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# An Integrated Methodology of Knowledge-based Rules with Fuzzy Logic for Material Handling Equipment Selection

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This paper describes a methodology for automating the material handling equipment (MHE) evaluation and selection processes by combining knowledge-based rules and fuzzy multi-criteria decision making approach. The methodology is proposed to solve the MHE selection problems under fuzzy environment. At the primary stage, the most appropriate MHE type among the alternatives for each material flow link is searched. Knowledge-based rules are employed to retrieve the alternatives for each material flow link. To consider and compare the alternatives, multiple design factors are considered. These factors include both quantitative and qualitative measures. The qualitative measures are converted to numerical measures using fuzzy logic. The concept of fuzzy logic is applied to evaluation matrices used for the selection of the most suitable MHE through a fuzzy linguistic approach. Thus, this paper demonstrates the potential applicability of fuzzy theory in the MHE applications and provides a systemic guidance in the decision-making process.

**Key words** : Knowledge-based rules, Fuzzy logic, Material handling equipment

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## 1. Introduction

In material handling systems (MHS) design, the selection of material handling equipment (MHE) types and the determination of the specifications of the selected MHE are important design issues. However, because of the wide variety of MHE types available, MHE selection is an extremely difficult and time-consuming task. The other important factors contributing to the complexity of MHE selection are constraints imposed by the structural environment of the facility, the combination and characteristics of the materials to be handled, and the uncertainty in the operational environment. Owing to the unstructured nature of the problem, many researchers have proposed various approaches. Previous research work on MHE selection can be classified largely into three categories: (1) optimization modeling; (2) knowledge-based rules; and (3) combination of knowledge-based rules and analytic hierarchy approach (AHP).

The optimization modeling approaches are focused on the improvement of the utilization of MHE. A minimum cost MHE is selected first and then some moves are assigned to the MHE until its utilization meets an acceptable level. Mohsen (1985) and Johnson and Brandeau (1993) formulated the selection problem as a mix integer program with the objective of minimizing the total operating and purchasing costs of the selected MHE. Heragu (1997) introduced a deterministic optimization model to help material-handling designers select the required MHE. The objective function of the model minimizes a cost function subject to some specified constraints. Bard and Feo (1991) proposed a nonlinear cost minimization model that can be used by facility plannersto analyze the general manufacturing equipment selection. The objective is to determine how many of each machine type to purchase, as well as what fraction of time each machine has to be charged to a particular type of operation. However these mathematical modeling approaches are extremely difficult to solve for any reasonable size problems. As a result, search technique is normally used instead.

The MHE selection problem is difficult and knowledge-intensive because there are several feasible solutions of varying efficiency, and numerous and conflicting objective functions. Thus, the use of knowledge-based rules has been proposed in solving the problems of MHE selection. This approach emulates the decision-making process of a human expert in a given area. Even though the decision procedure is complicated and not well understood, knowledge-based rules have been used to a limited extent in some problem areas (Heragu, 1997). Fisher and Farber (1988) presented a knowledge-based approach for the selection of MHE to be used in transporting unit loads between facilities. Gabbert and Brown (1989) introduced a knowledge-based design approach to combine expert system and decision methodology. Kim and Eom (1997) developed a MHE selection expert system for electronic assembly. Malmborg and Simons (1986) introduced a prototype expert system for the selection of industrial trucks. Chu, Egbelu, and Wu (1995) developed a computer-aided MHE selection system to automate the equipment selection process. An economic analysis was included in the decision making process. Welgama and Gibson (1995 & 1996) combined expert system and optimization algorithm to solve the MHE selection problem.

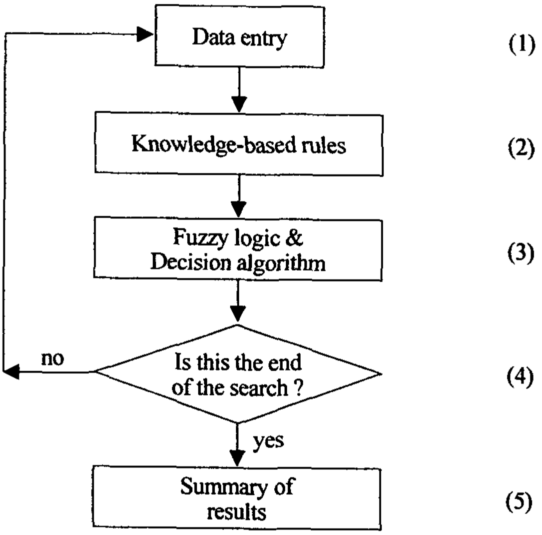
Because of the complexities involved in the problem of selection of MHE, knowledge-based rules seem to have a great potential for the problem. However, a general limitation of knowledge-base approaches is that they commonly suggest feasible alternatives based on certain requirement. Thus, the multi-criteria decision-making procedure using AHPs has been proposed in solving the problems of MHE selection. Park (1996) introduced an intelligent consultant system called ICMESE for MHE selection and evaluation. A knowledge-based system and with an AHP were used in choosing the MHE. Chan (2002) integrated an expert system with an AHP for the selection of MHE for material transport and storage in a facility.

