An Intelligent Consultant for Material Handling Equipment Selection and Evaluation*

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ABSTRACT

The material handling equipment selection, that is a key task in the material handling system design, is a complex, difficult task, and requires a massive technical knowledge and systematic analysis. It is invaluable to justify the selected equipment model by the performance evaluation before its actual implementation. This paper presents an intelligent knowledge-based expert system called "IMESE" created by authors, for the selection and evaluation of material handling equipment model suitable for movement and storage of materials in a manufacturing facility. The IMESE is consisted of four modules: a knowledge base to select an appropriate equipment type, a multiple criteria decision making procedure to choose the most favorable commercial model of the selected equipment type, a database to store the list of commercial models of equipment types with their specifications, and simulators to evaluate the performance of the equipment model. The whole process of IMESE is executed under VP-Expert expert system environment.

* This paper was supported by NON DIRECTED RESEARCH FUND, Korea Reasearch Foundation, 1993.

1. Introduction

A key task in the material handling system design is the selection and configuration of equipment that requires an massive technical knowledge and systematic analysis. Material handling equipment selection is an extremely complex and tedious task. In recent years, the equipment selection problem has become to be very important, dueing to the frequent changes in facility design and the rapid advances in technology in the area of automation.

Unfortunately, there are few tools other than checklists to aid the material handling engineer in the selection of appropriate, cost-effective material handling equipment. Although a number of quantitative techniques have developed, they have not often been applied in industry because they generally consider only quantifiable factors such as cost and utilization with unrealistic assumptions. Miller and Davis[1], and kusiak[2] have surveyed, classified, and compared a number of them. With this lack of decision aids, especially computerized aids, designers of material handling system have attempted to develop knowledge-based systems to solve such a complex equipment selection problem.

To date, relatively few knowledge-based expert systems for equipment selection have been developed. Farber and Fisher[3] introduced a rule-based expert system for the selection of material handling equipment to be used in transporting unit loads between facilities in manufacturing environment. Gabbert and Brown[4] presented a knowledge-based design aid that seeks to combine expert system and decision science methodologies. Matson et al.[5] developed an expert system for material handling equipment selection that is suitable for movement of discrete parts in a manufacturing facility. Luxhoj et al.[6] presented a prototype expert system for the selection of automated guided vehicle.

There are several limitations of existing expert systems for material handling equipment selection. Most of them are incomplete prototypes that consider only a limited number of equipment types and attributes. In particular, the equipments for storage and warehousing are completely ignored in them. Another limitation of the expert systems is the lack of the solution of the most favorable commercial model for the equipment type identified. Furthermore, they do not include the performance evaluation process of the selected equipment. It is invaluable to justify the selected equipment model by the performance prediction before its actual implementation.

This paper presents a knowledge-based expert system, called IMESE(Intelligent consultant for Material handling Equipment Selection and Evaluation) created by authors, that resolves the limitations of existing expert systems for material handling equipment selection. The IMESE is restricted to handling equipment suitable for movement, storage, and warehousing of materials in a manufacturing facility. The whole process of IMESE is executed under VP-Expert expert system environment.

2. Design of the Knowledge Base

A knowledge base of IMESE includes the knowledge for selecting a material handling equipment type. The knowledge was obtained from published literature. The major sources from which the knowledge base was compiled are: Tompkins and White[7], Apple[8], Konz[9], Meyers[10], Sandler[11], Rehg[12], Miller[13], Luxhoj et al.[6], White and Muth[14], and various journal articles from Industrial Engineering, Plant Engineering, Modern Materials Handling and

Manufacturing Engineering.

2.1 Equipment types and attributes

A total of 50 types of material handling equipment were identified from a survey of literature. Figure 1 shows the equipment types that are included in the knowledge base. The equipment types are initially classified into two groups based on their functions: move equipments and storage equipments. Storage equipments mean storage systems. The move equipments are consisted of pipes, conveyors, industrial trucks, monorails, automated guided vehicles, robots, and cranes. The storage equipments are consisted of bulk storage systems, rack systems, and automated storage and retrieval systems. These represent the major categories of equipment used for in-plant handling today.

