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A Knowledge-Based Approach for Selection of Material Handling Equipment and Material Handling System Pre-design

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Abstract

For material handling system design, material handling equipment selection is the first stage. Also the material handling system and facility layout design problems are coupled. Solving these problems needs consideration of these three different problems. Right material handling equipment selection and good design of the material handling system and facility layout can increase productivity and reduce investments and operations' costs. In this study, after describing the material handling equipment selection and pre-design of material handling systems problems and explaining their complexity and solution approaches, it is shown that material handling equipment selection and pre-design of a material handling system can be combined by using a knowledge-based approach.

Key Words: Material handling system design, Knowledge-based system

Malzeme Taşıma Ekipmanı Seçimi ve Malzeme Taşıma Sistemi Ön-Tasarımı için Bilgi Temeli Yaklaşımı

Özet

Malzeme taşıma sistemlerinin tasarımında ilk aşama malzeme taşıma ekipmanlarının seçimidir. Aynı zamanda, malzeme taşıma sistemi tasarımı ve imkanların yerleştirilmesi problemleri birlikte çözülmelidir. Doğru malzeme taşıma ekipmanı seçimi, iyi malzeme taşıma sistemi tasarımı ve imkanların doğru yerleştirilmesi üretkenliği artırır ve yatırım ve işletme masraflarını düşürür. Bu çalışmada, malzeme taşıma ekipmanları seçimi ve malzeme taşıma sistemi ön-tasarım problemlerinin tanımlanması ve karmaşıklığının ve çözüm yaklaşımlarının açıklanmasından sonra, malzeme taşıma ekipmanı seçimi ve malzeme taşıma sisteminin ön-tasarımı bilgi tabanı kullanılarak örneklenmiştir.

Anahtar Sözcükler: Malzeme taşıma ekipmanları, malzeme taşıma sistemi tasarımı, bilgi temeli

Introduction

The cost of material handling is an important factor in the facility layout design process which consequently concentrates mainly on its minimisation. With increasing competitive commercial pressure this imposes the requirements for the manufacturing facility to be designed for optimal economy, which indicates the need for careful planning. Well-designed layouts and a Material Handling System (MHS) are thus crucial for cost reduction. The material handling cost can comprise between 30% and 70% of the total manufacturing cost (Sule, 1988).

Many manufacturing industries are adopting a Computer Integrated Manufacturing (CIM) strategy, an important part of which features computer control and a high level of automation. In doing so, the selection and pre-design of the MHS and facility layout design form an important stage, which is a long-term costly proposition. Also any modification or rearrangement of existing systems represents a large expense and can often not be accomplished easily.

In this study, a knowledge-based system for material handling equipment selection and pre-design of these equipments in the facility layout will be discussed. The study comprises two sections. The first is the selection of material handling equipment for related product requirements. The second is decision making for equipment between departments. Another stage can be added to these strategic stages, notably the fine detail of the MHS design.

Material handling was once defined very narrowly, as simply handling of materials. However, it is defined more comprehensively as using the right method to provide the right amount of 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 (White and Apple, 1985). From this most comprehensive definition it can be deduced that there are many aspects which impact upon the MHS design relating to both strategic and detail considerations. Detail consideration of the specific equipment starts with a consideration of the specific parts to be handled, whereas strategic design focuses on more general aspects which comprise the following (Matson et al., 1992):

- the characteristics of the material to be moved,
- the attributes of the method,
- the physical facility constraints under which the task is to be done.

It is the latter, more general aspects which enable the application of expert systems to assist with MHS design (Malmborg et al., 1986). The complexity of the MHS design problem is reason enough for the development of a knowledge-based design aid. However, in order to ensure the effectiveness of this aid, it is necessary to understand fully the components of the problem which contribute to this complexity. These components are multiple, conflicting and noncommensurate design criteria such as the changing design specifications, rapidly changing commercial products and the uncertainty in the operational environment. As with most design problems, MHS design involves trade-offs between the performance of the system based on multiple criteria. For instance, it is generally not possible to implement a system which minimises cost and maximises reliability. Hence, the MHS designer must either explicitly or implicitly consider multiple, conflicting and noncommensurate objectives. These objectives may be well defined in the design specifications (Gabbert and Brown, 1987).