There are several limitations related to the problem of MHE selection in the set of approaches that has been reported in the literature. Most are incomplete prototypes that consider only a limited number of MHE types and attributes, and are not very successful to deal with the qualitative factors associated with the problem. Very little attention has been paid for selecting accurate MHE from a set of alternatives under fuzzy environment. To be useful in practice, material handling system design must not only consider quantifiable factors such as cost and aisle space but also technical and strategic factors such as working condition and environmental condition of the facility. The emphasis on equipment selection has been limited mostly on quantitative measures instead of both quantitative and qualitative factors. Furthermore, there are no attempts are made to optimize the overall material handling system. The approaches reported in the referenced papers above tend to ignore these points.

In this paper, a methodology for automating the material handling system design problem is presented. The approach combines knowledge-based rules and fuzzy logic, so called an integrated methodology for MHE evaluation and selection. Namely, a decision-support system and a decision-making system are combined. The methodology considers the issues that were generally ignored by some of the earlier reported works. The following section provides the descriptions of the knowledge-based rules that search for alternatives for each material flow. This is followed by multi-criteria decision making procedure that evaluates and obtains the ranking of the alternatives with consideration of the qualitative factors. The procedure consists of evaluation factors, fuzzy membership function, and evaluation matrices. Also an example is provided to demonstrate the use of the methodology.

## 2. Design of knowledge-based rules

Knowledge-based rules search and generate several alternative solutions for a given move using the attribute values specified by the user for the move. The fuzzy multi-criteria decision making procedure evaluates the alternative solutions generated by the knowledge-based rules to provide a recommended solution. The overall decision



[Fig. 1] Summary of algorithmic steps

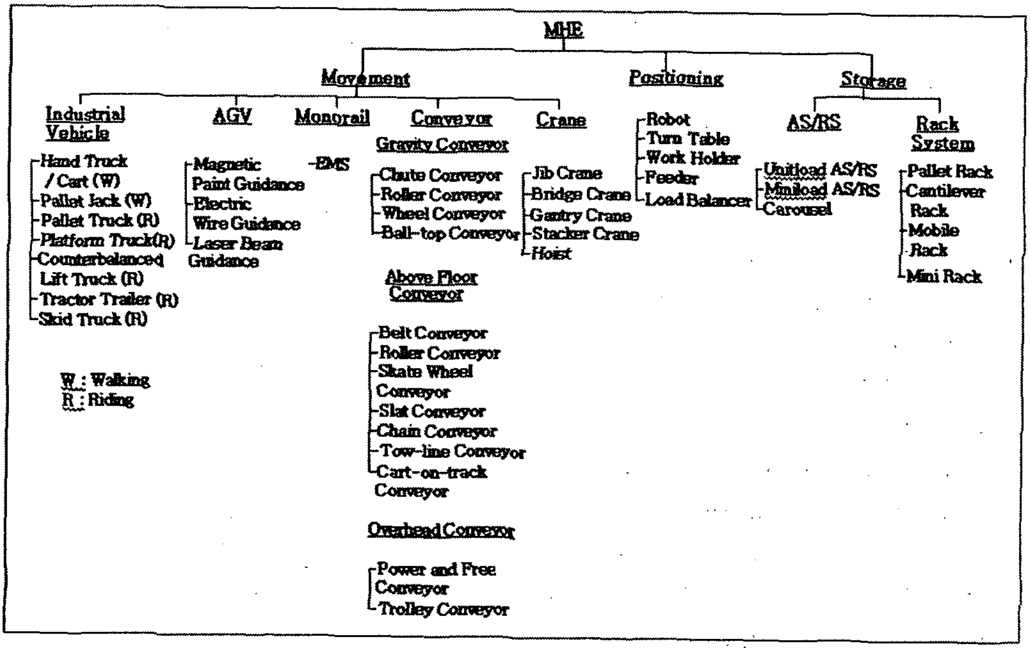
steps for the search procedure of the methodology are summarized in [Fig. 1].

In this section, knowledge-based rules are presented to address the major criteria that influence MHE selection.

## 2.1 MHE types and attributes

A total of 41 MHE types are considered for the knowledge-based rules in this study. Provision has also been made for the addition of more MHE types in the future as the user's need may call for. [Fig. 2] shows the list of MHE types identified from literature (Park, 1996; Chan, 2002; Chu et al., 1995; Fisher and Farber, 1988; Gabbert and Brown, 1989; Kim and Eom, 1997). These represent the major types of MHE used for in-plant material handling. These MHE were classified into three groups based on their functions: equipment for movement, equipment for storage, and equipment for positioning.

