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MULTI-ATTRIBUTE MATERIAL HANDLING EQUIPMENT SELECTION USING INFORMATION AXIOM

Osman Kulak*,
okulak@itu.edu.tr
Pamukkale University,,
Industrial Engineering Department,
Kınıklı, Denizli, Turkey

Sule Itır Satoglu
onbaslis@itu.edu.tr
Istanbul Technical University,
Industrial Engineering Department,
Macka, Istanbul, Turkey

M. Bulent Durmusoglu
durmusogl1@itu.edu.tr
Istanbul Technical University,
Industrial Engineering Department,
Macka, Istanbul, Turkey

ABSTRACT

Effective use of labor, providing system flexibility, increasing productivity, decreasing lead times and costs are some of the most important factors influencing selection of material handling equipment. In this study, a decision support system (MHAD) considering these factors for material handling equipment selection is developed. MHAD consists of a database, a rule-based system and multi-attribute decision making modules. Database includes the detailed data about equipment types and their properties. The rule-based system module provides rules which are utilized by inference engine for determining the most proper material handling equipment type. Ultimately, a final decision is made for the most proper equipment among the alternatives of the same type using the information axiom of axiomatic design principles. Evaluation of alternatives is made for the cases of both complete and incomplete information. This paper introduces the fuzzy Information axiom approach and uses it in the selection of material handling equipment in a real world problem.

Keywords: Material handling equipment selection, axiomatic design, fuzzy sets, information

1. INTRODUCTION

Material handling equipment selection is an important activity in the design of an effective manufacturing system design. Selecting appropriate material handling equipment can decrease manufacturing lead times, increase the efficiency of material flow, improve facility utilization and increase productivity. Material handling can account for 30-75 percent of the total cost, and efficient material handling can be primarily responsible for reducing a plant's operating cost by 15-30 percent [1]. Therefore determination of proper material handling system is very important for reduced costs and increased profits. As a wide variety of equipment is available today, each having distinct characteristics and cost that distinguish from others, determination of the proper equipment for a designed manufacturing system is a very difficult decision.

In the literature, there are various studies focused on the solution of this complicated problem. Intelligent computer systems have been developed such as expert systems and decision support systems for the selection of material handling equipments. One of the most successful applications of experts systems is SEMH-Selection of equipment for material handling. SEMH searches its knowledge base to recommend on the degree of mechanization, and the type of material handling equipment to be used, based on the characteristics, i.e. type, weight, size, etc [2]. Malmborg et al. have developed a prototype expert system considering 17 equipment attributes and 47 devices for industrial truck type selection [3]. Fisher and Farber have introduced MATHES-material handling equipment selection expert systems for the selection of a material handling equipment from 16 possible choices. MATHES including 172 rules considers path, volume of flow, sizes of unit and distance between departments as parameters [4]. MATHES II has been provided with the same procedure as MATHES. However MATHES II has a larger working scope and greater consultation functions. EXCİTE addressing 35 equipment types, and 28 material, move, and method attributes has been developed by Swaminathan et al. [5].

Chu et al. have provided a computer –aided material handling equipment selection system including an economic analysis in the decision-making process [6]. Park has developed ICMESE-Intelligent consultant system for material handling equipment selection, including 50 equipment types and 29 attributes, i.e. move attributes, material characteristics, operation requirements and area constraints [7]. Kim and Eom have introduced MAHSES-Material handling selection expert system. It carries out its inference on the basis of user supplied attribute values and the heuristic rules stored in the knowledge base [8]. Chan et al. have developed an intelligent material handling equipment selection system called MHESA-Material handling equipment selection advisor. An expert system has been integrated with analytic hierarchy process for the selection [9]. Fonseca et al. has developed a prototype computer-based system to select suitable

* Corresponding author: Osman Kulak, okulak@itu.edu.tr,

conveyor solutions from a list of 76 conveyor types. The system ranks the conveyor types on the basis of their suitability scores, computed through the Weighted Evaluation Method and the Expected Value Criterion [2].

