) OEM (www.equipfind.com/oem.htm)

15) American Crane & Equipment Corporation (www.americancrane.com)

16) Material Flow and Conveyor Systems (www.materialflow.com)

17) Handlingnet-Material Handling Equipment Directory(www.handlingnet.com)

18) Vendor Index On Line- Material Handling Source (www.cisco-eagle.com/ vendors/index.html)

Each of these sites contained, on average, information on many hundreds of piece of handling equipment and therefore represented a very large quantity of literature on material handling equipment. It is clearly impossible to gather all of the information available globally on all material handling equipment and so it was assumed that the 18 sources of information listed above was in some way representative of the total global population of material handling equipment. These sources were used to estimate the proportions of equipment in each group and the method and results are shown in Appendix A. The accuracy that can be attributed to figures derived from these sources must be accepted as being low, but it nevertheless provides a basis for estimation.

An estimate is provided in Appendix A for the total amount of material handling equipment available in today's market was roughly 3.5 million pieces. Therefore the number of pieces in each group is given by:

Number of piece of equipment in each group = Total global number of equipment x Proportion of the market held by each group

In Phase-2, first obtain the number of fuzzy areas (NFA) in a given number (N) of groups based on examination of the possible "overlaps" between pairs of groups. To accommodate redundant pairs, i.e. where A borders B and B borders A, the NFA is equal to N * (N-1) / 2. After obtaining the NFA in a given set, generate a size estimate for each fuzzy area between pairs of groups of equipment in these different sets. This is performed by estimating a fuzzy area based on a comparison between pairs of groups to attain an amount of fuzziness as a proportion of their areas. There is an issue of "judgement" in phase 2 concerning what is fuzzy as well as what is not in producing this area. Then calculate the total fuzzy area (TFA) by summing all areas of fuzziness in a particular set. The set which provides the lowest TFA gives the best grouping.

Set 1: this set contains the estimated total population of material handling equipment 3.5 million pieces in a single group. It is assumed that there is 100% fuzziness between the makes and models of equipment within this single group.

Set 2: is used to evaluate a set with 4 groups (Apple [11] grouping system). (Conveyors, Industrial trucks, Cranes&Hoists, and Auxiliary equipment).

Phase-1: The following Table-2.2 provides an estimated number of pieces of equipment in each group based on the information from the on-line catalogues and brochures found on the internet (refer to Appendix A).

Group	Equipment %
Conveyors	25%
Trucks	55%
Crane&Hoist	10%
Auxiliary	10%

Table-2.2

Phase-2: calculating the size of the fuzzy area in this set. This set has 4 groups, then NFA is = (4 x 3) / 2 = 6 areas of fuzziness. The following Table-2.3 shows these 4 equipment groups together with the 6 fuzzy areas (shaded) between each pair of groups and the proportion that were considered to fall into each group. The areas of fuzziness are summed to obtain the total percentage of fuzziness in this set.

Group	Equipment share
Conveyors	10%
Auxiliary	2%
Trucks	20%

Crane&Hoist	5%
conveyor/truck	4%
conveyor/crane	12%
conveyor/ auxiliary	15%
truck/crane	0%
truck/auxiliary	22%
crane/auxiliary	10%
Total Fuzzy Area	63%

Table-2.3

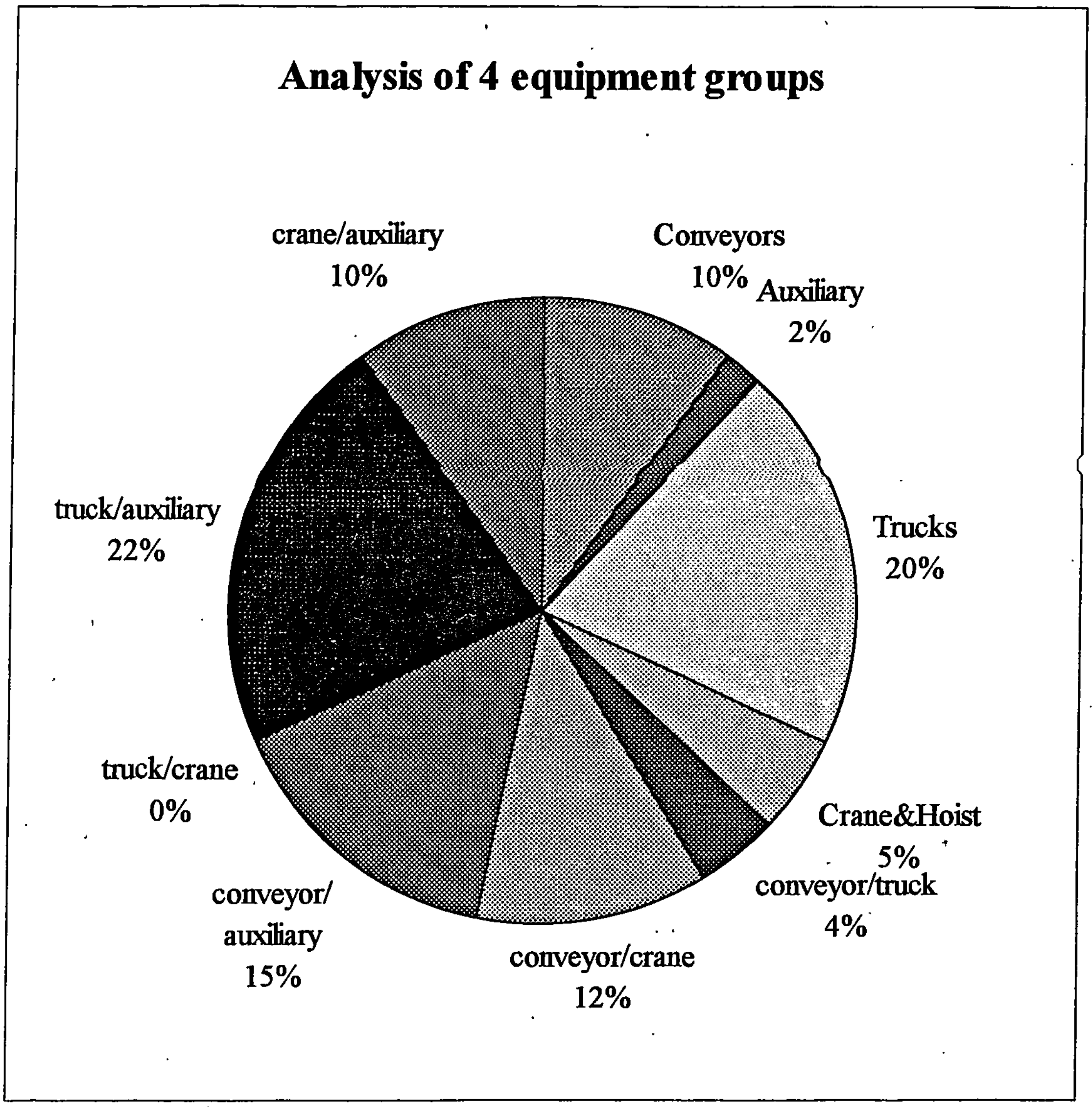

Figure 2.16

To illustrate the data in Table-2.3, Figure (2.16) provides the percentage of each group as well as fuzzy areas between pairs of groups with respect to the total global population of equipment.

Set 3: utilises 8 groups based on Liang's [16] grouping of equipment (Forklift truck, Tractor trailer, AGV tugger, Unit load AGV, Other equipment, Manual handling, Conveyor, Towline).

Phase-1: Table-2.4 shows the amount of equipment in each of the 8 groups in this set provided from the sample data.

Group	Equipment share
Forklift truck	45%
Tractor trailer	1%
AGV tugger	0.02%
AGV unit load	0.02%
Other equipment	26%
Manual handling	2.95%
Conveyors	25%
Towline	0.01%

Table-2.4

Phase-2: Determines the percentage of fuzzy area in this set. There are 8 groups in the set, so the NFA is = (8 x 7) / 2 = 28 areas of fuzziness. Table-2.5 demonstrates the estimated amount of equipment in both groups and fuzzy areas (shaded) as well as the TFA for this set.

Group	Equipment share
Forklift truck	24%
Tractor trailer	0.2%
AGV tugger	0.01%
AGV unit load	0.01%
Other	22%
Manual handling	0.8%
Conveyors	12%
Towline	0.005%
forklift/tractor trailer	0.1%
tractor trailer/AGV tugger	1%
unit-load AGV/other	0.1%
other/manual handling	2%

manual handling/conveyor	0.1%
conveyor/towline	0.1%
forklift/other	22%
tractor trailer/other	0.4%
tractor trailer/conveyor	0.1%
AGV tugger/other	0.05%
other/conveyor	15%
other/towline	0.03%
Total Fuzzy Area	41%

Table-2.5

Figure 2.17 illustrates the data in Table-2.5.

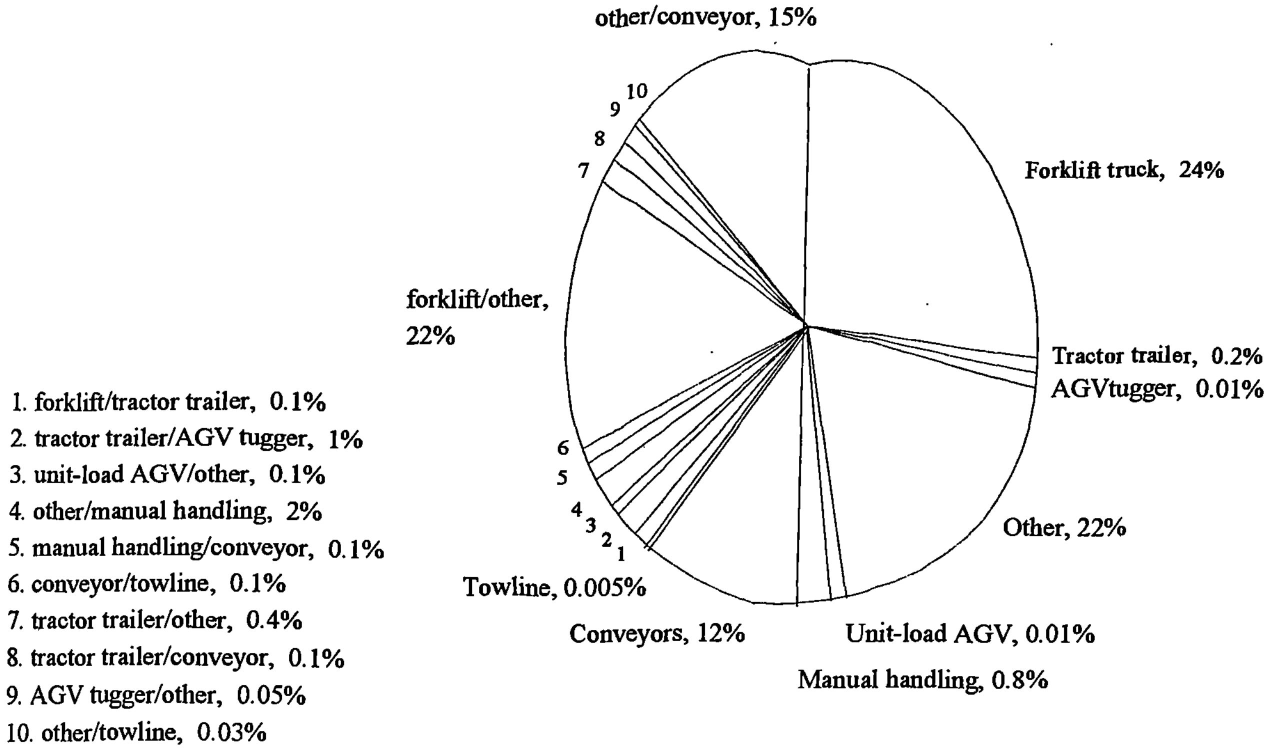

Figure 2.17- Analysis of 8 equipment groups

Because of the clear differences that existed between the remaining 16 pairs of types of equipment, there were no overlaps and hence no fuzziness.

Set 4: uses a set with 11 equipment groups again based on Liang's [16] approach (Forklift truck, Tractor trailer, AGV tugger, Unit load AGV, Other equipment, Manual handling, Mono-rail Conveyor, P&F Conveyor, Chain Conveyor, Roller Conveyor, Towline).

Phase-1: estimating the number of piece of equipment in each group based on the internet information (Table-2.6).

Group	Equipment share
Forklift truck	45%
Tractor trailer	1%
AGV tugger	0.02%
AGV unit load	0.02%
Other	26%
Manual handling	2.95%
P&F conveyor	5%
Mono-rail conveyor	5%
Roller conveyor	7%
Chain conveyor	8%
Towline	0.01%

Table-2.6

Phase-2: Deriving the percentage of fuzziness in this set. TFA for 11 groups is the sum of 55 fuzzy areas. Table-2.7 shows the equipment groups and those pairs of groups between which there was significant fuzziness as determined from the classification attempted from the on-line catalogues. The percentage of equipment falling into each pair is shown, all the other 35 pairs were found not to have any significant overlap, i.e. 0%.

Group	Equipment share
Forklift truck	24.0%
Tractor trailer	0.05%
AGV tugger	0.01%
AGV unit load	0.01%
Other	21%
Manual handling	0.4%
P&F conveyor	4%

Mono-rail conveyor	4%
Roller conveyor	6%
Chain conveyor	6%
Towline	0.005%
forklift/tractor trailer	0.1%
forklift/other	22%
tractor trailer/AGV tugger	1%
tractor trailer/other	0.4%
tractor trailer/chain conveyor	0.1%
AGV tugger/other	0.05%
unit-load AGV/other	0.1%
other/manual handling	2%
other/p&f conveyor	2%
other/mono-rail conveyor	2%
other/roller conveyor	1%
other/chain conveyor	1%
other/towline	0.03%
manual handling/roller conveyor	0.1%
p&f conveyor/mono-rail conveyor	0.75%
p&f conveyor/roller conveyor	0.1%
p&f conveyor/chain conveyor	0.05%
mono-rail conveyor/chain conveyor	0.1%
roller conveyor/chain conveyor	0.1%
chain conveyor/towline	1.55%
Total Fuzzy Area	34.5%

Table-2.7

Figure-2.18 provides an illustration of the information contained in Table-2.7.

Set 5: tests a set with 13 groups of equipment based on Liang's [16] grouping of equipment (Counter balance forklift truck, Reach forklift truck, Side loader forklift truck, Tractor trailer, AGV tugger, Unit load AGV, Other equipment, Manual handling, Mono-rail Conveyor, P&F Conveyor, Chain Conveyor, Roller Conveyor, Towline).

Phase-1: illustrates the amount of equipment in each group from the analysis of sales catalogues (see Table-2.8).

1. forklift/tractor trailer, 0.1%
2. tractor trailer/AGV tugger, 1%
3. unit-load AGV/other, 0.1%
4. other/manual handling, 2%
5. manual handling/roller conveyor, 0.1
6. chain conveyor/towline, 0.155%
7. tractor trailer/other, 0.4%
8. tractor trailer/chain conveyor, 0.1%
9. AGV tugger/other, 0.05%
10. other/towline, 0.03%
11. other/p&f conveyor, 2%
12. other/mono-rail conveyor, 2%
13. other/roller conveyor, 1%
14. other/chain conveyor, 1%
15. p&f/mono-rail conveyors, 0.75%
16. p&f/roller conveyors, 0.1%
17. p&f/chain conveyors, 0.05%
18. mono-rail/chain conveyors, 0.1%
19. roller/chain conveyors, 0.1%

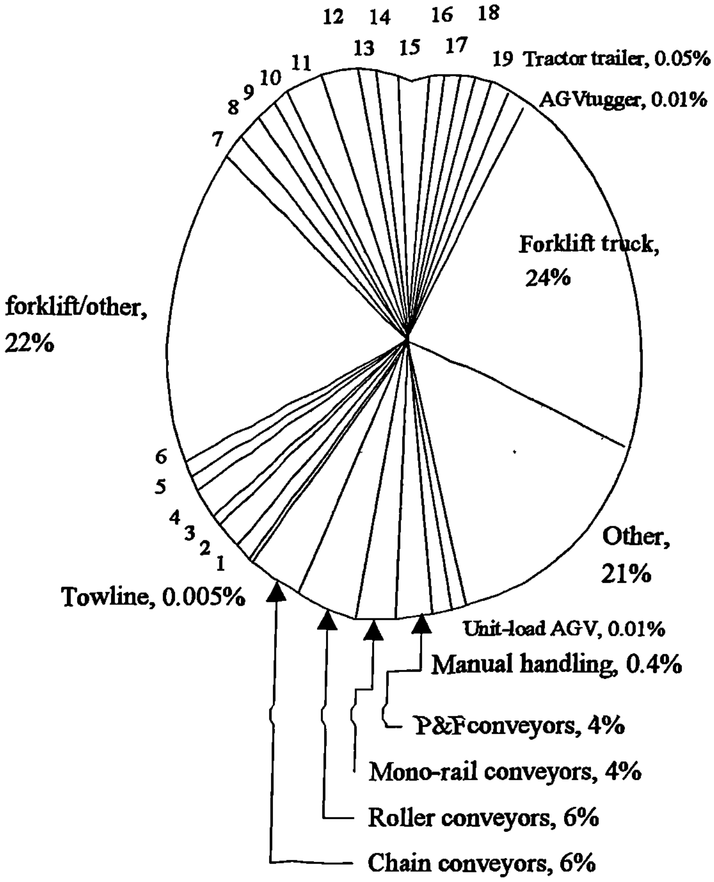

Figure 2.18- Analysis of 11 equipment groups

Group	Equipment share
Counter balance forklift truck	23%
Reach forklift truck	12%
Side loader forklift truck	10%
Tractor trailer	1%
AGV tugger	0.02%
AGV unit load	0.02%
Other	26%

Group	Equipment share
Manual handling	2.95%
P&F conveyor	5%
Mono-rail conveyor	5%
Roller conveyor	7%
Chain conveyor	8%
Towline	0.01%

Table-2.8

Phase-2: this provides the fuzzy areas between the 13 groups and the fuzziness percentage produced by this set. TFA is equal to the sum of 78 areas; Table-2.9 shows the groups and only the fuzzy areas which were found to contain equipment. All the other 53 fuzzy areas contained no equipment as there were clear distinctions between the equipment within each pair.

Group	Equipment share
Counter balance forklift truck	10%
Reach forklift truck	8%
Side loader forklift truck	7%
Tractor trailer	0.05%
AGV tugger	0.01%
AGV unit load	0.01%
Other	15%
Manual handling	0.4%
P&F conveyor	4%
Mono-rail conveyor	4%
Roller conveyor	6%
Chain conveyor	6%
Towline	0.005%
counter balance/reach forklifts	7%
counter balance/side loader forklifts	5%
counter balance forklift/tractor trailer	0.1%
counter balance forklift/other	5%
reach/side loader forklifts	3%
reach forklift/other	3.5%
side loader forklift/other	3%
tractor trailer/AGV tugger	1%
tractor trailer/other	0.4%
tractor trailer/chain conveyor	0.1%
AGV tugger/other	0.05%
unit-load AGV/other	0.1%
other/manual handling	2%
other/p&f conveyor	2%
other/mono-rail conveyor	2%
other/roller conveyor	1%
other/chain conveyor	1%
other/towline	0.03%
manual handling/roller conveyor	0.1%
p&f conveyor/mono-rail conveyor	0.75%
p&f conveyor/roller conveyor	0.1%

p&f conveyor/chain conveyor	0.05%
mono-rail conveyor/chain conveyor	0.1%
roller conveyor/chain conveyor	0.1%
chain conveyor/towline	1.55%
Total Fuzzy Area	39.03%

Table-2.9

Figure (2.19) is intended to illustrate the contents of Table-2.9.

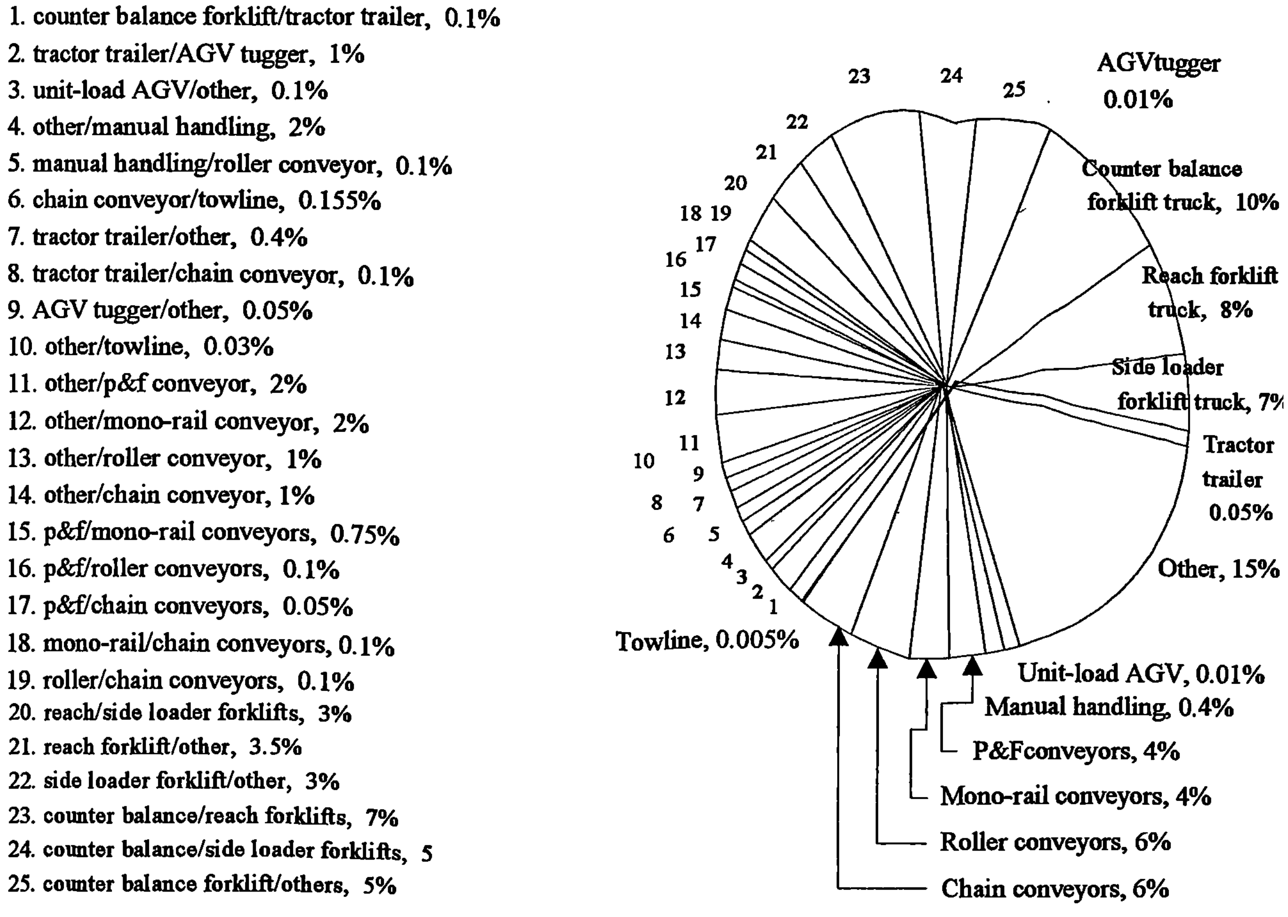

Figure 2.19- Analysis of 13 equipment groups

Set 6: Using Liang's [16] grouping, set 6 will be tested with 15 equipment groups (Counter balance forklift truck, Reach forklift truck, Side loader forklift truck, Tractor trailer, AGV tugger, Unit load AGV, Other equipment, Manual handling, Mono-rail Conveyor, P&F Conveyor, Chain Conveyor, Roller Conveyor, Towline, Trolleys, Cranes).

Phase-1: The estimated amount of equipment in each group is contained in Table-2.10.

Group	Equipment share
Counter balance forklift truck	23%
Reach forklift truck	12%
Side loader forklift truck	10%
Tractor trailer	1%
AGV tugger	0.02%
AGV unit load	0.02%
Other	14%
Manual handling	2.95%
P&F conveyor	5%
Mono-rail conveyor	5%
Roller conveyor	7%
Chain conveyor	8%
Towline	0.01%
Crane	10%
Trolleys	2%

Table-2.10

Phase-2: the NFA in this set is = (15 x 14) / 2 = 105 areas of fuzziness. Table-2.11 shows only the fuzzy areas (shaded) which contained equipment between the 15 groups of equipment which constituted the TFA for this set. The remaining 75 pairs of groups produced 0% of fuzziness since there were no overlaps between them.

Group	Equipment share
Counter balance forklift truck	10%
Reach forklift truck	8%
Side loader forklift truck	7%
Tractor trailer	0.05%
AGV tugger	0.01%

AGV unit load	0.01%
Other	5%
Manual handling	0.1%
P&F conveyor	4%
Mono-rail conveyor	3%
Roller conveyor	6%
Chain conveyor	6%
Towline	0.003%
Crane	6%
Trolleys	0.3%
counter balance/reach forklifts	7%
counter balance/side loader forklifts	5%
counter balance forklift/tractor trailer	0.1%
counter balance forklift/other	5%
reach/side loader forklifts	3%
reach forklift/other	3.5%
side loader forklift/other	3%
tractor trailer/AGV tugger	1%
tractor trailer/other	0.4%
tractor trailer/chain conveyor	0.1%
AGV tugger/other	0.05%
unit-load AGV/other	0.1%
other/manual handling	2%
other/p&f conveyor	2%
other/mono-rail conveyor	2%
other/roller conveyor	1%
other/chain conveyor	1%
other/towline	0.02%
other/crane	2.5%
other/trolleys	1.5%
manual handling/roller conveyor	0.1%
manual handling/trolleys	1.0%
p&f conveyor/mono-rail conveyor	0.75%
p&f conveyor/roller conveyor	0.1%
p&f conveyor/chain conveyor	0.05%
mono-rail conveyor/chain conveyor	0.1%
mono-rail conveyor/crane	0.5%
roller conveyor/chain conveyor	0.1%
chain conveyor/towline	1.55%
towline/trolleys	0.02%
Total Fuzzy Area	44.5%

Table-2.11

Figure-2.20 shows the information contained Table-2.11.

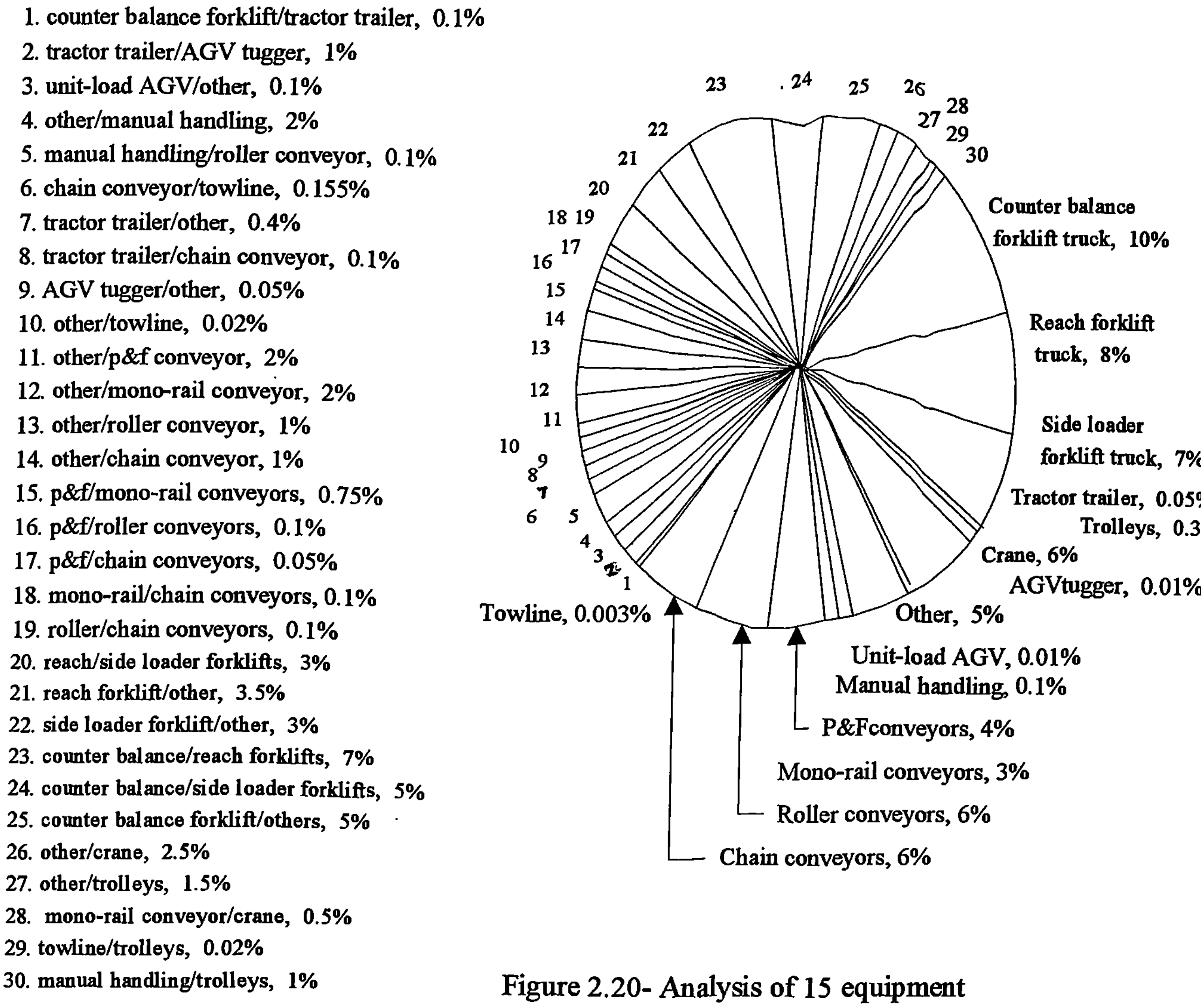

Figure 2.20- Analysis of 15 equipment groups

From the figures obtained from the 6 sets, it can be seen that the percentage of fuzziness is a minimum when the number of groups is around 11. Refer to Table-2.12 and Figure (2.21).

Number Of Groups	Total Fuzzy Area
1	100%
4	63%
8	41%
11	35%
13	39%
15	45%

Table-2.12

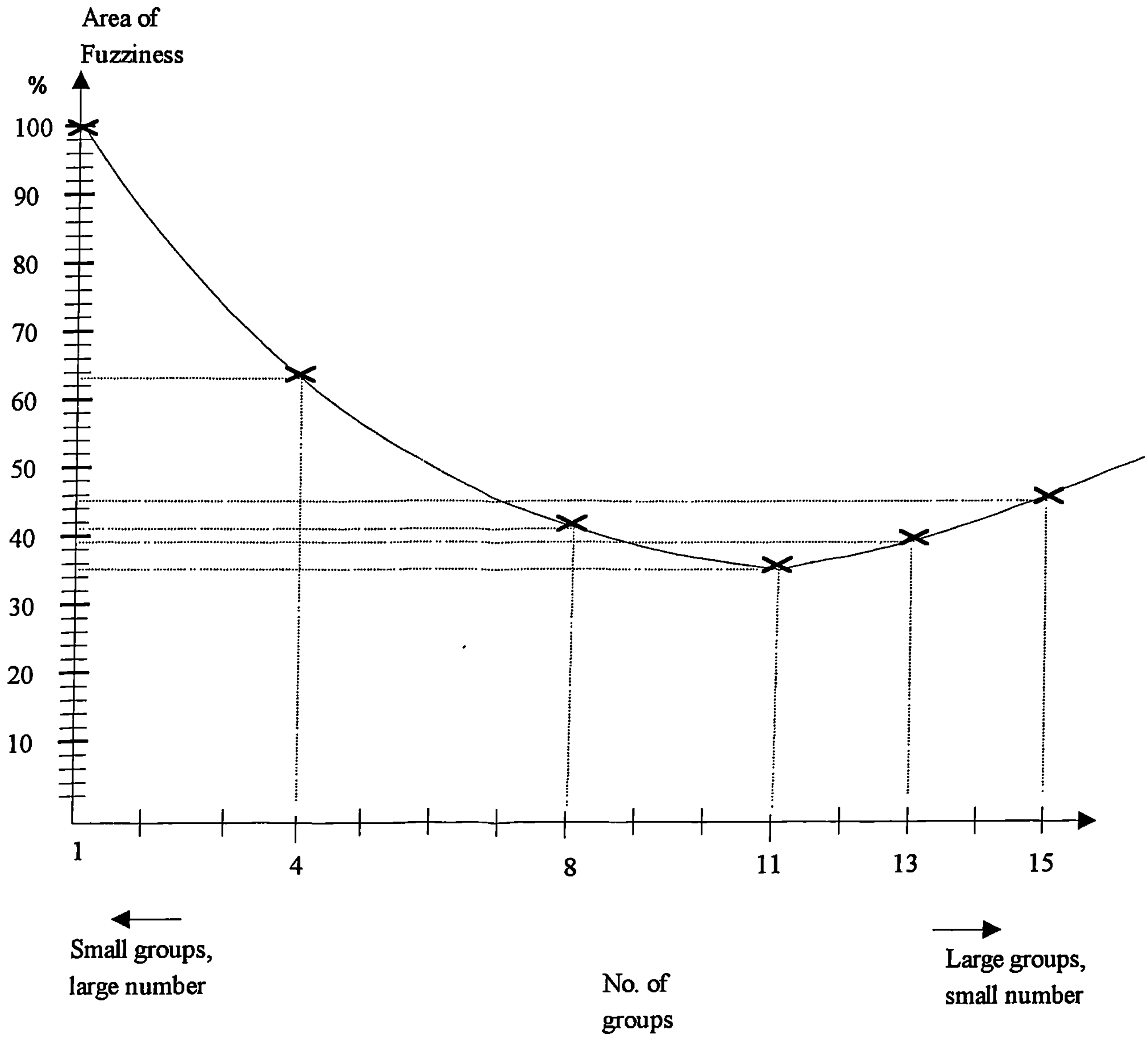

Figure- 2.21, the effect of number of equipment groups on the percentage of fuzzy area

It must be recognised that there are a huge number of ways of forming a particular number of groups, so this analysis is only approximate. Nevertheless it suggests that 11 is a reasonable choice for the number of groups to use to minimise the risks of faulty selection.