In the design of the methodology, 37 relevant attributes of the 41 MHE types were identified and included in the knowledge-based rules. These attributes constitute the primary elements for matching the equipment alternatives to the moves. These attributes were classified into four groups: *(a) general attributes related to the manufacturing facility, (b) attributes related to the material to be handled, (c) attributes related to the move, and (d) attributes related to the operation and data treatment.* To select as a suitable MHE for a move, extensive matching of these attributes to the move under consideration is required. The



[Fig. 2] MHE types used in this research

<Table 1> General and material attributes included

| General attributes | Material attributes |
|---|---|
| • Automation level: manual, semi-programmable, Programmable<br>• Expected production trend: increasing, highly increasing, decreasing, highly decreasing, stable<br>• Product mix: high, medium, low<br>• Budget<br>• Weights assigned to evaluation factors: for economic (%), for applicability (%), for adaptability & integratability (%), for maintenance & safety (%), other factors (%)<br>• Operation time per day | • Unit load type: in-container, on-pallet, individual, tote box, barstock, bulk<br>• Unit load weight: light, medium, heavy<br>• Length of unit load: short, medium, long<br>• Width of unit load: short, medium, long<br>• Height of unit load: short, medium, long<br>• Unit load volume: small, medium, large<br>• Bottom surface: rigid, not rigid<br>• Quantity of unit loads to be handled |

<Table 2> Attributes associated with move, operation, and data treatment

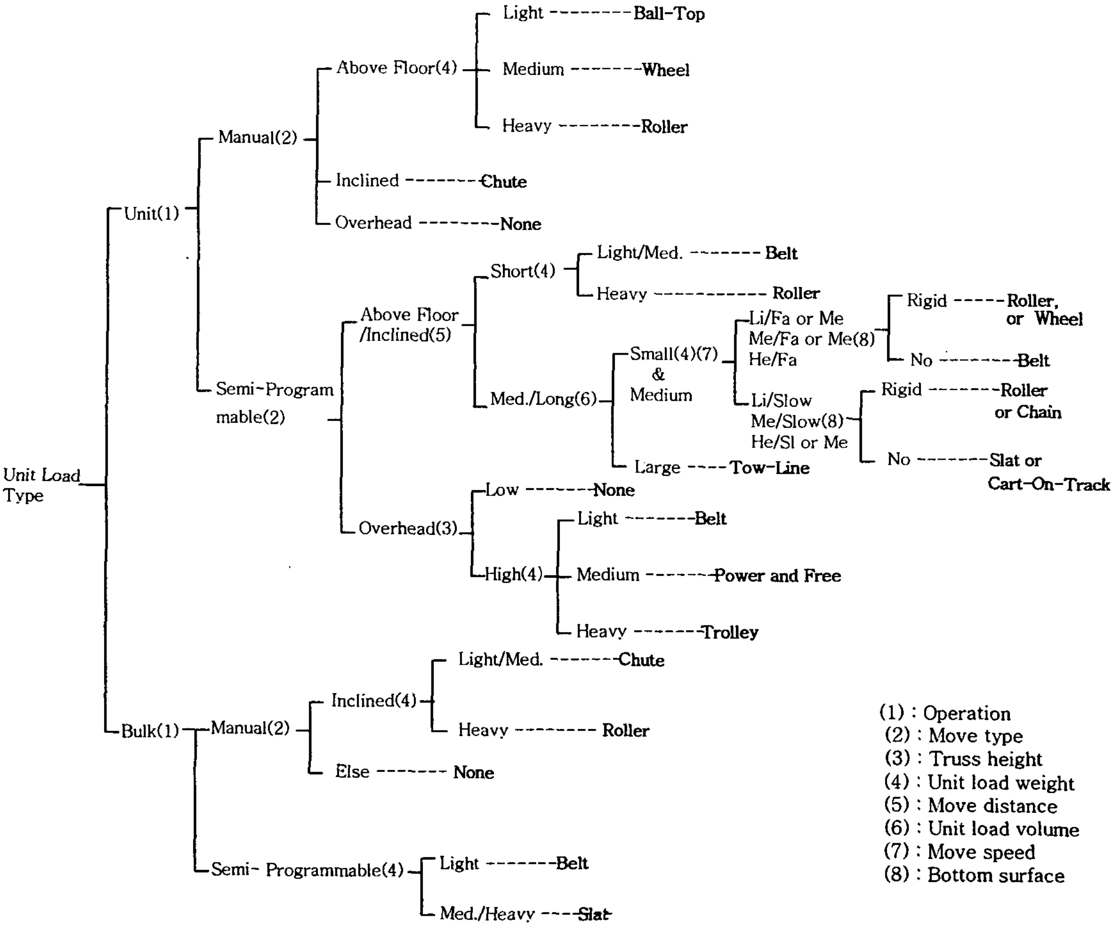
| Move attributes | Operation and data treatment attributes |
|---|---|
| • Move type: horizontal (above floor, overhead), inclined, rotational<br>• Move distance : short, medium, long<br>• Move path : fixed, variable<br>• Move speed required : slow, medium, fast<br>• Length of available space for MHE<br>• Width of available space for MHE<br>• Height of available space for MHE(truss height)<br>• Move pattern : continuous, intermittent<br>• Floor surface : smooth, rough<br>• Loading/unloading speed needed at workstation : slow, medium, fast<br>• Loading/unloading(L/U) automation level : manual, machine L/U, automatic L/U<br>• Type of workstations associated with the move : 1:1, 1:several,<br>• Direction of the move : one-way, two-way<br>• Type of MHE to be connected : manual MHE, semi-programmable MHE, programmable MHE<br>• MHE type transporting into storage : not decided, manual, industrial truck, AGV, Monorail, conveyor, crane<br>• MHE type transporting out of storage : not decided, manual, industrial truck, AGV, Monorail, conveyor, crane | • Type of equipment : movement, storage, positioning<br>• Operation type : manual, semi-programmable, programmable<br>• MHE motion type : transferring, rotating, gripping, feeding<br>• Accuracy required : low, medium, high<br>• Frequency : continuous, intermittent<br>• Weight control needed : yes(load cell), no<br>• Transaction data treatment : manual, semi-auto, automatic (bar code or RFID) |