Existing expert systems for the selection of material handling equipment have several limitations. Most of these systems do not consider all of the technical, strategic and economic criteria simultaneously in the selection of the most appropriate equipment. Approaches that include more than one measure of performance in the evaluation process are termed multi-attribute or multi-criteria decision methods. The advantage of these methods is that they can account for both financial and non-financial impacts. The information axiom which is the second axiom of Axiomatic Design (AD) provides the basis for decision-making when there are many choices [10]. A new model based on this axiom is generated to support decision-makers in material handling equipment selection process. In order to avoid the pitfalls of preceding methods, AD based method enables decision-makers to evaluate both qualitative and quantitative criteria together.

Many AD applications in designing products, systems, organizations and software have appeared in the literature in the last 10 years. Suh has introduced AD theory and principles first time [11]. Kim et al. applied AD principles on software design [12]. AD principles have also been used in design of quality systems [13] and general system design [14]. Suh and Cochran have provided a manufacturing system design using AD principles [15]. AD principles have also been applied in designing flexible manufacturing systems [16]. Chen et al. Have proposed a knowledge-based decision support system using independence axiom of AD in order to improve cell performance [17]. Kulak et al. have provided a road map for designers who are ready to transform their traditional production system from process layout to cellular layout, based on Axiomatic Design (AD) principles [18]. Kulak and Kahraman have applied multi-attribute AD and AHP approaches for the selection of transportation company under determined criteria (such as cost, time, damage/loss, flexibility and documentation ability) [19]. Other applications of Axiomatic Design include process and product development [10]. These studies have convincingly shown the applicability and benefits of AD in solving industrial problems.

In this paper, a fuzzy multi-attribute ınformation axiom approach for selection of the most proper material handling equipment meeting the designer requirements will be introduced and the implementation process will be shown by a real world example.

2. SYSTEM STRUCTURE OF MHAD

Expert systems are programs in which domain knowledge about a problem is embodied in a set of modular chunks, known as rules, frames, objects, or scripts, that are stored in a repository called a knowledge base. MHAD which is developed in order to simplify the selection process of the most appropriate material handling system consists of the following modules (See Figure 1):

2.1. Introduction Modules:

The MHAD System consists of Material Handling Equipment IM, Axiomatic Design and Principles IM, and Expert Systems IM modules. The user is provided detailed information in the user-guide modules about the system.

2.3. Database for material handling equipments:
In the literature, the material handling equipments are classified at the main groups of industrial trucks, conveyors, automated guided vehicles, cranes, industrial robots and storage/retrieval systems. This module of the system includes the material handling equipments and their properties (Table1).

2.2. Database for Manufacturing Systems:
This module of the system includes the relevant data of the production system that needs material-handling equipment. The data mentioned in Table 2 should be entered to the system accurately and in a reliable way for the selection of the equipment for the production system.