2.6.2 Selected Categories Of Handling Equipment

The 11 equipment groups evaluated in the previous section display a wide range of material handling methods covering many handling activities. These 11 categories are divided such that each contains a large number of individual types of equipment, but all using basically the same principle. This section will provide a description of each group to assist the analysis process of equipment selection and provide guidance on the development of a decision selection tool.

The following are the 11 handling methods:

1. Manual handling: manual handling is performed over short distances with movement of light weight material using human physical power [11]. In the UK, regulations [17] have been produced for this sort of handling activity which a business has to observe. The physical force is of a limited nature and should be restricted to a certain load characteristics to avoid any harm to people. Therefore the manual handling regulations for such tasks are developed to work as guidelines for a business which needs to establish whether manual handling is a legally allowed option, or whether other handling equipment may be needed to remove people from risk of injury.

2. Forklift truck: a self-loading, counterbalanced, self-propelled, wheeled vehicle, carrying an operator, and designed to carry a load on a fork fastened to telescoping mast which is mounted ahead of the vehicle to permit lifting and stacking [11]. This category is by far the most popular because it has several sub-classifications with a range of features and operating functions. For example there are several types which use a variety of power source (petrol, diesel, gas, and electric). Also, there are some

types which can work in different modes within a working area , i.e. they use electric power inside and when they are outside they use petrol or diesel to charge the battery. Their speed and acceleration can be controlled to perform several tasks. They can cover variable paths with a uniform load. With a range of load capacities to accommodate different material handling weight per load factor. But they rate low on safety criteria and damage to products in transit can be high.

3. Tractor trailer: a handling system consisting of a 3- or 4-wheeled, self-propelled vehicle designed for pulling loaded carts or trailers [11].

4. Unit load automated guide vehicle (AGV): this vehicle is self-propelled either electronically through a wire below the ground on a fixed route or laser guided controlled by central computer which can carry a single unit load from work station-to-work station [11].

5. AGV tugger trailer: this method is similar to the unit load AGV but in the form of tractor trailer which can pull several loaded carts. It is preferred over forklift truck when handling large quantities because of greater capacity than forklift truck [11].

6. Monorail conveyors: one rail of moving chain, track mounted from the ceiling or roof of the building. Frees floor; no interference with other traffic. Track may dip to lower level for more convenient access to carts. Carts are connected to conveyor by hook and chain-or link [11].

7. Power and free conveyors: a combination of powered trolley conveyors and un-powered monorail-type free conveyors. Two sets of tracks are used, usually suspended one above the other. The upper track carries the powered trolley conveyor, and the lower is the free monorail track. Load-carrying free trolleys are engaged by pushers attached to the powered trolley conveyors. Load trolleys can be switched to and from adjacent un-powered free tracks [11].

8. Roller conveyors: a conveyor which supports the load on a series of rollers, turning on fixed bearing and mounted between side rails at fixed intervals determined by the size of the object to be carried. The load is usually moved manually or by gravity or power is applied to some or all of the rollers to propel the material [11].

9. Chain conveyors: the load is carried in a container attached to chains mounted on shafts with a fixed interval between them.

10. Towline: a series of trolleys or pallet trucks connected to conveyor by pin through slot in floor to pick up devices on chain. The pick-up action tends to be smoother than overhead [11].

11. Other equipment groups: there are many types not included in the first ten. The user should investigate other handling method like cranes and hoists, for example, jib crane is a lifting device travelling on a horizontal boom that is mounted on a column or mast, which is fastened to a floor, or floor and a top support, or wall bracket or rails [11]. Also Other types of conveyors (flexi, belt), scissors tables, air vacuum tubes,

gravity chutes, lifting elevators, manually operated trucks, different handling accessories (e.g. containers, wood pallets, metal pallets, scanning systems, bar code systems, and different types of fork attachments for forklift trucks for special situations).

These 11 groups represent one way of dividing the whole population of handling equipment into reasonably clear divisions due to the reduction of fuzziness between groups using this compromise number (refer to section 2.6.1).

It should be emphasised that the selection process by the decision tool that is to be developed, is intended to select the group. It will not select particular equipment from within the group. Nevertheless selecting a particular equipment model becomes a less difficult task because having narrowed down the choice to a particular group, the selection is more straight forward and based on more easily quantifiable criteria like size, weight limit etc. Therefore these 11 groups of equipment will be used in the rest of the thesis to develop the new decision tool of handling method selection.

CHAPTER THREE Complexity In System Selection

3.1 Introduction

The problem of selecting material handling equipment consists of two phases. Firstly, an analysis of the material handling equipment to define a number of feasible equipment groups for the selection process.

Secondly, the selection process itself. This phase should be dealt with very carefully because of its importance. Selecting the wrong group of equipment creates many problems. Usually there are many handling methods which are technically possible for a particular situation, but selecting the most suitable one is a complex task. This is because of the number and the diversity of the factors (e.g. very many types of material handling equipment, different handling characteristics for different situations etc.) involved in the selection process. Therefore, it is necessary to identify the major areas of difficulty in the process to try to tackle the aspects of complexity.

It is emphasised that the selection process is to choose the group, not a specific piece of equipment from within the group. This is because having chosen the most suitable type of equipment, the selection decision then becomes one which involves non-technical criteria and factors which are very specific to a particular problem.

3.2 Complexity Of The Selection Process

There are many factors that should be analysed to understand and to determine their effect on the selection process. This analysis can be divided into two parts. Firstly, defining the major factors. Secondly, analysing the relative importance affecting selection of handling method, but the investigator should realise that it is a difficult task because the number of factors is vast and in many situations might overlap which brings about the problem of ambiguity. Matson et al [18] stated that "material handling equipment selection is a complex, tedious task and there is usually more than one good answer for any particular situation". Equipment that can be used for a move in one environment might not be suitable for a similar move in another environment because of constraints imposed by the facility.

Matson's argument did not provide obvious reasons as to the complexity of this process. There are more factors effecting the suitability of equipment beside the constraints presented by facilities. Even the constraints that are most visible (e.g. layout, or processes employed, or products) need to be clarified for the selection analysis. Also we need to know more about the factors influencing the suitability of equipment.

Then the question is 'what factors are involved in the selection process and why is it complex?' Matson echoed the findings of Gabbert and Brown [19] who identified some factors contributing to the complexity of the equipment selection problem. Their factors included the following :

1) Products which produce conflicting requirements, e.g. a light weight product which can be handled manually but contains a dangerous substance which requires automation.

2) Change in design specifications with resulting changes in layout, i.e. a change in design specification may initiate a sort of chain reaction. The specification change may require a change in product design and then a change of process to cope with the new design. This might need different machinery/equipment to perform the new process and this produces a new handling activity which leads to a changes in the existing layout to accommodate the new equipment.

3) New products and changes in existing products. Planning to produce new products and introducing new changes to existing ones to satisfy a rising demand for special features (e.g. different load capabilities) is likely to cause complexity at any stage of the previously stated chain reaction or steps which in the end creates difficulty for selecting an appropriate handling method.

4) Uncertainties in the operational environment, e.g. it is difficult to determine the forthcoming variability of customer demand for different products.

The problem thus involves a multitude of factors, many of which require subjective assessment since they are difficult to quantify. We have to observe that even though both Matson as well as Gabbert and Brown agreed on the complexity of this problem, and the latter produced many factors which are considered to hinder this process, nevertheless these factors present more complexity in the process, i.e.

predicting future changes to the operational environment is difficult. Therefore this will produce uncertainty for the selection process. These factors were not clearly defined at a level that allows them to be used directly in any analysis procedure. This is because of the difficulty of evaluating the importance of some factors in a particular situation. Also, defining and establishing relative importance between so many and varied factors tends to increase the complexity of choosing the best equipment type. Finally, there is the difficulty of assessing the non-quantifiable factors whose relative importance cannot be easily assessed.

The previous discussion on the complexity of the selection process raised several points which ought to be considered in probing this process. Firstly, even if the basic movement problem is the same in different environments, in particular situations it usually requires a different handling method. This is because different situations can alter the importance of factors making some irrelevant and others critically important which leads to different optimum handling methods. Secondly, the materials/products to be moved must be a factor in the selection process. It is obvious that if this factor changes, then the solution will probably be different. It may be necessary to find the 'least worst' solution that satisfies the situation. Thirdly, facility constraints require to be identified clearly to provide the physical limitations which might affect equipment selection. Finally, it must be recognised that factors which contribute to the complexity of the selection process are divided into two categories as follows :

a) Quantifiable (e.g. unit load weight, distance, floor load capacity)

b) Not quantifiable (e.g. flexibility, adaptability, reliability)

The selection process contains many areas for investigation which tend to produce difficulty. They can be classified into two areas and they are as follows:

1. Defining the attributes of the problem
2. Establishing the selection criteria

3.2.1 Difficulty Of Defining The Attributes Of The Problem

Defining the attributes of the problem is a major step which requires detailed and lengthy analysis to gather the necessary data from many sources, i.e. because of the effect of facility constraints it is necessary to identify particular features which affect equipment suitability. Apple [11] produced a list of features related to facility constraints; i.e. aisle width, floor load capacity, shop floor area etc. These features can be used as a starting point, but we should realise that they vary from one situation to another. This is because facility constraints might be represented by many variables (e.g. process layout, or the design of buildings etc.). Also it might be due to the diversity of such constraints. However the fact that most of these features are quantifiable makes their measurement relatively easy to attain during the analysis steps. But the main point is that the facility constraints are not the only attribute here and there are others like the 'material to be moved' and the 'movement requirements'.

The material attribute has its own factors which need to be discussed. There are three factors influencing the material according to Apple [11] as follows :

1. Type: to identify the material, unit load, mass, volume, bulk etc.
2. Characteristics: these are represented by weight of load, shape, size etc.

3. Quantity: concerned with the material quantity, per move, per time period, etc.

We have to observe that these factors contained in the material attribute need further analysis. This is because there are several sub-factors within each factor which enable the investigator to produce information relevant to the selection analysis. The use of type, characteristics, and quantity to determine the material attribute is considered sufficient because they cover all the required variables relating to the material under investigation which are likely to affect the possible type of equipment. The difficulty with the material attribute lies in the number of factors involved, and how to combine these factors to define the relationships between them and their influence on each other in the analysis process.

The other attribute is "movement requirements". This attribute can be decomposed into several factors. Apple [11] specified four factors which fall under this attribute. He has produced all the necessary sub factors (e.g. speed, distance, path etc.) within the characteristics factor of the move attribute to identify the type of equipment. However the source and destination, logistics, and type factors of the move attribute should be considered to examine the whole problem of handling but they make the problem complex. This is because it is difficult to identify the relationship between these factors and to be able to produce sufficient information from their sub-factors to assist the investigation process. For instance, it has been shown in chapter 2 how difficult it is to distinguish between the different types of movement such as transporting, transferring, and conveying.

We have to observe that the previous attributes (facility constraints, material, and movement of material) and especially their factors were developed more than 20 years ago, nevertheless most of them are still currently applicable for such analysis. This is due to the fact that advanced technology has generally enhanced the characteristics and performance of equipment, rather than replace the handling attributes with radically new ones. For instance, different forklift truck and fork attachments to handle many load capacities and awkward shape materials, new materials to cope with new handling activities and equipment characteristics etc. These examples display an increase in complexity in the selection process because advanced technology equipment, for instance, could increase flexibility and capacity of particular equipment's performance which then reduces the difference between equipment types even within a specific group of equipment. This leads to difficulty in distinguishing between them and therefore creates more overlaps between different equipment.

3.2.2 Difficulty Of Establishing The Selection Criteria

The selection criteria are as important as the problem attributes in the selection process to attain the best handling solution. Referring to Matson's et al [18] statement that suitability of handling equipment varies from one situation to another, the selection criteria are among the factors which are bound to change to suit each particular situation. Therefore the complexity lies in determining how to identify the criteria for a given situation since there are not any explicit rules for this task. Several researchers have produced lists of selection criteria [20], [21], some of which were mentioned previously in chapter 2. These lists are presented with different relative arrangements of the same criteria but without describing the way in which they evolved or discussion of the order in which they should be considered during prioritisation of criteria. There is also no indication as to whether prioritisation of criteria influences the selection process. The problem with the prioritisation lies in the interpretation of whether it is important to order (most - least) or to attach a weighting (scaled value) to criteria. Also handling activity specifications vary from one case to another which require these criteria to be redefined to meet the new requirements.

For example, in an electronic production site (e.g. circuit boards) the presence of humans are often not required since it is frequently a fully automated operation, then safety criteria will not be as important as for a production plant where human presence is high, so safety must be a top priority. Therefore the dependency of selection criteria on the circumstances of the situation greatly influence the handling method, which is why there are no explicit guidelines for developing selection criteria.

Listing and developing of many selection criteria by previous researchers based on a particular case would not aid in the selection of the right criteria for a different case because of the differences and the influence of the circumstances of the situation which lead to criteria priority changes.

Another aspect regarding the complexity of establishing selection criteria is that most selection criteria are non-quantifiable (e.g. flexibility of layout change, flexibility of equipment routing, availability of handling space, compatibility, and adaptability) which produces difficulty in a mathematical analysis of the equipment selection process.

3.3 Selection System Approaches

There are generally two types of approaches to the handling equipment selection problem. Firstly, the non-systematic selection approach and secondly, the systematic selection approach.

3.3.1 The Non-Systematic Selection Approach

Past experience and knowledge in the field of material handling represents the major influence over the non-systematic selection approach of equipment. Apple [11] stated that the most important contributions to either analysing or designing material handling systems is experience. But it takes years of exposure to a wide variety of situations to accumulate this background.

However past experience and knowledge are restricted to a small group of people (experts). This restriction will benefit only the experts in the selection process. This is because they can audit their thought process and say why they have rejected or accepted some options based on manipulation of their knowledge. In contrast, this thinking process will not benefit the non-experts, because they simply lack the necessary foundation (past experience) to build such decisions. This situation can be tackled through gathering information from, for instance, conferences on industrial handling or international equipment exhibitions to see the new and upgraded technologies throughout the range of equipment. But it must be realised that this is a long, and sometimes tedious, task and when an expert is consulted for a few hours, it is the years of experience that are being sought.

The person responsible for the selection should be aware of both the new equipment technology introduced since the last equipment of the same type was purchased to update their experience, and use the past knowledge as a foundation for the analysis process. Obviously material handling situations cannot depend solely on historical information but it must be approached in a rational way to choose appropriate handling methods and equipment. In the previous section were presented many issues which are considered sources of complexity of the selection process. In addition to the limited memory capacity of any individual, this raises an important question as to the ability of a non-systematic approach to deal with so many aspects and be able to produce a reasonable solution. The natural solution is to capture the expertise and then embed it in a large knowledge base. This knowledge base could be developed to aid and ease the selection process, but if used in a non-systematic way is unlikely to produce consistent and reliable solutions when used by non-experts.

3.3.2 The Systematic Selection Approach

The previous section 3.3.1 displays major concerns regarding the suitability of using the non-systematic approach as a selection process. This is because it is confined to a small segment of people (experts). Also there are no clearly defined routes to an optimal solution guided by explicit steps. So there is a need for a systematic process to cover all aspects of the selection process.

In general for any handling situation there are three aspects which must be considered according to what is called "the material handling equation" by Apple (see Figure 3.1) and they are as follows:

1. Material type, characteristics, and quantity
2. Move characteristics and requirements
3. Method (equipment) capabilities, and characteristics

Successful selection of appropriate handling equipment requires proper matching of these three issues within the framework of existing physical facilities constraints and operational environment [11]. It is however possible to segment the selection process of material handling equipment into several stages. Therefore it is the author's intention to establish a segmentation of the selection process which provides explicit steps (see Figure 3.2). These may be used by either experts or non-experts to assist their investigation and to enable the analysis of the problem systematically to arrive at a suitable solution.

It is proposed that the process can be conducted in five steps (see Figure 3.2):

Step 1: Define the problem and test to see if equipment is needed

Apple stated that a factor frequently overlooked in the rush to mechanise or automate is that manual handling may in fact be the easiest, most efficient, and least expensive method of moving material. "Only after it has been proven that manual handling is more costly, too dangerous, or too slow, should the analyst turn his attention to the use of equipment" [11]. This statement emphasises the message of thoroughly investigating and exhausting manual handling as an important alternative.

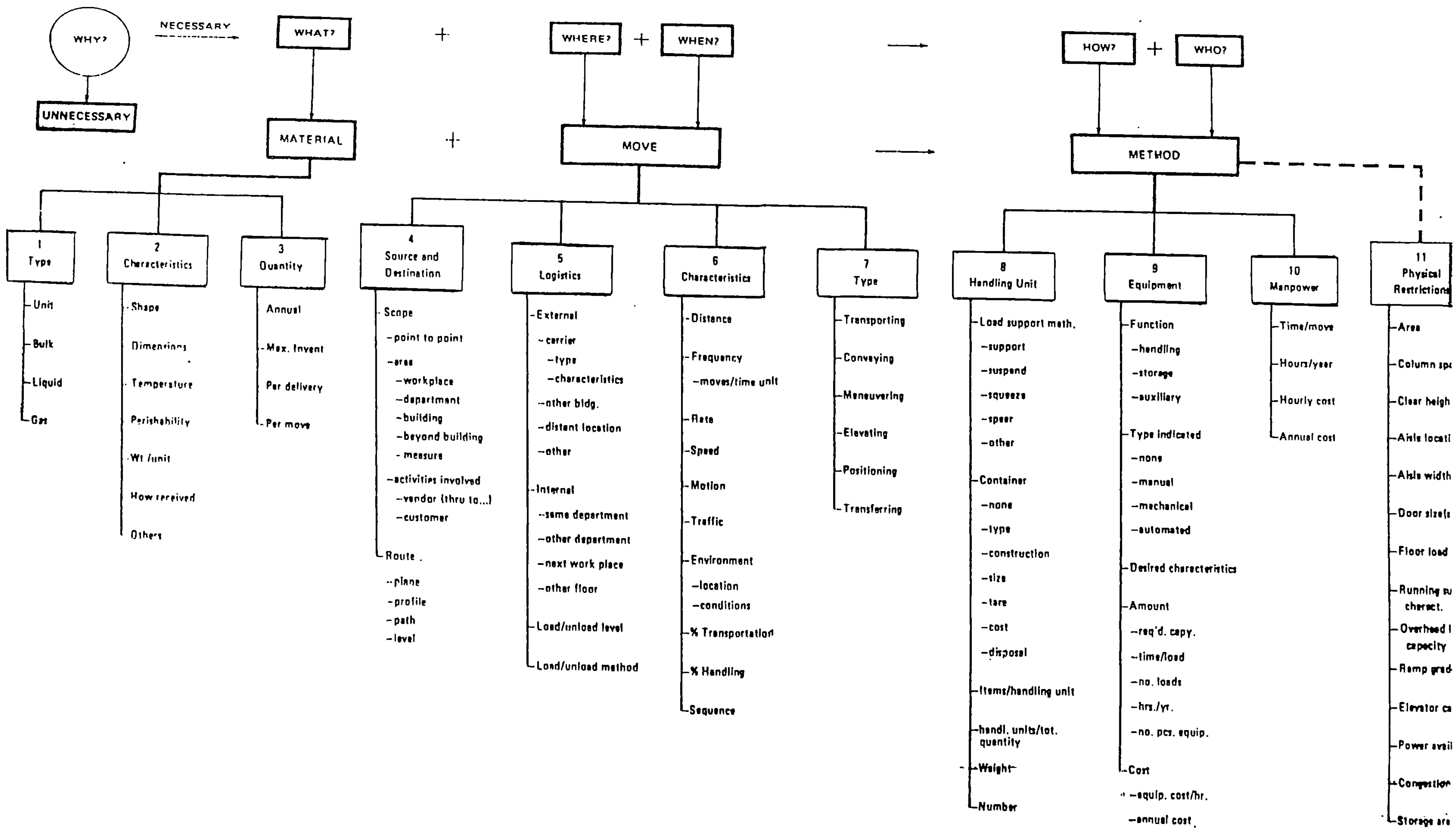

Figure 3.1- Apple's Material Handling Equation

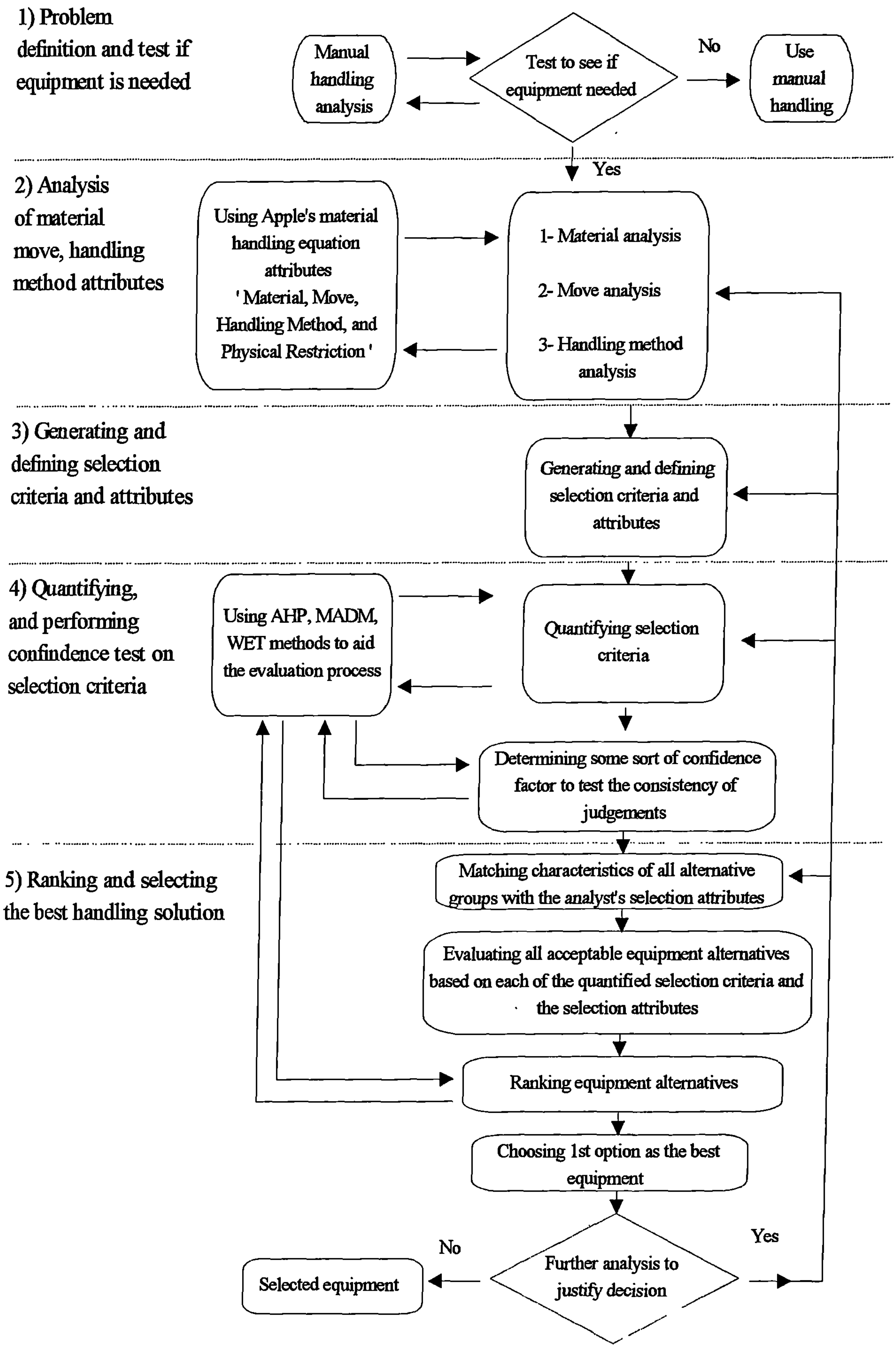

Figure 3.2- Steps of Equipment Selection Process

Also it displays an important point that the selection analysis process should not be rushed in any enterprise or the simplest solution can be overlooked. Therefore this step is concerned with defining the problem and determining whether equipment is required for this situation (see Appendix B). Also, to aid an investigation into the possibility of using manual handling for a particular situation are regulations [17] introduced in the UK. This matter has been discussed in section 2.5.

For example Figure 3.3 shows the weight limits which a human can safely handle at different locations relative to the body. Also the possibility of using containers, or hand truck or other auxiliary equipment needs a physical force to move material (also refer to section 2.5), so these methods also need to consider the constraints of the human body. If manual handling is not feasible then it is necessary to continue to find the best equipment.

Step 2: Analysis of material, move, and handling method attributes

This step is composed of many factors and sub-factors to be analysed thoroughly to prepare the necessary information and data for further analysis. The discussion on this step has been dealt with earlier in this section and in section 3.2.1. Also, the material handling equipment analysis has been investigated in chapter 2 which produced 11 equipment groups for the selection analysis process. To help visualise the many factors and sub-factors of the material, move, and method attributes which should be matched with the facility constraints factors, refer to Apple's handling equation (see figure 3.1) [11].

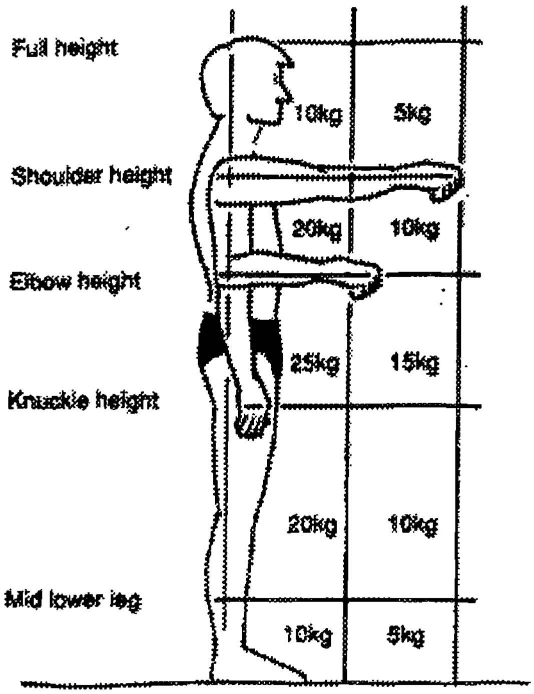

Figure 3.3- Weight limits at different positions relative to the human body. From the manual handling regulations [17]

Step 3: Generating and defining selection criteria and attributes

Since each handling problem or situation has its own requirements and specifications, it is the task of the company's management team to define and generate the list of criteria (e.g. flexibility, reliability etc.) and attributes (e.g. unit load material, load capacity required etc.) which they intend to use to evaluate the suitability of the material handling system before any equipment selection attempt. Previous discussion in section 3.2 provided several points regarding these requirements of the selection process.

Step 4: Quantifying and performing a confidence test on selection criteria

This step is carried out in two stages. Firstly, quantifying selection criteria. This is a far from easy task to perform by a person due to the subjective judgements involved. However there are specific evaluation methods which can perform this task. Secondly, a confidence test is performed on the result of quantification of selection criteria. This is to check the consistency of the analyst's subjective judgements on these criteria. Some of these techniques have the facility to produce some sort of confidence factor to be utilised during the selection procedure. The consistency value is an indication of the validity of the quantification process which enables the analyst to choose to accept the result or to repeat the process. The evaluation methods and the confidence test issue will be discussed later in this chapter.

Step 5: Ranking and selecting the best equipment

There are usually several equipment types which suit a single handling case but in varying degrees according to the required selection attributes and criteria. There are 3 stages in this step. Firstly, matching characteristics of all alternative groups of equipment with the selection attributes of the analyst. Secondly, evaluating all the acceptable alternatives based on each of the quantified selection criteria, and the selection attributes. Thirdly, equipment alternatives are ranked (e.g. 1st option, 2nd option, etc.) as a result of this evaluation process. There can also be sensitivity analysis [22] to determine how sensitive the results produced are to minor changes if introduced during the evaluation and selection of best equipment. Thus it determines how likely the 1st option is to be the best option. The investigator has the chance for further analysis to justify the selection decision if he requires.

It can be seen that these steps cover all the relevant aspects of the selection process. They are easy to use by the non-expert to determine the best handling solution and they can produce enough information to aid the decision making process.

These suggested 5 steps for a selection process are one way in which the person required to choose handling equipment might use. This classification is not the only approach but it represents a logical and systematic procedure. These steps will be used to develop the inquiry part and matching process for the previously suggested knowledge base for the development of a decision tool to aid the selection of a suitable handling method.

3.4 Complexity Of The Decision Process

The previous sections described many aspects which are contained in the selection process. These tangible and non-tangible factors create a huge selection problem which results in a difficulty of the selection decision analysis for the novice investigator. This is because of limited expertise in this field and shortage of knowledge which enable them to deal with an overwhelming number of variables to produce a logical decision for a suitable handling solution.

A discussion on the difficulty associated with the selection decision is therefore required to identify the decision making constraints encountered by the analyst. By revealing the difficulty of the problem, it becomes relatively easy for the investigator to understand the role of different variables involved in the selection process and where to expect the complexity to arise. This will assist in trying to solve the problem.

3.4.1 Decision Process Difficulty

There are two basic sources of decision difficulty according to Clemen [22]. They are as follows:

1) A decision can be difficult because there is not an optimal solution or an ideal solution. Any decision will have some advantages and some limitations. So, it is a matter of reducing the limitations and increasing the merits of a solution as close as possible to the optimal or ideal situation. For example, a decision maker might utilise a trade-off between many factors like preferring an automated system with low operating costs over a low initial equipment cost. The effects of many factors may tend to negate ideal solutions.

2) Different perspectives lead to different conclusions. The issues of material handling vary from one case to another. For example, in one situation it may be that safety is the main concern because of dangerous materials or environment. In other situations equipment flexibility is paramount to meet the frequent changes in product design. Even in a single problem the decision makers might disagree on the evaluation of attributes influencing the equipment selection decision. This situation leads to different views of the same problem which produce a variety of solutions even for a single case.

These 2 sources of decision difficulty are considered important areas of this subject. Also, they explain several aspects influencing the decision process which ought to be considered in future analysis. But it should be emphasised that they produce complexity in this process because each point requires extensive investigation to be able to produce sufficient information for the analysis process. It should be observed that the second difficulty produces two important points. Firstly, it displays a relationship between the difficulty of defining the problem (discussed previously) and the difficulty of making the decision. Secondly, this difficulty has a direct effect on the definition of what is optimal which is due to different interpretation by people even for the same situation.

We might add as a third decision difficulty the need to choose a well defined systematic method to solve such problems, i.e. how do we choose the method to solve the problem which will in turn select the material handling solution? Clemen [22] suggested the use of the decision analysis approach as a possible solution. However section 3.3.2 presented one way of systematic selection and identified steps to aid the decision analysis process for selection of a suitable handling method. The next section will clarify the decision analysis aspect as part of the selection process.

3.4.2 Decision Analysis

Decision analysis is intended to help people deal with difficult decisions [22]. In other words, it is the art of arranging or organising the problem's information in a systematic way and using this information to arrive at a decision. According to Clemen [22] there are single criteria and multiple criteria problems in the domain of the decision analysis. Our problem always involves multiple criteria. Therefore a multiple criteria evaluation technique is required to deal with this type of problem. A discussion of multi-criteria evaluation methods for material handling analysis follows in the next section.

3.5 Evaluation Of Multi-Criteria Methods

It has been stated that it is the task of management to identify and prioritise selection criteria because handling situations vary from one case to another. Therefore the decision maker is required to clearly set the criteria for selection. But these criteria are non-quantifiable and so a way is required to deal with this situation. There are several methods using non quantifiable factors and multiple criteria evaluation to perform the task.