All the relevant attributes to the equipment types are identified and included in the knowledge base to select an appropriate equipment type to the given material handling system. A total of 29 attributes were selected from available literature. Selecting an appropriate solution to a given handling problem involves extensive matching of the attributes of move, material, operation, and area with the capabilities of equipment type. The equipment attributes and their values are shown in Table 1.

2.2 Decision tree

In selecting an equipment type, a solution is searched in a sequence of steps with the inference at each step being used to guide the search. Not all equipment attributes are required to arrive at a particular solution in the search. For example, move distance, bulk type, and loading/unloading type are not needed as decision criteria in selecting AGV types. It is effective to the combinatorial problems with these features to design a knowledge base by constructing decision trees.

The decision tree represents a hierarchy of attributes pertinent for selecting an equipment. Following the branches of decision tree are the choices for the values of equipment attributes that become increasingly specific. At the final branch, one equipment type that is unique based on its attributes is recommended. Actually, this is the way experts typically reason about a problem.

Several approaches were used in developing the decision trees. They are:

(1) The decision trees were constructed for selecting the equipment category and equipment type for each category, respectively. So, the search should go through two stages to arrive at the solution of equipment type. This approach simplifies the development of the decision tree and reduces its size significantly.

(2) Only the set of attributes that are important for the selection of each equipment category or type were included in its search path. The longest search path involves 11 attributes for selecting a slat conveyor in conveyor type decision tree.

(3) The orderings of attributes to be searched were designed in the way to divide the equipment options exclusively as many as possible by values of an attribute at each inference step. This method reduced significantly the number of steps to arrive at conclusions. This heuristic approach has an advantage of reducing the search space quickly and thus shortening the search time.