There is a necessity to describe the relationship between MHS design and facility layouts since these two problems are clearly related closely. Because one of the main objectives of facility layout is that of minimising the material handling system cost, these two design problems have to be solved together. The two alternatives for the solution sequence are shown in Figure 1.

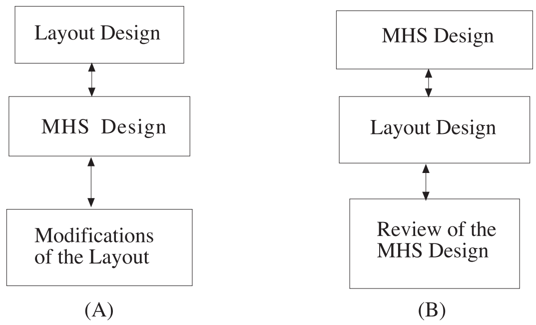

Figure 1. The Solution Sequence and Preferable Relations Between MHS and Facility Layout Design

The preferred method depends on the problem. If the layout can be modified easily, sequence **A** can be selected, otherwise sequence **B** is more appropriate.

The selection of equipment and design of the MHS can be done using four ways:

- by means of a traditional selection method,
- using an analytical model,
- by knowledge-based approaches,
- hybrid approaches (analytical and knowledge-based approaches).

In traditional selection, the designer relies principally on handbooks and experience. This approach may not be cost-effective because of the limitation of personnel experience. Only consulting agencies and large companies are likely to have a specialised planner with full-time facility planning responsibilities. In medium and small size companies, facility layout forms a part of the responsibilities of an industrial or plant engineers activities.

Analytical models have not often been applied in industry, because they generally consider only quantifiable factors such as cost and utilisation and are often difficult to implement (Matson et al., 1992). However, a knowledge-based approach involves the use of expert guidelines and 'rules of thumb' and allows extensive matching of equipment characteristics to application requirements. Practically, this expertise needs to be established over a period of time, based on operational experience.

There are tools other than a checklist to assist the engineer in the selection of MHS equipment and their design with the aim of reducing the total material handling cost (Matson et al., 1992). Knowledge-based approaches have been developed since 1985; however the concept of computerised material handling equipment selection was established in about 1966 (Edt. Art., 1966).

In this first approach (traditional selection method), described in an editorial article published in Modern Material Handling (Editorial Article, 1966), the equipment selection problem and MHS equipment attributes were converted to numerical values using special codes and from among the alternatives the best solution was selected. This best solution was based on a numerical match between the requirement value and the equipment score.

In 1971, the difficulties and complexity of the problem were brought out in a mathematical formulation presented by Webster and Reed (1971). In their study, equipment selection was viewed as an assignment problem where the handling equipment was chosen to perform given moves in order to minimise the material handling cost associated with those moves. The difficulty is one of finding the global optimum; however, heuristic methods may be used for feasible solutions. Both of these approaches were limited by numerical programming restrictions and computing facilities at the time. Since this early work, many articles have been published on the importance of MHS equipment selection and their design (Malmborg et al., 1986; Apple, 1972; Reed, 1976). Most of the facility layout solution articles have mentioned MHS design and its effect on the solutions (Apple and Deiseenroth, 1972). When CIM gained importance, the MHS design problem was again recognised as a key issue since automation and flexibility requirements for manufacturing systems have grown. White and Apple (1985) has brought out the importance of the MHS design and CIM problem together. Multi-criteria selection techniques for MHS design have been summarised by Frazelle (1985). He divided the specifications into five different major areas: return on investment, flexibility, safety, compatibility and maintainability. He also offered decision hierarchy and a graph for decision making. In 1988, Fisher et al. developed an expert system material handling equipment selection, which is based on rules which have been gathered from an expert. The equipment types are selected by applying heuristic selection rules and equipment types have certainty factors. A hybrid approach (1997) was recently published by Velgama et al. The approach combines knowledge-base and optimisation procedures with selection of the material handling system.