attributes considered and their values are summarized in <Table 1> and <Table 2>.

## 2.2 Knowledge organization schemes

There are no rigid guidelines for constructing decision rules in a knowledge-based system. One reasonable way to form knowledge is to represent the knowledge rules in terms of the attributes and values specified. However, this approach cannot be applied to a large problem because it would result in thousands of rule combinations. The rule space will be extremely large for a problem involving 41 MHE types and

37 attributes. It is inefficient and unrealistic to consider a large number of these combinations in the knowledge base. Thus, the problem needs to be solved more appropriately with some more critical attributes in decision-making. In the selection of a suitable MHE for a move, a solution can be found in a sequence of a few steps with the critical attributes (Park, 1996). Each step further directs the search. Therefore, an exhaustive attribute space search and matching are not required to find a fit. This is the general way experts reason about problems and find solutions to them. The user is expected to respond to a series of questions associated with critical attributes. The responses are used in finding a solution to the MHE selection problem. Decision chains are developed to design a knowledge-based system having the features, for example, as shown in [Fig. 3]. This decision chain in [Fig. 3] is used for conveyor type selection.



[Fig. 3] Decision chain for conveyor types

System users are expected to select one MHE group they are considering among the three material handling equipment groups. For example, the user chooses the *movement material handling equipment* as the group of equipment to be considered. In this case the user has chosen equipment type for material movement or transfer. At this stage, the possible MHE sub-groups are conveyor, man-rider industrial vehicle, manual industrial vehicle, AGV, monorail, and crane as shown in [Fig. 2]. Seven different attributes are considered in guiding the search. These attributes include quantity, operation type, move path, move distance, move type, unit load weight, and truss height. If for example in a given design instance the user provides the following specifications: the quantity is *many* (e.g., more than 300 unit loads per day), the operation type required is *semi-programmable*, the move path and the move distance are *fixed* and *short/medium* respectively, then the MHE subgroup that may be suggested is conveyor. After a subgroup is selected, [Fig. 3] is used to further search for the type of conveyor most suitable for the task. Using the decision chain in [Fig. 3], nine attributes are used to select an alternative MHE for the move. Early in the chain, the unit load type is identified as either a *unit* type or *bulk* type. If the attribute is *"unit"* type, then all eight attributes are checked to find the MHE type. If it is *"bulk"* type, then attributes such as operation, move type, unit load weight are checked. When the user specifies *"unit"* as the unit load type, *"semi-programmable"* as the operation type, *"above floor or inclined"* as the move type, *"short"* as the move distance, and *"heavy"* as the unit load weight, a roller conveyer is recommended as a possible MHE type for the move. The alternatives (e.g. chain conveyor, AGV, gantry crane, pallet truck) to a roller conveyor are retrieved from the alternative table in the database. The knowledge was obtained from published literature and related materials. The processing logic for each branch in the entire decision chain for the MHE type selected is applied in a similar manner.

A total of 259 rules were stored in the knowledge base and the knowledge base was executed under the ART-IM expert system environment. Part of the rules that refers to the above example is represented as below:

```
Rule 45_Conveyor
   IF :  unit load type is "unit" and
         operation type is "semi-programmable" and
         move type is ("above floor" or "inclined") and
         move distance is "short" and
         unit load weight is "heavy"
 THEN:  [recommended_MHE type is "roller conveyor"
         alternative #1 is chain conveyor
         alternative #2 is AGV
         alternative #3 is gantry crane
         alternative #4 is pallet truck]
```

## 3. Multi-criteria decision-making procedure

The decision-making procedure to select the final suitable MHE type among alternatives for each move (material flow link) after considering the selection factors described in next section is developed. Alternatives MHE for a move are obtained from the knowledge-based rules. To consider and compare the MHE alternatives based on the selection factors, fuzzy membership function and evaluation matrices are employed.