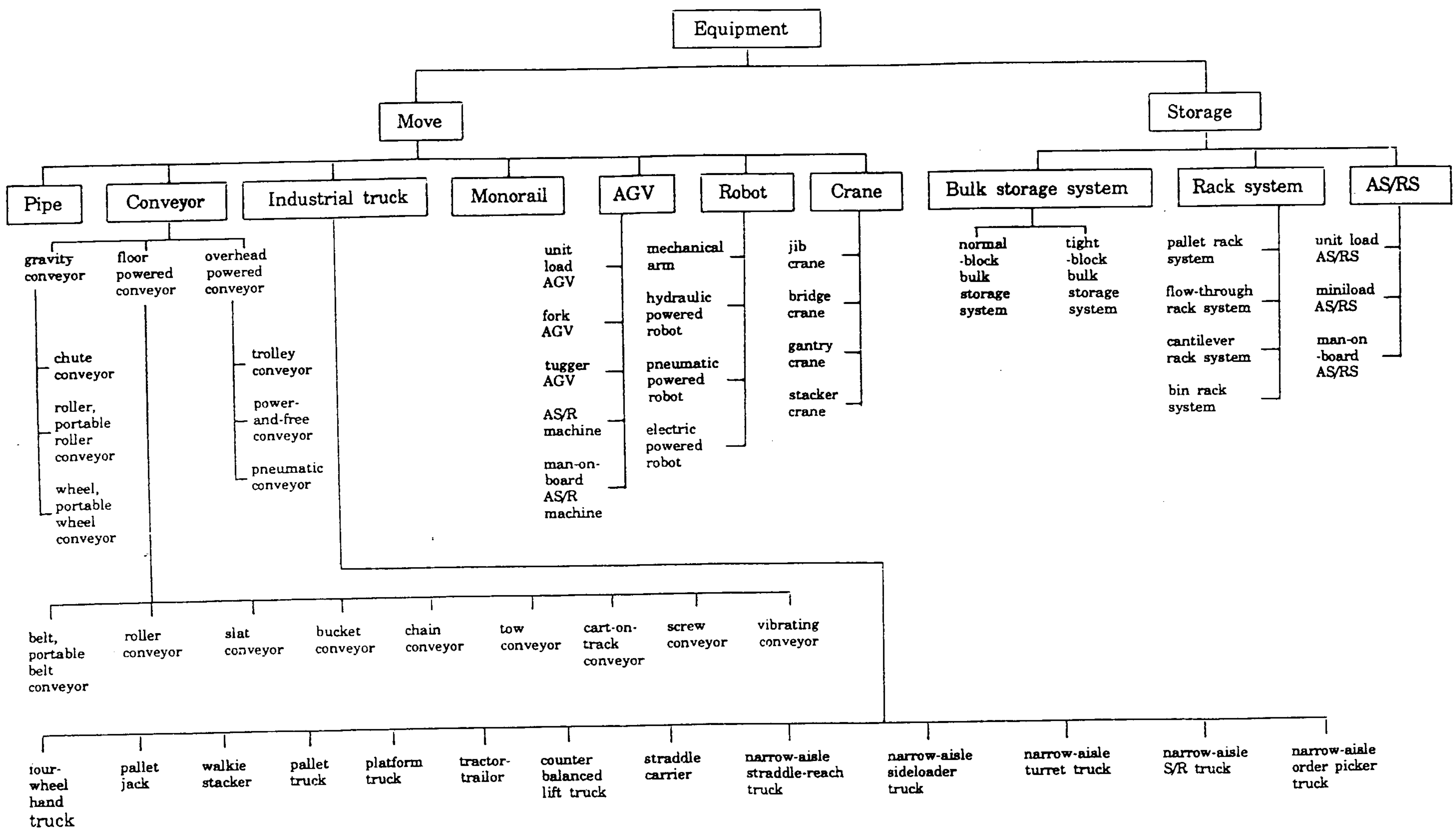


Figure 1. Equipment types included in IMESE.

Table 1. Equipment attributes and their values incorporated in IMESE.

<u>Move</u>

Move type: conveying, transportation, loading/unloading, storage/retrieval
Move distance: very short(∼7m), short(7∼20m), medium(20∼70m), long(70m∼)
Move course: straight, straight/curved or curved
Move level: on floor, above floor — Move path: fixed, variable
Move loop: open, closed — Move area: fixed, variable
Move direction: horizontal, incline, vertical upward, vertical downward, vertical/combinations
Move height: low(∼1m), medium(1∼7m), high(7∼12m), very high(12m∼)

<u>Material</u>

Material size: small, medium, large — Material temperature: low(∼50℃), high(50℃∼)
Material nature: fragile, sturdy — Material quantity: low, medium, high
Bottom surface: flat, no flat — Individual type: unit, packaged
Bulk type: liquid, granule
Material weight: light(∼30kg), medium(30∼500kg), heavy(500kg∼)
Material type: bulk, individual unit, barstock, pallet unit load

<u>Operation</u>

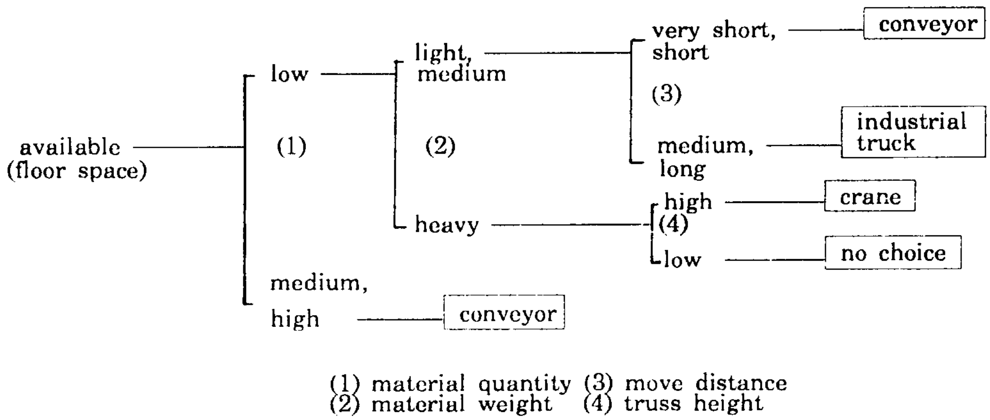
Motion path: fixed, variable — Operation control: uncontrollable, controllable
Load handled: uniform, variable — Automation: not required, required
Accuracy: low, high(±1mm) — Function: move, storage
Loading/Unloading type: pick and place, machine L/U, palletizing