3.5.1 Weighted Evaluation Technique (WET)

Frazelle [20] stated that the weighted evaluation technique (WET) is a very useful multi-criteria evaluation/decision making tool. There are many steps in this technique which quantify selection criteria, evaluate and produce a decision on the best equipment. A description of the steps within this method is provided by Frazelle. If we have 4 different criteria, each criterion is evaluated and given a weight on a scale 0-100 (zero is least important and 100 means most important). E.g. in a particular case the criteria are rated with the following weightings:

1) Flexibility has a weight of 90

2) Compatibility is 80

3) Reliability is 90

4) Adaptability is 40

The total of all weights is = 300

Next, normalise each criterion's weight by dividing it by the total of all weights as follows:

1) Flexibility has the normalised weight of 0.3

2) Compatibility is 0.27

3) Reliability is 0.3

4) Adaptability is 0.13

Then, for example, if we are attempting to rank three different types of equipment (AGV, Conveyor, Towline). The following Table-3.1 provides an evaluation of each type of equipment based on each criterion and on the same scale :

Criterion / Equipment	Flexibility	Compatibility	Reliability	Adaptability
AGV	85	75	70	60
Conveyor	50	80	70	75
Towline	65	60	90	40

Table-3.1

Finally determining the value for each type of equipment by multiplying its weights with the corresponding normalised criterion weight and adding the values for each one as follows:

AGV = (85*0.3)+(75*0.27)+(70*0.3)+(60*0.13) = 74.55

Conveyor = (50*0.3)+(80*0.27)+(70*0.3)+(75*0.13) = 67.35

Towline = (65*0.3)+(60*0.27)+(90*0.3)+(40*0.13) = 67.9

Then select the equipment with the highest score, which for this example is the AGV.

But what is important about these steps is that there are two critical points. Firstly, this method starts by weighting different criteria on a scale zero-100 (zero means least important, and 100 means most important). This step raises several questions, i.e. 'how many people perform the weighting?', 'what expertise do they need to have?', 'what is important?, and 'what is bad?'. These questions present major concern as to the validity of weighting the criteria on such a scale. This is because of the subjectivity in determining the right value and the level of accuracy that can reasonably be assigned to any value. This problem might be tackled by repeating the weighting process many times by different people to produce an average value for each criterion but there is still difficulty in validating this average. The second point is that each handling alternative is evaluated on the same scale with respect to each criterion. This presents similar difficulties for validating the weights used. Also, it is not clear whether the number of criteria and the number of alternatives will or will not affect the result of this process.

The use of this technique has the following merits :

1. Easy and clear steps to use
2. Simple and short calculation

In contrast this technique has several limitations and they are as follows :

1. Simplistic evaluation of very important factors (selection criteria, and handling alternatives)
2. Difficulty of verifying weights for criteria and alternatives
3. The inability to validate the final result.

3.5.2 Analytic Hierarchy Process (AHP)

This multi-criteria analysis technique [23] starts by structuring a problem's criteria, and alternatives hierarchically (e.g. material handling problem (Figure 3.4)). A hierarchy is a "particular type of system, which is based on the assumption that the entities (in this case the criteria, and alternatives), which we have identified, can be grouped into disjoint sets". A 'disjoint set' is a group which contains a number of independent entities. "The entities (the criteria) of the higher group influence the lower group of entities (the alternatives) only, and the group of criteria being influenced by the highest entities or a goal (e.g. suitability of equipment) only. The entities in each group of the hierarchy are assumed to be independent" [23].

Figure (3.4) displays a hierarchical structure of the problem which breaks down this problem to the individual groups at different levels and eases identification of its factors for the investigator. Firstly, level 1 as the main goal is 'to find the suitable handling method'. Secondly, level 2 is where selection criteria reside and influence equipment alternatives which are grouped in level 3. This presents a systematic definition to the problem. The following Figure (3.5) is a mathematical representation of this method with the aid of selection criteria in Figure (3.4) (for more details see [Appendix C]).

Suppose there are 5 selection criteria; Flexibility (f), Compatibility (c), Reliability (r), Availability of handling space (a), Adaptability (ad). Pairwise comparisons between them produce the following matrix in Figure (3.5).

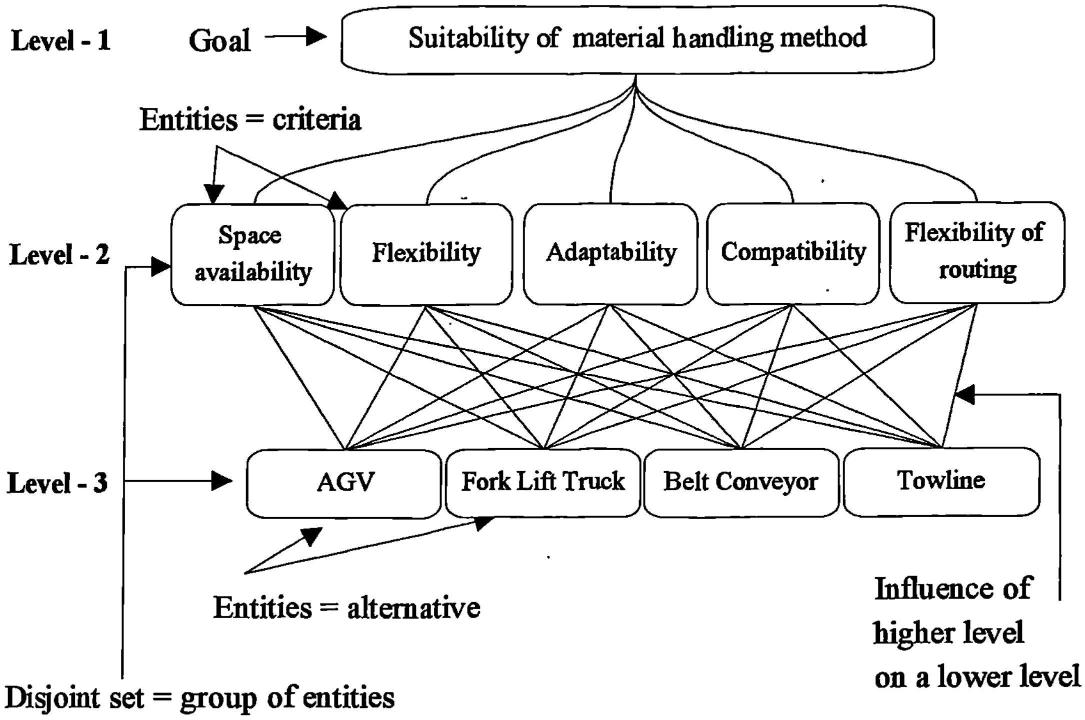

Figure 3.4 - Material Handling Decision Hierarchy

	f	c	r	a	ad
f	1	2	4	5	2
c	0.5	1	2	1	1
r	0.25	0.5	1	2	4
a	0.2	1	0.5	1	1
ad	0.5	1	0.25	1	1

Comparison values

Reciprocal values

Diagonal of unity

f = flexibility
c = compatibility

r = reliability
a = availibility

ad = adaptability

Figure 3.5 - Comparison matrix

Saaty [23] considered the use of pairwise comparison in this situation. A pairwise comparison is a comparison between a pair of non-quantifiable entities (e.g. flexibility and compatibility) to determine a specific value on a fixed scale. This value represents a subjective measurement which indicates the importance of one variable over the other for a particular situation, therefore solving the problem of quantifying such variables.

The qualitative criteria are interpreted as "relative property" in which people's assessment is used to determine a suitable value for these criteria. Saaty commented that "the pairwise comparison was a powerful instrument which varies its scale with the relativity of circumstance of the human mind itself. The intensity of our feeling serves as a scale-adjustment device to put the measurement of some entities on a scale with that of other entities". Even though pairwise comparison developed a more logical way to evaluate the criteria than the WET method, nevertheless the influence of human judgement in the evaluation process can introduce inconsistency due to variability in people's judgement which might affect the final result. To overcome this difficulty it might be necessary to find a way that can evaluate consistency to validate the final result. Consistency means producing the same values on different occasions with the same data. The AHP method has the ability to determine a measure of consistency to evaluate the comparison process of criteria and alternative equipment. This is needed to overcome the inconsistency problem of rational judgement. Saaty [23] stated that this method can introduce a procedure for getting a crude estimate of consistency [Appendix C]. If it falls within the range of values (0 - 0.1, see Appendix C) specified as "acceptable" for this method then the selection can be considered to be based on consistent data. However if the consistency value is outside the limits of the range, it is necessary to re-examine the data on which the pairwise comparison was performed. This produces the following difficulties :

1) Difficulty of redefining the comparison values to overcome the problem of inconsistency because there are no guidelines to perform this task.
2) Difficulty for the investigator because of the sensitivity of this process to changes in the subjectively assigned values. Sensitivity analysis [22] can be combined with the AHP method to determine how sensitive the results produced are to minor changes if introduced during the evaluation and selection process.

These can be considered as a limitation of this technique. However this method provides two validating steps :

1) Consistency of quantification of criteria
2) Consistency of selection decision (see Appendix C).

These two steps if verified with sensitivity analysis to evaluate results stability could give greater confidence in the decision.

3.5.3 Multiple Attributes Decision Making (MADM)

Consider a set of potential solutions, which requires that several factors should be accommodated. Multiple Attributes Decision Making (MADM) constitutes one method to make this selection [24], [25].

The idea behind this method is the ranking of different alternatives based on minimising what is called "distance" which is the closeness of each alternative to (non-existent) ideal equipment for the particular application (see Figure 3.6). The distances for each of the alternatives are derived through MADM [Appendix D].

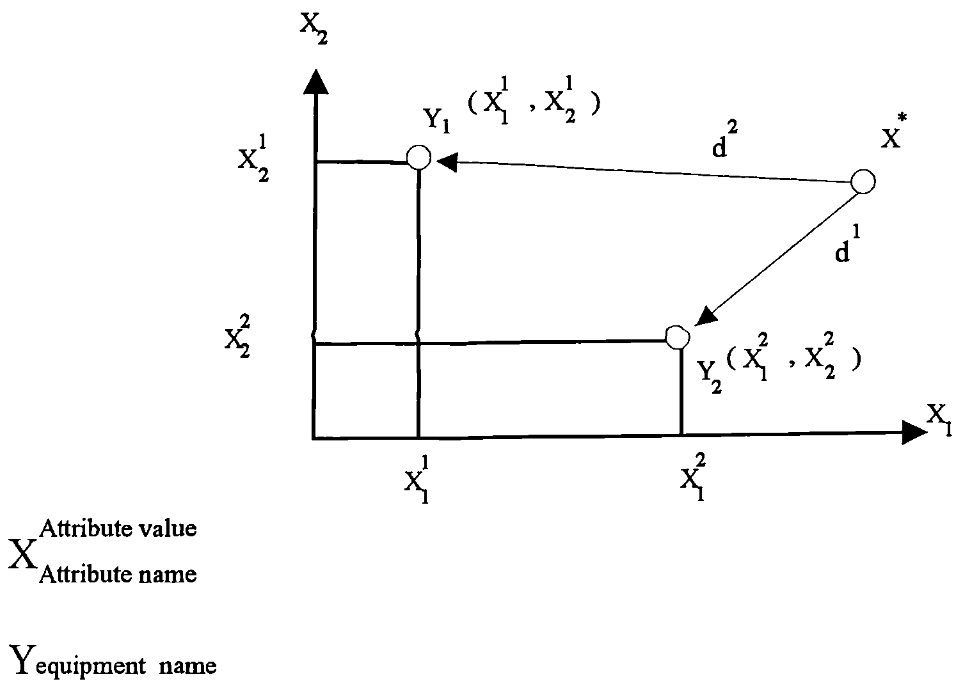

Figure 3.6-Distances d^1 and d^2 to the ideal point X^*, based on two attributes X_1 and X_2, for alternatives Y_1 and Y_2 [24]

It has been stated before that different circumstances produce different solutions because of their influence on selection factors which can introduce changes to these factors. Also, one of the difficulties of decision making is that there is not necessarily a single optimal or ideal solution. Therefore complexity lies in defining the theoretical ideal solution. Although this method depends on quantifiable factors, nevertheless the ideal attributes are difficult to set for the selection process because of difficulty in defining the ideal.

Although there may be a specific formula to determine the best handling method which produces an accurate result, nevertheless it lacks a means of validating the final result. Also, inconsistency might affect the final result since this method depends on people's judgements to define the values of attributes for the ideal solution. We have to recognise that this method lacks the facility to quantify selection criteria, therefore it must be used with another method that can perform quantification to enable the investigator to determine the best handling method.

3.6 Discussion On Multiple Criteria Methods

The previous section presented three multiple criteria methods. On the basis of ease of use, WET is the best because of the simple conventional mathematical operations it uses. However it lacks any sort of calculations for the decision consistency. So it is not possible to check the validity of a solution.

The MADM technique takes a different approach toward the selection of the best system. The features of the different alternatives are checked by a benchmark which is an ideal set of equipment/system characteristics. The best system is the closest to the ideal. This method is relatively easy to use compared with the AHP method. But the difficulty of this method lies with the definition of an ideal solution. The inability to quantify selection criteria requires it to be used with other techniques to fulfil this task. Also it lacks any means of verifying the selected handling method. The AHP has a large number of calculation steps because of the matrix multiplication and data manipulation. Also, the larger the number of criteria and alternatives, the larger the number of calculations needed (e.g. 5 criteria will produce a 5x5 matrix and so on).

The process is long and tedious if not computer aided. Nevertheless, the AHP method provides a decomposition of hierarchy components to aid visualisation of the problem which assists in its analysis. The pairwise comparison used by this method provides a logical way to determine relatively accurate judgements on selection criteria. Furthermore, the AHP method utilises a consistency calculation to cover the validation part of the final decision. Table 3.2, below, illustrates the comparison between the 3 decision analysis methods.

Decision method Comparison factors	WET	MADM	AHP
Calculation of decision	Easy and conventional	Require bench mark or ideal solution	Matrices manipulation
Provides consistency	No	No	Yes
Quantify subjective judgement	No	No	Yes
Verification of final solution	Difficult to verify solution	Difficult to establish the ideal	Easy to verify solution

Table 3.2 - Comparison between 3 decision methods

For the reasons given above the AHP method is considered to be the most suitable of the three techniques used to quantify the selection criteria.

CHAPTER FOUR Computerisation Approach And Review Of Selection Systems

4.1 Introduction

A systematic approach for selecting material handling equipment was sought to enhance the ability of the non-expert in choosing the right equipment. However this approach has many difficulties which were explored in chapter 3. It has been shown that there are many steps and each can involve the need to process large amounts of data or need long and tedious calculation. This is a hard task and can be time consuming as well as prone to error but it is worthwhile because the material handling issue is a long term strategic decision and a careful analysis procedure is needed to guide a business to assess and choose appropriate handling equipment.

An important aspect is the inability of non-experts to deal with the very large number of factors related to this problem. It contains some factors which are readily quantifiable and some which are not, as stated in chapter 3. There are a large number of equipment characteristics which lead to a difficulty of establishing parameters for the selection process and the lack of human ability to deal logically with enormous amounts of data. This can, in turn, contribute to errors particularly in equipment selectability and to mistakes in the evaluation procedure which result in producing wrong judgements. Evaluation of these factors requires a decision analysis technique that combines both qualitative and quantitative factors with equipment data which can be contained in a knowledge base to systematically arrive at the best solution.

We can summarise the difficulties of a systematic selection procedure in the following points :

1. The huge amount of data
2. Long and sometimes tedious calculation
3. Difficulty of establishing selection rules
4. Relating several diverse factors (qualitative and quantitative) of the problem

We should recognise that the first 2 points are reasonable indicators that a computerised approach would be useful because traditional computer techniques are better at these tasks than a human. However the difficulty in establishing selection rules and relating diverse factors as well as a need to deal with not quantifiable factors do not suggest the use of a computer, because it is precisely these sorts of problems that people are generally better at solving than computers. In order to consider a method, it is very important that this method is capable of dealing with such difficulties. Therefore our goal is to ease this problem, and to attempt to analyse as well as to evaluate a computerised technique coupled with a knowledge base responsible for selecting equipment which is able to produce a similar result to that produced by a human expert.

Matson et al [18] stated that there are a number of computerised methods available to aid the layout process, but there are few computerised tools to aid the material handling engineer in the selection of appropriate handling equipment.

An analyst ought to know the benefits and limitations before any attempt is made to implement a computerised approach. Such an approach has the following potential advantages:

1. Works faster than people in accessing and retrieving information
2. Deals with large amount of raw data and can accommodate huge amounts information
3. Repeatability and consistency of results when compared with human cognitive process
4. It is relatively easy to update its information to maintain its validity

In the same manner there are some potential limitations to using a computerised equipment selection technique and they are as follows:

1. Analysis is limited to the information contained in the knowledge base
2. Dependency on human to update its information at present
3. Limited facility of inquiry to evaluate validity of stored information (e.g. is the stored information old? Does it need updating? Is there any new technology since the last time that an update was performed? etc.). There can be inquiry routines built in, but only to query whether it might need changing, as it requires additional input to know whether it definitely needs changing.

The previous points illustrate the pros and cons of this approach, but there is a need to ask an important question which is 'what sort of computer-based approach is suitable for this problem?' There are two points which have to be considered in order to be able to answer this question as follows:

1) Recognising the type of difficulties associated with this problem.

2) Searching for an appropriate method which can tackle these difficulties.

The first part of this section demonstrated the difficulty associated with the equipment selection problem (e.g. dealing with qualitative factors) which required the use of a knowledge base to aid the selection process. Consequently if a computer is going to be used, it cannot be a simple computer application and it must employ a means of simulating the "intelligence" possessed by an expert. Therefore it was decided that a computerised technique with artificial intelligence (AI) capability is needed to overcome the shortage of expertise in this field to deal logically with its tangible and non-tangible factors and arrive at sensible solutions. There is a great potential in the AI environment which can provide an appropriate method to assist in solving this problem. This is because AI is capable of mimicking human reasoning characteristics which is one of the requirement to solve the problem. The remaining part of this chapter will consider currently available AI techniques.

4.2 Artificial Intelligence

Jackson [26] used the following definition by Barr and Feigenbaum [27] which stated that artificial intelligence is part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour - understanding language, learning, ability of reasoning, solving problems, providing logical decision making and so on.

Minsky [28] defined AI as " the field which is concerned with programming computers to perform tasks that are presently done better by humans, because they involve such higher mental processes such as perceptual learning, memory organisation and judgmental reasoning". However Jackson [26] summarised AI as "it is about the emulation of human behaviour".

According to Jackson [26] and Hinde et al [29] artificial intelligence may by roughly divided into two areas:

i) It is about building intelligent artefacts, such as robots

ii) It tries to explain and model human intelligence

The interest of this research is to evaluate the modelling of human intelligence in order to consider a suitable approach which is capable of solving the problem. There is a great potential to develop the decision making tool necessary for the non-expert by combining the above mentioned characteristics of artificial intelligence with a knowledge base of the selection requirements. However it is important, firstly, to identify the AI technique which is most applicable to this problem.

There are several areas of AI which must be examined to determine their feasibility as a possible technique for this problem. From a review of AI techniques capable of dealing with "selection" problems, there is evidence that there are four that could be considered as possible methods for this problem and they are; artificial neural networks (ANNs), genetic algorithms (GAs), fuzzy logic (FL), and expert systems (ESs). These 4 techniques will be reviewed in the following sections.

4.2.1 Artificial Neural Networks

The use of artificial neural networks (ANNs) is an important technique in the artificial intelligence environment. There are many definitions of ANNs in the literature. Turban [30] stated that it is "a different approach to intelligent systems which involves constructing computers with architectures and processing capabilities that mimic some processing capabilities of the human brain. The results may be knowledge representations based on massive parallel processing, fast retrieval of large amounts of information, and the ability to recognise patterns based on experience. The technology that attempts to achieve these results is called neural computing, or artificial neural networks (ANNs)".

Hinde et al [29] used Wasserman's [31] evidence of the connectivity of the brain to elaborate that the study of how interconnected neurones of the human brain compute and collectively behave is the study of neural networks. The principle behind this method is creating linkages with different weights between inputs and outputs by training interconnected layers of neurones (Figure 4.1).

ANNs have been used for many different problems in the literature. Widrow et al [32] stated that most neural network applications address problems described by one of the following three categories:

i) Pattern classification;

ii) Predication and financial analysis;

iii) Control and optimisation.

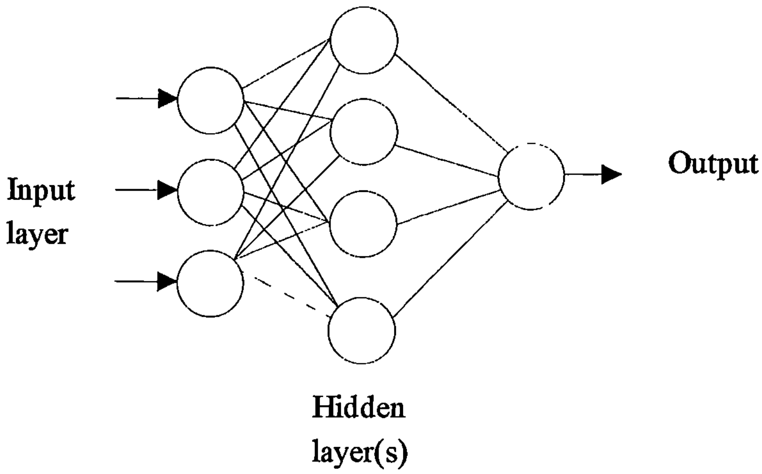

Figure 4.1 - Neural Network Structure

The authors [32] provided a variety of examples in each category. Moore [33] provided the following similar classification for applications which used ANN's as an approach:

1) Pattern classification and associative memory

2) Self-organisation and feature extraction

3) Optimisation

4) Non-linear mapping

Again Moore gave a broad description of each category to point out the difference between them. Furthermore this review showed a huge amount of literature on artificial neural networks used in a range of applications. The following papers [34], [35], [36], [37], [38], [39], [40], [41], and [42] are some examples in which this technique has been employed to produce a solution within the broad classification provided by Widrow et al [32] and Moore [33].

Many of the applications are inappropriate to the equipment selection problem, however there were two categories, pattern recognition and optimisation, which suggested ANN's as a possible approach to solve the problem.

Firstly, it must be noted that the pattern recognition and pattern classification utilised within ANNs provides some sort of differentiation between inputs and outputs of patterns (e.g. image [39] and [43], signals [40], as well as data [41]) which might be considered as a sort of selection process. For these problems the networks were trained to identify a new pattern(s) input to the network which either match or did not match a specific pattern encoded and recognised within the structure of the networks. Here we might recognise that there is some similarity with the selection problem. But for choosing handling equipment the case is different because each handling situation varies from case to case and this would require training and re-training for the network to stabilise the weights used for judgement in order to produce a reasonable solution. This step is tedious and time consuming. Moreover it is difficult to build a specific pattern of selection criteria for a particular handling method in order for the network to identify such a method if presented with a different or new situation. The difficulty stems first from the type of information in the problem and second from the evaluation and weighing of such information in each new case. In other words heuristic rules of selection are not exact. They are not able to produce a precise solution for the same case and in some cases might even provide the least appropriate solution [30]. The variability in the conflicting information of the problem produces difficulty for ANNs to cope with such diversity.

Secondly, ANNs have been utilised in many optimisation problems in which the intention was to identify the best solution from among many alternatives. This can be viewed as a class of selection which can be implemented to solve the problem. Nevertheless it is difficult to establish the best or the "ideal" solution(s) for material handling situation(s) for the purpose of training the network. This is because of the inability to uniquely relate a particular handling method to a specific problem and this hinders the capability of ANNs as an optimisation tool to find the best method. This could affect the performance of ANNs when dealing with this type of problem.

The survey revealed other potential disadvantages of this technique. Tsoukalas et al [44] reported that ANNs are trained using available data, tested, and put into use. All they can do is recall an output when presented with inputs consistent with the training data. Furthermore there is the problem of structuring the network for the selection problem and the inability to produce a confidence value for a given output. Turban [30] elaborated that neural networks lack explanation facilities. Justification for a result are difficult to obtain because the connection weights do not usually have obvious interpretations. Neural computing usually requires large amount of data and lengthy training time, thus, the need for frequent re-training may make a particular application impractical.

Similar shortcomings of ANNs were reported by Tsoukalas et al [44] who stated that neural networks, in spite of their extraordinary usefulness, have relatively limited capabilities. They cannot reason, seek data from available databases to assist their operation, or provide an explanation of their outputs. They need a structured environment (well defined layers of neurones) in which to operate properly. Cook et al [41] also mentioned that a key limitation of this technique is the large amount of training time required to produce a sensible output. Moreover the authors [41] indicated that there is a very high dependency on data for this technique to obtain good performance. Botros [39] showed that ANNs failed because of noise introduced while gathering the data which affected the performance of this method. Furthermore Luxhoj et al [35] commented that neural networks created with un-grouped data do not provide acceptable results. In the same manner both Burke et al [34] and Flood [37] stressed that there is still considerable trial and error in the structure of these networks.

The main limitations of this method can be summarised as follows:

1) Lack of logical explanation for final decision;
2) Training time can be excessive and tedious;
3) Not cost effective for the time used on training and re-training of network;
4) Network architectures are still mostly subject to trial and error, therefore its performance not predictable;
5) Well documented and organised data in large quantity is required for better performance.

Therefore, while it is recognised that this technique could perhaps be applied to this problem given sufficient further research and development, there is no evidence that it is the best approach to use. The fact that no selection applications of a similar type have been found which used neural networks tends to support this view.

4.2.2 Genetic Algorithms

Genetic algorithms (GAs) are another class of artificial intelligence that are mostly used for optimisation [44]. Turban [30] referred to Grefenstett's [45] definition of GAs as "an iterative procedure maintaining a population of structures that are candidate solutions to specific domain challenges. During each temporal increment (called a generation), the structures in the current population are rated for their effectiveness as domain solutions, and on the basis of these evaluations, a new population of candidate solutions is formed using specific 'genetic operators' such as reproduction, crossover, and mutation". Ng et al [46] stated that "GAs use biological evolution models to develop a series of search space points which lead toward an optimal solution".

Hines et al [47] referred to Davis's [48] definition of GAs which stated that genetic algorithms are generally concerned with the manipulation of multiple alternative solutions, from which an optimal solution can be derived. This technique is distinguished by the use of digits.

In principle the structure of genetic algorithms is fairly simple. GAs model a solution by means of binary strings (see Figure 4.2). Such a string is made up of sub-strings, each sub-string representing a different variable in a solution. In the terminology of GAs the bits are referred to as 'genes' and the total string as a 'chromosome'. A chromosome, therefore, represents a solution, several chromosomes representing different solutions which comprise a 'population' [49] [50]. Hall [51] described GAs as "an iterative process where each successive generation is produced by reproduction among the members of the previous generation." There is what is called the 'principle of natural selection' in biology on which genetic algorithms are based Hall [51], Holland [52], and Roston et al [53]. It is this search capability which is useful in providing this best possible solution and sometimes the optimal one.

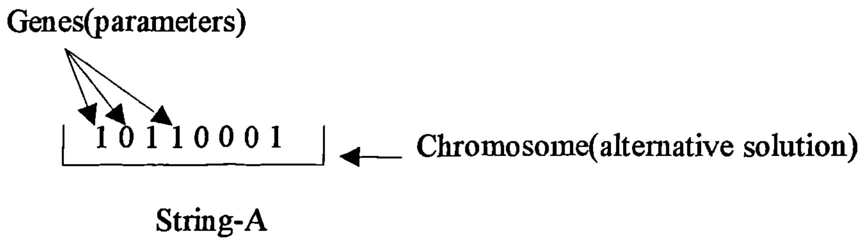

Figure 4.2 - GA structure

GA techniques have been applied mainly in optimisation problems because of the ability of this method to search and provide the optimum solution among different alternatives. In the literature there are many cases in which GAs were reported to be the prime method for modelling and solving optimisation problems, for example [47], [51], [53], [54], [55], and [56]. GAs are a way to find an optimal solution from a given population of competing solutions. This can be treated as a type of selection approach which might be able to deal with the problem. However it is not easy to characterise what is optimal for the problem in order for a GA to perform this task. Furthermore GAs as a proposed approach for analogous selection problems have not appeared in this survey.

There are reported limitations of the GAs technique which hinder attempts to use it as an approach to this type of problem. Several investigators have identified deficiencies associated with GAs. Giordana and Sale [57] stated that the fundamental difficulty, in order to apply GAs, consists of formulating the problem in such a way that it can be processed by the genetic operators such as crossover and mutation. The most common practice is to represent the individuals as strings of bits. Furthermore Fogarty [58] found a performance deficiency using genetic algorithms with zero-population (no solutions to start with) in comparison to the performance of a rule based system for the same situation. Ng et al [46] noticed a convergence problem with GAs when the coded genetic strings became too large. This demonstrated that the technique has a limited capability when presented with too many alternative solutions and with many selection criteria due to dependency and lack of flexibility of the coding format for such cases. Hence, this results in creating long genetic codes which in turn affect the performance of such a technique.

There are several problems with GAs. Firstly there is a difficulty of representing the information contained in a variety of handling solutions. Secondly, the difficulty of distinguishing the 'ideal' or optimal solutions in these cases. Lastly, its lack of structure to suit this problem.

The diversity of such shortcomings found in GA techniques as well as the lack of problems of the selection type which have been reported to use this approach, suggested that GAs were not likely to be a good solution to this problem.

4.2.3 Fuzzy logic

This technique was built on a mathematical theory founded by Lotfi Zadeh in 1965 [59] which was called 'fuzzy sets'. Turban [30] commented on this technique by stating that some AI programs exploit the technique 'approximate reasoning' which uses the mathematical theory of fuzzy sets. He elaborated that "this method simulates the process of normal human reasoning by allowing the computer to behave less precisely and logically than conventional computers do".

Fuzzy set theory was proposed as an alternative to traditional set theory. In traditional set theory, an object is either in a set or it is not, and this is sometimes called 'crisp logic'. In contrast, in fuzzy logic the object is given membership in possibly several fuzzy sets. The membership value is a value between 0 and 1. A membership close to zero implies 'weak' membership in the given fuzzy set, whereas membership close to 1 means 'strong' membership [60].

Fuzzy logic (FL) is considered to be a potential method for dealing with information uncertainty and particularly when the uncertainty lies in human language [30]. Mendel's [61] literature survey showed that there are two distinct types of knowledge. The first is objective knowledge which is often used in the formulation of engineering problems. The second is subjective knowledge which is typified by linguistic information that is usually impossible to quantify using traditional mathematics, but which can be converted to rules then quantified using FL [62], and [63]. Mendel [61] emphasised that both forms of knowledge can be dealt with logically using FL.

Turban [30], Ng [46], Barrett et al [60], and Mendel [61] showed that fuzzy logic is capable of dealing with uncertainty, and subjective as well as objective knowledge in order to be able to provide a sensible reasoning for imprecise or approximate information given.

Guiffrida et al [64] has produced a literature survey compiled from 73 journal articles and nine books to assess the application of fuzzy set theory in production management research areas. This work showed some past surveys conducted in this area between the period, 1965-1994. The authors [64] identified several areas in production management which had used a FL approach:

1) New product development
2) Facilities location and layout
3) Production scheduling and control
4) Inventory management and planning
5) Quality and cost-benefit analysis
6) Project scheduling
7) Forecasting

The authors then provided an array of cases which represented each category. It is important to recognise that facilities location and layout selection problems [65], [66], [67], [68], [69], and [70] contained in this paper showed that fuzzy logic could play an important part to tackle and interpret their information (qualitative and quantitative) properly in order to select either the best facilities location or the best layout. Similarly Khonja et al [71] presented a decision model for the robot selection problem. This model uses fuzzy cluster analysis technique for identifying a better-performing robot.

The literature revealed several shortcomings with the FL approach with respect to the development of decision rules. Kartalopoulos [72], Driankov et al [73], and Henning et al [74] stated that fuzzy systems deal with current fuzzy information and are capable of providing crisp outputs. However in fuzzy systems there is no learning and, even vaguely, the input-output relationships -the fuzzy rules- must be known a priori. In addition the fuzzy systems require a thorough understanding of the fuzzy variables and membership functions, of the input-output relationships as well as 'good judgement' to select the fuzzy rules that contribute the most to the solution of application. Driankov et al [73] reported that the fuzzy variables should be well identified; otherwise the investigator tends to create too many fuzzy rules which will affect the performance of the system.

Furthermore the survey did not reveal any selection cases in which FL has been the only method to provide the full analysis for such cases. In these cases, the main objective of FL was to enhance selection performance because of its capability to deal with conflicting information and this provided logical solutions. This indicates that this method is used as a secondary method or a vehicle which refines other techniques. Moreover it should be recognised that this technique is able to formulate a difficult problem in mathematical terms, hence it plays an essential role in an analysis process to evaluate and to determine the final results.

Therefore it is suggested that this technique might be considered as an option with another AI method which can provide decision analysis capability to tackle the problem's both information types in order to seek improved solutions and provide a complete decision system.

4.2.4 Expert Systems

The expert system (ES) is another popular AI approach. Scott et al [75] defined an expert system as a computer program that can perform a particular task significantly better than can the average person. Jackson [26] commented that " an expert system is a computer program that represents and reasons with knowledge on some specialist subject with a view to solving problems or giving advice". Giarratano et al [76] stated that an expert system is a program which emulates a human expert's reasoning in solving problems. They are sometimes referred to as knowledge-based systems. Jackson [26] elaborated that a knowledge-based system is any system which performs a task by applying rules of thumb (heuristic or approximate) to a symbolic representation of knowledge, instead of employing more algorithmic statistical methods.