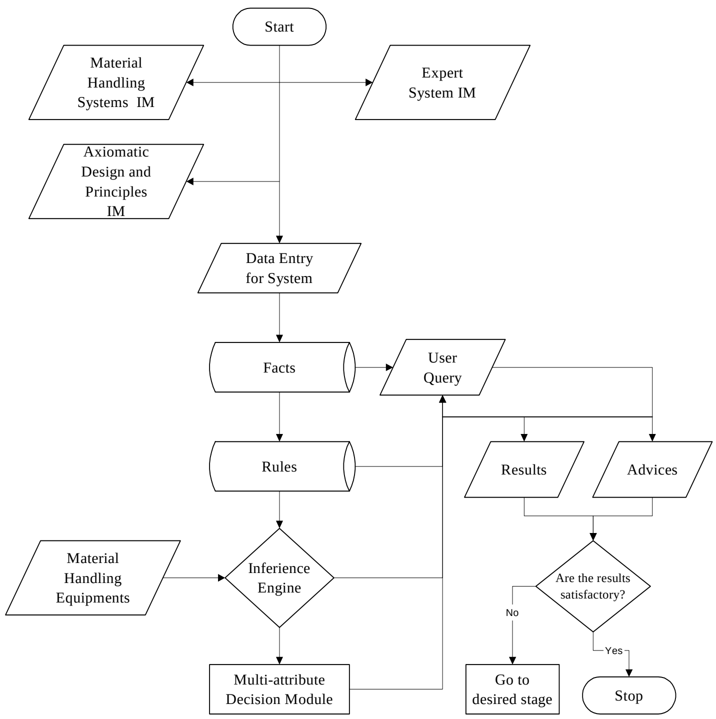

Figure 1. Configuration of MHAD

Table 1. Material handling equipment types

1	Industrial Trucks	Handcart, tier platform truck, hand lift truck, power-driven handtruck, power-driven platform truck, forklift truck, narrow-aisle trucks, material lift, tractor-trailer train, drum truck, drum lifter.
2	Conveyors	Belt conveyor, roller conveyor, chute conveyor, slat conveyor, screw conveyor, chain conveyor, plain chain conveyor, trolley conveyor, wheel conveyor, tow conveyor, bucket conveyor, cart-on-track conveyor, pneumatic tube conveyor, overhead monorail conveyor
3	Automated guided vehicles (AGV)	Manual load/unload AGV, low-lift AGV, high-lift AGV, tugged AGV, roller deck AGV, stationary deck AGV, lift deck AGV
4	Cranes	Stacker crane, tower crane, gantry crane, jib crane.
5	Storage/retrieval systems	Unit load AS/RS, man-on-board AS/RS, shelf storage system, pallet rack system, block stocking on floor, block stocking in rack
6	Robots	Pneumatic robot, electric robot, hydraulic robot, mechanized manipulator

Table 2. Database for manufacturing systems

Material	Material type: individual unit, pallet unit, loose, bulk, packed, bar-stock, etc.
	Material weight :light, medium, heavy
	Bottom surface: flat, no flat
	Material nature: fragile, sturdy
	Material size: small, medium, large
	The annual demands of the material: <X, X or above
Operation	Function: move, storage-retrieval
	Operation control: controllable, uncontrollable
	Automation: required, not required
	Method of transportation: carry, tow
	Transfer frequency (per shift) : <X, X or above
	Storage-retrieval order: FIFO, FILO
Move	Move type: transportation, conveying, loading/unloading
	Move direction: decline, horizontal, vertical
	Move level: on floor, above floor
	Move area and path: fixed, variable
	Move distance: <X, X or above
	Move height: <X, X or above
Area Constraints	Floor space: available, not available
	Aisle width: <X, X or above
	Truss height: <X, X or above
	Rack deep: single, double

2.4. Knowledge base

MHAD which is a rule-based expert system has already included 142 rules. These rules in MHAD are acquired from experts in the manufacturing systems and the literature about Material handling equipments. Arity PROLOG language was used so that MHAD system will not be badly influenced by the variations in the methods or the changes in the knowledge base and the inference mechanism can be updated easily. Some examples of the rules of the knowledge base that are in accordance with IF-THEN structure are presented below.

Rule 27:
IF Function type_move and
Move area and path_fixed and
Floor space_available
THEN Most proper move type_conveying.

Rule68:
IF Move type_conveying and
Individual type_packaged and
Move direction_horizontal and
Operation control_uncontrollable and
Bottom surface_not flat
THEN Most proper conveyor type_Wheel conveyor.

Rule69:
IF Move type_conveying and
Individual type_packaged and
Move direction _horizontal and
Operation control_controllable and
Bottom surface_not flat and
Material weight_X<100 kg
THEN Most proper conveyor type_Belt conveyor.

2.5. Inference Engine

The Inference mechanism works in interaction with the both knowledge base and database, searches all of the material-handling equipments and determines the most appropriate material-handling equipment. By the way, the candidate equipment type that will be evaluated at the multi-criteria decision making module is determined.

2.6 Multi-attribute Decision Making Module,

A final decision is made for the most proper equipment among the alternatives of the same type using the multi-attribute decision-making module. This module utilizes the information axiom of axiomatic design principles. Evaluation of alternatives is made for the cases of both complete and incomplete information. The crisp information axiom approach for complete information and the fuzzy information axiom approach for incomplete information are used.