These existing approaches help to speed up the design process and to extend personal abilities. However, these approaches and prototypes need to be extended and improved with regard to flexibility and simplicity. In this study, the MHS equipment selection will be defined as a matching problem between product, process handling requirements and equipment specifications using rule sets. A new development will be added with a view to rationalisation of handling equipment between centres, since in a manufacturing system, equipment rationalisation must be adopted to simplify the system and reduce total investment and operation cost.

This work is complementary to previous work (Fisher et al., 1988) because its rationalisation stage reduces selected equipment types to reduce the investment cost of the system. Also, when compared (Welgama and Gibson, 1997), it is more simple and leaves the final stages of the selection and design to the designer.

The Approach

In this study, as described above, the MHS design can be divided into three stages: selection, rationalisation (Yaman et al., 1992) and detail. This is represented in Figure 2 and each of these stages is explained in the following sections.

Product and process specifications and MHS equipment selection for each product

Material handling equipment selection is a complex task and there is usually more than one good solution for any particular situation. These complexities and difficulties have been brought out in many articles (Matson et al., 1991; Gabbert and Brown, 1987). The choice of MHS equipment depends on the product and process requirements. For this reason, MHS equipment can be selected according to the product and process specifications. However, the product specifications need to be considered on the basis of a unit load, which reflects the fact that, where possible, it is more economical to move items and materials in loads rather than individual parts or stock. Then a unit load can be defined as a number of items arranged such that they can be handled as a single object. Each unit load type is most suitable for specific situations. For example, a pallet is most suitable for stacking similar items that have regular shapes. Items that have different shapes and sizes can be grouped inside a container. In general, the factors that influence the selection of the unit load type are the weight, size and shape of the material; compatibility with the material handling equipment; cost of the unit load; and the additional functions provided by the unit load such as stacking and protection of the material (Sule,1988).

According to a previous study (Matson et al., 1992), a product can have up to 35 utilities. However, these 35 specifications can be grouped into two main classes: product features (unit load specifications) and process MHS requirements. These main utilities and their sub-branches can be represented as shown in Figure 3.

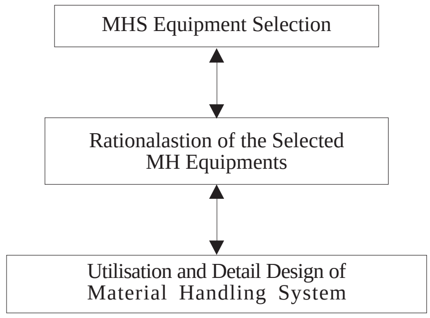

Figure 2. MHS Design Stages

The types of material handling equipment most often belong to one of the seven categories as shown in Table 1 (Greenwood, 1988). These main groups may not cover all MHS equipment types and the attributes may not be sufficient to select the most appropriate equipment. However, these classes and attributes provide a basis for a solution approach.