### 3.1 Evaluation factors

To narrow the choice of alternatives to a final suitable MHE type for each material flow link, not only does the system consider the economic competitiveness of the alternatives but also their applicability, adaptability and integratability, maintenance and safety, and other evaluation factors a user deems worthy of consideration. These factors include both quantitative and qualitative measures. The main elements of the factors are summarized in <Table 3>. [Fig. 4] is a graphical illustration showing how the evaluation factors are jointly considered to arrive at the final selection of the appropriate equipment.

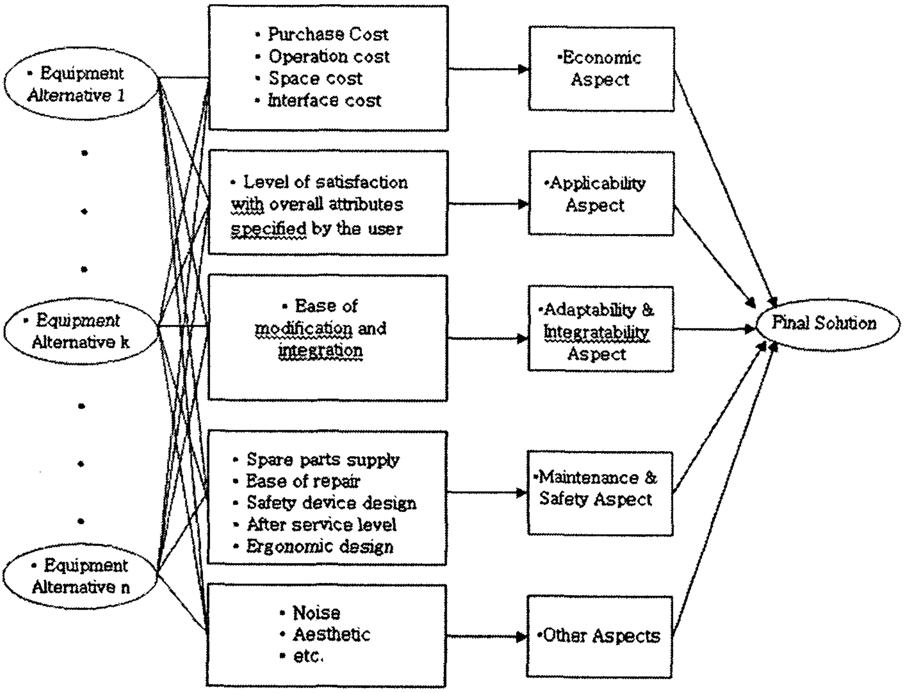
### 3.2 Fuzzy membership functions

The fuzzy set theory, which originated with Zadeh (1975), allows for the existence of some level of uncertainty in decision-making due to vagueness or fuzziness rather than due to randomness alone. In this research, fuzzy logic was applied to consider subjective factors such as applicability, adaptability & integratability, and maintenance & safety, to evaluate the MHE alternatives in terms of these factors. The use of fuzzy logic makes it possible to consider subjective factors in the decision process. The procedure selects the final suitable MHE type among alternatives for each move after jointly considering the five evaluation factors mentioned in the previous section. Generally knowledge-based rules suggest feasible alternatives for a move based on certain requirement. A combined approach that uses both knowledge-based rules & fuzzy logic is a more practical and realistic way of making MHE selection decisions.

While some of the evaluation factors such as

<Table 3> Evaluation factors for each aspect

| Aspect | Evaluation factors |
|---|---|
| Economic | How economical is the MHE? The purchase cost, operation cost, space cost, and interface cost are considered. |
| Applicability | How well does the MHE meet the production requirements and the constraints of the production environment specified by a user? |
| Adaptability & integratability | How easy can the MHE be modified to suit a new product or production environment and how well can the MHE be readily integrated with the existing MHE? |
| Maintenance & Safety | How economical and safe is the MHE for maintenance and safety? Spare parts supply, easiness of repair, safety device design, after service, and ergonomic design can be considered. |
| Other | How acceptable is the MHE based on the factors the user deems worthy of consideration such as noise, beauty, etc.? |



[Fig. 4] Decision chain for the final solution for a move

the economic measure are objective and easy to quantify, other factors such as applicability, adaptability & integratability, maintenance & safety, and others are subjective and not easy to quantify. In addition, while the objective factors can be evaluated in monetary terms, the subjective factors can only be stated qualitatively using imprecise or fuzzy language such as good, poor, average, etc. In this research, a fuzzy linguistic approach is used to quantify the subjective factors that are considered for the selection of the final MHE for each material flow link.

Let's suppose that the universe is represented as: $S = \{V_1, V_2, V_3, V_4, V_5\}$, where $V_1, V_2, V_3, V_4, and\ V_5$ are the measures of five different evaluation factors constituting the elements of *S*. Element $V_1$ represents the measure of the economic factor of an alternative MHE; $V_2$, the applicability factor; $V_3$, the adaptability and integratability factor; $V_4$, the maintenance and safety factor; and $V_5$, any the other factors considered by the user. The fuzzy set "suitable" MHE of a universe *S* is characterized by a membership function $\mu(V)$ and this notion of membership in fuzzy sets becomes a matter of degree, which is a number between 0 and 1. This means that a number in $\mu(V)$ in the closed interval [0, 1] is associated with each element of *S*. The closer the value $\mu(V)$ is to 1, the higher is the indication that the alternative MHE is more suitable for the material flow link based on the factor.