This method has been utilised in many situations over several different disciplines. Turban [30], and Giarratano et al [76] reported on a variety of ES cases in different fields. In the same vein Spur et al [77] provided a list of tasks within the manufacturing environment where ES has been implemented as follows:

a) Diagnosis

b) Planning

c) Configuration and selection

d) Monitoring and control

e) Prediction and knowledge acquisition

Of greatest interest, which was not evident in the previous review of the other 3 AI techniques, is that the literature survey displayed many cases in which expert systems have been employed in selection problems, [78], [79], [80], [81], and [82]. Furthermore the literature showed that this technique has been implemented specifically for material handling equipment selection. Ten different systems were found to exist from an extensive literature survey [18], [25], [83], [84], [85], [86], [87], [88], [89], and [90]. Moreover the same literature survey revealed that this method is highly recommended for this type of problem because it is capable of dealing with both types of knowledge (qualitative, and quantitative) contained within the problem domain. In addition the ability of ESs to provide logical reasoning and produce certainty values for the decision are considered important requirements to solve such a problem. However there are some limitations which should be recognised when dealing with this method. Turban [30], Giarratano et al [76], and Kartam et al [91] generated some shortcomings associated with this technique (e.g. knowledge needs to be updated, reasoning is limited by rules encoded, expertise is hard to extract from a human source, different interpretation of the same knowledge). Although there are some weaknesses in this approach, nevertheless its advantages and the previous similar applications provide a potential indication that it has superiority over the 3 previously reviewed AI methods.

The foregoing literature survey has shown that the expert system technique was the only method which has been utilised to solve problems closely associated with selecting material handling equipment. Also it exposed several deficiencies related to this technique. However expert systems as a technique are able to perform the tasks of decision analysis and decision making to produce a selection tool. Therefore ESs are considered superior to the other 3 AI methods when dealing with this sort of problem.

The existing evidence provided on this method suggested that it was a viable way to tackle the problem. This provided the foundation to pursue and to implement such a method for the solution to the handling equipment selection problem.

4.3 Expert System (ES) Technique

The term 'expert systems' is often applied today to any system which uses 'expert system technology'. This technology may include special expert system languages, and programmes designed to aid in the development and execution of an expert system [75], [76]. It is necessary to understand how an expert system works and the important aspects of its structure to provide the necessary information for an appropriate development process (e.g. type of software package required to fulfil this task, knowledge search method etc.). The basic concept of an expert system is that the user supplies facts or information to the system and receives expert advice or 'expertise' in response (see Figure 4.3).

In order for the system to produce advice, it has to perform some sort of matching process through the 'inference engine' on the knowledge in the knowledge base with the user's information. The 'inference engine' is where the expert system reasons or makes 'inferences' in the same way that a human expert would infer the solution of a problem. That is, given some facts, a conclusion that follows is inferred.

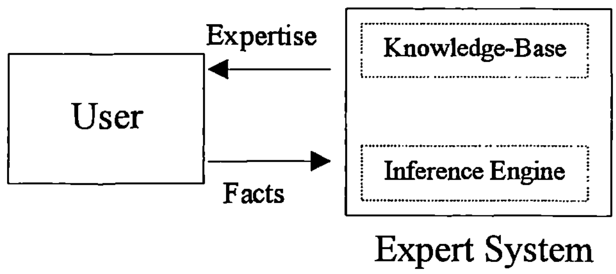

Figure 4.3- Basic Concept of an Expert System Function

There are two general methods of inferencing in common use [26], [76]:

1) Forward chaining : reasoning from facts to the conclusions resulting from those facts.
2) Backward chaining : involves reasoning from a hypothesis which is a potential conclusion yet to be proved, back to the facts which support the hypothesis.

The building tool (software) is an influential part of an expert system because its main task is to control the knowledge search method which controls the speed of search and the structure of data in the knowledge base. Waterman [92] has identified several types of ES building tools as follows :

1. General purpose programming languages (e.g. FORTRAN)
2. Knowledge engineering languages : the search method is already built; it only needs a knowledge base. In this form it is called a 'skeletal' system, or a 'shell'.

3. System-building aids : these provide advanced capabilities which aid the design of an expert system (e.g. how to structure a knowledge base to produce faster response or decision).

The programming languages offer more flexibility in building an ES in terms of structuring rules and storing information. They are relatively inexpensive, but they need an expert programmer because of the complexity of this task. In contrast, knowledge engineering tools and system-building aids lack flexibility when building an expert system because they have an existing structure of search modes and defined methods of storing information and facts. However these tools provide a relatively easy way to develop such systems for the non-expert.

How knowledge is structured in the knowledge base, is important in an expert system development process because it affects the speed of information search. The following are the most common knowledge representation structures [76], [92], and [30]:

1) Rule-based : is based on 'IF' condition 'THEN' action to perform forward or backward chaining.
2) Frame-based : a frame is a data structure that includes all the knowledge about a particular object. This knowledge is organised in a special hierarchical structure that permits a diagnosis of knowledge independence.
3) Semantic Nets : used for propositional information. A proposition is a statement that is either true or false. It also provides a network with a structure of facts and information.

In general, expert systems consist of the following components [30], [76]:

1. User interface: a mechanism by which the user and the expert system communicates (software or the code of the program)
2. Explanation facility: explains the reasoning of the system to a user
3. Working memory: a 'global database' of facts used by the rules
4. Inference engine capitalisation: makes inferences by deciding which rules are satisfied by facts
5. Agenda: a prioritised list of rules created by the inference engine, whose patterns are satisfied by facts in working memory
6. Knowledge acquisition facility: an automatic way for the user to enter knowledge into the system rather than by having the engineer explicitly code the knowledge (using the hardware to enter the information from the user when prompted by the program).

These six components can be considered to be a general layout of an expert system which provides a foundation for the development of such a system. Also there are several tasks involved in building an expert system incorporating the previous six components which complete the process of development and they are as follows [26], [92] :

1) Identification : is identifying the problem parameters or characteristics and its suitability for this method.

2) Conceptualisation: is preparing and analysing the problem's information, rules, and facts for computer coding (e.g. what type of search mechanism is required?).

3) Formalisation: is expressing the problem's knowledge in a framework of an ES building language.

4) Implementation: is developing a prototype for preliminary testing.

5) Testing: in-house and in-field testing for feedback, refinement, and final validation.

We have to observe that the development of an expert system requires two aspects. Firstly, preparing the hardware and software necessary for building such system. Secondly, defining and arranging the problem's attributes, and solution technique to establish an appropriate system.

However the pros and cons provided previously define boundaries for the area of the expert system application. Also they are intended to aid the analyst's formulation of the problem in order to produce the best performance of this system, i.e. in developing specific modules within the expert system to notify the analyst if changes or upgrading is required on the knowledge or the attributes as well as selection rules. These advantages and disadvantages are common to all ES applications but the differences in performance from one approach to another depends on several factors (e.g. type of software package, complexity of knowledge within a field). The comparison of existing systems to review their differences will be the main topic of discussion in the next section.

4.4 Review Of Current Selection Systems

During the past decade many researchers have developed a variety of expert system approaches for the purpose of selection among different pieces of materials handling equipment.

These systems can be divided into two categories as follows (see figure 4.4) :

1- Special purpose expert systems : which are designed to select the most appropriate materials handling equipment model from a predetermined type and group (e.g. the system will determine a specific AGV model from a particular manufacturer on the basis that it has already been decided that AGV's are the "correct" type of equipment to use).

2- General purpose expert systems : which do not start with a particular type of equipment but given a particular problem will determine the most appropriate group of handling methods.

We have stated in chapter 2 that the intended decision tool will be to determine the group of equipment not a specific make and model. Therefore only the systems in category 2 will be reviewed to identify their types of rules, development software, knowledge acquisition methods, types of information within the knowledge base, inferencing mechanisms etc. This will assist in appreciation of many aspects of expert systems which aid the development of a new decision tool.

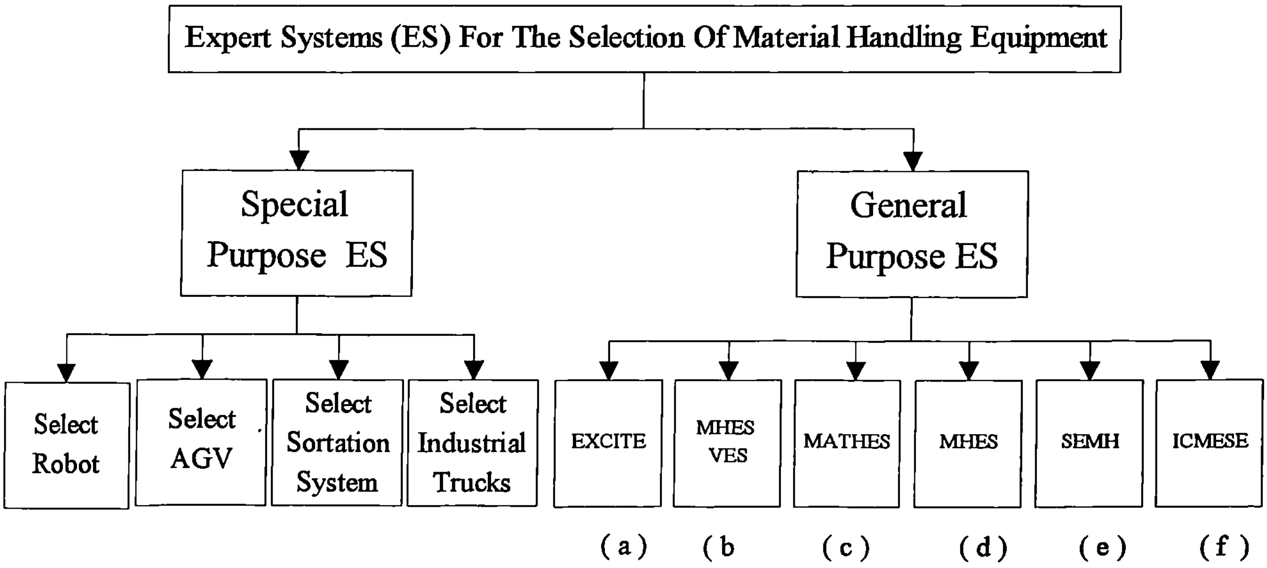

Figure 4.4 - Categories of expert systems and examples

The second category contains the following expert systems :

a- EXCITE: Expert Consultant for In-plant Transportation Equipment [18]

b- MHESVES: Material-Handling Equipment Selection Via An Expert System [25]

c- MATHES: Material Handling Equipment Selection [87]

d- MHES: Material Handling Expert System [88]

e- HEXPERT (SEMH: Selection of Equipment for Material Handling) [89]

f- ICMESE: Intelligent Consultant System for Material Handling Equipment Selection and Evaluation [90].

Details of each of the above system are given in Appendix E. From an understanding of the method of development and analysis of the different building stages of the 10 systems, the author identified 8 key issues which were involved in the production of each system. Table 4.1 was constructed to permit easy comparison between the different systems of the second category. A discussion and an information analysis of the different systems follows in the next chapter.

Issue / ES	KB	KA	BT	KR	IM	DAM	CF	VES
EXCITE	6 basic groups and 35 types of equipment. 28 attributes, 340 rules, and 3 criteria	FL	OPS83	Rule-based 'if - then'	Forward chaining	WET	Yes	NA
MHESVES	3 basic groups and 30 types of equipment. 6 attributes and 13 rules.	FL	VP-EXPERT	Database files using the package 'dBase III'	Forward chaining	MADM	No	NA
MATHES	3 basic groups and 24 types of equipment including 'manual' and ' other' options	HE	NC - Shell	Rule-based 'if - then'	Back-ward chaining	Certain-ty Calculus	Yes	Yes
MHES	3 basic groups and 30 types of equipment. 11 attributes.	FL	Experi-menting with several	Suggested frame-base	Forward and Back-ward	Support decision analysis	Yes	NA
H-EXPERT (SEMH)	NA	FL	LISP	Rule-based 'if - then'	Back-ward chaining	NA	NA	NA
ICMESE	2 basic groups and 50 types and models. 30 attributes. 3 criteria.	FL	VP-EXPERT	Rule-based 'if - then. Database files using the package 'dBase III plus.	Back-ward chaining	AHP	Yes	NA

KB = Information contained within the Knowledge Base
KA = Knowledge Acquisition
BT = Building Tool
KR = Knowledge Representation
IM = Inference Mechanism
DAM = Decision Analysis Method
CF = Certainty Factor
FC = Forward Chaining
VES = Validation of ES
WET = Weighted Evaluation Technique
FL = From Literature
HE = Human Expert
NA = Not Available

Table 4.1- information on 2nd category of expert systems

CHAPTER FIVE Information Analysis Of The Review Of Six Current Expert Systems

5.1 Discussion On Current Selection Systems

The examination of the six existing expert systems [see Appendix E] is of a comparative nature and has highlighted the differences between them. The comparison revealed several issues about the development process of ES which require investigating.

Issues are discussed as follows:

1) Types of Equipment

Table 4.1 shows that all expert systems have different basic groups and types of equipment stored within their knowledge base. But the 'manual', and 'other equipment' groups are only represented separately within EXCITE [18], MATHES [87], and ICMESE [90]. There are no clear and explicit reasons given by developers regarding choice of the type of equipment for the selection analysis in their expert systems. Nevertheless for the reasons given in chapter 2, the proposed decision tool will select a group of equipment, and 'manual' as well as 'other equipment' are included as groups from which the solution may be selected.

2) Software used in the implementation stage of the system

The expert systems discussed have been encoded by a variety of software means. All systems were implemented using different building tools for reasons stated in chapter 4 and it is clear that all developers of these systems have selected building tools to ease the development process even though it is less flexible. This might be because these tools offer many features (e.g. support rule-based methods for knowledge representation) which enable the investigator to minimise the restriction of lack of flexibility.

3) Knowledge representation

Four of the systems have used a rule-based technique to represent the rules and also to structure information in the knowledge base. However, the MHESVES system [25] depends on performance attributes as rules for equipment selection which were encoded in the VP-EXPERT [93] package. Moreover the MHESVES and the ICMESE systems utilised the package 'dBase III' to store handling equipment information, as well as the data on their individual attributes. This might be for reasons of better organisation of the expert system to separate rules from the database or it may be because it is much easier to change and update database files. Hosni [88] suggested the use of a frame-based structure within the same expert system package because the frame architecture allows for ease of adding to or deleting information from the knowledge base without interfering with the rule itself as occurs with the rule-based representation.

4) Type of information within the knowledge base

All systems have different amounts of information which is gathered either from literature or directly from experts for the selection analysis process. This information falls into 4 categories as follows :

1. A number of equipment groups and types

2. Selection attributes

3. Selection rules

4. Criteria of selection

The knowledge base of every system that was reviewed consisted of the first three categories. Matson et al [18] and Park [90] added a fourth category which used selection criteria as a final step in the selection process within EXCITE [18] and ICMESE [90] to produce a certainty factor for the final recommendation. Selection attributes were always the basis for the selection analysis in all systems. However for the reasons given in chapter 2 the new system will consider selection attributes as well as selection criteria in the analysis process. Selection rules were obtained from the literature except for MATHES [87] which were produced by a single human expert. The comparison here is between a single human expert and the amalgamated expertise derived from multiple experts published in the literature. We should observe that SEMH [94] is one module within HEXPERT [89] and Tabibzadeh provided no more information about this system except that found in Table 4.1.

5) Inference Mechanism

Regarding the inference engine, a forward-chaining representation scheme was employed in EXCITE [18] and in Material-Handling Equipment Selection Via An Expert System (MHESVES) [25]. In contrast MATHES [87], HEXPERT [89] (SEME) [94], and ICMESE [90] used a backward-chaining inference mechanism. Only Hosni [88] suggested the use of a package which supports both mechanisms (forward and backward chaining) so that the computer can perform either by knowing the goal state or by knowing initial technical information concerning a particular situation. But this method was not implemented by Hosni and there is no indication why this idea was not pursued.

6) Use of decision analysis methods

Decision analysis was adopted in only 4 systems. Matson et al [18] and Bookbinder et al [25] have used different decision analysis methods in different situations. EXCITE [18] utilised a method known as 'weighted evaluation technique (WET)' [20] to validate the final recommendation based on 3 criteria. MHESVES [25] adopted the 'multiple attributes decision making (MADM)' [24] to produce the final recommendation. The analytic hierarchy process (AHP) [23] used for decision validation in ICMESE [90].

However Fisher et al [87] applied a method called 'certainty calculus' within MATHES to evaluate the system performance during the decision making analysis and for the final recommendation. Hosni [88] suggested a decision analysis method to analyse and complete the decision making process, but again he did not implement it.

7) Use of certainty factor

The use of certainty factors was emphasised in all systems in the second group. EXCITE provides a certainty factor as a by-product of the WET method. MATHES produced 5 certainty factors from the 'certainty calculus' method of which four factors are for the evaluation of the system performance and the fifth one is used to rank final recommendations. In the same manner Hosni suggested the use of a certainty factor to provide the user with some confidence in the result of the analysis. Even though a decision analysis method was utilised by MHESVES [25] to produce the final recommendation, this method lacked a facility to produce a certainty factor. Bookbinder et al [25] stated that the use of MADM [24] results in a major advantage of MHESVES over MATHES. But he did not provide convincing arguments for this conclusion. The ICMESE system is capable of providing a certainty factor with the aid of the AHP [23] method.

8) Testing to validate the expert systems

Only MATHES claimed to have a validation test. It is considered important for an expert system to be widely accepted and some form of objective validation is needed to gain this acceptance. However this review did not reveal any explicit validation procedure and this issue requires greater study.

This discussion of the 8 issues reveals several points concerning the development process of each system. These points can be summarised as follows :

1) Software package issues

2) Expert system issues

The features which characterise the difference between software packages are :

1) Type of knowledge representation which it supports

2) Type of inferencing mechanism that it offers

3) Capabilities of interaction with other software

In the same manner the expert system issues are as follows :

1) Selection rules used (from literature or by human expert)

2) Type of software package (e.g. expert system shell)

3) Decision analysis technique adopted

4) Utilisation of certainty factor

5) Validation of expert system

From these 8 points produced from the survey of 10 current expert systems, it is possible to investigate the development of an improved expert system. This investigation will be discussed in the next section.

5.2 Discussion

The review of 10 current expert systems has identified 8 key issues as follows :

1. Type of information within the knowledge base
2. Source of knowledge acquired
3. Building tool used
4. Ways of knowledge representation
5. Type of inference mechanism
6. Utilisation of decision analysis method
7. Employment of certainty factor
8. Validation of expert system

These 8 issues can be used as guidelines for analysis and investigation during the development process of an expert system. The guidelines produced by this review will be developed into a systematic procedure to assist in building the proposed system for material handling equipment selection.

The author suggests that these 8 issues can be classified into 3 groups based on the task performed by each group which distinguish it from the rest. This grouping provides a systematic development procedure for producing an expert system. The grouping of the 8 issues is as follows :

1) Building group : represents the organisation stage for an expert system which contains the following aspects:

   a) Type of information within the knowledge base

   b) Source of knowledge acquired

   c) Building tool used

2) Performance group: concerns the manipulation of knowledge within the knowledge base of an expert system which consists of aspects as follows :

   a) Ways of knowledge representation

   b) Type of inference mechanism

   c) Utilisation of decision analysis method

3) Confidence group : contains aspects which determine the degree of feasibility of the final solution for a particular situation :

   a) Employment of certainty factor

   b) Validation of expert system

Within the building and the confidence groups there is some degree of agreement between the different systems (e.g. the use of expert system shell, and the use of published literature as a main source for knowledge acquisition). However there are several differences between the six expert systems with regard to the issues of the performance group. These issues are considered to have a direct influence on the performance of an expert system and a discussion of these issues follows :

1) Knowledge representation

Table 4.1 illustrated 3 types of knowledge representation as follows :

a- Rule-based

b- Database files and ES shell routine

c- Frame-based

The first scheme was found to have been implemented in 4 systems which means that the majority were in favour of this approach. However there are two other methods that have appeared in this review (b, and c) which indicates that other methods are possible. Only the frame-based scheme has previously been suggested by Hosni [88]; this approach has not been implemented in any expert system appearing in this survey. For further detail on this issue refer to chapter 6.

2) Inference mechanism

Regarding the inferencing technique, Table 4.1 showed a split in which two systems have utilised forward chaining (EXCITE, and MHESVES), and three systems have used backward chaining (MATHES, SEMH, and ICMESE). However forward <u>and</u> backward chaining has been suggested by Hosni but it has not been implemented.

In view of the lack of a clear favourite, and because no evidence could be found in the literature of research to objectively determine their relative merits, it was decided to examine three alternative inferencing methods (forward, backward, as well as forward and backward) for the development of the new system. It was anticipated that results would reveal which method provides better search capability in this type of package so that a single mechanism could be implemented in the final system.

3) Decision analysis method

Decision analysis methods provide a strong foundation for the decision making process to select suitable equipment. This is because they are capable of interpreting as well as combining qualitative with quantitative information required for the analysis of the selection process. Also they have the ability to produce a certainty factor to evaluate the final recommendation. This will build confidence in expert system decisions. So a decision analysis method should be adopted to enhance the performance of the new expert system.

5.3 Recommendations

The analysis of the three performance issues in the previous section makes it possible to suggest several recommendations which need to be considered during the development process of the new system. These issues are the main candidates to introduce improvement into the new ES and they are as follows:

1) The consideration of a knowledge representation method which best utilises the information encoded during the development stage of the new expert system.

2) A comparison of the three types of inference scheme (backward, forward, forward and backward) to clarify their pros and cons in order to see which one is appropriate for the new system.

3) A decision analysis method should be employed to improve system's performance.

These 3 important points will be the main goals during the discussion and the analysis of the development procedure of the new system which will be tackled in the next chapter.

CHAPTER SIX Development Methodology For The New System

6.1 Introduction

The previous chapter has highlighted and discussed 8 key issues concerning the development process of an expert system. The 8 issues will be used as a systematic procedure to produce the new expert system. Previously these 8 issues (refer to chapters 4 and 5) have been separated into three different groups as follows (see Figure 6.1) :

1) Building group
2) Performance group
3) Confidence group

The issues needing to be resolved in each group represent the different phases of development of the new ES. These issues were grouped according to the nature of the activity of the particular group. The following sections will deal with the different activities within the development phases.

6.2 The Basis Of The System

Planning the basis for constructing an expert system requires a combination of three things. Firstly, identifying the field of knowledge of the particular problem. Secondly, acquiring and establishing the knowledge base with the proper information. Finally, selecting a suitable software to encode the acquired information.

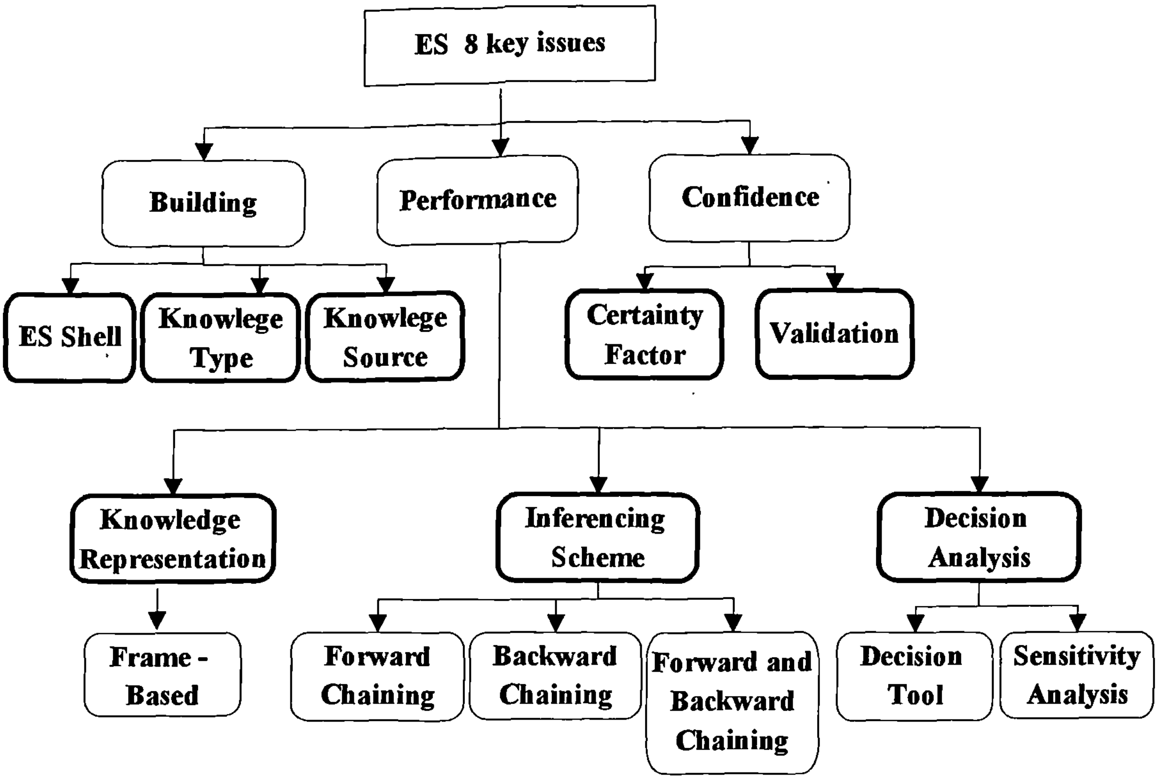

Figure 6.1 - 8 key issues of Expert System

6.2.1 The Field Of Knowledge

The knowledge base for the intended system was obtained from published literature. There were a wide variety of sources which contributed to the development of the knowledge base, for example Wu [5], Apple [11], Meyers [12], Allred[13], Liang [16], Matson et al [18], Muller [98], Lindkvist [99], Conpendex and BIDS engineering databases as well as The Health and Safety at Work Regulations [17] and a variety of journal articles from *Modern Materials Handling, International Journal Of Production Research, IIE Solutions, Industrial Engineering, Journal of Business Logistics, Material Handling News, and Industrial Handling and Storage* .

6.2.2 Acquisition Of Knowledge

Jackson [26] cited Buchanan's et al [100] definition of Knowledge acquisition as "the transfer and transformation of potential problem-solving expertise from some knowledge sources to program". This step is concerned with gathering the relevant information from the whole field of knowledge. Next comes interpreting, organising, and combining relative information (emulating the human expert thinking process which performs this activity [75]) to be stored in the knowledge base of the new system.

An analysis has shown that it is possible to divide the whole field of knowledge into 11 groups and that any equipment can be placed in one of these groups with minimal overlap. So the selection process of the intended system will be based upon a group of equipment not a specific vendors model for the many reasons provided in chapter 2.

Apple [11], Meyers [12], Liang et al [16], The Health and Safety at Work Regulations [17] Matson et al [18], Frazelle [20], Bookbinder et al [25], and Malmborg et al [86] as well as published literature from vendors have assisted in producing tabulated information on the 11 different equipment groups which is to be adopted in the new system. It is considered to be acceptable for the following reasons :

1) It is a compilation of equipment information from many literature sources;
2) It covers a large amount of information relevant to this problem and is readily available;
3) It accommodates both the quantifiable information as well as the non-quantifiable information.

An analysis of the complexity of the selection process was discussed in chapter 3. Several authors have shown the lack of clearly defined selection factors and criteria due to the difficulty of conflicting information from case to case (e.g. Apple [11], Matson et al [18], Frazelle [20], and Kennedy [21]). 7 selection factors were chosen, namely the 'load weight', the 'frequency of move', the 'distance travelled', the 'path of movement', the 'intermittent rate', the 'handling method speed', and the 'on/off floor capability'. This was followed by 5 selection criteria which were the 'flexibility of layout change', the 'flexibility of equipment routing', the 'availability of handling space', the 'compatibility', and the 'adaptability' (Appendix F). The selection of these factors and criteria can be arranged according to their relative importance in a particular situation, and they represent one way of dealing with the complexity of the selection process.

6.2.3 The System's Building Tool

It has been decided in the previous chapter that an expert system shell with frame-based knowledge base capability is appropriate for the new system. A language called "Flex" [101], [102] is selected to perform this task. This ES shell offers the required capability as well as ease of use. Also since it is developed from "Prolog" the user can use "Prolog" syntax while coding in the "Flex" language. This flexibility gives this shell an advantage of both languages. Also it runs under Microsoft Windows™ as well as being widely used by Warwick Simulation Group at the University of Warwick. It's only difficulty lies with the requirement for preliminary training (e.g. to arrange execution of files, step-by-step procedure for programming) as these are all specific to the package and must be learned (see Appendix L for further details).

6.3 Performance Phase Of The System

It was decided that three issues would be addressed in the performance phase of the system. Firstly, knowledge representation in the knowledge base. Secondly, Inferencing schemes or search methods. Thirdly, decision analysis.

6.3.1 Knowledge Representation

Due to the diverse nature of information and selection rules included in the problem of selection, a frame-based representation of knowledge will be tested in the new expert system. This type of representation provides two features which are especially suitable for the problem because :-

i) It allows segmentation of information which influences the structure of the knowledge base. This separation process of relevant information permits better organisation and information can be easily identified and accessed for future upgrading or introducing any changes.

ii) The hierarchical structure produced by this method allows inheritance of information from a higher node to a lower one without the need to create separate code to perform this task. This makes the knowledge base less congested with less rules which in turn improves ES performance.

Turban [30] stated that "frames are normally used to represent stereotyped knowledge or knowledge built on well-known characteristics and experience". This provides a means of organising knowledge in slots that contain characteristics and attributes. In addition, once the frames are stored in memory, various search and pattern-matching techniques are invoked to answer questions or otherwise make deductions from the knowledge available [30].

Jackson [26] commented that frame-based systems are useful because they provide a way of structuring the heuristic knowledge associated with the application of rules and the classification of objects. Both reasons for the use of frame-based knowledge representation are supported by the information in this type of problem. This capability assists the organisation of the information of the problem as well as the rest of the phases of the implementation process (Chapter 7).

6.3.2 Inferencing Schemes

Consideration of inferencing schemes revealed three types of search methods, forward chaining, backward chaining, and forward as well as backward chaining. All three types will be examined for possible implementation in the new system.

Therefore the objective of this step is to analyse each search scheme in order to identify and to select the best one which is to be implemented in the final system.

6.3.2.1 Forward Chaining Scheme

Turban [30], and Giarratano et al [76] define forward chaining as a data driven approach which starts from available information as it comes in, then tries to draw a conclusion. Figure 6.2 shows that this search scheme works on direct responses from the user based on the information supplied through the questioning session. However inferred (previously defined) information cannot be used by this method since it cannot reverse its execution pattern and find the required information. This results in discontinuation of the decision making process. For example at the stage where no equipment has been found this programme will halt all of its activities and abort its decision making process. This method presents the problem of lack of flexibility of the decision making process since it treats the programme as separate stages because of its execution pattern. A forward chaining scheme could be used in the new system but it needs a better inferencing technique to overcome the shortcomings of the existing forward chaining methods.

6.3.2.2 Backward Chaining Scheme

Backward chaining is a goal-driven scheme which starts from an expectation of what is to happen, then seeks evidence that supports (or contradicts) the expectation [26], [30]. The backward chaining search method (see figure 6.3) is the opposite of the forward chaining inferencing scheme. Although this method has to be presented with a possible solution by the user, it still needs direct consultation with the user to acquire the handling requirements.

This is because it does not support inferred information which is an important part of the analysis of the problem. However Jackson [26] commented that this method is more focused than forward chaining. Similarly this approach presents the problem of lack of flexibility as with the forward chaining method because of its execution pattern. This is due to the inability of the programme to reverse its pattern to use the inferred information which causes disruption of the decision making process. Also it is incapable of producing an analysis of the final decision due to the pattern of execution.