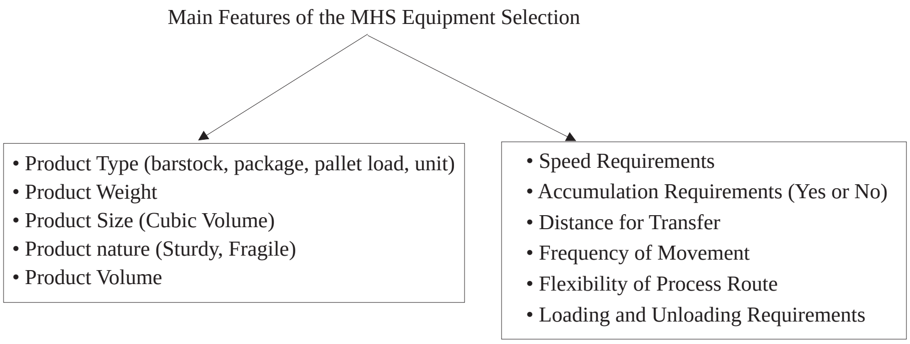

Figure 3. Product and Process Features for MHS Equipment Selection

Finding appropriate equipment for a handling problem involves extensive matching of product and process features and material handling equipment specifications. For this related selection the knowledge-based implementation will be set out in the following section.

The rationalisation of the MHS between departments (nodes)

It is very common that a department or a cell can receive or send more than one product type. Different product types are likely to require different details in the MHS equipment. For this reason, when the selection of the equipment has been completed, rationalisation of this equipment is very desirable for reducing the total investment and operating cost of the MHS.

During this rationalisation, the first point is to establish the equipment alternatives. For example, an AGV and a Rail Guided Vehicle (RGV) have quite similar attributes and if there are material transfers between two departments and they require these two types of equipment at the same time, rather than employing these two types, a rail guided vehicle could be selected. The equipment types and their alternatives have been considered and alternative choices established and arranged in a form in Table 2. These suggested alternatives will clearly need development with experience of operating the design system.

Table 1. Main Classes and Attributes of Material Handling Equipments

MHS Equipment Type	Load Type	Load Capacity	Size	Nature	Speed of System	Accumulation Requi.	Distance	Frequency of Move	Flexibility of Path	Loading and Unloading Ability
Robots	Discrete	Low-Medium	Medium	Solid-Fragile	Low - Medium	No	Short	Often	Low	High
AGVs	Discrete	Medium	Medium	Solid-Fragile	Medium	No	Medium	Often	High	High
Rail Guided Vehicles	Discrete	High	Medium -Large	Solid	High	No	Long	Low	Low	Medium
Gantry	Discrete	Low-Medium	Medium	Solid	Low	No	Medium	Low	Low	High
Fork-lift	Discrete	High	Large	Solid	Medium	No	Long	High	High	High
Conveyor	Continuos	Low-Medium	Small-Medium	Solid	Medium -High	Yes	Short-Medium	Low	Low	Medium
Manual	Discrete	Low	Medium	Solid-	Low	No	Short	High	High	High

In this arrangement, the first row represents the equipment types which have been derived from Table 1. The subsequent rows represent alternative equipment types in order of suitability for replacement. For example, a robot can only be replaced by manual handling for specific conditions. Conversely, manual handling may be replaced by a robot under some specific conditions. This basic approach may be expanded for different MHS equipment and conditions according to the MHS equipment database.

Implementation

The main approach stages have been explained above and the flow chart for the procedure can be seen in Figure 4. The approach comprises three stages which are represented by two different knowledge-bases and one external program.

Implementation of the two knowledge-bases have been accomplished using the Leonardo Expert System Shell (Creative Logic, 1989). Leonardo is an example of a relatively new type of software for developing expert system applications. It is a complete program for developing and running expert system applications which may involve hundreds of rules for manipulating expert behaviour. Developing an expert system with Leonardo requires far less commitment of time than developing conventional programs of similar complexity. It does not need a knowledge-base structured in any rigorous way since the Leonardo inference engine takes care of it. Expert system applications are built up step by step in an evolutionary manner, so that it can be checked at each stage of development.

The knowledge-base contains all the rules and the objects which describe a particular topic. It can also contain additional information, such as messages giving extra information to the user, procedures performing mathematical computations and layouts for screens or forms for displaying or inputting information. All this additional information is stored in a knowledge-base which includes object frames.

The function of the external program is to reorganise the data for the MHS selection phase and has been developed using FORTRAN. These aspects will be explained in the following paragraphs.