<u>Area</u>

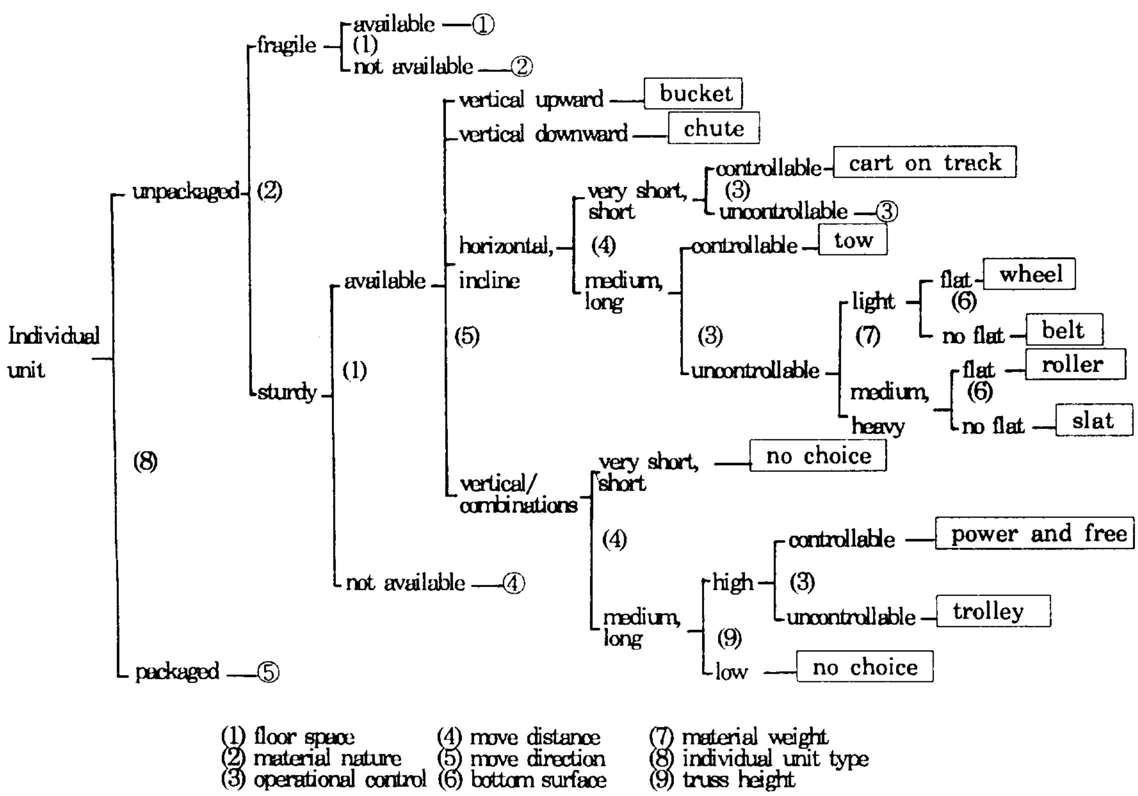
Storage area: floor, rack, AS/RS — Floor space: not available, available
Truss height: low(∼4m), high(4m∼) — Rack deep: single, double
Aisle width: small(1.5∼2.5m), medium(2.5∼3.5m), large(3.5m∼)

(4) When two or more equipment alternatives were available at the final branch, one of them was chosen as the conclusion on the basis of economic evaluation addressed in the literature.
(5) The conclusion of 'no equipment option available' or 'manual handling option' was included when there was no suitable equipment option.

As an example, Figure 2 shows the segments of two decision trees. Decision tree (a) is for identifying the equipment category, and is entered if the operation function is move, the move type is considered as conveying, the material type is individual unit, and the floor space is available. Decision tree (b) is to select the conveyor type.



(a) Decision tree for equipment category



(b) Decision tree for conveyor type

Key) ⓘ : continue on search path

▭ : recommendation

Figure 2. Example of decision trees.

3. IMESE

The IMESE is consisted of four major modules: (1) a knowledge base to select an appropriate equipment type; (2) a multiple criteria decision making(MCDM) procedure to choose the most favorable commercial model of the equipment type selected; (3) a database to store the list of commercial models of equipment types with their specifications; and (4) simulators to evaluate the performance of the equipment model chosen. The configuration of IMESE is given in Figure 3.