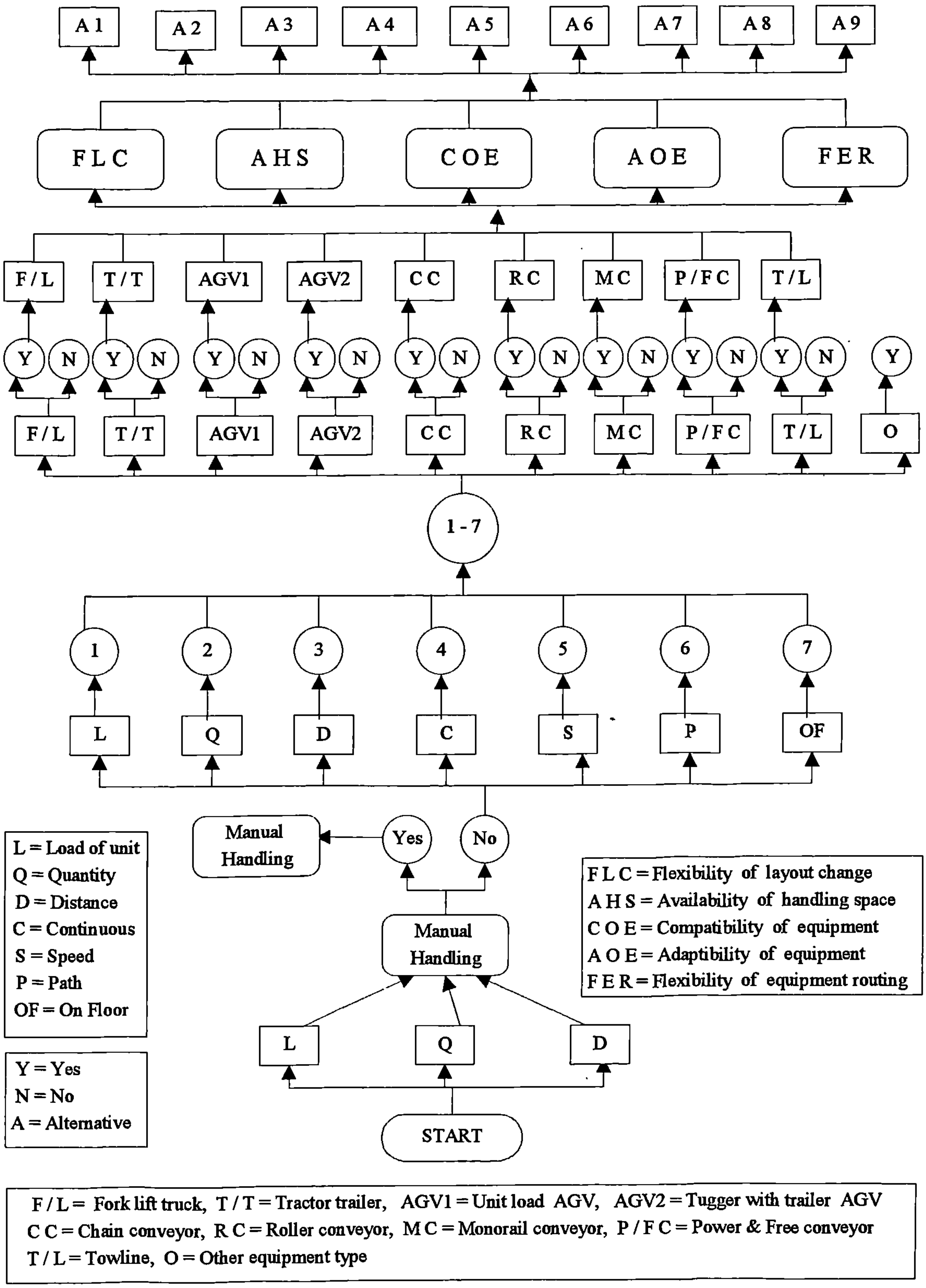

Figure 6.2 - Forward chaining decision tree

Furthermore it relies on the fragmentation of the programme since it treats each set of codes separately which contributes to the lack of flexibility for the system's decision making procedure. Turban [30] elaborated that there are systems which use forward chaining and others which use backward chaining, but the question is "which is better"? The answer depends on the purpose of performing the reasoning.

Although a backward chaining scheme is considered as an option for implementation in the new system, ideally this system requires a better search method which is capable of producing greater search and reasoning flexibility in the decision making process.

6.3.2.3 Forward and Backward Chaining Scheme

This scheme has the ability to tackle the problem of the previous two methods by connecting the different phases of the programme together (see figure 6.4). The previous two approaches dealt with separate segments or steps within the programme but the joining of both search methods produces the missing linkage between the different phases of the programme.

This proposed approach should produce greater search flexibility for the decision making process since it can relate to inferred information while executing another segment of the programme by direct consultation with the user. Also it potentially eases the task of analysis of foundation for the system's decision by retracing the steps which led to this particular decision. It has not been used in any of the previously described expert systems (see chapters 4 and 5), but due to its potential advantages an attempt will be made to implement this method in the intended system.

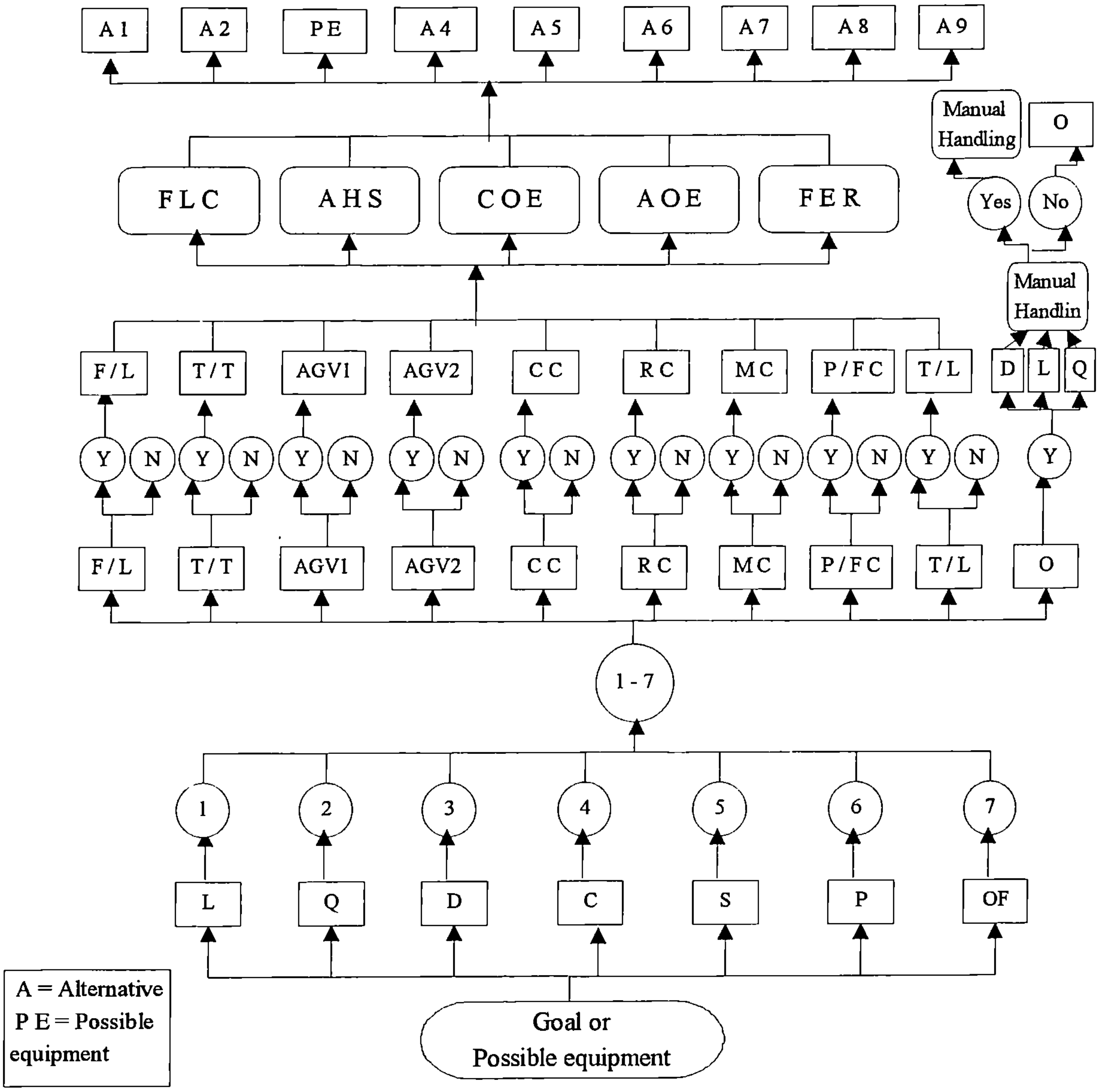

Figure 6.3 - Backward chaining decision tree

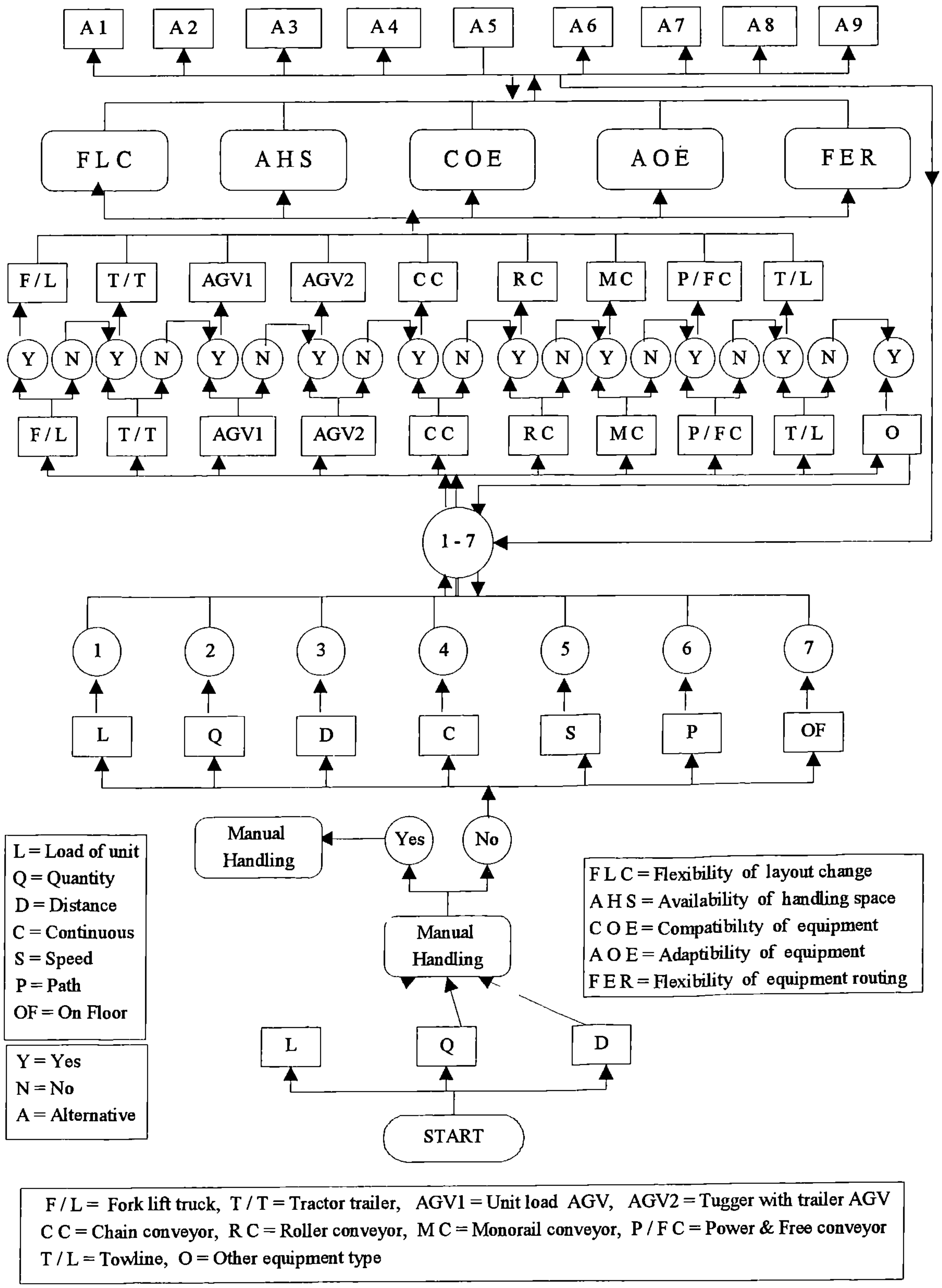

Figure 6.4 - Forward and backward chaining decision tree

6.3.3 Decision Analysis Of The System

In the previous chapter it was decided to implement this phase in two steps. Firstly the new system has to utilise a decision analysis method during the decision making process due to the difficulty of interpreting an important part (non-quantifiable) of the information defining the problem.

Secondly, a sensitivity analysis procedure to determine whether a small change introduced in selection information will influence the outcome of the system decision. In other words the system will provide more confidence in its decision by checking the sensitivity of the result to the user's information since it is accepted that this may be somewhat subjective.

6.3.3.1 System's Decision Analysis Technique

Chapter 3 has reviewed several types of decision analysis techniques (DAT). Then it was decided to use the analytical hierarchy process (AHP) technique in the new system. The AHP technique is utilised to quantify the non-quantified information acquired during the consultation session. However the quantifiable information (e.g. equipment information) has to be considered together with the non-quantifiable information to be able to produce a final decision. Therefore the quantifiable information will be used by the system in the preliminary selection phase to aid in identifying some possible alternatives. Then the system will try to rank them according to their applicability in a particular situation.

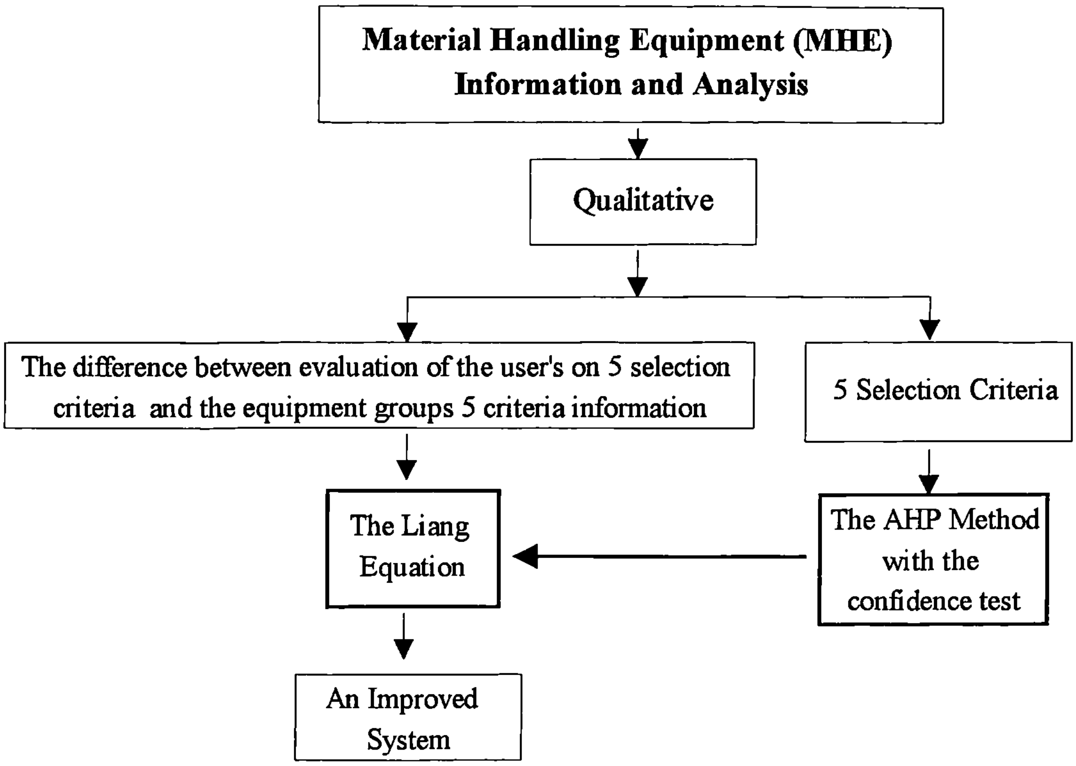

Figure 6.5 - A joining step between qualitative information of MHE and the user

There will be testing of two approaches as an attempt to rank those options. Firstly, Liang et al [16] produced a joining step (see Figure 6.5) in the form of a formula which combines the result of the quantification of selection criteria produced by the AHP method with the difference between the non-quantifiable information (evaluation of selection criteria) of the user and equipment groups' selection criteria information stored in the knowledge base of the system. But Liang did not use the confidence test of the AHP method in his formula nor did he attempt to implement the formula in a decision analysis tool. The intended system will adopt this formula with the addition to the confidence test of the AHP method in the first trial to improve the final result of the system's decision. Secondly, The AHP method will be used as the main DAT to perform the whole analysis process toward producing the final choice in the second trial. These two trials will be discussed in the next chapter.

6.3.3.2 System Sensitivity Analysis Step

The second measure in this phase is enhancing the system's decisions by applying the sensitivity analysis test on the final result produced by both tests of ranked groups of equipment options. This will assist in providing a distinction between the two approaches during decision analysis by the system. The issue of applying sensitivity analysis to the two approaches of ranking will be dealt with in the next chapter. In chapter 3 the AHP method was selected to perform the quantification process on the non-quantifiable information of the problem. The AHP method uses a scale of 1-9 in addition to their reciprocals for the quantification process which make the total number of values on this scale 17. A change of (± 2) steps, which is equivalent to $\pm 12\%$ of the 17 values, is selected because surveying different people's opinion on evaluating such specifications produced a change of nearly 2 steps (see Appendix H). The system during the sensitivity analysis phase will introduce a change of (± 2) steps to the user's evaluation of specifications based on the AHP scale and monitor this change to see how sensitive is the system result and what is the influence or effects produced by this change. Therefore testing the result by varying the values by (± 2) steps allows it to test the robustness of the solution of the selected group of equipment.

6.4 System Confidence Phase

The last phase of the development process of the new system is the confidence stage which is concerned with establishing certainty in the outcome and validating the result.

6.4.1 Certainty Factor

After each consultation by the user the system will produce a final decision. This decision needs some sort of evaluation of the user's confidence in this result. A confidence factor is produced to measure the confidence in the system's decision. The AHP decision analysis method intended to be implemented in the new system has the ability to produce such a factor towards the end of the consultation session. This factor is also important because it will show the ranking of different alternatives based on the given specifications of the present situation.

6.4.2 Validation Of The System

It is very important to validate an expert system. However the process of validation is difficult because there is no universally accepted method on how to carry out such an activity. Nevertheless there are some possibilities to try to perform this task. Testing can be done by three methods. Firstly, using real data from industry. Secondly, by engineers specialising in this field. Finally, investigation in the field which is especially difficult due to the vast number and variety of manufacturing situations which make validation hard to assess. This makes the first two options more appropriate to use to conduct the validation stage on the new system in order to be able to assess its performance and decision confidence (refer to chapter 9).

6.5 Methodology To Be Implemented

The previous sections have considered the different stages included in the development process of the new system (see Figure 6.6). This sequence of events identified by Figure 6.6 show the order in which the new system will be devised.

Therefore this development methodology will be implemented in the new system which will be the main topic for the next chapter.

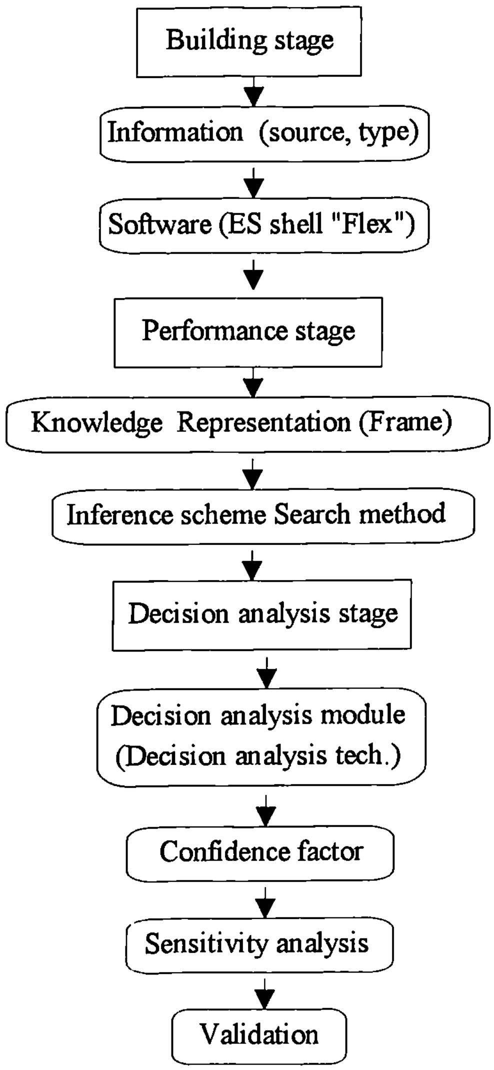

Figure 6.6 - The development methodology for the new system

CHAPTER SEVEN Implementation Of The New System

7.1 Introduction

The previous chapter described and discussed the framework of the new system. It highlighted important issues (e.g. the selection of the building tool, inferencing scheme etc.) concerning the production of the new expert system. This chapter illustrates the way in which the issues lead to the implementation of the new system (see Figure 7.1). The activities within the different phases show the procedure which is carried out during a decision making session using the system.

The building tool selected in chapter 6 was Flex [101], [102]. A preliminary implementation phase was performed to develop the foundation for the new expert system which is called 'SMART SELECT'. This phase contained the following steps in its selection process :

1) Preparing the information

2) Developing manual material handling module

3) Building the selection procedure of equipment alternatives

SMART SELECT at this preliminary stage is capable of producing handling options and the discussion of these steps as well as an introduction to the next phase is in the following sections. However a full investigation of the ranking procedure of alternatives which is the next stage of development for SMART SELECT is the topic for the next chapter.

7.2 Preparing The Information

This is a very important stage because during the consultation session it is the most used segment of the system to establish and to produce the final selection decision.

The discussion in the previous chapter showed how the tabulated information is composed to provide the information necessary on the 10 different groups of equipment (chapter 2) for the new system. These 10 groups of equipment have two types of information which were discussed in chapter 3. Firstly, quantitative information. Secondly, qualitative information. However the 11th group which is the 'other equipment group' would be selected if no option has been found during the consultation. A file called 'NEWF1.KSL' (see Appendix L) was established using the Flex language to accommodate this information. There is an important third part in this phase which is the user's specifications. The system acquires the user's specification through a series of questions generated by the system during the consultation session. These three parts complete the information preparation stage.

7.2.1 Quantitative Information

The 7 selection factors which are present in this segment are as follows :

1. Mass of unit load to be moved
2. Frequency with which loads need to be moved
3. Distance to be moved
4. Uniform / variable speed of movement
5. Continuous / discrete movement
6. Fixed / variable path of movements
7. On floor / off floor movement

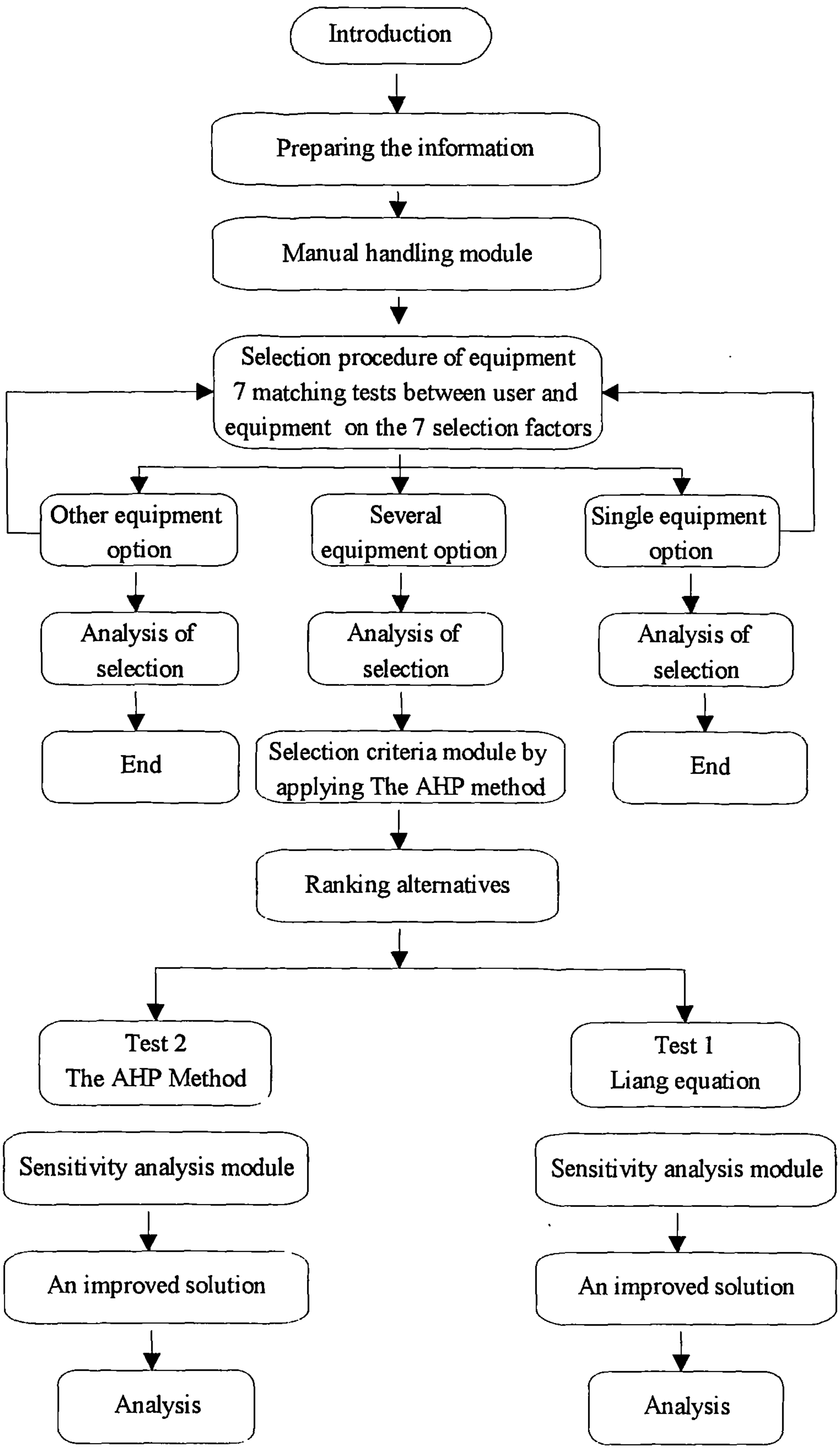

Figure 7.1- Implementation of the new system with 2 alternative tests

The data file created by Flex comprises a main frame called 'equipment'. The 'equipment' frame branches to 10 sub-frames. Each sub-fame carries the name of a specific equipment group (e.g. Forklift truck, Unit load AGV, Chain conveyor, Roller conveyor, Towline, Power and free conveyor, Tractor trailer, AGV tugger with trailer, Monorail Conveyor, Manual handling). Then attaching to each sub-frame (group of equipment) are the selection factors belonging to this particular group which are stored in seven locations.

Those seven locations are also named according to each factor's name. Although the last 4 selection factors were represented with different quantification, nevertheless they are different from the first 3 factors due to the nature of measurement for these particular factors. However they can be treated within this segment because their information can be converted to a specific numerical value (e.g. No = 0 and Yes = 1). This results in seven locations each containing numerical values. Furthermore the locations of each sub-frame provides the information whenever needed during the consultation session.

7.2.2 Qualitative Information

A list of 5 selection criteria represented this specific part of the information as follows :

1. Flexibility of layout change
2. Flexibility of equipment routing
3. Availability of handling space
4. Adaptability of equipment
5. Compatibility of equipment

These 5 selection criteria will be used in a different phase later in the program for the final assessment of selected alternative groups of equipment in order to determine the best equipment group. A later section provides a discussion of this phase.

7.2.3 The User's Specifications

The system acquires the user's specification during the consultation session. The information provided by the user, in the form of answers to the system's questions, is used in a matching procedure with the previous types of information stored in the knowledge base of the system to enable the process of decision making to work.

Therefore a different file is created to contain the 'user' frame and to generate a series of questions to acquire the user's information. The information input by the user is stored in the corresponding locations attached to the 'user' frame. Then the user's information within the locations of the 'user' frame is matched with the quantitative as well as the qualitative information in the knowledge base. This process initiates the decision making process of the system by analysing the appropriateness of a manual material handling method.

7.3 Manual Material Handling Module

There is no clear definition about when a manual material handling approach can be considered a viable option to be used. The literature provided no definite guide for selection criteria limits which clearly indicate the need to utilise this particular method when such a situation arises. Therefore it was necessary to develop a module which defines selection boundaries for this method in order to allow it to be selected from among the other handling options.

If the given weight does not exceed 25 kg as specified by the Health and Safety at Work Regulations [17], then with the information available this module starts to evaluate the manual handling approach as a possible solution to the particular situation. Based on the analysis of manual material handling (see Appendix B), a manual handling file is developed to analyse the given information of the problem by the user.

The manual material handling module is concerned with 3 factors. Appendix B has emphasised the fact that manual material handling is influenced by the following factors :

1) Mass of unit in kilograms (M)
2) Distance to be moved in metres (D)
3) Quantity in number of deliveries / hr (Q)

This analysis of manual material handling derived from ergonomic limits (see Appendix B) which produced the following formula :

$$M \times D \times Q \leq 22500 \text{ joules}$$

$$\text{and } M \leq 25 \text{ kg}$$

$$\text{and } Q \leq 3600/D$$

$$\text{and } 21 \geq M \geq 25 \text{ when } 5 \geq D \geq 0$$

$$\text{and } 16 \geq M \geq 20 \text{ when } 10 \geq D \geq 0$$

$$\text{and } 11 \geq M \geq 15 \text{ when } 15 \geq D \geq 0$$

$$\text{and } 6 \geq M \geq 10 \text{ when } 20 \geq D \geq 0$$

$$\text{and } 0 \geq M \geq 5 \text{ when } 250 \geq D \geq 0$$

The system locates the values of the three factors M, D, and Q stored under the 'user' frame which are then multiplied together and if the product is less than or equal to 22500 joules (refer to Appendix B), and the other conditions are met then the manual handling approach is considered to be feasible. The next stage of selection is initiated to find another method of handling among the 9 groups of equipment.

7.4 Selection Procedure Of Equipment Alternatives

This is a preliminary stage of the decision making process which starts regardless of whether the manual handling option is feasible or not. The distinguishing feature of this phase is the series of matching tests which the system performs. The matching process involves the user's 7 answers on the selection factors questions and the 7 selection specifications of each group of equipment stored in the knowledge base.

This testing phase is intended to determine the feasibility of each group of equipment as a handling method to suit a situation given by the user by producing a list of options. A selection file was constructed to organise such events. This is done by consulting each sub-frame's (equipment group) locations which represent the quantitative information on each group and simultaneously match it with the corresponding information contained in the 'user' frame's locations. Also this file contains three frames, one for the unmatched equipment, a second one is for unmatched equipment but pending further feasibility investigation, and the last frame is to contain the finally validated options for the next phase which is the ranking process. This will aid the analysis process toward finding a suitable handling solution.

There are 7 matching tests at this stage which can conveniently be divided into three categories according to their relationship with the user specifications as follows :

Category 'A' contains the following 3 tests :

1) Mass of unit matching test

2) Quantity to be moved matching test

3) Distance travelled matching test

These 3 tests follow a similar pattern in trying to match both the user and equipment information. The algorithm at each test first compares the value of the 'load', 'quantity', and 'distance' locations attached to the 'user' frame with the ones attached to the first sub-frame 'equipment group'. These check, to establish whether the user's values exceed any of the limits in any of the equipment groups. If any limit is exceeded then one of the three relationships becomes true and this group will be attached to the 'unmatched' frame. The system is instructed to pick the next group in a descending sequence to start this testing procedure again, otherwise if this particular group satisfies all the 3 tests then it will enter the next category of matching tests.

Category 'B' comprises of the following test :

4) On floor/off floor matching test

This category of matching tests is based on an inequality relationship between the 'user' frame's location of requirement for 'on floor/off floor' and the specific group's location for 'on floor/off floor' information which satisfied tests of category 'A'. If the user's answers to the this factor did not equate to the equipment information, then this is an unmatched situation and this equipment is moved to the unmatched frame. This will let the system select the next group in the queue to repeat the testing process again, otherwise the system will move this equipment group to matching tests of category 'C'.

Category 'C' consists of 3 tests as follows :

5) Path of equipment matching test

6) Speed of equipment matching test

7) Continuous movement matching test

These three tests are conducted on an inequality relationship. There are 2 possible outcomes for each test. Firstly, matched specifications means that both user and equipment information are the same which results in advancing this equipment group to the last validation test. Secondly, the unmatched information is checked to determine whether equipment capabilities can fulfil user's requirements (e.g. user required specification is uniform speed and equipment offers both possibilities, uniform / variable). If so this equipment will enter the final validation test, otherwise it will be included in the unmatched frame.

After these 7 tests matching the user's specification with its equivalent in the equipment information, a final algorithm checks all 7 factors for each group of equipment which satisfied the individual testing before this final verification step. Therefore each equipment group that fulfilled all 7 tests separately will enter this final matching test. This final test determines and validates the matched equipment groups as well as attaches these options to the finally validated options frame. Then these equipment groups will be ranked through the system's decision making process to produce the final choice.

7.5 Quantification Of Selection Criteria Module

This segment will be activated to produce an interpretation of the 5 selection criteria provided in section 7.2 to aid the ranking process of the several handling alternatives produced from the previous phase of this system. This module is developed through the use of the AHP method (see chapters 3, and 6 for more details). The AHP method utilises a pairwise comparison between the 5 criteria stored in the knowledge base of the system. During the consultation session the user is asked 10 comparison questions on each pair of criteria. These questions are generated by the system to determine the user's judgements of the different criteria in order to enable the system to quantify these criteria. They simply require the user to compare the relative importance of each pair of criteria and the result is used to produce the final selection. These ten answers produce a 5x5 matrix of comparisons (refer to Appendix C) which shows the evaluation of judgements by the user. Then the system, through a series of mathematical manipulations of the information of the produced matrix, provides a priority vector (PV) which shows the values of each corresponding criterion as well as a certainty factor to validate the user's judgements on the pairwise comparison process which produced this PV. The value of this factor must fall within an identified range (0 - 0.1) to validate the user's answers relating to quantification of these criteria (Appendix C). But if this value falls outside this range, the user's judgements need to be re-examined because of inconsistency of those answers and this process must be performed again (Appendix C). The system will notify the user of this inconsistency as a result of the calculation of the certainty factor as well as giving the user the option to repeat this process until it satisfies this part of the AHP method with a consistent set of PV values for the next phase which is the ranking of alternatives.