As described earlier, when the MHS equipment selection has been completed and department connections have been described, there will be a requirement for different type of MHS equipment and the rationalisation of these equipment types is essential. This will be discussed in the next section.

Table 2. The MHS Equipment Replacement Conditions

MHS Equipment	Robot	AGV	RGV	Gantry	Forklift	Conveyor	Manual
Alternative 1			AGV	AGV	AGV		Robot
Alternative 2	Manual	RGV			RGV		AGV
Alternative 3	AGV				Gantry	AGV	

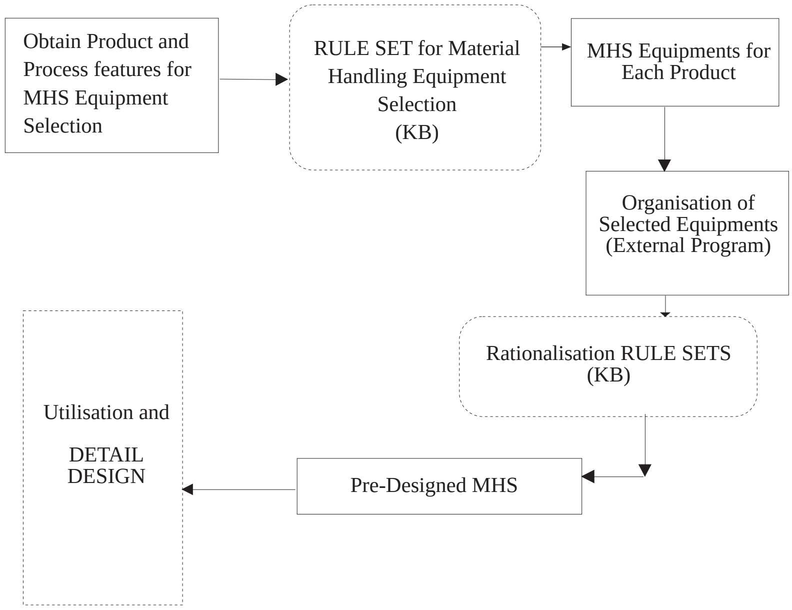

Figure 4. The Main Flow Chart of the Approach

MHS equipment selection for products

The features of the products and process can be obtained from the designer using a multi-choice menu or it can be read from the related database. After completing the features of the products and processes, the inference engine attempts to find from the knowledge-base the appropriate material handling equipment. Then, within the expert system, the read procedure gets the features of the product and processes, and a rule set tries to match these features with the material handling equipment features as discussed in Section 2. A material handling equipment selection rule set example is presented in Figure A1.

By means of an example, in a MHS equipment selection, the selection procedure can be carried out as follows:

If the distances involved within the plant are relatively large, and the components are also relatively large, it is likely that the event intervals between arrival times will be relatively large. In such an instance, an AGV system is likely to prove appropriate, especially if there are many load/unload locations, and the connecting routing is random in nature (Greenwood, 1988).

For this type of reasoning, the possibility of compiling the related rules is favourable. For generalisation, each MHS equipment has been taken as a member of a class, which has a certain number of features and which can be represented by slots in Leonardo. The slots can take different values and therefore different MHS equipment can be represented.

For example, an AGV may be represented using a class object and the details are given in Figure 5.

```
1: Name: AGV
2:     Long Name:
3:         Type:
4:   Value:
5:   Certainty:
6:   Derived From:
7:         IsA: mhs
8: Member Slots:
8:     load_type: discrete
9:       we_ran: high
10:    load_size: mdm
11: req_speed: high
13:    req_acc: very high
14:  req_diss: high
15: frequ_req: often
16: path_flexi: high
17: load_un_ab: high
```

Figure 5. The Frame Structure of an Object in Leonardo

When this selection has been completed, the decision needs to be presented to the designer and written to the related database. This procedure is iterated up to the point where all the products are completed. When all the products are completed the system runs the external FORTRAN program which organises the MHS equipment between departments by means of an arrangement which leads to its rationalisation. The flow chart of the arrangement procedure can be seen in Figure 6; the arrangement procedure works as follows:

- read MHS equipment types of parts,
- record required MHS equipments according to the part process routes,
- create a new file which consists of connected nodes and their MHS equipment types,
- repeat until all the connected nodes are completed.