The fuzzy set "suitable" MHE with J factors (i.e., $|S| = J$, the size of the universe) under consideration can be defined through enumeration using the following expression:

$$\text{Suitable} = [\mu(V_1)/V_1,\ \mu(V_2)/V_2,\ \mu(V_3)/V_3,\ \mu(V_4)/V_4,,\ \mu(V_5)/V_5,\ \text{——},\ \mu(V_J)/V_J] = \sum_j \mu(V_j)/V_j$$

where the summation operator refers to the union (disjunction) operation and the notation $\mu(V_j)/V_j$ refers to a fuzzy set containing exactly one element $V_j$ with a membership degree $\mu(V_j)$. Some elements in a fuzzy set may represent objective factors; for example, the economic measure in the case of the example is an objective measure. In this case, the membership function would represent the total cost of the MHE, including the initial equipment cost, annual operating cost, interface cost, space cost, salvage cost at the end of the equipment economic life, and any other sources costs associated with the equipment. The MHE alternative whose total cost (TC) corresponds to the highest possible cost ($\alpha$) among the alternatives is assigned a membership function value of 0, indicating the least suitable equipment based on cost. On the other hand, if there is a MHE alternative with a total cost (TC) of \$0, a very unlikely situation, the membership function will be assigned a value of 1, indicating most suitable from the point of view of cost. The membership function for the economic factor is calculated as below.

$$\mu(V_1) = \begin{cases} \dfrac{(\alpha - TC)}{\alpha} & 0 \le TC \le \alpha \\ 0 & TC > \alpha \end{cases} \tag{1}$$

where $\alpha$ = total cost of the most expensive MHE alternative or the reference MHE alternative

$TC$ = total cost of the MHE alternative whose membership degree is to be computed

$\mu(V_1)$ = a function that maps the fuzzy specification to a membership degree

In essence, the membership function maps the cost associated with each material handling equipment alternative to the range between zero and 1. The more expensive the equipment, the closer to zero its degree of membership becomes and vice versa.

When a factor is assessed qualitatively, its membership value in "suitable" MHE is determined differently. In order to build the membership function for such factors, an estimation method of membership functions called *exemplification* can be applied. For example, to derive the membership function for how good roller conveyors are with respected to applicability aspect, one may ask experts on MHE whether roller conveyors are good from the view point of applicability. To answer the question, an expert may use one of several possible linguistic truth-values such as *true, more or less true,* *borderline, more or less false, and false*. These linguistic levels can then be translated into numerical values such as: 1, 0.75, 0.5, 0.25, and 0, respectively. A discrete representation of the membership function is thus obtained by repeating the query for different MHE. In this research, information from published papers and experience is used to estimate the value of the membership function for qualitative factors instead of conducting an actual survey since conducting such a survey is time consuming and yet yield non-definitive results (i.e., results that may not be superior than that already available in the literature)(Kulweic, 1980, 1985; Heragu, 1997; Modern Material Handling, 1975).

Two types of membership functions commonly used in practice are employed. The Gaussian membership function is used for the linguistic term of *average* because the shape of the function (thin or flat) can be controlled by adjusting the parameter δ. The S membership function is used for the linguistic terms of *good and poor* because this membership function is a smooth function with two parameters, a and b, and the shape is well fitted to the terms of good and poor. These two membership functions are available in the Membership Editor of the Fuzzy Logic Toolbox for MATLAB. For example, [Fig. 5] shows the membership function for the applicability factor. These linguistic terms can be defined by giving each a fuzzy representation on a universe of discourse such as $w$, where

$$w = [0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1]$$

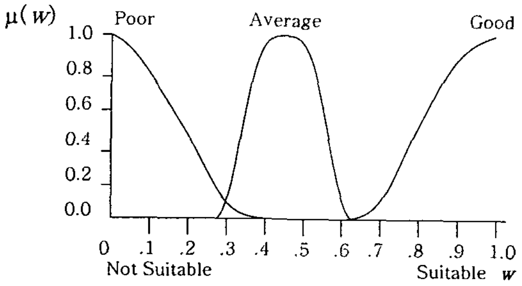
with the membership intervals [0, 1] as follows:

$$\text{good} = [0/0,\ 0/.1,\ 0/.2,\ 0/.3,\ 0/.4,\ 0/.5,\ 0/.6,\ .125/.7,\ .5/.8,\ .875/.9,\ 1/1] \quad (2)$$

$$\text{average} = [0/0,\ 0/.1,\ 0/.2,\ .7/.3,\ 1/.4,\ .7\ /.5,\ 0/.6,\ 0/.7,\ 0/.8,\ 0/.9,\ 0/1] \quad (3)$$