7.6 Ranking Of Alternatives

The preliminary phase of selection which depended on a series of matching tests of 7 selection factors, produced several handling alternatives which require sorting. This sorting, or ranking, of alternatives is the part which determines the best solution when more than 1 group is selected and is therefore of extreme importance. However there is no generally accepted best method to perform this ranking and it was decided to implement practical tests using 2 different procedures that had been applied by other authors but never previously directly compared. The objective of these 2 tests is to examine the effects of a different ranking procedure on the decision analysis and on the final selection decision of the system.

7.6.1 First Test To Rank Handling Alternatives

In this test the Liang equation [16] will be applied to determine the ranking of different groups of equipment by calculating what is called 'weight deviation value' for each group of equipment with the aid of the AHP method in addition to using the certainty factor part of the AHP to validate its results (see chapter 6, Appendix G). The equipment with the lowest value is selected, because this method tries to reduce the difference between the user needs and the features of this particular equipment. Therefore the handling method with the least difference is the closest to the "ideal" so this handling method is selected by the system.

7.6.2 Second Test To Rank Handling Options

Test number 2 is concerned with using the AHP method as the main decision analysis technique not as part of Liang's formula. The procedure here starts by applying a pairwise comparison process on the different handling methods produced in the preliminary selection stage. This pairwise comparison is based on each criterion to produce PV values for each criterion. Since there are 5 selection criteria, the system will produce 5 PVs. These 5 PVs will be contained in a matrix according to the arrangement of the order of the selection criteria (see Appendix C). The PV produced for the selection criteria in section 7.5 will be multiplied by the 5 PVs matrix to yield a column vector which presents the final ranking of alternatives. The best option is the one with the highest score, because it is the accumulation of all the scores on each particular factor which affects the handling method performance in this situation. Therefore the method with the highest score is selected because it means that it is the closest to the "ideal" (refer to Appendix C). These two tests will help in determining the difference between both approaches to find the better one which will be implemented in the final system.

7.7 Sensitivity Analysis Phase

The sensitivity analysis segment will be applied to both tests involving ranking groups of equipment. It has been decided in chapter 6 that a (±2) step variation will be used to perform this analysis on the results produced by the previous stage. In test one where the Liang equation is applied, the analysis will be performed on the selection criteria module to test the sensitivity of the results produced through this formula (see Figure 7.1). The results of this testing will establish if the change introduced in selection criteria produces any effects, and the degree of sensitivity on the final selection decision. In contrast the sensitivity analysis will be used twice in the second test of ranking handling options (see figure 7.1) for which the AHP method is the main decision analysis method. The first analysis will be performed on the selection criteria module and the second analysis on the pairwise process of equipment on each selection criterion. The result of the sensitivity analysis on both tests will reveal the behaviour of each approach when change is introduce to their initial decision. In both cases the best selection decision is the one that can sustain and confine the changes introduced to the user's specification without any major changes to the initial decision. This also will be another step toward finding the best decision making procedure for the final system.

7.8 Analysis Of Final Selection Decision

A final step to conclude the consultation session with the user is an analysis phase of the final decision. The system gives an option for the user to review the reasons behind the system's final selection. This step is performed by retracing the previous analysis steps during the consultation session which arrived at the particular decision on this group. In this way it will support and justify its decision for the user by confirming the basis on which alternatives were rejected.

7.9 Conclusion

This systematic procedure implemented in the new system (Appendix K) enables the user to analyse different handling situations and determine possible solutions that are ranked in the order in which they most closely satisfy the users requirements. It also allows the user to have confidence in the selected option by seeing how sensitive the option is to changes in selection criteria and provides reasons for rejection of non-selected options.

CHAPTER 8 Investigation Of Decision Analysis Method

8.1 Introduction

Chapter 7 described the framework of the different phases of the new system which were implemented to perform the task of selecting a suitable handling option from among 11 equipment groups. This task contained a variety of elements which enabled the decision making process to be carried out. The same chapter highlighted the issue of ranking equipment groups. Furthermore it was suggested that this ranking procedure could be performed by either of two alternative decision analysis methods. This chapter is intended to investigate and discuss this key phase of the decision making process to be able to select the most appropriate decision analysis method which is to be implemented in the final system.

8.2 Testing Of Two Decision Analysis Methods

In order to provide the new system with quality decision analysis capability to produce a sensible result, experimental work was carried out to determine the best decision analysis method for the new system. This investigation was performed on two alternative methods. Firstly, Liang's decision equation. Secondly, the AHP technique.

For the purpose of testing the new system it was necessary to have information for the decision making process. The invented data was generated randomly because it represented any possible problem that a user might pose and it is not biased towards a particular set solution. Freedman et al [103] commented that the reason behind the failure of 1936 presidential election poll carried out by Digest in the US was 'selection bias' because their questionnaire was sent to a selected sample (rich people only) which produced biased opinion.

This data consisted of all the relevant information required by the system during the consultation session with the user to develop the specifications for a particular handling situation. There are four major areas of concern within this data as follows :

1) Selection factors

2) Selection criteria

3) Weights of pairwise comparison of selection criteria

4) Weights of pairwise comparison between options

These 4 areas have been dealt with in earlier chapters. It was decided that data for 100 different handling situations was sufficient to test the two alternative decision analysis methods because this sample size produced a result with a standard error of only 5% when selecting one method or the other (see Appendix J). These 100 cases were provided in tabulated form in Appendix I.

A set of data (see Appendix I) was composed to provide answers to all the questions posed by the system. Another set of data was produced for the calculation of pairwise comparison between a pair of options based on each selection criteria (see Appendix I, Tables I-1 and I-2). Each pair of options were compared on the basis of the five selection criteria.

It should be recognised that this testing stage is conducted to evaluate the 2 decision analysis methods in order to determine the better one. However an investigation into SMART SELECT performance is the main topic of the next chapter. So the following result is only for the evaluation process to complete the final stage of the system.

The analysis of the system's results for the 100 cases showed that at the preliminary selection level it had produced 96 cases where equipment had been selected and 4 cases received an 'other equipment' decision because they did not match the equipment selection factors stored in the knowledge base. Random data can be expected to produced some cases of requirements which are impossible to satisfy and it should not be possible to generate a valid selection from invalid data. The system provided the analysis to show reasons behind the 'other equipment' decision for the user before finishing the consultation session.

The 96 cases of selecting handling options were distributed over 7 categories as follows:

1) 30 cases where a single group was selected, i.e. only one option
2) 27 cases where two groups were selected, i.e. 2 options
3) 10 cases where 3 groups were selected, i.e. 3 options
4) 10 cases where 4 groups were selected, i.e. 4 options
5) 9 cases where 5 groups were selected, i.e. 5 options
6) 5 cases where 7 groups were selected, i.e. 7 options
7) 5 cases where 8 groups were selected, i.e. 8 options

It is clear that the two categories of four cases of 'other equipment' and the 30 cases of single handling option required no further analysis. It is the remaining 66 cases or categories 2 to 7 where there are more than one handling option which needed a decision analysis method to rank them.

The results of the ranking experiment on the 66 cases using these two methods produced 47% of these cases where the two methods had different results and 53% of the cases produced the same outcomes by both methods.

The tables of comparison of final results between the two methods (see Appendix I, Tables I-3 to I-8) showed that there were 35 cases in which both methods produced the same results. But similarity of results will not show the differences between the two methods. However in 31 cases the two methods provided different outcomes. By examining the cases where there were different outcomes, the intention was to show which decision analysis method is the best method. This investigation is in the following section.

8.3 Selecting The Best Decision Analysis Method

The main emphasis of this step is to determine the reason behind the differences between the two methods in order to establish which is the best method for the new system. This is carried out by testing the elements of each method. Hence, it shows the part of each method that influences the decision making process.

The 31 cases where different results were obtained were compared with the 35 cases of the same outcomes. This comparison was based on two conditions to achieve consistency of results as follows :

1) It was performed on handling options of the same category (e.g. 2, 3 etc. handling options)
2) It was performed on the same selected options from the preliminary selection phase.

For example, if the preliminary selection step produced two options (forklift truck and tractor trailer groups) for the ranking tests, and the results of ranking produced are different for the two methods, in this particular situation the comparison conditions are as follows :

1) Cases with 2 options
2) Groups of equipment for ranking are forklift truck and tractor trailer.

Then all the cases with these two conditions must be tested together on each method.

This stage of investigation has been divided into two steps in accordance with the previous 2 conditions. Firstly, the 66 cases were re-tested with Liang's equation. Secondly, these cases were re-tested with the AHP method.

8.3.1 Re-testing Using Liang's Equation

Liang's equation consists of two parts. Firstly, a pairwise comparison between selection criteria using the AHP method. Secondly, a calculation of the differences between the user and equipment selection criteria. The summation of the product of these two parts is used to rank handling options (see Appendix G). The purpose of defining these two parts of this method is to determine the effect of information change on the decision making process and its final result.

The comparison testing of the 66 cases using this method was performed by replacing the pairwise weightings of the cases giving the same results with the ones from the cases with different outcomes.

The results of this re-testing stage showed that even though different pairwise weightings had been used, nevertheless the original decision was retained in 84% of the 31 cases used in this investigation (see Appendix I, Tables I-9 - I-14).

In Liang's case, the final decision is fixed each time the test is performed on any options category. This is because its ranking procedure is influenced greatly by differences in selection criteria between the user and the equipment itself. The AHP part of this method has no significant effect on the final result. For example a comparison between cases 1, 23, 43, 66, 81 (all have the same outcomes) and 14 (which has different results) (see Appendix I, Table I-3) on pairwise comparison data of selection criteria with Liang's equation, showed that there is not a great difference in the final outcomes because of its fixed solution procedure and especially the influence of criteria differences on the final decision. Also since this equation depends on any possible criteria differences (user's and equipment) it can easily distinguish between groups of equipment no matter how many groups require ranking. The limitation of this method lies in its difficulty to establish the user criteria values since criteria are based on non-quantifiable factors. This qualitative part is provided by Liang which is based on a subjective assessment of each criterion over a given range (e.g. low, medium, high). This produces some uncertainty which affects the final results because differences between user and equipment criteria are a crucial part of this method. However it is not easy to overcome this uncertainty in this type of problem, because it is either limited by the number of people who have significant knowledge in this field to generate the necessary data, or the process has to be carried out using a large sample of people but the quality of information given is low because of their inadequate expertise.

8.3.2 Re-testing With The Analytic Hierarchy Process (AHP) Method

As with Liang's equation, the AHP method also depends on two steps. Firstly, pairwise comparison between selection criteria. Secondly, pairwise comparison between handling alternatives based on each selection criteria (see Appendix C).

The 66 cases were re-tested but this time with the AHP method. For the purpose of consistency of final results of this investigation, the pairwise weightings of selection criteria were exchanged between these cases using the same methodology followed in Liang's re-testing phase.

This stage produced different results from those found with Liang's stage. The tests performed revealed decision sensitivity of the AHP method when pairwise comparison data has been exchanged from one case to another. This means that the pairwise comparison has a greater role in this technique, because by changing comparison weights of selection criteria the method produces different outcomes. This sensitivity of results will affect the final decision for the same situation each time new information is entered. Furthermore the comparison and ranking of equipment becomes less clear when the number of handling options increases since the comparison result for any option category has to sum to unity. Although the AHP method can produce a clear ranking for the cases with few options, the original decision was retained in only 29% of the cases tested (see Appendix I, Tables I-15 - I-20).

For example in case 1 where there are two options, the ranking produced a clear winner where the AGV tugger with trailer group is selected as the best option because it has the higher score by a factor of 2 (see Table 8.1).

Number of Option(s) 2			
Case Number	agv	ul	Best option
1	0.666	0.334	agv

Table-8.1 Ranking Values Of 2 options

But in case 55 where there are 8 options, the method produced 2 options as first choice and there is no clear distinction between the remaining 6 (see Table 8.2). This is because it did not produce the necessary factor that could distinguish the preferred option as in the previous case due to its internal decision procedure.

Number of Option(s) 8									
Case Number	mh	flt	tt	agv	ul	rc	cc	tl	Best option
55	0.146	0.146	0.115	0.129	0.118	0.123	0.099	0.124	mh, flt

Table-8.2

This limits the ability of this method to produce a distinctive and clear selection decision especially when the number of handling options is large.

8.4 Choosing The Best Decision Analysis Method For The Final System

The investigation performed in the previous sections showed that Liang's method can produce more consistent results than the AHP method because its results are not sensitive to changes in the pairwise weightings of the selection criteria which maintained appropriate outcomes. Final ranking scores with this particular method can produce a clear and distinctive ordering of handling options which makes it easy to select the best alternative.

In contrast the AHP method's results are very sensitive regarding replacing the pairwise weightings. This affects the final decision of a particular situation since it changes results based on minimal differences in comparison of criteria. Also there is lack of a clear ranking between handling options when their number increases. Therefore Liang's decision equation is considered to be better than the AHP method and it is implemented in the final system which is detailed in Appendix L.

CHAPTER 9 Validation Of The New System

9.1 Introduction

This chapter is concerned with testing the expert system (SMART SELECT) developed as a result of this research, a full listing of which appears in Appendix L. Previously in chapters 4 and 5 an analysis of 5 expert systems showed that these systems appeared to lack proper validation. It is very important to validate expert systems in order to determine the quality of their performance when dealing with real cases. It was suggested in chapter 6 that a validation stage must be performed on the new system to assess its performance and decision quality. The validation stage consists of the following steps :

1) Gathering necessary information

2) Testing the final system

3) Evaluating system's results

4) Conclusion

9.2 Gathering Information

To perform this important task it was necessary to prepare the information needed to test the new expert system (SMART SELECT). For the purpose of gathering information, it was decided to develop a questionnaire as an interview means. This is because it allows more people to be sampled and respondents can complete it in their own time. However it should be mentioned that there are several drawbacks such as no opportunity for the respondents to question what the investigator means or provide the sort of detailed open ended answers that might emerge in a face to face interview.

Several considerations were taken into account during the design stage of the interview form. This questionnaire consisted of 3 modules of questions each concerned with different variables. This follows the work of Oppenheim [104] who suggested that questionnaires should be divided into several modules to distinguish between the role of each question in acquiring the specific information needed. In the case of this selection problem there are 3 distinctly different types of information that are sought.

Turban [30] stated that transferring information from one person to another is difficult because of their different backgrounds which affects the interpretation of knowledge. Furthermore in artificial intelligence (AI) it is more difficult to transfer the knowledge because it is necessary to elicit not only the knowledge, but also its structure. Turban [30], referred to the work proposed by McGraw and Harbison-Briggs [108] on structured interviews which force an organised communication between the knowledge engineer and the expert using specific replies to gather the certain knowledge. This method is used to prevent the distortion caused by the subjectivity of the expert domain. Therefore the questions in these modules were structured as "closed-ended" in which the respondents were offered a choice of alternative replies. These questions were used to elicit the specific information required to determine a "sensible" solution. They are intended to produce answers with less subjectivity which lend themselves to be structured into a formal computer language. The limitations are that these questions provided no opportunity for different replies or additional comments. Closed-ended questions can result in mis-leading information because they force very simple responses which may not be at all adequate to answer a question in all cases. If the respondent is able to understand what the question is getting at they might give a "sensible" response because they have thought how their response will be analysed.

The instructions on how to answer the questionnaire are important because they act as a guidelines for respondents when answering these specific questions as well as giving the respondents time to adjust to the next set of questions [104], [108]. Therefore each module of questions was preceded by a set of instructions which provided the necessary information to assist the respondent.

Wording of questions is an important matter since it affects the attitude of the respondents during the answering session. This questionnaire followed principles proposed by Oppenheim [104] and McGraw and Harbison-Briggs [108] for establishing such questions. For example, the length of question was considered because long questions tends to combine several aspects which are difficult to answer with a simple response. As a result there will be often be a need for some qualifying information which, if not included, may make the simple response inaccurate.

Most of the questions in this form allowed for the possibility that the respondent has no preference for particular answer given (e.g. either possibility is true). This can be important since it gives wider choice and provides more information to the analyst [104].

This questionnaire uses simple words because respondents who do not know what the terms mean may feel intimidated and may guess or pretend to know the answer.

The process of developing this questionnaire made it possible to elicit the required information from many respondents in a convenient manner. It provided sufficient information with an acceptable amount of time spent in producing the responses to the questionnaire and in producing analysis of the responses.

Based on the previous guidelines by Oppenheim [104], Turban [30], and McGraw and Harbison-Briggs [108] a questionnaire was composed. It consisted of the 3 major areas of data (selection factors, selection criteria, pairwise comparison weights) (refer to chapters 3, and 8). This is because the consultation sessions of SMART SELECT utilised these 3 areas for the process of eliciting information from the user in order to build its decisions. The questionnaire (see Appendix K) was distributed to a number of practising engineers who had expert knowledge of particular manufacturing systems and this produced 20 cases which are presented in Appendix K, Table K-1.

Table K-1 shows 3 categories, first the case number, second the type of product to be moved, and third the existing handling method. The existing handling method category is used to evaluate system decisions in a later section. The tabulated data from these 20 cases are provided in Appendix K, Table K-2. 6 cases contained an unexpected answer that it "did not matter" whether the handling equipment was on floor or off floor and so it was decided to generate 2 possibilities for each case, resulting in 26 different sets of data.

9.3 Testing The New System

By analysing the preliminary results (see Table 9.1) obtained from testing the 26 cases, it was seen that there were no cases where equipment was not selected. The selected groups were distributed over 6 categories with their corresponding percentage (refer to Appendix K, Tables K3 - K8) as follows :

1) 7 cases where a single group was selected, i.e. only single option
2) 7 cases where two groups were selected, i.e. 2 options
3) 2 case where three groups were selected, i.e. 3 options
4) 8 cases where four groups were selected, i.e. 4 options
5) 1 case where six groups were selected, i.e. 6 options
6) 1 case where seven groups were selected, i.e. 7 options

CASE	Existing Method	System Options
1	AGVs	AGV Tugger, Unit-load AGV, and Roller Conveyor
2	Power and Free Overhead Conveyor	Power and Free Conveyor, Mono-rail Conveyor
3	Roller Track Conveyor	Roller Conveyor
4	Belt or Slat Conveyor on floor	Unit-load and Tugger AGV, Roller Conveyor, Towline
5	Manual Trolleys	Chain and Roller Conveyors, Unit-load and Tugger AGVs, Tractor trailer, Forklift truck, Manual Handling
6	Forklift Truck	Unit-load and Tugger AGVs, Roller Conveyor, Tractor Trailer
7	Forklift Truck	Chain and Roller Conveyors, Unit-load and Tugger AGVs, Tractor Trailer and Forklift Truck
8	Manual (with Trolleys)	Chain and Roller Conveyors, Tractor Trailer and Forklift Truck
9	Overhead Mono-rail	Power and Free Conveyor and Mono-rail Conveyor
10	Overhead Mono-rail	Overhead Mono-rail Conveyor
11	Forklift Truck	Forklift Truck
12	Forklift Truck	Roller Conveyor, Unit-load, and Tugger AGVs, Tractor Trailer
13	Overhead Mono-rail	Power and Free Conveyor
14	Manual Trolleys	Chain and Roller Conveyors, Tractor Trailer and Forklift Truck
15	Forklift Truck	Roller Conveyor, Tractor Trailer

16	Crane	Mono-rail Conveyor
17	Floor, Power and Free Conveyors	Roller Conveyor, Unit-load and Tugger AGVs, and Tractor Trailer
18	Slat Conveyor (Chain type)	Towline and Chain Conveyor
19	Unit-load AGV	Chain and Roller Conveyors, Tractor Trailer
20	Tractor Trailer	Tractor Trailer
21	Power and Free Overhead Conveyor	Towline, Roller Conveyor, Unit-load and Tugger AGV
22	Manual Trolleys	Power and Free and Mono-rail Conveyors
23	Forklift Truck	Power and Free Conveyor Mono-rail Conveyor
24	Forklift Truck	Mono-rail Conveyor
25	Forklift Truck	Mono-rail Conveyor
26	Floor, Power and Free Conveyors	Mono-rail Conveyor

Table-9.1, Preliminary results

The results of analysis for the 26 cases that had more than one option selected (see Table 9.1) in the preliminary step is in Table 9.2.

The calculation using Liang's [16] equation to produce the ranking results for these cases and the two sensitivity analysis tests (refer to section 9.4) on the ranking results using the (±2) factor is also in the following Table-9.2.

Case #	Ranking of Equipment	Sensitivity (+2 steps)	Sensitivity (-2 steps)	Final choice
1	AGV Tugger (-2.56) Unit-load AGV (-1.75) Roller Conveyor (1.62)	AGV Tugger (-2.71) Unit-load AGV (-1.93) Roller Conveyor (1.57)	AGV Tugger (-1.72) Unit-load AGV (-0.77) Roller Conveyor (1.91)	AGV Tugger
2	P & F Conveyor (-3.61) Mono-rail Conv. (-3.23)	P & F Conveyor (-3.75) Mono-rail Conv. (-3.24)	P & F Conveyor(-3.22) Mono-rail Conv.(-2.83)	P&F Conveyor
4	AGV Tugger (1.58) Roller Conveyor (2.41) Towline (2.69) Unit-load AGV (2.88)	AGV Tugger (1.65) Roller Conveyor (2.58) Towline (2.63) Unit-load AGV (3.11)	AGV Tugger (1.41) Roller Conveyor (2.28) Towline (2.81) Unit-load AGV (2.48)	AGV Tugger
5	Manual Handling(-1.36) Tractor Trailer (-1.25) Chain Conveyor (-1.05) Roller Conveyor (-0.66) Forklift Truck (-0.41) AGV Tugger (-0.26) Unit-load AGV (0.20)	Manual Handling(-1.32) Chain Conveyor (-1.17) Tractor Trailer (-1.05) Roller Conveyor (-0.78) AGV Tugger (-0.29) Forklift Truck (-0.20) Unit-load AGV (0.25)	Manual Handling(-1.83) Tractor Trailer (-1.79) Forklift Truck (-0.92) Chain Conveyor (-0.78) AGV Tugger (-0.68) Roller Conveyor (-0.34) Unit-load AGV (-0.22)	Manual Handling
6	Tractor Trailer (-3.83) AGV Tugger (-3.11) Unit-load AGV (-2.69) Roller Conveyor (0.42)	Tractor Trailer (-4.24) AGV Tugger (-3.89) Unit-load AGV (-3.49) Roller Conveyor (0.40)	Tractor Trailer (-2.79) AGV Tugger (-1.49) Unit-load AGV (-1.00) Roller Conveyor (0.49)	Tractor Trailer

7	Tractor Trailer (-2.92) Forklift Truck (-2.41) AGV Tugger (-2.25) Unit-load AGV (-1.99) Chain Conveyor (0.04) Roller Conveyor (1.14)	Tractor Trailer (-3.03) Forklift Truck (-2.67) AGV Tugger (-2.67) Unit-load AGV (-2.45) Chain Conveyor (-0.07) Roller Conveyor (1.27)	Tractor Trailer (-2.09) Forklift Truck (-1.01) AGV Tugger (-0.78) Unit-load AGV (-0.19) Chain Conveyor (0.49) Roller Conveyor (1.08)	Tractor Trailer
8	Tractor Trailer (-2.50) Forklift Truck (-2.01) Chain Conveyor (-1.29) Roller Conveyor (-1.13)	Tractor Trailer (-2.29) Forklift Truck (-1.79) Chain Conveyor (-1.40) Roller Conveyor (-1.29)	Tractor Trailer (-2.93) Forklift Truck (-2.34) Chain Conveyor (-1.07) Roller Conveyor (-0.78)	Tractor Trailer
9	P & F Conveyor (-2.78) Mono-rail Conv. (-2.00)	P & F Conveyor (-3.38) Mono-rail Conv. (-2.50)	P & F Conveyor (-2.67) Mono-rail Conv. (-1.97)	P&F Conveyor
10	P & F Conveyor (-4.19) Mono-rail Conv. (-4.50)	P & F Conveyor (-4.02) Mono-rail Conv. (-4 16)	P & F Conveyor (-3.81) Mono-rail Conv. (-4.36)	Mono-rail Conveyor
11	Forklift Truck (-2.67) Tractor Trailer (-2.18) Chain Conveyor (1.14) Roller Conveyor (2.43)	Forklift Truck (-2.16) Tractor Trailer (-1.53) Chain Conveyor (1.36) Roller Conveyor (2.79)	Forklift Truck (-2.58) Tractor Trailer (-2.07) Chain Conveyor (1.22) Roller Conveyor (2.39)	Forklift Truck
12	Tractor Trailer (-0.38) AGV Tugger (1.19) Unit-load AGV (1.77) Roller Conveyor (1.95)	Tractor Trailer (0.24) AGV Tugger (1.24) Unit-load AGV (1.91) Roller Conveyor (2.61)	Tractor Trailer (-0.98) AGV Tugger (0.89) Unit-load AGV (1.44) Roller Conveyor (1.16)	Tractor Trailer
14	Forklift Truck (-3.83) Tractor Trailer (-3.18) Chain Conveyor (1.46) Roller Conveyor (0.37)	Forklift Truck (-3.52) Tractor Trailer (-2.84) Chain Conveyor (1.71) Roller Conveyor (0.33)	Forklift Truck (-3.67) Tractor Trailer (-2.97) Chain Conveyor (1.48) Roller Conveyor (0.49)	Forklift Truck
15	Tractor Trailer (-3.17) Roller Conveyor (1.47)	Tractor Trailer (-2.96) Roller Conveyor (1.71)	Tractor Trailer (-2.50) Roller Conveyor (1.44)	Tractor Trailer
17	Tractor Trailer (-0.19) Roller Conveyor (1.32) AGV Tugger (1.49) Unit-load AGV (2.44)	Tractor Trailer (-0.02) AGV Tugger (1.17) Roller Conveyor (1.59) Unit-load AGV (2.20)	Tractor Trailer (-0.31) AGV Tugger (0.85) Roller Conveyor (1.32) Unit-load AGV (1.73)	Tractor Trailer
18	Chain Conveyor (-0.52) Towline (1.68)	Chain Conveyor (-0.57) Towline (1.82)	Chain Conveyor (-0.33) Towline (1.65)	Chain Conveyor
19	Tractor Trailer (-2.52) Chain Conveyor (1.33) Roller Conveyor (2.62)	Tractor Trailer (-1.67) Chain Conveyor (1.67) Roller Conveyor (3.18)	Tractor Trailer (-2.41) Chain Conveyor (1.30) Roller Conveyor (2.53)	Tractor Trailer
21	Roller Conveyor (-1.39) AGV Tugger (0.06) Unit-load AGV (0.44) Towline (0.80)	Roller Conveyor (-1.24) AGV Tugger (0.15) Unit-load AGV (0.66) Towline (0.74)	Roller Conveyor (-1.13) AGV Tugger (-0.4) Unit-load AGV (-0.01) Towline (0.8)	Roller Conveyor
22	P & F Conveyor (-3.15) Mono-rail Conv. (-2.68)	P & F Conveyor (-3.64) Mono-rail Conv. (-3.08)	P & F Conveyor (-2.51) Mono-rail Conv. (-2.05)	P & F Conveyor
23	P & F Conveyor (-1.00) Mono-rail Conv. (-0.58)	P & F Conveyor (-1.13) Mono-rail Conv. (-0.73)	P & F Conveyor (-1.01) Mono-rail Conv. (-0.52)	P & F Conveyor

Table 9.2, Ranking and sensitivity analysis results

The previous results of the initial selection and the ranking processes show the comparison between the existing handling method and expert system choice for the 26 cases in Table 9.3.

CASE	Existing Method	System Choice	Comparison
1	AGV	AGV Tugger	Same
2	Power and Free Overhead Chain Conveyor	P&F Conveyor	Same
3	Roller Track Conveyor	Roller Conveyor	Same
4	Belt or Slat Conveyor on floor	AGV Tugger	Different
5	Manual Trolleys	Manual Handling	Same
6	Forklift Truck	Tractor Trailer	Different
7	Forklift Truck	Tractor Trailer	Different
8	Manual (with Trolleys)	Tractor Trailer	Different
9	Overhead Mono-rail	P&F Conveyor	Different
10	Overhead Mono-rail	Overhead Mono-rail	Same
11	Forklift Truck	Forklift Truck	Same
12	Forklift Truck	Tractor Trailer	Different
13	Overhead Mono-rail	P&F Conveyor	Different
14	Manual Trolleys	Forklift Truck	Different
15	Forklift Truck	Tractor Trailer	Different
16	Crane	Mono-rail Conveyor	Different
17	Floor and P&F Conveyors	Tractor Trailer	Different
18	Slat Conveyor (Chain type)	Chain Conveyor	Same
19	Unit-load AGV	Tractor Trailer	Different
20	Tractor Trailer	Tractor Trailer	Same
21	Power and Free Overhead Chain Conveyor	Roller Conveyor	Different
22	Manual Trolleys	P&F Conveyor	Different
23	Forklift Truck	Power and Free	Different
24	Forklift Truck	Mono-rail Conveyor	Different
25	Forklift Truck	Mono-rail Conveyor	Different
26	P&F Conveyor	Mono-rail Conveyor	Different

Table 9.3, Comparison between existing method and system choice

Then Table 9.3 was initially divided into 2 sets for evaluation purpose as follows :

1) 8 cases where the expert system produced the same result as the existing handling method (see Appendix K, Table K-9)
2) 18 cases where the expert system produced a different result from the existing handling method (Appendix K, Table K-10)

This appeared to demonstrate very poor performance of the expert system. However the generation of 2 possibilities from each of the six cases (2, 5, 6, 7, 12, and 17) where a "does not matter" response was obtained to the on floor/off floor question it was *guaranteed* to provide 6 cases which produced a different handling method from the existing one. Therefore it could be predicted that these 6 cases would <u>not</u> produce a match with the existing method, and indeed if they did, it would indicate an invalid decision by the expert system. Furthermore in cases 8, and 14 the expert's views were that the existing method was far from ideal so a match with the expert system choice would not be expected. Also in case 16 the engineer attempted to evaluate the expert system choice against their existing method which was not provided as a separate group so a match would not expected. Thus 9 of the 18 cases where different handling equipment was selected by the expert system can be regarded as valid decisions. Nevertheless, it was considered necessary to examine all cases to fully test the decision making capabilities in producing valid results. Therefore these 18 cases were separated into two different sets for a proper evaluation (see Tables K-9, K-10, K-11, and K12) making three sets of cases produced for evaluation as follows:

a) 8 cases matched, expected to match

b) 9 cases do not match, expected not to match

c) 9 cases do not match, expected to match

9.4 Evaluation Of System Results

In this section is an evaluation of the three sets of cases produced in section 9.3. It was based on firstly the preliminary selection phase, which was matching equipment factors to the requirements provided from the data in the questionnaire. Secondly it was based on determining the differences in selection criteria between the selected options and matching the system final choice with the equipment currently installed. Thirdly two sensitivity analysis tests to provide confidence in the selection performance because some of the engineers commented that they found great difficulty in being any more precise with pairwise comparison evaluation.

Furthermore, a match between the handling equipment selected by the expert system and equipment currently installed does not necessarily mean that the expert system has performed well. Conversely a different result does not necessarily mean that the expert system has performed badly and it is necessary in both cases to examine the reasons for the agreement or disagreement to establish whether the reasons are due to :

a) The validity of the decision criteria used in the expert system

b) The validity of the data input to the system

c) The validity of the existing handling equipment as the 'best' solution

9.4.1 Cases Matched, Expected To Match

Table K-9 in Appendix K showed that 32% of the cases tested by the system selected the same handling method as the one found in the current situation. These 8 (see Table K-9, Appendix K) arose from cases where different numbers of equipment groups were initially selected. The following is an analysis to detect the factors that influenced the system decision.

a) Case 1

The information given for the selection factors in this particular situation generated 3 equipment groups which were 'AGV tugger', 'unit-load AGV', and 'roller conveyor'. The rest of the groups were eliminated because they did not fulfil the following factors; 'chain conveyor' and 'manual handling' could not meet the 'weight' factor. The 'on floor' requirement was the reason for not considering the 2 overhead conveyors groups ('power and free' as well as 'mono-rail'). 'Towline' group did not meet intermittent operation requirement. The delivery rate failed the 'forklift truck' group. Path specification made 'tractor trailer' option not suitable.

The 3 selected options were ranked on the basis of their selection criteria suitability against the ones in the existing situations. Then Liang's equation was used to produce the ranking which determined that the 'AGV tugger' was the best choice because it had the highest negativity value among these option (see Table 9.2).

In an attempt to provide more confidence in the final decision of the system, two sensitivity analysis tests were carried out. The result showed (refer Table 9.2) that even though a ± 2 factor was introduced to the evaluation of selection criteria (see Appendix G), the system still selected the 'AGV tugger' group as the best.