An example file can be seen in Figure A2 in the Appendix.

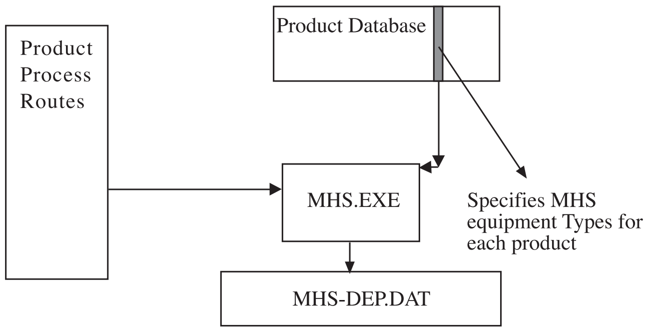

Figure 6. Flow Chart of the Arrangement Procedure

MHS equipment rationalisation between departments

The second stage of the approach involves the set of rationalisation rules, an example of which is illustrated in Figure A3 in the Appendix. This knowledge-base reads the selected MHS equipment which is needed for different products travelling between the two departments. If more than one type of MHS equipment is required between the two departments and any rationalisation is possible then, this is established using these rule sets. This rule set is based currently on Table 2, which describes briefly the alternative MHS equipment. This rule set may be defined simply as follows:

if the requirement of mhs types is more than one

and these types of equipment can replace each other

then select the dominant one.

The process excludes a consideration of utilisation at this stage of development. The principal requirement has been to rationalise on a single type of transportation system and to establish its complete duty in terms of pieces of equipment. This quantification could be completed at the rationalisation stage; in this work it has been categorised as a detail design activity in Figure 4. This may be compared with the approach set out by Apple (1972), where the material handling equipment selection and system design have been considered as a system approach.

This approach and its use for the MHS design will be exemplified in a case study in the following section. Some of the rule sets are given in Figures A1 and A3.

User interfaces

An important point for knowledge-based approaches is user interfaces. This approach has interfaces which mainly help the user during the input sesion and decision making. The first interface directs the user to select product specifications. This interface also has an explanation facility about options. The second interface shows rule-set selected material handling equipments between departments with their percentages. Also in this stage, the user has a chance to change selected equipment between departments. The user interface screens (Figure A4, and A5) are presented in the Appendix.

Case Study

A scenario has been established to fulfil sensitivity tests on the approach. The stages will be discussed in the following paragraphs.

Problem:

An MHS is going to be pre-designed for a plant. The plant is designed for 9 processes and 7 different parts. The parts and process routes and their specifications are presented in Table 3.

When the part and process routes and their MHS equipment information have been gathered, the first stage can be carried out for MHS equipment selection. In this selection, for example, heavy loads, frequent trips, long distances, and low flexibility of the path for Part 1, suggests the use of a Rail Guided Vehicle (RGV). Another example can be given for Part 6. This part is of medium weight, small size and has a fragile nature; these requirements can be satisfied using an AGV. The above features have been considered for all the parts using the first stage of the knowledge-base applications, and the results are presented in Table 4.