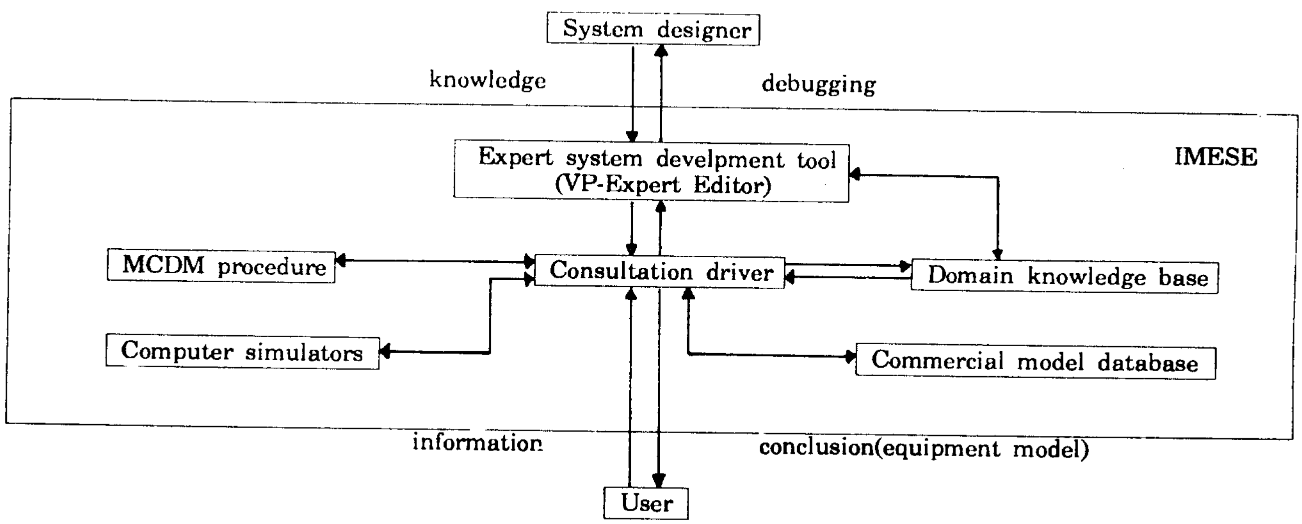


Figure 3. Configuration of IMESE.

3.1 Knowledge base and database

A knowledge base was created by translating the hierarchy of information from the decision trees into a language that the expert system's consultation driver understands. This was accomplished through the development of production rules by using VP-Expert expert system development tool[15].

The order of attributes in each rule follows directly from the hierarchy depicted in the decision trees. Total of 336 rules were stored in the knowledge base, assuming 100% confidence.

A database was constructed to store the lists of commercial models with specifications for 41 move equipment types, using dBASEIII plus. The major sources from which the database was compiled are the equipment catalogues published by manufacturing companies and the magazines related to material handling.

3.2 Multicriteria decision making procedure

A MCDM procedure was developed to choose the most favorable commercial equipment model. The MCDM procedure is consisted of two major stages, a screening process and an analytic hierarchy process(AHP). In the first stage, those commercial models that do not meet the minimum requirements of the critical specifications are eliminated from futher consideration. A specification is classified as critical if its minimum requirement must be met by the equipment for the normal operation in the given material handling environment. Table 2 shows the critical specifications of seven move equipment categories. The screening process was programmed by rules and VP-Expert commands.

Table 2. Critical specifications of seven move equipment categories

Pipe: diameter
Conveyor: speed, width, load capacity
Industrial truck: driving speed, climbing capacity, turning radius, overall width, load capacity, lift height
Monorail: speed, load capacity, load quantity
AGV: driving speed, turning radius, overall width, load capacity, positional accuracy
Robot: degrees of freedom, moving speed, load capacity, repeatability, accuracy
Crane: speed, load capacity, lift height

In the second stage, the AHP is applied to choose the best alternative among the commercial models screened in the first stage. Figure 4 shows a four-level hierarchy for the commercial model choice problem. Table 3 summarizes the evaluation criteria structured in the decision hierarchy.