The match between the existing method and system's choice does not provide conclusive proof that the existing solution is the best for the current situation but it does suggest that the expert system is capable of producing good decisions.

b) Case 2

Preliminary selection for case 2 produced 'power and free conveyor' and 'mono-rail conveyor' for the ranking step. The remaining 8 groups had failed because they did not match the 'off floor' factor which was required in this case. This is considered a correct first step in the decision process. To produce the best of the two overhead conveyors groups (power and free as well as mono-rail), the differences in criteria between the actual situation and each group criteria were performed (see Appendix H). The result of this step showed that 'power and free conveyor' group was the best method (refer to Table 9.2). Then expert system selected the most suitable method for this case which happened to be the same as the existing one. The two sensitivity tests were performed to check the sensitivity of system final decision.

Although the outcomes of both tests (Table 9.2) illustrated that the 'power and free conveyor' group had the higher negativity value which indicates it as being the best, nevertheless the difference of final evaluation values between the two methods was not as great a margin as with the first case in this set (see Table 9.2).

c) Case 3

Case 3 was a single option selection which produced the 'roller conveyor' group. This is because 'manual handling' and 'chain conveyor' did not match the given weight in this case. The higher delivery rate required failed the following groups 'forklift truck', 'tractor trailer', 'unit-load AGV', 'tugger AGV', and 'towline'. The two overhead conveyors were excluded because of the on floor specification. Therefore the only group selected is 'roller conveyor' since it matched every factor.

The match between the system choice and the existing method provides a strong implication that the existing method is a good one. However it still does not guarantee that the expert system always produces the best overall decisions and it may be wise to consider the other selected options.

d) Case 5

The preliminary selection step produced 7 handling options for case 5. The 2 overhead conveyors group were not considered because they did not match 'on floor' requirement. The 'towline' group did not satisfy the intermittent movement specified. The 'manual handling' group was selected from among the remaining 7 handling options because its selection criteria were the most suitable for the given situation since it produced the highest negativity value among the rest (see Table 9.2). This decision was generated as it gave the best result of difference of selection criteria between this case and the groups (see Appendix H).

Although the final evaluation indicated that manual handling is the best (see Table 9.2), nevertheless it was not a clear choice because the calculation showed that the 'tractor trailer' and the 'roller conveyor' groups scores were very close to the score of the existing method. The two sensitivity tests (see Table 9.2) illustrated the small margin between the top three choices which made the 'manual handling' the final choice. Furthermore at the (+2) factor step the 'chain conveyor' group changed rank with the 'tractor trailer' group, but at the (-2) factor step the 'tractor trailer' group retained its initial rank and 'chain conveyor' group changed rank with the 'forklift truck' group (see Table 9.2). This indicated that the outcome of this case was sensitive to change in the pairwise evaluation of selection criteria. This sensitivity is due to the subjective judgement in the questionnaire data. However, the analysis carried out in the two sensitivity tests clearly indicates that the result is not highly dependent on this inevitable subjectivity.

e) case 10

The preliminary selection phase produce the two overhead methods because the rest of the groups did not satisfy the off floor requirement. However the ranking process and the two sensitivity tests showed that the existing system which was the 'mono-rail conveyor' was better than the 'power and free conveyor'. The final decision was based on better selection criteria and negativity value for the existing method (refer Table 9.2). The selection of the existing system by this decision tool provides more assurance in its capability.

f) Case 11

4 groups ('chain conveyor', 'roller conveyor', 'tractor trailer', and 'forklift truck) were selected in the first stage. However the two overhead methods failed the on ground factor, the 'manual handling' did not match the weight, the 2 AGV groups and the 'towline' group were not counted because of the path factor.

The ranking stage for the 4 selected groups produced the existing system ('forklift truck') as the favourite. Moreover in this stage the margin of negativity between the existing method and the 'tractor trailer' was small. But the two sensitivity steps showed the existing system is better (Table 9.2).

g) Case 18

The preliminary selection phase failed 8 groups. The 'forklift truck', and the 'tractor trailer' groups did not meet the specified path, speed, and intermittent factors. The 2 overhead conveyors were not suitable because of on ground requirement. Intermittent and speed factors failed the 2 'AGV', and the 'towline' as well as the 'manual handling' groups. The ranking procedure was performed on the remaining 2 groups the 'chain conveyor' and the 'towline'.

The final decision of SMART SELECT made the existing method is the best. The better selection criteria and the significant negativity value produce by the ranking as well as the two sensitivity tests showed clearly that the existing method, the 'chain conveyor', is more suitable for this situation than the 'towline' method (Table 9.2).

h) Case 20

SMART SELECT provided a single choice from the preliminary stage which happened to be the existing method ('tractor trailer') because it fulfilled all the given requirements of this situation. The following Table 9.4 shows the factor(s) which failed the remaining 9 groups :

Factor/ Group	Frequency	Intermittent	Path	Load	Floor	Distance
Towline	x	x	x	-	-	-
Chain Conveyor	x	-	-	x	-	x
Roller Conveyor	-	-	-	x	-	-
P&F Conveyor	x	-	-	-	x	-

Mono-rail Conveyor	x	-	x	-	x	-
Unit-load AGV	x	-	x	-	-	-
AGV tugger	x	-	x	-	-	-
Forklift Truck	x	-	-	-	-	x
Manual Handling	x	-	-	x	-	x

x: failed

Table 9.4 Failed groups of equipment

Table 9.4 shows a variety of factor(s) which caused 9 groups to fall short of meeting the requirement of this situation.

In each of the previous 8 cases, the engineers familiar with the relevant manufacturing system stated that they were satisfied with the performance of the existing handling equipment. The fact that the expert system selected identical equipment does not in itself validate the system, but it does provide some confidence that the system is capable of producing valid results.

9.4.2 Cases Do Not Match, Expected Not To Match

This examination evaluates the 34% of cases produced from the questionnaire where the testing results for these cases showed that they did not match the existing method in circumstances where a match was not expected. These 9 cases were listed in Table K-11, Appendix K.

a) Case 8

In this case there was a dissatisfaction regarding the existing method ('manual' with trolleys) from the manufacturing engineer who answered the questionnaire as they considered that manual handling was not an ideal solution. There were four equipment groups produced during the preliminary phase of selection ('roller conveyor', 'chain conveyor', 'tractor trailer', and 'forklift truck') and the existing method and the rest of the groups were excluded. 'On floor' requirement failed the 2 overhead conveyors. The 'towline' group did not match the continuous movement factor. The 2 'AGV' ('tugger', and 'unit-load') did not match path specification. The best handling solution selected was the 'tractor trailer' group due to the better selection criteria and the highest ranking (negativity) score among the 4 selected groups (see Table 9.2).

The 'tractor trailer' group retained its first position in the ranking order during the two sensitivity tests, nevertheless the 'forklift truck' group produced a significant score which came close to matching the first group score especially in (+2) factor step (see Table 9.2). The subjective nature of the information lead to the small margin between first and second choices and either 'tractor trailer' or 'forklift truck' could be considered to be suitable alternatives to the current manual method.

b) Case 14

The information provided for this situation was to assess the existing method against another alternative for future improvement. Manual trolleys are utilised to perform the handling task for such situation. However the SMART SELECT consultation produced 4 groups in the introductory stage which were the 'chain conveyor', the 'roller conveyor', the 'tractor trailer', and the 'forklift truck'. The 2 overhead conveyors were not selected because they are off ground methods. The path requirement was behind the omission of the 2 'AGV' and the 'towline' groups. Manual handling was regarded not suitable for this weight.

The 'forklift truck' group became the top choice because it had better selection criteria and scored the highest negativity value when the ranking process and 2 sensitivity tests were performed on the 4 pre-selected groups (see Table 9.2). Consequently the 'forklift truck' group might provide better replacement for this situation in the future.

c) Case 16

This case was used to investigate the system choice in comparison to the existing method which was a 'crane'. The existing system was not represented in a separate group; this was the reason behind this query to determine the final choice of SMART SELECT. There was 1 group (mono-rail conveyor) selected based on the information provided. The 'power and free conveyor' did not match speed factor. The remaining 8 groups were not suitable because of the off floor factor.

d) Case 21

The information produced in case 2 provided "did not matter" for the on floor/off floor factor. This case has an off floor existing method which was 'power and free conveyor'. It had been decided to create this case to analyse the information of case 2 by changing this particular factor to an on floor alternative. This was an attempt to see a suggested outcome from the expert system and to see if its result was valid. In the preliminary selection phase the 2 overhead options were not considered because of the 'on floor' requirement. The 'manual handling' and 'chain conveyor' groups did not match the required weight. The path requirement was incompatible with the 'tractor trailer' and 'forklift truck' groups. The selected 4 groups were 'AGV tugger', 'unit-load AGV', 'roller conveyor', and 'towline' see Table 9.1.

The ranking process performed on these options produced the 'roller conveyor' group as the best choice due to its better selection criteria and the large margin of negativity between the selected options (refer to Table 9.2). The 'roller conveyor' group proved to be better than the rest in the two sensitivity tests (see Table 9.2). Therefore if an on-floor option was required it appears that a roller conveyor is a good choice.

e) Case 22

The existing method in case 5 was an 'on floor' method but it was necessary to see what type of 'off floor' option the system can produce. The only 2 were 'power and free' and 'mono-rail' conveyors produced in the preliminary selection stage.

The ranking procedure showed that the 'power and free' conveyor is better for its selection criteria and it was ranked first because of its higher negativity value (see Table 9.2).

The two sensitivity tests showed a relatively small margin of negativity value between the two options (see Tables 9.2). Therefore both options should be considered if an off-floor solution is an acceptable requirement.

f) Case 23

This case was created to investigate the off floor option for the on floor existing method in case 6 which was the 'forklift truck'. The 'off floor' option was confined within the 2 overhead conveyors the 'power and free' and the 'mono-rail' groups which were selected initially. To see the final calculation which lead to the 'power and free' solution refer to Table 9.2. The 'power and free' was considered the best option as a result of the two sensitivity tests where it scored the higher negativity value in comparison to the 'mono-rail' group.

g) Case 24

As an alternative this case has been provided by the questionnaire to determine a handling solution for an 'off ground' option for the existing 'on floor' method in case 7. The 'mono-rail' overhead conveyor was the only choice produced (see Table 9.1). The final decision was attributed to the limits of selection criteria used in the system which disqualified 9 equipment groups.

h) Case 25

The existing handling method for case 12 was forklift truck. However on floor/off floor indicated that "it does not matter", so the information of this case was tested for an off floor handling solution to seek other alternative. The introductory choice of SMART SELECT produced one group which was the ‘mono-rail conveyor’. This was because the ‘power and free conveyor’ did not meet the speed requirement of this situation. A need for off floor operation made the rest of the groups redundant.

i) Case 26

This case is similar to case 25 which was created to evaluate an off ground solution for the existing on ground solution. Again at the preliminary selection phase the system produced 1 group which was the ‘mono-rail conveyor’. The ‘power and free conveyor’ could not meet the speed needed for this problem. Again the remaining 8 system could not be used because of off floor requirement in this case.

9.4.3 Cases Do Not Match, Expected To Match

34% of the cases produced a different handling option from the existing method, and these cases were listed in Table K-12, Appendix K. There is no reason why the remaining 9 cases might have had these predicted outcomes. A comparison procedure between the existing method and the system decision was carried out to determine the reason for differences between the two. An investigation was performed to check the crucial factors that lead to the particular decision in each of the 9 cases, in addition to the two sensitivity tests to illustrate the effect of change introduced on the raw data as follows.

a) Case 4

The existing method in this case was ‘belt or slat conveyor’ which did not exist as an individual group in itself but was a member of the ‘roller conveyor’ group. An initial analysis for case 4 selection factors showed that 4 options had been selected which were 'towline', 'AGV tugger', 'unit-load AGV', and 'roller conveyor' groups in comparison to the existing method which was included within these options. The weight capacity specified made 'manual handling' and 'chain conveyor' short of that limit. The following groups 'forklift truck', and 'tractor trailer' did not match the continuous movement factor in this case. The 'on floor' requirement failed the 2 overhead conveyors. Ranking these 4 methods by Liang's formula resulted in the 'AGV tugger' group being the best of the 4 selected groups because it had better selection criteria than the rest and had the highest negativity score (see Table 9.2). Table 9.2 showed that all the scores produced were positive, which is interpreted as meaning that no handling option was particularly well matched to the situation. The two sensitivity tests had produced a positive ranking and made the 'AGV tugger' group better than the rest in both cases (refer to Table 9.2).

The existing method was deemed to be acceptable in terms of its handling performance for the existing situation according to the manufacturing engineer, despite the fact that it was ranked second. Nevertheless the analysis carried out on the situation requirements had always produced positive ranking scores which illustrated poor matching and the need to evaluate other options with different capabilities in order to meet situation specifications and produce better scoring.

b) Case 6

The second case in this set is case 6 where the 'tractor trailer' group was selected by the system as the best choice for this particular case as opposed to the existing one which was 'forklift truck'. The existing method was disqualified at the initial stage. The basis for that decision was carried out in two stages. Firstly, at the preliminary selection step 'forklift truck' and 'manual handling' groups did not match the delivery rate in this case. The 'on floor' specification failed the 2 overhead conveyors groups. The 'towline' group was not considered at this step because it was only available with a continuous movement feature which is not required by this case. The only 4 groups that match the given specifications were the 2 AGVs ('tugger', 'unit-load'), 'roller conveyor', and 'tractor trailer'.

The 4 remaining groups then entered the ranking stage to determine the best one. The selection criteria of the 'tractor trailer' group was the best match to this situation which showed the greater negativity score, therefore it was selected by the system as the best method (see Table 9.2). The two sensitivity tests conducted on the selection criteria indicated that the 'tractor trailer' group was first choice in both tests. The difference between the 2 handling methods (existing, system's choice) can be considered to be due to the subjectivity of the information in this case. The other factor can be attributed to the setting of limits of the selection criteria which lead to the mismatching of the 'forklift truck' group.

c) Case 7

Case 7 preliminary results indicated that 6 groups were selected because they matched selection factors given in this particular case. The remaining 4 failed this step because the 2 overhead conveyors did not match 'on floor' requirement and weight capacity could not be met by 'manual handling' limits as well as 'towline' group which did not match the continuous movement factor.

The 6 selected options were ranked by the decision analysis part of the system to determine the best choice. The selection criteria of the 'tractor trailer' as well as its negativity value were better than the existing method (forklift truck) which was ranked second among the selected 6 groups, thus made the 'tractor trailer' the most suitable handling method (see Table 9.2). Although the difference in selection criteria between the first and the second options made the 'tractor trailer' the better choice (see Table 9.2), nevertheless it was significant. The margin of difference between the first (tractor trailer) and the second (forklift truck) groups was not considerable in either of the two sensitivity tests (refer to Tables 9.2).

Although the practising engineer who provided the information stated that the existing method was satisfying production demands, it is not necessarily the best system. Furthermore the system ranked the existing method as the second choice after the 'tractor trailer' group.

d) Case 9

The 'off ground' requirement failed 8 equipment groups in the first stage of selection. The only 2 remaining were the 2 overhead conveyors of which the existing method is one of them. The final outcome of the ranking process determined that the 'power and free' group was the one with the better criteria and higher negativity score and it was considered a better choice than the existing method (mono-rail conveyor) (see Table 9.2).

The existing method ranked second, in both the initial ranking and the two sensitivity tests (Table 9.2). Even though the expert stated that the existing method was suitable for their manufacturing operation, there appears to be strong evidence that there was a better technical alternative.

e) Case 12

The existing handling method provided in this case was a 'forklift truck'. However the introductory selection phase selected 4 groups (the 'roller conveyor', the 'unit-load AGV', the 'AGV tugger', and the 'tractor trailer') in which the existing method was not included. The reasons for this pre-selection stage were that the on floor requirement omitted the 2 'overhead' methods, the 'manual handling' and the 'chain conveyor' fell short of load and distance specified, the 'forklift truck' (existing method) was dismissed because frequency and distance, and the 'towline' did not match speed and intermittent specifications.

Although the final choice was the 'tractor trailer' group, nevertheless the results in terms of negativity values either in the ranking or in the 2 sensitivity tests have not provided a single method with significant negativity value to distinguish it from the others (see Table 9.2). The main problem was probably the crispness of boundaries as well as the subjectivity associated with the selection criteria. This caused the exclusion of the existing method the 'forklift truck' group.

f) Case 13

The SMART SELECT initial stage dismissed 8 groups because they did not satisfy the off floor specification. The remaining were the 2 overhead alternatives the 'power and free' as well as the 'monorail' conveyor which corresponded to the existing method. However the existing method did not match the limit for intermittent factor set by SMART SELECT which caused disqualification for the 'mono-rail' solution. In this case the system was providing the right alternatives as a possible solution for this situation, but it produced a different method from the existing one. The dismissal of the existing method was caused by the pre-determined limits for this specific factor. Moreover it is likely that it was the subjectivity of the information given by the engineer which lead to such a decision.

g) Case 15

The expert system produced 2 groups, the 'roller conveyor' and the ' tractor trailer' as a potential solution for this case. However 8 groups and among them the existing method (forklift truck) were dismissed in the initial selection stage. There were several reasons behind the rejection of the 8 groups. The on floor requirement made the overhead solution not practical. The path factor caused the dismissal of the 2 AGV groups. Manual handling was not feasible for the load and the distance as well as the frequency required for this particular situation. The 'chain conveyor' failed to maintain the specified travel distance necessary in this case. 3 factors (path, speed, and intermittent) made the 'towline' group not a viable alternative. However the existing system (forklift truck) was disqualified because of 2 factors, frequency and distance.

The ranking procedure as well as the two sensitivity tests have shown clearly that the 'tractor trailer' group was the better choice in comparison to the ' roller conveyor' group (see Table 9.2). SMART SELECT choice have demonstrated significant negativity values because its selection criteria matched the given specification. This suggested that there is a better technical solution than the existing one.

h) Case 17

4 out 10 groups succeeded in the initial phase of SMART SELECT. These groups were the 'roller conveyor', the 'unit-load AGV', the 'AGV tugger', and the 'tractor trailer'. Although the system had selected a conveyor group which matched the existing method, it did not make it the top choice.

The ranking process and the 2 sensitivity tests witnessed 2 different results. In the ranking step the 'roller conveyor' group came second in rank. However in the 2 sensitivity steps the 'roller conveyor' exchanged its second position with the 'AGV tugger' group which was third. Furthermore all the scores either in the ranking or in the following two steps have not provided strong evidence that the system choice can be considered a possible solution because its selection criteria produced a small negativity value. These findings can be read as follows; the system did provide the right group even though it was not the top choice. However the sensitivity shown in the system results indicated that it might be due to the subjectivity in terms of the person who answered the selection criteria which caused this result.

i) Case 19

The introductory selection stage dismissed the existing method (unit-load AGV) as a possible solution and provided 3 alternative groups which were the 'chain conveyor', the 'roller conveyor', and the 'tractor trailer'. The 'manual handling' could not handle the given weight. The on floor activity disregarded the 2 overhead possibilities. The path specified made it impossible to be selected for the 2 AGV groups which the existing system happened to be one of them. The 'forklift truck' group was not selected because it did not match the given frequency. Finally the intermittent operation disqualified the 'towline' group.

It was very obvious that the 'tractor trailer' was the better choice because during both the ranking procedure and the 2 sensitivity tests it produced 3 significant negativity values which distinguished it from the rest. This outcomes illustrated that it is likely that the narrow boundaries set for selection factors caused the missing of the existing method from the beginning. However the selection criteria provided were a perfect match for the SMART SELECT choice which might be technically better for this situation.

The task of investigating these cases in which the expert system did not produce an expected result was to be able to distinguish between handling methods (existing and proposed). This investigation produced two categories regarding the comparison on the basis of considering the existing method as an option as follows:

1) Selected at the preliminary stage but not ranked as the best

2) Not selected at the preliminary stage

In category 1 where the existing method was selected as an option (cases 4, 7, 9 and 17) it can be seen that it was the subjective information given in the questionnaire that caused the system to produce different results. In contrast, category 2 where the existing method was disqualified initially (cases 6, 12, 13, 15, and 19) showed that setting of selection limits was the reason behind this disqualification. In only 5 of the 26 cases did boundaries of the selection limits affect the final outcome. This in itself gives some confidence in the final selection and supports the validity of the new expert system.

9.5 Conclusion Of Investigation

Even though the number of cases tested was 26, they did cover a variety of real handling situations from manufacturing industry in the UK. Investigation of the results provided by the expert system produced significant outcomes which revealed the system performance capability when dealing with real data. The system generated results which were divided into 3 categories of which :

1) 8 cases matched, expected to match
2) 9 cases did not match, expected not to match
3) 9 cases did not match, expected to match

Thus in 17 out of 26 (66%) of cases the expert system performed according to expectations. It has been seen that there were 3 reasons to be investigated during the evaluation of the 26 cases. Firstly the validity of decision criteria used. Secondly the validity of information used during the consultation session with the system. Finally the validity of the existing handling method as the best solution.

In the first category, decisions showed that the expert system agreed with the existing handling method and for these particular cases they could be expected to match because the engineers rated the existing handling method as highly suitable. The reasons for the match were that the selected equipment specifications and, its selection criteria, were better in comparison to the other options resident in the knowledge base. Thus the analysis of these cases showed clearly why the existing method was the best one to use.

In the second category where the system provided different solutions, this was expected because either the existing method was not suitable in the opinion of the manufacturing engineer, or an alternative requirement was specified (on/off floor) contrary to the existing situation. The selections made by the expert system were put to the manufacturing engineers to establish their views on the alternatives.

In case 8 where the engineer disliked the existing manual method, he felt that the top ranked method of tractor trailer was technically a good one, although features in the current layout (narrow aisles and sharp corners) made this impractical and he would prefer the second ranked solution of forklift truck.

However in case 14 the expert system was tested to compare its outcome with the existing system. SMART SELECT provided a different alternative for the given problem which was considered by the engineer as a possible future improvement for the existing method.

Case 16 was used to compare between the existing method and the system choice. Although the existing system did not have a specific group, nevertheless the system provided the 'mono-rail conveyor' as a possible alternative.

In cases 21, 23, and 24 the 3 engineers all agreed that if the on floor /off floor option was opposite to that of the currently installed equipment, the top ranked selection was a viable option. However they all declared a bias for the existing equipment as this was a "known quantity".

In case 22 the engineer had a distinct preference for the second ranked option of mono-rail as opposed to the top ranked power and free solution. However since the sensitivity tests showed only a small margin between these two, some discrepancy is understandable.

The final category was where different solutions from the existing methods were generated and there was no obvious reasons why a match should not have been obtained. In these cases the system results illustrated why there was a difference between the 2 methods. The individuals who provided the information were satisfied with the performance of the existing handling method because of its ability to meet operational demands. Furthermore these conflicting results were considered to be contributed by the information provided in the questionnaire which was either not interpreted clearly in a way to define the situation and the subjective judgement involved in creating the raw data, or could be errors in decision making procedure due to the established limits (boundaries) of the selection criteria which caused this outcome and the equipment group not to match the existing handling method.

To attempt to establish which of these possibilities was true, the selections made by the expert system were put to the manufacturing engineers. In case 4 the engineer was familiar with 'unit-load AGV's' but not with 'AGV tugger' which was the expert system's choice. He was unwilling to accept 'AGV tugger' mainly due to unfamiliarity. He agreed that if an expert system suggested this as an option he would feel obliged to investigate its capabilities.

In cases 6, and 7 the 2 engineers were adamant that top ranked choice of tractor trailer was unsatisfactory but it emerged that this was for reason of narrow aisles in the existing layouts. However they personally preferred the existing forklift truck option and would not consider any alternative. In case 7 the forklift truck was ranked a very close second so the difference can be attributed to the subjective judgement of the experts. However in case 6 the forklift truck was dismissed at the initial stage and this appears to indicate an error in the decision making procedure.

In case 9 the engineer fully accepted that 'power and free' was a viable alternative to the existing mono-rail and that if changes in the handling system were required in the future, he would probably consider 'power and free'. However he would not consider changing the existing mono-rail equipment in the short term.

From this evaluation it has been seen in all cases except 5 cases (6, 12, 13, 15, and 19); (19%), that the expert system has produced solutions which practising engineers either agree with (47%) or they accepted that they are feasible options on technical grounds (34%). Thus in 81% of cases the result was considered satisfactory by experts. However in the 5 cases mentioned above, the selection criteria appeared to be a contributing factor in producing a conflicting result. For example in case 6, further examination showed that this was due to the selection criteria eliminating forklift truck above 2 deliveries/hr. In retrospect the use of a sharp boundary as a pass/fail decision tool is rather crude which showed that Liang's selection criteria limits did not performed as expected in this particular case. Thus it is necessary to find a way to re-examine these limits and fuzzy boundaries between selection criteria which may perform better. There can be fuzziness in setting these boundaries between selection criteria in the same manner as has already been discussed between group boundaries (refer to chapter 2).

9.6 Difficulty Of Benchmarking SMART SELECT

To attempt to perform a benchmarking on a newly developed expert system like SMART SELECT, there ideally has to be an existing similar type and fully functioning expert system against which to evaluate the new system performance. The literature survey in this area did not reveal any expert system which provided the same output for a similar process in order to be compared with the result produced by SMART SELECT.

Since there are no similar expert systems available then the benchmarking of the new system performance becomes impossible to conduct against a similar product, but it is possible to consider benchmarking it against the performance of human experts.

This in itself raises difficulties because of the lack of definitive "right" and "wrong" solutions arising from the inevitable inability of "experts" to agree when presented with the same problem. However, by definition, an expert system is supposed to replicate the behaviour and decision making capability of "an expert", and so the ultimate benchmarking must be against such an expert.

To obtain an accurate assessment of performance, it is necessary to compare results for many selection problems, but there are few experts who have experience of many problems covering the full range of handling equipment that SMART SELECT handles. Therefore it is necessary in practice to resort to using many experts who have a narrow but intimate knowledge of specific handling problems and particular handling equipment. This was the approach that has already been used to assess the performance of SMART SELECT and it is acknowledged that the quantitative results are not readily comparable with any other published data. However a senior industrial engineer employed by a large company [107] commented that "within the team working environment used for equipment selection it is rare for those involved to agree unanimously on a particular solution and agreement between '3 out of 4' (75%) experienced engineers is sufficient to select equipment". This compares with the ability of SMART SELECT to generate results acceptable to 81% of the experts who provided the information.

9.7 Suggestions To Improve SMART SELECT Performance

It has been suggested that providing a way to handle the fuzzification of the selection criteria is likely to improve performance, but suitable software is needed for this task. Currently there are two options. The first is to continue using the existing Flex software with the addition of a recently released fuzzy extension to the software. Secondly, trying to seek a different tool which supports fuzzification.

The second option includes a variety of packages with different features. As an example, a package called Fril [105] was reviewed to highlight some of the features present in comparison to the existing Flex package.

Fril is written in "C" language and is commercially available. Fril is an abbreviation of 'Fuzzy Rational Inferencing Language' and it is an AI logic programming language where each problem can be viewed as a set of logical statements. The individual statements are known as a clauses. Each clause expresses a relationship between terms related to the problem. The data types in the Fril language are known as terms, which can either be a variable, a constant, a number, a fuzzy set, or a list. In general there are two types of clauses, an unconditional clause or fact, and a conditional clause or rule. A Fril program consist basically of sets of clauses which are either facts or rules and are known as the knowledge base [105].

Logic programs are executed by means of queries. The query can be viewed as a theorem to be deduced using the facts and rules in the knowledge base and this is known as querying the knowledge base. The basic operation in executing Fril is unification, which is essentially a pattern-matching process. Syntactic unification is a typical pattern-matching process used in Fril. This process succeeds if two terms are the same or can be made the same by a suitable choice of value for some or all of the variables in the terms, i.e. a constant matches an identical constant, or a variable will match any term and become bound to that term etc. [105].

A query is used to extract information by matching a fact in the knowledge base. The query consists of a list of goals which are considered from start to finish and all the goals must be satisfied for the query to be satisfied. In the cases where there are compound queries with different goals, Fril finds the first solution to each goal; if a goal has no solution then the program returns to the most recent goal where there is an alternative, and tries again. This strategy of finding the first matching clause, and then looking for alternatives if subsequent goals fail is known as backtracking [105].

Fril uses different types of built-in predicates. For example the 'fail' predicate forces Fril to backtrack and find alternative solution, even though the query has succeeded. In contrast the 'cut (!)' predicate avoids an explicit check for alternative solution and prevent backtracking.

Recursion is used as another strategy in Fril which breaks the problem down into easier sub-problems until some elementary case is reached in order to satisfy the query goals. This strategy is frequently the natural programming style in Fril [105].

Fril is capable of treating different types of uncertainty which allows both probabilistic uncertainties and fuzzy sets to be included. If no uncertainties are sought then Fril is equivalent to Prolog with a different syntax. In addition to the Fril Prolog rules, three types of uncertainty rules can be represented in Fril as follows:

1) Basic Rule

2) Extended Rule

3) Evidential Logic Rule

These rules are used with the application provided by the Fril software. The basic rule can be used for 'Fuzzy Control' problems. The extended rule is used to model the 'Fuzzy Causal Nets'. The evidential logic rule can be used for case-based reasoning as well as many applications to pattern recognition types of problem [105].

Lists are used to store different types of data in Fril. A List is a sequence of one or more terms enclosed in parentheses. The fundamental data structure in Fril is the list which is required to group related pieces of information together.

Fril could be considered one of the alternative packages to implement the system. However there are 2 issues associated with this software which need to be highlighted as follows:

1) Mathematical manipulation

2) Program source and data

Baldwin et al [105] stated that the arithmetic capabilities of the Fril software are adequate although it is sometime tedious to split a calculation into component steps. The decision analysis of the system requires different mathematical manipulations in order to derive the final result. This matter should be considered if Fril was chosen for implementation in the new system.

On the second issue Baldwin et al [105] commented that with the querying language adopted it is inconvenient for the non-expert user to conform to a language such as Fril when adding information or posing queries to the database. The user needs to know the form of the relational tables and be familiar with the underlying database structure. Furthermore the similarity between the program source code (facts, rules, and lists) provides an indistinguishable difficulty especially in long programs.

The SMART SELECT existing building tool is Flex (refer to chapters 5 and 6 for more information).

The following table- 9.5 provides a comparison between FLEX and FRIL packages.

Comparison Issues	FLEX	FRIL
Language	Prolog - KSL	Prolog - C
Knowledge Representation	Frames - If ...Then Rules	Facts, Rules (clauses), and Lists
Inferencing Scheme	Forward - Backward	Backward
Uses of Built-in predicates	Yes	Yes
Ability for multi-paradigms	Yes	Yes
Ability to provide fuzzy - Non-fuzzy relations	Yes	Yes
Program segmentation	Files and frames	Statements and lists
Facilities to trace and debug	Yes	Yes

Mathematics Manipulation	Long and tedious	Tedious, it can not be splitted into components
Programming	Not difficult to add information	Not easy to add information

Table-9.5

Table 9.5 shows comparisons between the Flex and Fril packages, and it is seen that there are relatively few difference between the two. The merits and shortcomings of the two packages did not establish a clear basis to choose between them for the fuzzification part of this problem. The fact that the fuzzy extension to Flex will inevitably be quicker and easier to implement when extending the current work is considered sufficient to suggest that it should be tried.

A proposed solution to enhance the selection performance of the expert system is to introduce a fuzzy area between the selection criteria and equipment features boundaries to fully reflect the fact that overlaps occur in practice. For example in real cases equipment is expected to perform under different circumstances to accommodate a range of demands. By creating an overlapped area between equipment features specifications (e.g. setting rate of deliveries/hr at 0-10, 3-60, and > 30 deliveries per hour) this enables the system to select 2 or more pieces of equipment if a situation specifies a delivery rate in the overlap areas 3-10 and 30-60. Furthermore the introduction of fuzziness is capable of covering the subjectivity of data produced by different experts. Nevertheless there is a limitation to this approach which is in selecting the size of areas for the fuzzy boundaries since these could be either too small to produce a significant change in results, or too large which might produce inconclusive outcomes. One way to overcome the difficulty of setting this area may be to use experimental data with the aid of sensitivity analysis testing for final results. This can help in determining the sensitivity of outcomes when changes in fuzzy area are introduced.

A preliminary investigation to evaluate and test fuzzy limits for several selection factors was performed. These fuzzy limits are intended to examine the effect of fuzzification on the initial selection process.

This investigation could not re-use the data from the previous 20 handling situations because the questionnaire did not elicit the actual values for the 'load', 'frequency', and 'distance' factors. Therefore a further investigation was conducted on 9 additional cases using sample values for the selection factors in order to establish suitable fuzzy values. First these 9 cases were evaluated with the existing selection limits which yielded the results shown in Table-9.6:

Case	Existing Method	Preliminary Selection
1	Forklift Truck	Tractor Trailer AGV Tugger Unit-load AGV Roller Conveyor
2	Forklift Truck	Tractor Trailer AGV Tugger Unit-load AGV Roller Conveyor
3	Manual Handling	Manual Handling Tractor Trailer Forklift Truck Chain Conveyor Roller Conveyor
4	Mono-Rail Conveyor	Mono-Rail Conveyor P&F Conveyor

5	Roller Conveyor	Manual Handling AGV Tugger Unit-load AGV Chain Conveyor Roller Conveyor
6	On floor P&F Conveyor	Manual Handling AGV Tugger Chain Conveyor Unit-load AGV Roller Conveyor
7	Forklift Truck	Tractor Trailer AGV Tugger Unit-load AGV Chain Conveyor Roller Conveyor
8	Chain Conveyor	Towline
9	Scissors lift Table	AGV Tugger Unit-load AGV Roller Conveyor

Table-9.6

Table 9.6 shows that in 4 (3, 4, 5, and 8) out 9 cases the system selected the existing handling method in the preliminary selection phase and in cases 9 and 6 it suggested other methods because these existing methods are not represented in a particular groups in the knowledge base. However in the remaining 3 (1, 2, and 7) cases, the system has dismissed the existing methods in this particular phase. These cases will be re-tested when some fuzziness has been introduced to the selection criteria.