Table 3. Product and Process Feature for MHS Equipment Selection

Part No	Part Volumes	Part Routes Process	Material Handling System Requirements of Parts and Processes									
			Type	Loading Capacity	Size	Nature	Speed Requirement	Accumulation Requirement	Distance	Frequency Transfer of	Flexibility of Path	Loading Unloading
1	40	1-3-5-7-4-6	Discrete	High	Big	Solid	High	No	Far	High	Low	Frequently
2	50	1-2-5-6-3-8	Discrete	Medium	Medium	Solid	Low	No	Far	High	Low	Rare
3	40	1-3-4-7-5-9	Discrete	High	Small	Fragile	Medium	No	Short	Low	High	No
4	70	1-2-6-5-8-9	Discrete	Very High	Very Big	Solid	High	No	Medium	Low	Low	Rare
5	20	1-3-2-6-4-9	Discrete	Low	Medium	Fragile	Medium	Yes	Medium	Medium	Medium	Very Frequently
6	70	1-5-3-2-6-8	Discrete	Medium	Small	Fragile	Medium	No	Medium	Medium	Low	Often
7	10	1-3-2-4-6-8	Discrete	Low	Small	Fragile	Medium	No	Medium	Low	High	Often

Table 4. MHS Equipment for Parts

Product No	Pr. 1	Pr.2	Pr. 3	Pr. 4	Pr. 5	Pr. 6	Pr. 7
MHS Equipment	RGV	RGV	Man	Forklift	AGV	AGV	Man

However, this is based on one part requirement and since there are different parts moving between processes, the full MHS equipment requirements between departments are summarised in Table 5. For example, departments 1 and 2 need to be connected with an RGV for part 2, and a forklift truck for part 4. Departments 1 and 3 need to have a RGV, AGV and manual transportation for the different parts. All these requirements are arranged by the external FORTRAN program and lead to the rationalised list itemised in Table 5.

Table 5. MHS Equipment Requirements Between Departments

From Dept. #	To Dept. #	Required MHS Equipment	Rationalised MHS Equipment	From Dept. #	To #	Required MHS Equipment	Rationalised MHS Equipment
1	2	RGV*, Fork Lift, AGV	RGV	4	9	AGV*	AGV
1	3	RGV*, Man, AGV, Man	RGV	5	6	RGV*	RGV
1	5	AGV*	AGV	5	7	RGV*	RGV
2	4	Man*	Man	5	8	Fork Lift*	Fork Lift
2	5	RGV*	RGV	5	9	Man*	Man
2	6	Fork Lift, AGV*, AGV	AGV	6	3	RGV*	RGV
3	2	AGV*, AGV	AGV	6	4	AGV*	AGV
3	4	Man*	Man	6	5	Fork Lift*	Fork Lift
3	5	RGV*	RGV	6	8	AGV*, Man*	AGV, Man
3	8	RGV*	RGV	7	4	RGV*	RGV
4	6	RGV*, Man	RGV	7	5	Man*	Man
4	7	Man*	Man	8	9	Fork Lift*	Fork Lift

* Selected equipment after rationalasition

Conclusions

This study describes a decision aid which may be used by a designer who is not very familiar with selection of material handling systems. The case study exemplifies the selection of MHS equipment using the approach and a recommended rationalisation procedure. Using the rationalisation procedure it is possible to reduce the number of equipment types needed from 35 to 25.

The time-consuming task of MHS equipment selection can be handled using a knowledge-based approach, with interaction by a designer. A knowledge-based approach can overcome the limitations of analytical approaches which are generally limited with only quantifiable factors. Rationalisations of MHS equipment will reduce total investment and operation costs.

This study differs from similar previous approaches, providing the designer with the opportunity to finalise the system selection. It highlights the importance of the material handling system design and facility layout problem, requiring an integrated solution strategy.