$$\text{poor} = [1/0,\ .875/.1,\ .5/.2,\ .125/.3,\ .0/.4,\ 0/.5,\ 0/.6,\ 0/.7,\ 0/.8,\ 0/.9,\ 0/1] \quad (4)$$

where the numerators and the denominators in equations (2)-(4) represent the degrees of membership and the degrees of satisfaction respectively for a MHE based on the applicability aspect. For example, equation 2 implies that for some equipment, a degree of satisfaction expressed in the range of zero to 0.6 maps to a membership function value of zero while degrees of satisfaction of 0.7, 0.8, 0.9, and 1.0 map to degrees of membership function values of 0.125, 0.5, 0.875, and 1.0 respectively. This in effect states that there are different grades of "good" and that low grades of "good" map to zero values of degree of membership and that higher ratings of "good" translate to non-zero values of degree of membership. Similarly, other linguistic variables, such as adaptability and integratability, and any other user specified qualitative factors could be defined quantitatively or converted to quantitative measures by using membership functions. For applicability, the highest degree of satisfaction, 1.0, is given to the material handling equipment suggested by the knowledge-based rules for a material flow link.

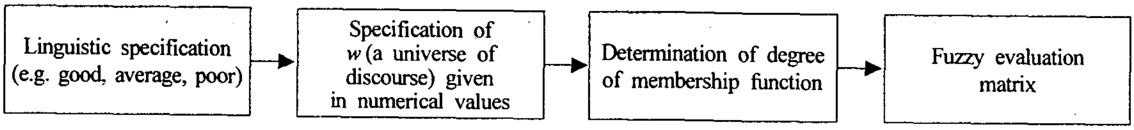


[Fig. 5] Membership function for applicability aspect

Once all aspects involved are quantified, "suitable index" for a MHE can be expressed as a mixed fuzzy numerical set.

$$\begin{aligned}\text{Suitable} = [&\mu(V_1)/V_1,\ (0/.1,\ 0/.2,\ 0/.3,\ 0/.4,\ 0/.5,\\ &0/.6,\ .125/.7,\ .5/.8,\ .875/.9,\ 1/1)/V_2,\\ &(0/.1,\ 0/.2,\ 0/.3,\ 0/.4,\ 0/.5,\ 0/.6,\ 0/.7,\\ &.22/.8,\ .78/.9,\ 1/1)/V_3,\\ &(0/.1,\ 0/.2,\ 0/.3,\ 0/.4,\ 0/.5,\ 0/.6,\ .125/.7,\\ &.5/.8,\ .875/.9,\ 1/1)/V_4,\\ &(0/.1,\ 0/.2,\ 0/.3,\ 0/.4,\ 0/.5,\ 0/.6,\ 0/.7,\\ &.22/.8,\ .78/.9,\ 1/1)/V_5] \qquad (5)\end{aligned}$$

Equation (1) is used for calculating the measure of membership function for the economic aspect $\mu(V_1)$. For the other qualitative measures, the membership functions for the linguistic term of *good* are used. The entire process of determining the 'suitability' of an MHE using linguistic terms (e.g. good, average, poor) and the degree of membership function can be expressed as shown below.



However, since all the evaluation factors or aspects are not equally important, the contribution of each aspect can be adjusted in proportion to its importance. Therefore, the expression of "suitable index" for the MHE needs to be modified as follows to include the weighting values specified by the user in order to obtain numerical values that can be compared among MHE alternatives.

$$\begin{aligned}\text{Suitable} = [&(T_1)\mu(V_1) + (T_2)\mu(V_2) + (T_3)\mu(V_3)\\ &+ (T_4)\mu(V_4) + (T_5)\mu(V_5)] \qquad (6)\end{aligned}$$

where $T_1$, ..., $T_5$ are the weighting values given by the user for the factors in evaluating the material handling alternatives.

### 3.3 Example

In this section, a hypothetical MHE selection problem is designed to explain the application of the procedure. As an illustration of how rating factors are mapped to numerical measures, consider a move i that has four different alternatives. <Table 4> is the corresponding ratings for the alternatives in fuzzy terms based on the five evaluation factors.

In the above expression (5), the numerators indicate the degree of membership function while the denominators are the universe of discourse. Given a membership function with its parameters, the fuzzy linguistic terms are mapped to the equivalent measures $\mu(V_j)$ in the [0,1] domain as shown below in <Table 5>. Suppose MHE 1 is selected as the suitable MHE type for this move by the knowledge-based rules and $\alpha$ is \$100,000. Using equation (1) and the fuzzy subsets of $w$ defined previously as shown in <Table 5>, the values in <Table 5> are mapped into the measures in <Table 6> using equation (5). For example, the total cost (TC) of the MHE 1 is \$60,000, thus the measure of membership function of economic factor for MHE 1 $\mu(V_1)$ is obtained as follows:

$$\mu(V_1) = \frac{(\alpha - TC)}{\alpha} = \frac{40000}{100000} = 0.4$$

The value of $w$ for the applicability factor of the MHE 1 is 1; therefore it is mapped into 1 by the fuzzy subset of *good* for the applicability