The company called Logic Programming Associates (LPA) which produces the Flex software [101] supplied documentation and disks containing several pre-built examples to demonstrate a fuzzy extension of the Flex package. By examining these examples it was possible to simulate the effect of fuzzy boundaries with the existing crisp boundary software. This testing showed that it was possible to introduce an improvement in the initial phase of the selection process.

To improve selection performance it was decided to fuzzify limits of 3 selection factors, namely the 'load', the 'frequency', and the 'distance' because in a significant number of cases (8 cases) these factors either individually or combined were the reason for rejecting viable alternatives. So by providing overlap areas for their limits this might improve the initial selection phase of the system.

But the important question is how to translate crisp values into fuzzy ones? Ross [49] defined fuzzification as the process of making a crisp quantity fuzzy. He elaborated that if the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably fuzzy and can be represented by a membership function. Zimmerman [106] emphasised that for a fuzzy set, the characteristic function allows various degrees of membership for the elements of a given set. However the principle of fuzzy set theory (refer to chapter 4) stated that an object is given a membership value between 0 and 1 in the given fuzzy set which shows its grade of membership to this set.

The mapping process or the fuzzification of crisp data has to follow certain guidelines. Ross [49] listed many methods to assign membership values or functions to fuzzy variables and they are as follows:

1. Intuition

2. Inference

3. Rank ordering

4. Angular fuzzy sets

5. Neural networks

6. Genetic algorithms

7. Inductive reasoning

8. Soft partitioning

9. Meta rules

10. Fuzzy statistics

By comparing both the actual data provided on the 3 selection factors from these particular cases coupled with the selection criteria limits, it was seen that the selection criteria limits require approximately a 50% overlap in which to be able to include the existing methods in the introductory selection phase. It should be recognised that the approximation of the amount of the overlap percentage was based on limited data but it is considered sufficient for this preliminary investigation.

If for example an attempt to generate the membership functions for the 3 selection factors (load, frequency, and distance) based on the 50% overlap, deduced previously, between each pair of sets; the following is the result:

1- Load

Crisp limits in kg	Overlap
0 - 25	12.5
26 - 100	50

101 - 1000	500
Over 1000	-

Table-9.7

Table-9.7 shows the crisp limits of the load factor and the corresponding overlap percentage. In this case the overlap is considered to be only on the lower side of the crisp limits because of the manual handling restriction limit of 25 kg. Then the lower limits will be as follows:

First lower limit = 25 - 12.5 = 12.5

Second lower limit = 100 - 50 = 50

Third lower limit = 1000 - 500 = 500

Therefore the fuzzy limits for the load factor are :

a) 0 ≥ manual handling ≥ 25

b) 12.5 ≥ low ≥ 100

c) 50 ≥ medium ≥ 1000

d) high > 500

2- Frequency

Crisp limits in deliveries/hr	Overlap
0 - 4	2
5 - 60	30
Over 60	-

Table-9.8

The crisp limits of the frequency factor and the corresponding overlap percentage are in Table-9.8. The first crisp range was doubled based on the questionnaire's result as well as to accommodate for the introduction of overlap for this category. In this case there is no particular reason for the overlap to be to one side or other of the crisp limit, therefore it is considered to be on both sides. Then the limits will be as follows:

First lower limit = 4 - 2 = 2

Second lower limit = 60 - 30 = 30

First upper limit = 4 + 2 = 6

second upper limit = 60 + 30 = 90

Therefore the fuzzy limits for the frequency factor are :

a) $0 \geq$ low ≥ 6

b) $2 \geq$ medium ≥ 90

c) high > 30

3. Distance

Crisp limits in metres	Overlap
0 - 10	5
11 - 100	50
Over 100	-

Table-9.9

Table-9.9 consists of the crisp limits of the distance factor and the overlaps. Again applying to both sides of the crisp limits, the limits are as follows:

First lower limit = 10 - 5 = 5

Second lower limit = 100 - 50 = 50

First upper limit = 10 + 5 = 15

Second upper limit = 100 + 50 = 150

Therefore the fuzzy limits for the distance factor are as follows:

a) $0 \geq \text{low} \geq 15$

b) $5 \geq \text{medium} \geq 150$

c) $\text{high} > 50$

Although this fuzzification procedure provided one way of tackling the issue of selection factor crispness, nevertheless complexity arises in deciding which method to use and the amount of data required to obtain optimum values for these fuzzy limits.

Cases 1, 2, and 7 have been re-tested with the fuzzy limits produced previously which resulted in selecting the existing method for cases 2, and 7 (see Table-9.10). This increased the preliminary selection ability of the system from 67% to 89%, i.e. an improvement of 22%. However in just one case the existing method is still eliminated during the preliminary selection phase because of the distance factor limits and this required further adjustment and re-testing for the overlap area.

Case	Existing Method	Preliminary Selection	Ranking	+ 2 Step	-2 Step	System Choice
2	Forklift Truck	Forklift Truck	- 2.91	- 2.89	- 2.21	Forklift Truck
		Tractor Trailer	- 2.32	- 2.49	- 1.57	
		AGV Tugger	- 2.00	- 2.31	- 0.93	
		Unit-load AGV	- 1.84	- 2.14	- 0.64	
		Roller Conveyor	1.43	1.73	1.73	
7	Forklift Truck	Forklift Truck	- 1.96	- 2.41	- 1.79	Forklift Truck
		Tractor Trailer	- 1.24	- 1.67	- 1.19	
		AGV Tugger	- 0.31	- 1.39	- 0.19	
		Unit-load AGV	0.19	- 1.10	0.40	
		Chain Conveyor	0.51	0.29	0.60	
		Roller Conveyor	1.10	1.11	1.20	

Table-9.10

When overlap limits were introduced in the 3 selection factors of the initial selection stage this contributed to a more than 20% improvement in the performance of this stage. Furthermore the overall performance of the system was 89% of which 67% of solutions coincided with the choice of practicing engineers and 22% were technically feasible solutions. In comparison with the 81% performance figure for crisp boundaries this suggests that this approach makes the system more capable of overcoming the rigidity of the boundaries of the selection criteria. However the amount of overlap was based on a small number of handling cases and so must be regarded cautiously, and a larger sample size would provide results leading to determination of an optimal amount of overlap. Hence this investigation provides a foundation for an approach to be used in further work.

The preliminary investigation result of simulating the effect of fuzzifying the selection limits by creating the overlaps showed an increase of overall performance to 89% whereas the existing crisp limits software provided 81%. Therefore the emphasis of further work should be focused on the development of this approach in order to optimise the fuzzification of selection criteria.

CHAPTER TEN Conclusion And Recommendations

Intense competition between local and global enterprises has contributed to the need to develop means for enhancing manufacturing operations, one of which is the 'agile' manufacturing concept. This concept ideally requires frequent changes in layout of a plant to respond to new requirements. However since this is rarely practical for reasons of cost and lost production due to time needed for physical re-location of facilities, handling of material may become a major issue to provide the necessary agility. Changing the handling system will generally be a far less disruptive process than changing the facility layout, but it must be recognised that handling cost will increase as a result of more complex material flow. This is the price that must be paid for <u>not</u> changing the layout.

This means that material handling will play a greater role in the implementation of the new manufacturing paradigm (agility). In these situations it is necessary to have information on what the best handling equipment would be in order to determine the cost penalty associated with the existing handling equipment. It should be recognised that by knowing the best handling equipment for a particular case in comparison to the existing equipment it does not mean that it is necessary to keep changing handling equipment. This investigation is intended to produce a tool to enable an enterprise to investigate the suitability of the existing handling method for the production requirements to determine <u>when</u> it is appropriate to change. The point here is that it is necessary to re-evaluate the handling equipment on a regular basis to stay competitive.

Selecting a suitable material handling method in agile manufacturing situations is a complex task. This complexity is attributed to two important sources of this problem. Firstly the overwhelming number of criteria, factors, and equipment features influencing the selection process. Secondly the issue of interaction between these different elements. Tackling such issues can be difficult because it requires both knowledge and expertise in decision making in this field. This experience is limited to only a few individuals so access to such experts is naturally restricted because of the scarcity of suitable experts. Therefore computerisation of the selection process approach has been used to tackle these difficulties, by creating a systematic selection algorithm capable of handling both the tangible and the non-tangible issues of the problem. This provided the necessary synthesised expertise to carry out analysis in order to rank possible solutions and choose the best handling method.

An expert system approach was adopted for this task because it is capable of providing the required evaluation ability and it fulfilled the need for producing continuous availability of expertise for frequent use in dynamic manufacturing environments. Furthermore it is the need for perpetual consultation in agile manufacturing that makes an expert system such a valuable tool.

A new expert system has been produced to tackle the selection of material handling equipment. The development stages for the system have been analysed in order to establish the knowledge required for the decision making procedure, and original contributions have been made in the following areas :

1) Determining the number of equipment groups

There are an estimated 3.5 million models of material handling equipment available in today's global market. It is impossible to generate a data-base for all these models for the selection purpose and keep it up-to-date. This research indicated that one crucial cause which contributed to the problem of selecting equipment is knowing the generic level (group of equipment) that is best suited to a particular task. Once it is defined, then determining the particular model from manufacturers sales literature is less of a technical problem and more of a business decision.

This work has proposed the concept of fuzziness between groups and has considered the means by which the size of the fuzzy area between groups can be minimised. An analysis resulted in producing 11 equipment groups which are argued to be enough to provide sufficient differentiation, but not too many to make allocation of equipment too ambiguous.

2) Developing 5 steps selection procedure

In an attempt to provide a systematic process for the selection of material handling equipment a 5 step procedure was generated. This is a procedure which guides the user through the necessary stages to acquire all of the information needed in an efficient and logical manner.

3) Defining selection factors and criteria

It was very important to determine the selection factors and criteria which were to be the guidelines for the selection decision making. An analysis provided 7 selection factors and 5 selection criteria for the evaluation process of handling alternatives. It has been suggested that these selection guidelines fall into two categories, namely quantitative and qualitative criteria.

4) Analysing multi-criteria evaluation methods

In an attempt to tackle the problem of quantifying the selection criteria, an investigation to evaluate different multi-criteria techniques was carried out to see which one was most suitable to quantify the qualitative part of the information as well as to provide a confidence factor to assess the consistency of this information. There was no evidence in the literature of an objective means of selecting the most appropriate multi-criteria evaluation methods having been used by any other author in this area. The result showed the AHP method to be the best method for the quantification process.

5) Generating development issues of an expert system

The analysis of ten existing expert systems, in this area, in the literature illustrated that there are 8 issues concerned with development of expert systems. These 8 issues were separated into 3 groups namely, "building", "performance", and "confidence". The original results at this stage provided the foundation for further experimental work to develop an enhanced expert system for the selection of material handling equipment.

Both the "performance", and the "confidence" group issues required further investigation to determine the best analysis methods needed for the decision making process of the new expert system in order to produce appropriate selection decisions.

6) Comparing 3 inference schemes

An analysis was carried out on 3 inferencing methods ("backward chaining", "forward chaining", "forward and backward chaining") to determine which one was most suitable for implementation in the new expert system. No examination of this type was evident in any of the literature surveyed. The "forward and backward chaining" search method, despite not being implemented in any of the examined systems, provided the best way of using the information during the consultation session (see chapter 6). This has been successfully implemented in the developed system.

7) Producing a module for manual material handling

Manual material handling is one of the options available as a solution to a variety of handling problems. The circumstances when manual handling is viable was found to have been overlooked by all but 3 of the expert systems ([18], [87], and [90]) examined and they failed to define clear selection limits for this method in order to be able to choose it. This provided the need to produce a module which contains limits derived from ergonomic data by the author (see Appendix B).

8) Determining decision analysis methods for ranking handling alternatives

Methods for decision analysis was another area where other authors had simply selected and used one method. This work is original in that it evaluates the operation of two decision analysis methods (Liang's [16] equation and the AHP [23] method) which were compared objectively to see which one was better in ranking handling alternatives. This examination of the two methods was carried out on a sample of 100 different cases drawn randomly from the total population of all possible handling situations. This data was tested on each method and showed that Liang's formula was far more consistent in its outcomes than its rival for the ranking stage of handling options (see chapter 8 for quantification).

9) Validating the final system

An important stage that produced original results which appeared to be lacking in approaches adopted by other authors was the validation of system selection performance using real data. This step showed that the new expert system produces valid decisions which are supported by an analysis of these decisions. In addition it provided a confidence factor to evaluate the consistency of judgements. Furthermore this validation stage was supported by two sensitivity analysis tests to check the sensitivity of the system's outcomes which in turn provided more confidence in the final results. Finally the results produced by the expert system were considered by more than 18 practising manufacturing engineers who indicated full agreement with 47% of the selections and accepted 34% as technically feasible. In only 19% of cases was the acknowledged best solution rejected.

These results are considered to demonstrate good performance of the expert system and confirm it as a practical tool for engineers to use to select the technically most appropriate handling equipment in any given situation. However the fact that it did reject an acknowledged best solution suggests that improvement should be possible. It is felt that rigidity in the selection limits which use a sharply defined (pass/fail) boundary on data acquired in the consultation phase is an area worthy of investigation.

A proposed approach to establish fuzzy boundaries for selection criteria (see chapter 9) was investigated. This preliminary experimental work was performed by introducing overlaps in the crisp limits in order to determine the effect of fuzzification on the overall system performance. The result showed an increase in system performance from 81% to 89%. This indicates that this approach can provide a potential base for further work. Therefore it is proposed that further work could be directed toward investigating the "optimisation" of the fuzzy selection criteria limits.

References:

1. Black, R, "*Design & Manufacture An Integrated Approach*", Macmillan Press Ltd., 1996.
2. Gould, P., "*What Is Agility, Manufacturing Engineer*", Pages 28-31, Feb. 1997.
3. Kidd, P., "*Agile Manufacturing Forging New Frontiers*", Addison-Wesley Publishers Ltd., 1994.
4. Sule, D., "*Manufacturing Facilities location, planning, and design*", ITP 1994.
5. Wu, B., "*Manufacturing Systems Design And Analysis*", Chapman & Hall, 1992.
6. Esmail, K., and Saggu J., "*A Changing Paradigm*", Manufacturing Engineer, pages 285-288, Dec. 1996.
7. Iacocca Institute, "*21st Century Manufacturing Enterprise Strategy*". An Industrial-Led View. Volumes 1&2, Bethlehem, PA: Iacocca Institute, 1991.
8. Owen, D, and Kruse G., "*Follow The Customer*", Manufacturing Engineer, Pages 65-68, April 1997.
9. Montgomery, J. C., and Levine L.O. "*The Transition To Agile Manufacturing: Staying Flexible For Competive Advantage*", ASQC, Quality Press, 1996.
10. Booth, R., "*In The Market*", Manufacturing Engineer, Pages 236-239, Oct. 1995.
11. Apple, J. M., "*Plant Layout and Material Handling*", Third Edition, John Wiley & Sons, 1977
12. Meyers, F., "*Plant Layout and Material Handling*", Regents/Prentice Hall, 1993.
13. Allred, J., "*Taking A New Direction In Factory Logistics And Material Handling*", IIE Solutions, Pages 21-25, April 1996.
14. Rembold, U., Nnaji B. O., and Storr A. "*Computer Integrated Manufacturing And Engineering*", Addison-Wesley Publishing Company, 1993.
15. Dux, S., "*Insight*", Industrial Handling & Storage, Page 4, Vol. 18, No. 3, July 1996.
16. Liang, M., Dutta, S.P., and Abdou, G., "*A New Approach to Material Handling Equipment Selection in A Manufacturing Environment*", Pages 255-230, International Industrial Engineering Conference Proceedings 1989.
17. *The Health and Safety At Work Regulations*, 1992.
18. Matson, J.; Mellichamp, J., and Swaminathan, S. R. , "*EXCITE: Expert Consultant For In-Plant Transportation Equipment*", International Journal Of Production Research, Vol. 30, No. 8, Pages 1969-1983, 1992.
19. Gabbert, P.; and Brown, D, "*A Knowledge-base Approach To Material Handling System Design In Manufacturing Facility*", Proceedings Of The International Industrial Engineering Conference, Pages 445-451, 1987.
20. Frazelle, E.; "*Suggested Techniques Enable Multi-Criteria Evaluation Of Material Handling Alternatives*", Industrial Engineering, Pages 42-48, Feb. 1985.
21. Kennedy, W, "*Choosing Equipment: Six Steps For Evaluating Non-Cost Characteristics*", Industrial Engineering, Issue 6, pages 53-55, June 1987.
22. Clemen, R., "*Making Hard Decision*", PWS-Kent Publishing Company, 1991.
23. Saaty, T.; "*The Analytic Hierarchy Process*", RWS Publications 1990.
24. Zeleny, M.; "*Multiple Criteria Decision Making*", McGraw-Hill, NY, 1982.
25. Bookbinder, J. H., and Gervais, D., "*Material-Handling Equipment Selection Via An Expert System*", Journal of Business Logistics, 1992, Vol. 13, No. 1, Pages 149-172.

26. Jackson, P., "*Introduction To Expert Systems*", Second Edition, Addison-Wesley Publishing Company, 1990.
27. Barr, A., and Feigenbaum, E., "*The Handbook Of Artificial Intelligence*", Vol 1, Morgan Kaufmann, Los Altos CA, 1981.
28. Minsky, M., "*Semantic Information Processing*", ed., Cambridge MA, MIT Press, 1968.
29. Hinde, C. J., Fletcher, G. P., West, A. A., and Williams, D. J., "*Neural Networks*", ICL Systems Journal, 11 (2), Pages 244-278, January 1997.
30. Turban, E., "*Expert Systems And Applied Artificial Intelligence*", Macmillan Publishing Company Inc., 1992.
31. Wasserman, G.D., "*Molecular Control Of Cell Differentiation And Morphogenesis: a systematic theory*", Marcel Dekker, New York, 1972.
32. Widrow, B., Rumelhart, D., and Lehr, M., "*Neural Networks: Applications in Industry, Business and Science*", Communications Of The ACM, Vol. 37, No. 3, Pages 93-105, March 1994.
33. Moore, K. L., "*Artificial Neural Networks:Weighing The Different Ways To Systematize Thinking*", IEEE, Pages 23-28, February 1992.
34. Burke, L., and Ignizio, J., "*A Practical Overview Of Neural Networks*", Journal Of Intelligent Manufacturing, No. 8, Pages, 157-165, 1997.
35. Luxhoj, J. T., Williams, T. P., and Shyur, H.,"*Comparison Of Regression And Neural Networks Models For Prediction Of Inspection Profile For Aging Aircraft*"IIE Transactions, Vol. 29, No. 2, Pages 91-101, February 1997.
36. Kartam, N., and Tongthong, T., "*Potential Of Artificial Neural Networks For Resource Scheduling*", Artificial Intelligence For Engineering Design Analysis And Manufacturing, No. 11, Pages 171-185, 1997.
37. Flood, I., "*Performing Calculus Operations On Poorly Understood Engineering Functions Using Neural Networks*", Artificial Intelligence For Engineering Design Analysis And Manufacturing, No. 9, Pages 419-426, 1995.
38. Arai, F., Fukuda, T., Tanaka, T, and Shibata, T., "*Hierarchical Control System For Flexible Material Handling Robot Using Neural Network*", Proceedings Of The IEEE/RSJ International Conference On Intelligent Robots And Systems, IEEE, Pages 534-541, 1992.
39. Botros, N. M., "*A PC-Based Tissue Classification System Using Artificial Neural Networks*", IEEE Transactions On Instrumentation And Measurement, Vol. 41, No. 5, Pages 633-638, October 1992.
40. Thompson, B., Picton, P., and Jones, N. B., "*A Comparison Of Neural Network And Traditional Signal Processing Techniques In Classification Of EMG Signals*", IEE Colloquium On AI Methods For Biomedical Data Processing,The Institution Of Electrical Engineers, Pages 8/1-8/5, 1996.
41. Cook, D. F., and Chiu, C., "*Using Radial Basis Function Neural Networks To Recognize Shifts In Correlated Manufacturing Process Parameters*", IIE Transactions, No. 3, Pages 227-234, March 1998.
42. Al-Tabtabai, H., Kartam, N., Flood, I., and Alex A. P., "*Construction Project Control Using Artificial Neural Networks*", Artificial Intelligence For Engineering Design Analysis And Manufacturing, No. 11, Pages 45-57, 1997.
43. Anthony, D., Hines, E., Taylor, D., and Barham, J., "*An Investigation Into The Use Of Neural Networks For An Expert System In Nuclear Medicine Image Analysis*", IEE Conference On Image Processing, Pages 338-342, University Of Warwick, July 1989.

44. Tsoukalas, L. H., and Uhrig, R. E., "*Fuzzy And Neural Approaches In Engineering*", John Wiley & Sons, 1997.
45. Grefenstette, J., "*Optimization Of Control Parameters For Genetic Algorithm*", IEEE Transactions On Systems Management and Cybernetics 16, No. 1, 1982.
46. Ng, H. N., Salama, M. M., and Chikhani, A. Y., "*A Survey Of The Application Of AI in Capacitor Allocation And Control*", IEEE Candian Conference On Electrical And Computer Engineering; Engineering Innovation, IEEE, Vol.1, Pages 161-164, 1997.
47. Hines, E. L., Gongora-Florian, M. A., and Goodhead, T. C., "*High Reliability Path Generation For Automated Systems*", Realiability Engineering And Its Application (REA) Conference, Pages 43-47, Honolulu Hawaii, USA, August 1994.
48. Davis, L., (Ed), "*Handbook Of Genetic Algorithms*", Van Nostrand Reinhold, New York, 1991.
49. Ross, T. J., "*Fuzzy Logic With Engineering Application*", McGraw-Hill, Inc., 1995.
50. Goldberg, D., "*Genetic Algorithms*", Addison-Wesley, New York, 1989.
51. Hall, M. A., "*Selection Of Attributes For Modeling Bach Chorales By A Genetic Algorithm*", Proceeding Of Second New Zealand International Conference On Artificial Neural Networks And Expert Systems, IEEE, Pages 182-185, 1995.
52. Holland, J. M., "*Adaption In Natural And Artificial Systems*", University Of Michigan Press, Ann Arbor, MI, USA, 1975.
53. Roston, G. P., and Sturges, R. H., "*Genetic Algorithm Synthesis Of Four-Bar Mechanisms*", Artificial Intelligence For Engineering Design Analysis And Manufacturing, No. 10, Pages 371-390, 1996.
54. Fagarasan, F., and Negoita, M., "*A Genetic-Based Method For Learning The Parameters Of A Fuzzy Inference System*", Proceeding Of Second New Zealand International Conference On Artificial Neural Networks And Expert Systems, IEEE, Pages 223-226, 1995.
55. Chen, S., and Wu, Y., "*Genetic Algorithm Optimisation For Maximum Likelihood Joint Channel And Data Estimation*", Proceedings Of The IEEE International Conference On Acoustic And Signal Processing, IEEE, Pages 1157-1160, 1998.
56. Cheung, N., Trautmann, S., and Horner, A., "*Head-Related Transfer Function Modeling In 3-D Sound Systems With Genetic Algorithms*", Proceedings Of The IEEE International Conference On Acoustic, Speech, And Signal Processing, IEEE, Vol. 6, Pages 3529-3532, 1998.
57. Giordana, A., and Sale, C., "*Learning Structured Concepts Using Genetic Algorithms*", Proceeding Of The Ninth International Workshop On Machine Learing, Pages 169-178, 1992.
58. Fogarty, T. C., "*An Incremental Genetic Algorithm For Real-Time Learing*", Proceeding Of The Sixth International Workshop On Machine Learing, Pages 416-419, June 1989.
59. Zadeh, L., "*Fuzzy Sets*", Information And Control, Vol. 8, Pages 338-353, 1965.
60. Barrett, J. D., and Woodall, W. H., "*A Probabilistics Alternative To Fuzzy Logic Controllers*", IIE Transactions (29), No. 6, Pages 459-467, June 1997.
61. Mendel, J. M., "*Fuzzy Logic Systems For Engineering: A Tutorial*", Proceedings Of The IEEE, Vol.83, No. 3, March 1995.
62. Popoli, R. F., "*Objective And Subjective Knowledge In Eestimation*", Ph.D. Dissertation, University Of Southern California, August 1989.

63. Alspach, D. L., and Sorenson, H. W., "*Nonlinear Bayesian Estimation Using Gaussian Sum Approximations*", IEEE Transactions Automatic Control, Vol. AC-17, Pages 439-448, August 1972.
64. Guiffrida, A. L., Rakesh, N. , "*Fuzzy Set Theory Applications In Production Management Research: A Literature Survey*", Journal Of Intelligent Manufacturing (9), Pages 39-56, 1998.
65. Darzentas, J., "*A Discrete Location Model With Fuzzy accessibility Measures*", Fuzzy Sets and Systems, 23(1), 149-154, 1987.
66. Mital, A., and Karwowski, W., "*A Framework Of The Fuzzy Linguistic Approach To Facilities Location Problem, In Applications Of Fuzzy Set Methodologies In Industrial Engineering*", Elsevier Science Publishers B. V., Amsterdam, Pages 323-230, 1989.
67. Bhattacharya, U., Rao, J., J. R. and Tiwari, R. N., "*Fuzzy Multi-Criteria Facility Location Problem*", Fuzzy Sets and Systems, 51(3), 277-287, 1992.
68. Grobelny, J., "*On One Possible Fuzzy Approach To Facilities Layout Problems*", International Journal Of Production Research, 25(8), Pages 1123-1141, 1987.
69. Chung, K., and Tcha, D., "*A Fuzzy Set-Theoretic Method For Public Facility Location*", European Journal Of Operational Research, 58(1), 90-98, 1992.
70. Dweiri, F., and Meier, F. A., "*Application Of Fuzzy Decision-Making In Facilities Layout Planning*", International Journal Of Production Research, 34(11), Pages 3207-3225, 1996.
71. Khouja, M., and Booth, D. E., "*Fuzzy Clustering Procedure For Evaluation And Selection Of Industrial Robots*", Journal Of Manufacturing Systems, Vol. 14, No.4, 1995.
72. Kartalopoulos, S., "*Understanding Neural Networks And Fuzzy Logic, Basic Concepts and Applications*", Institute Of Electrical and Electronics Engineers, Inc., 1996.
73. Driankov, D., Hellendoorn, H., and Reinfrank, M., "*An Introduction To Fuzzy Control*", 2nd Edition, Springer-Verlag Berlin Heidelberg, 1996.
74. Henning, H., Tryba, V., and Muhlenfield, E., "*Automatic Design Of Fuzzy Systems By Genetic Algorithms*", Fuzzy Logic And Soft Computing, World Scientific Publishing Company Ltd., 1995.
75. Scott, A. C., Clayton J. E., and Gibson E. L."*A Practical Guide To Knowledge Acquisition*", Addison-Wesley Publishing Company, 1991.
76. Giarratano, J.; and Riley, G., "*Expert Systems Principles and Programming*", Second Edition, PWA Publishing Company, 1994.
77. Spur, G., and Specht, D., "*Knowledge Engineering In Manufacturing*", Robotics & Computer-Integrated Manufacturing, Vol. 9, No. 4/5, Pages 303-309, 1992.
78. Chan, K., King, C., and Wright, P., "*COMPASS: Computer Oriented Materials, Processes, And Apparatus Selection System*", Journal Of Manufacturing Systems, Vol. 17, No. 4, Pages 275-286, 1998.
79. Ferguson, G. L., Robison, M., and Moynihan, G. P., "*Expert System For Selecting Speed Reduction Components For A Power Transmission*", Journal Of Manufacturing Systems, Vol. 18, No. 1, Pages 66-74, 1999.
80. Giachetti, R. E., "*A Decision Support System For Material And Manufacturing Process Selection*", Journal Of Intelligent Manufacturing (9), Pages 265-276, 1998.
81. Tiong, R., and Koo, T.K., "*Selecting Construction Formwork: An Expert System Adds Economy*", Expert Systems, Spring 1991.

82. Durale, S, "*PROSPECT: A Prototype Expert System To Select The Form Of Marketing Contacts*", Term Paper, The University Of Southern California, 1985.
83. Fisher, E. L., and Maimon O. Z., "*Specification And Robot Selection*", Artificial Intelligence: Implications For Computer Integrated Manufacturing, IFS Publications, Pages 162-187, Kempston, UK., and Springer-Verlag, New York.
84. Luxhoj, J. T., Hellman, S., Lee S. R., and Perdek, J., "*Using Prototype Expert Systems For AGV Selection*", Industrial Engineering, Pages 44-48, Sept. 1992.
85. Luxhoj, J. T., Forsythe, L. M, and Kazunas, S., "*Developing An Expert System To Choose A Sort Sub-System*", Industrial Engineering, Pages 22-26, August 1991.
86. Malmborg, C. J, Agee, M. H., Simons G. R., and Choudhry J. V., "*A Prototype Expert System For Industrial Truck Type Selection*", Industrial Engineering, Pages 58-64, March 1987.
87. Fisher, E. L., and Farber, J. B, "*MATHES: Material Handling Equipment Selection Expert System*", Technical Report NCSU-I.E.-85-17, Department of Industrial Engineering, North Carolina State University, Raleigh, NC., 1985.
88. Hosni, Y. A., "*MHES: Inference Engine For Material Handling Selection*", Computer & Industrial Engineering, Vol. 17, Nos. 1-4, Pages 79-84, 1989.
89. Tabibzadeh, K., "*HEXPERT: An Expert System Approach To Material Handling*", Robotics and Expert System Conference, Pages 57-61, 1985.
90. Park, Y., "*ICMESE: Intelligent Consultant System For Material Handling Equipment Selection And Evaluation*", Journal Of Manufacturing Systems, Vol. 15, No. 5, Pages 325- 333, 1996.
91. Kartam, N., Flood, I., and Tongthong, T, "*Integrating Knowledge-based Systems And Artificial Neural Networks For Engineering*", Artificial Intelligence For Engineering Design Analysis And Manufacturing, No. 9, Pages 13-22, 1995.
92. Waterman D., A Guide To Expert Systems, Addison-Wesley Publishing Company, 1984.
93. Sawyer, B., VP-EXPERT, Rule-Based Expert System Development Tool. (Berkeley, Calif.: Paperback Software International, 1987).
94. Naser, H. N., "*Expert Systems Techniques applied to engineering problems: A Prototype System for Material Handling*", Master's thesis, Dept. of Industrial Engineering, University of Houston- University Park, U. S. A., 1984.
95. Forgy, C. L., The OPS83 User Manual (642 Gettysburg Street, Pittsaburgh, PA: Production Systems Technologies, Inc.), 1984.
96. Tompkins, J. A., 1985. Personal communication, Columbia, SC.
97. NC-Shell Reference Manual, 1987, North Carolina State University, Raleigh, NC, USA.
98. Muller, W., "*Integrated Material Handling In Manufacturing*", 1985.
99. Lindkvist, R.G., "*Handbook Of Materials Handling*", Compiled By The Swedish Transport Research Commission, Publication Of Ellis Horwood Limited, 1985.
100. Buchanan, B. G., Barstow, D., Bechtel, R., Bennet, J., Clancey, W., Kulikowski, C., Mitchell, T. M. and Waterman, D. A., "*Constructing An Expert System*", In Hayes-Roth et al., Chapter 5, 1983.
101. Flex Expert System Toolkit, Reference Manual, Logic Programming Associates, 1990.
102. Win-PROLOG 3.0, Programming Guide, Logic Programming Associates, 1992-95.

103. Freedman, D, Pisani R., Purves R., and Adhikari A., "*Statistics Second Edition*", W. W. Norton & Company, Ltd, 1991.
104. Oppenheim A. N., "*Questionnaire Design, Interviewing And Attitude Measurement*", New Edition, Printer Publishers Ltd., 1992.
105. Baldwin, J. F., Martin, T. P., and Pilsworth B. W., "*Frill - Fuzzy And Evidential Reasoning In Artificial Intelligence*", Research Studies Press Ltd, 1995.
106. Zimmermann, H.-J., "*Fuzzy Set Theory - and Its Applications*", Second, Revised Edition, Kluwer Academic Publishers, 1991.
107. Personal Communication with Longbottom R., Senior Industrial Engineer, Rover Group Ltd., Longbridge, Birmingham.
108. McGraw, K.L., and Harbison-Briggs B.K., "*Knowledge Acquisition, Principles and Guidelines*", Englewood Cliffs, N.J.: Prentice-Hall, 1989.