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Appendix

MHS Selection Rule Set

The following rule set represents the equipment selection knowledge-base. Here, the requirements have been represented on the left side (i.e., the left side of ":") of the rule set and the equipment specifications are represented on the right side (i.e., the right side of ":"). Thus the gathered requirements of a product are compared with the MHS equipment specifications which are already established in the related knowledge-base. The structure is as follows:

```
for all mhs
if type_load is load_type: of mhs
and range_weight is we_ran: of mhs
and size_load is load_size: of mhs
and natu_load is load_natu: of mhs
and speed_req is req_speed: of mhs
and acc_requ is requ_acc: of mhs
and diss_reg is reg_diss: of mhs
and freq_mov is fre_eq: of mhs
and flexi_path is path_flexi: of mhs
and load_un_requ is load_un_ability: of mhs
then suitable sys includes name: of mhs
```

Figure A1. Example Ruleset of MHS Equipment Selection

```
DEP(1,2)=RGV,FLT,AGV
DEP(1,3)=RGV,MAN,AGV,MAN
DEP(1,5)=AGV
DEP(2,4)=MAN
DEP(2,5)=RGV
DEP(2,6)=FLT,AGV,AGV
..................
```

Figure A2. Departments' MHS Type Requirement Records Before Rationalisation

Rationalisation Rules

This rule set eliminates some of the MHS equipment types if there is more than one type of system and they can be rationalised. The following rule set shows an AGV replacement for an RGV and Forklift.

```
if read is done
and AGV_cert >= RGV_cert
and AGV_cert >= fork_lift_cert
then write_rat(dep1, dep2, agv);
rationalisation is done
```

Figure A3. Example Ruleset of MHS Equipment Rationalisation

User Interfaces

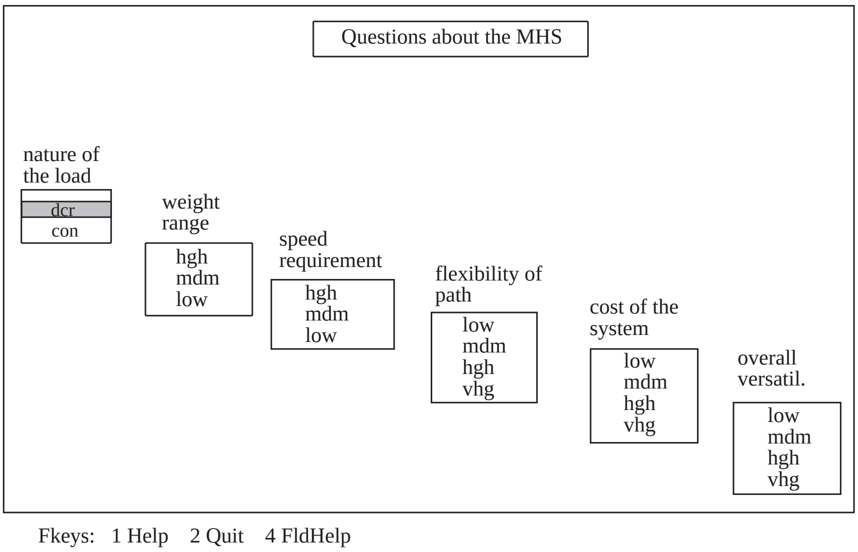

Figure A4. Input Preparation Screen for Selection of MHS Equipment Types

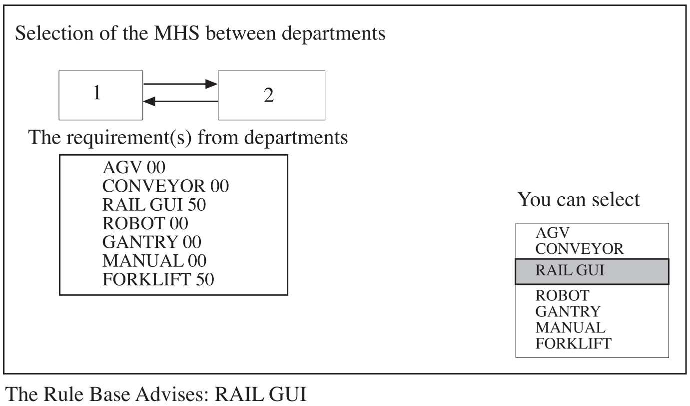

Figure A5. Decision Making Screen for Equipment Selection