<Table 4> Linguistic rating of alternative MHE

| Alternative MHE | Evaluation factor ratings in fuzzy linguistic terms | | | | |
|---|---|---|---|---|---|
| | Economics | Applicability | Adaptability/ Integratability | Maintenance/ Safety | Others |
| MHE 1 | average | very good | good | good | very good |
| MHE 2 | good | average | average | average | good |
| MHE 3 | poor | average | average | poor | poor |
| MHE 4 | average | good | good | average | very good |

<Table 5> Total cost and w values of alternative MHE

| | Total cost (\$) | *w* for App. factor | *w* for Ada. & Int. factor | *w* for Ma. & Sa. factor | *w* for Other factors |
|---|---|---|---|---|---|
| MHE 1 | 60,000 | 1 | 0.9 | 0.9 | 1 |
| MHE 2 | 24,000 | 0.8 | 0.8 | 0.7 | 0.9 |
| MHE 3 | 100,000 | 0.7 | 0.8 | 0.4 | 0.5 |
| MHE 4 | 85,000 | 0.9 | 0.9 | 0.8 | 1 |

<Table 6> Measures of the membership functions of alternative MHE

| | $\mu(V_1)$ | $\mu(V_2)$ | $\mu(V_3)$ | $\mu(V_4)$ | $\mu(V_5)$ |
|---|---|---|---|---|---|
| MHE 1 | 0.4 | 1 | 0.78 | 0.875 | 1 |
| MHE 2 | 0.76 | 0.5 | 0.22 | 0.125 | 0.78 |
| MHE 3 | 0 | 0.125 | 0.22 | 0 | 0 |
| MHE 4 | 0.15 | 0.875 | 0.78 | 0.5 | 1 |

factor. The *w* values for the other factors can be mapped into membership functions in the same manner. <Table 6> is used as a fuzzy evaluation matrix in the decision-making algorithm.

Let us say the weighting values that are specified by the user for the five factors are 30%, 20%, 10%, 25%, and 15%, respectively. By substituting these values in equation (6), the suitable indices for the alternatives can be calculated and compared to select the most appropriate MHE for the move in question. For example,

$$\text{Suitable index for the MHE 1} = [(.3)(.4) + (.2)(1) + (.1)(.78) + (.25)(.875) + (.15)(1)] = 0.77$$

The suitability index for the MHE 1 is 0.77; for MHE 2 is 0.5; for MHE 3 is 0.05; and for MHE 4 is 0.438. In this case, we can say, the MHE 1 is the most suitable MHE for the move since it has the highest suitable index of the four alternatives.

## 4. Conclusion

In this paper, an integrated methodology for the evaluation and selection of MHE under fuzzy environment is proposed. The conventional approaches are less sensitive in making effective decision when the evaluations of MHE alternatives versus criteria and the importance weights are given in linguistic terms. They are based on the concept of total investment and operating cost along with some arbitrary decision rules designed by experienced plant managers. The proposed methodology considers both quantitative and qualitative factors for final MHE selection. The framework of this methodology is based on knowledge-based rules and fuzzy linguistic assessment.

One of the difficulties in this research is to compare the effectiveness of the methodology with the existing approaches and present the results because of non-availability of relevant data. This present work demonstrates the applicability of the integrated methodology in this research area for both objective and subjective design and selection factors.

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## 요약

# 전문가 지식 및 퍼지 이론을 연계한 물류설비 선정 방안에 관한 연구

조지운*

제조 라인의 설계에 있어서 물류설비의 선정은 매우 중요한 부분이다. 생산라인의 특성을 충분히 고려하여 물류설비를 선정하기 위해서는 다양한 요소들이 고려되어야 하며 그 요소들 가운데는 정량적인 요소(예, 자재 부피, 무게)들 뿐만 아니라 정성적인 요소(예, 유지 보수, 통합성)들도 포함된다. 정량적인 요소는 해당 물류설비의 사양 등을 통해 보다 쉽게 평가가 가능하지만 정성적인 요소는 객관적인 분석이 매우 어려운 부분이다. 실제 사례에서도 물류설비 선정 시 정량적인 요소들만 검증되고 정성적인 요소들은 대부분 배제되는 것으로 나타나고 있다. 본 연구에서는 물류설비의 보다 효율적인 평가 및 선정을 위해 정량적인 요소 뿐만 아니라 정성적인 요소들을 반영할 수 있는 방안을 제시하고자 한다. 이를 위해 전문가 지식 기반의 룰(Rule) 및 퍼지 로직을 연계한 통합 방안을 개발하였다. 우선 전문가 지식 기반의 룰을 통해 해당 공정간 적절한 물류설비 유형 및 가능한 대안 유형들을 찾아내고 이들 중 정성적인 요소들까지를 반영하여 최적의 물류설비를 선정하기 위해 퍼지이론이 적용되었다. 본 연구를 통해 퍼지 이론의 제조 물류부분 적용 가능성을 제시하였다.

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