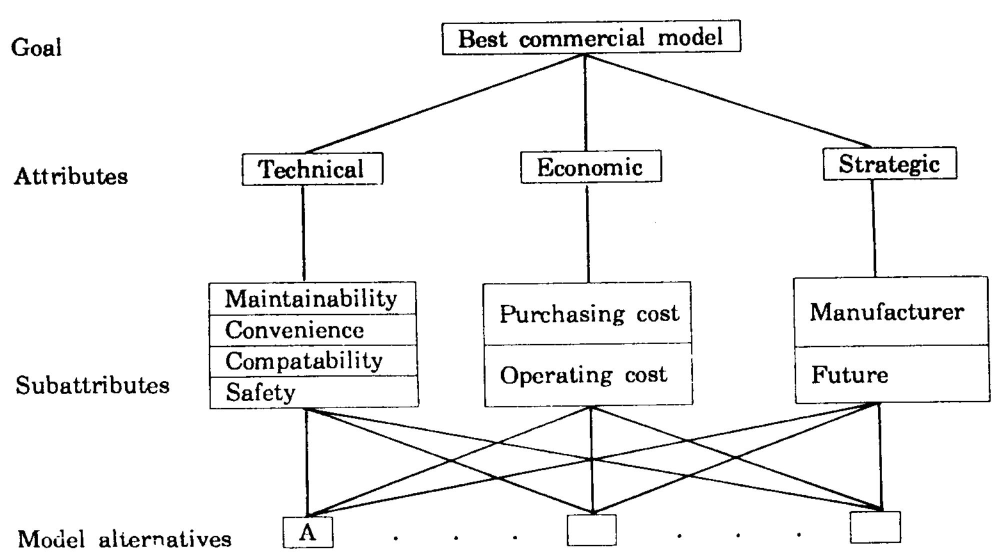


Figure 4. Decision hierarchy for commercial model choice problem.

A upper limit of the consistency ratio for pairwise comparisions was set as 0.1, following

Satty's suggestion[16]. The MCDM procedure was programmed using FORTAN77.

Table 3. Evaluation criteria structured in decision hierarchy for commercial model choice problem.

Technical aspect

- Maintenance: spare parts supply, durability of model production, repair easiness, after service level, battery charging time and time interval, etc.
- Convenience: operation convenience, automation level, unnecessary sophisticated functions, etc.
- Compatability: easiness of equipment interface at source and destination, etc.
- Safety: accidents record, safety device design, ergonomics design, operator's morale, etc.

Economic aspect

- Purchasing cost: equipment cost, tax, salvage cost, etc.
- Operating cost: labor cost, operator training cost, maintenance cost, energy cost, etc.

Strategic aspect

- Manufacturer: reputation, new model plan, relationship, etc.
- Future: capacity plan, process plan(FMS, automation), etc.

3.3 Simulators for equipment operation

A simulation technique was employed to evaluate the performance of the equipment model in the given material handling system. A total of seven simulators were developed for the seven different cases of equipment operation. The seven cases are shown in Table 4.

Table 4. Seven cases of equipment operation.

Equipment category	Move type	Storage area
1. Conveyor, Monorail	Conveying	
2. Industrial truck, Crane, AGV	Conveying	
3. Industrial truck, Crane, AGV	Transportation	
4. Industrial truck, Crane, AGV	Loading/Unloading	
5. Industrial truck, Crane, AGV	Storage/Retrieval	Rack, AS/RS
6. Industrial truck, Crane, AGV	Storage/Retrieval	Floor
7. Robot	Loading/Unloading	

As an example, the development of a prototype simulator called SIMRT(SIMulator for RoboT's operation) is briefly discussed, that is for case 7 where a robot performs a loading and unloading operation. The SIMRT assumes simply that a robot arm equipped with a single gripper moves parts between two points.

The SIMRT was programmed using SLAMII[17] and FORTRAN77. The program consists of SLAMII input statements, INTLC subprogram to set initial conditions by user's input, USERF function program to return the time between part arrivals, and OTPUT subprogram to print out results of the simulation run. The input data to run the SIMRT are mean time between part arrivals, robot's moving speed, robot's loading and unloading time, and distance between two points. The SIMRT, after the simulation run, prints out the outcomes of performance measures on the screen. The performance measures include the robot's throughput, average queue length of incoming parts, robot's utilization, etc.

3.4 Consultation process

Initially, the IMESE collects the information of equipment attributes by asking questions of the user, following the search path constructed in knowledge base. It then matches its knowledge to the specific values of the attributes and informs the user of the equipment type.

The user inputs a number from a menu in response to a question of qualitative attribute and enters a numerical value for a question of quantitative attribute. The IMESE allows the user to specify a confidence factor between 0% and 100% that accounts for a varying level of certainty for the answer. It then computes a confidence factor for the equipment type selected, by using the confidence factors for the answers specified by the user. If no confidence factor is specified, 100% confidence is assumed. An example screen for equipment attribute selection is shown in Figure 5.

The user is completely free from the inference process the system uses to arrive at its selection of equipment type. If the IMESE is considering a storage equipment, it recommends the user a storage equipment type as a conclusion with a confidence level and completes the consultation process. Otherwise, the process is continued.

The IMESE retrieves all the commercial models of the selected move equipment type from the database and lists on the screen. If there exist two or more models, it executes a MCDM procedure to choose the most favorable commercial model of the equipment type, by using the user's input about critical specifications and pairwise comparisons.

Finally, the IMESE evaluates the performance of the selected equipment model, by running a computer simulator corresponding to the equipment operation environment under consideration. The input data such as interarrival times of materials and equipment's moving speed to execute a simulator are obtained by asking questions of the user.

If the performance output is satisfactory, the IMESE recommends the user a specific commercial model as a final conclusion, with a list of important features of the equipment model such as a confidence level, a priority level among alternative commercial models, specifications, and performance measures. And it completes the whole consultation process. If not satisfactory, it moves its control back to the equipment type selection step and continues the succeeding process. An example screen for final output is shown in Figure 6.

*** MOVE TYPE MENU ***

This attribute aids in defining the type of move being considered.
There are four types of moves:

CONVEYING: Moves involve movement between specific points over a fixed path.
TRANSPORTATION: Moves involve movement over a variable path in a fixed area or over a fixed or variable path in a variable area.
LOADING/UNLOADING: Moves involve lifting, transferring, and positioning of loads in a small fixed area.
STORAGE/RETRIEVAL: Moves involve storing and retrieving of loads in a storage area.

1. CONVEYING
2. TRANSPORTATION
3. LOADING/UNLOADING
4. STORAGE/RETRIEVAL

ENTER YOUR CHOICE NUMBER AND RETURN : **3** ↲

Figure 5. Example screen for equipment attribute in IMESE.

*** EQUIPMENT RECOMMENDATION ***

The consultant system(IMESE) finally recommends HIRATA AR-Z1000F electric powered robot with a confidence level of 100% and a priority weight of 0.83.

SPECIFICATIONS
MFG. COMPANY: HIRATA CORP.
CONFIGURATION: ARTICULATING TYPE
DEGREES OF FREEDOM: 4
POWER SOURCE: AC SERVO MOTOR
MAX. PAYLOAD: 150Kg
MAX. SPEED(w/load): 8m/min
REPEATABILITY: ±0.3mm
ACCURACY: ±0.5mm

PERFORMANCE MEASURES
AVE. THROUGHPUT PER HOUR: 25.8units
AVE. WAITING TIME OF LOADS: 0.08min
AVE. NO. OF WAITING LOADS: 2.41units
AVE. UTILIZATION OF ROBOT: 77.3%

Figure 6. Example screen for final output in IMESE.

4. Conclusion

The focus in this research was on the expert system development for the selection and evaluation of material handling equipment commercial model suitable for movement and storage of materials in a manufacturing facility. It was the first attempt in the development of the expert system for material handling equipment selection to consider the selection of the most favorable commercial model and the performance evaluation of the selected model, in scientific ways. In particular, a significant effort was made to include all the important move and storage equipment types and their commercial models as many as possible. Existing techniques such as database management, AHP, and simulation were successfully incorporated in the consultant system, IMESE.

Regretfully, it was not possible to make the detailed comparisions among the IMESE and existing systems, because no detailed information about the known systems were available in the literature. Though IMESE seems to be excellent in completeness, efficiency and usefulness, comparing simply with some existing systems, more research are required for the improvement of decision trees, expansion of commercial model database, and development of simulators for all the possible equipment operation cases. IMESE will be a useful tool for material handling system designers in industry, especially for those who are not familiar with this task.

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