3. PRINCIPLES OF AXIOMATIC DESIGN

The most important concept in axiomatic design is the existence of the design axioms. The first design axiom is known as the Independence Axiom and the second axiom is known as the Information axiom. They are stated as follows [10].

Axiom1. The Independence Axiom: Maintain the independence of functional requirements
Axiom 2. The Information Axiom: Minimize the information content

The Independence Axiom states that the independence of functional requirements (FRs) must always be maintained, where FRs are defined as the minimum set of independent requirements that characterizes the design goals [11]. In the real world, engineers tend to tackle a complex problem by decomposing it into sub-problems and attempting to maintain independent solutions for these smaller problems. This calls for an effective method that provides guidelines for the decomposition of complex problems and independent mappings between problems and solutions

The Information Axiom states that among those designs that satisfy the Independence Axiom, the design that has the smallest information content is the best design [10]. Information is defined in terms of the information content, I_i, that is related in its simplest form to the probability of satisfying the given FRs. I_i determines that the design with the highest probability of success is the best design. Information content I_i for a given FR_i is defined as follows:

$$I_i = \log_2 \left(\frac{1}{p_i} \right) \qquad (1)$$

where p_i is the probability of achieving the functional requirement FR_i and log is either the logarithm in base 2 (with the unit of bits). This definition of information follows the definition of Shannon, although there are operational differences. Because there are n FRs, the total information content is the sum of all these probabilities. If I approaches infinity, the system will never work. When all probabilities are one, the information content is zero, and conversely, the information required is infinite when one or more probabilities are equal to zero [13].

In any design situation, the probability of success is given by what designer wishes to achieve in terms of tolerance (i.e. design range) and what the system is capable of delivering (i.e. system range). As shown in Figure 2, the overlap between the designer-specified "design range" and the system capability range "system range" is the region where the acceptable solution exists. Therefore, in the case of uniform probability distribution function p_i may be written as

$$p_i = \left(\frac{Common\ range}{System\ range} \right) \qquad (2)$$

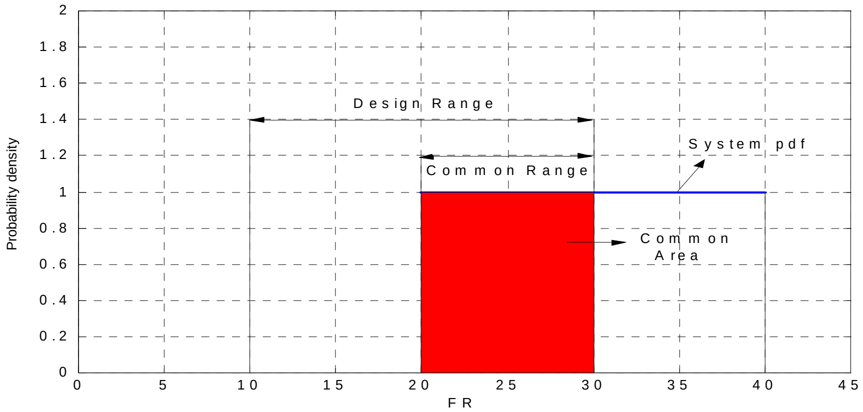

Figure 2. Design Range, System Range, Common Range and Probability Density Function of a FR

Therefore, the information content is equal to

$$I_i = \log_2 \left(\frac{System\ range}{Common\ range} \right) \qquad (3)$$

The probability of achieving FR_i in the design range may be expressed, if FR_i is a continuous random variable, as

$$p_i = \int_{dr^1}^{dr^u} p_s(FR_i).dFR_i \qquad (4)$$

where p_s *(FR_i)* is the system pdf (probability density function) for FR_i. Eq. (4) gives the probability of success by integrating the system pdf over the entire design range. (i.e. the lower bound of design range, dr^1, to the upper bound of the design range, dr^u). In Figure 3, the area of the common range (A_{cr}) is equal to the probability of success P [10].

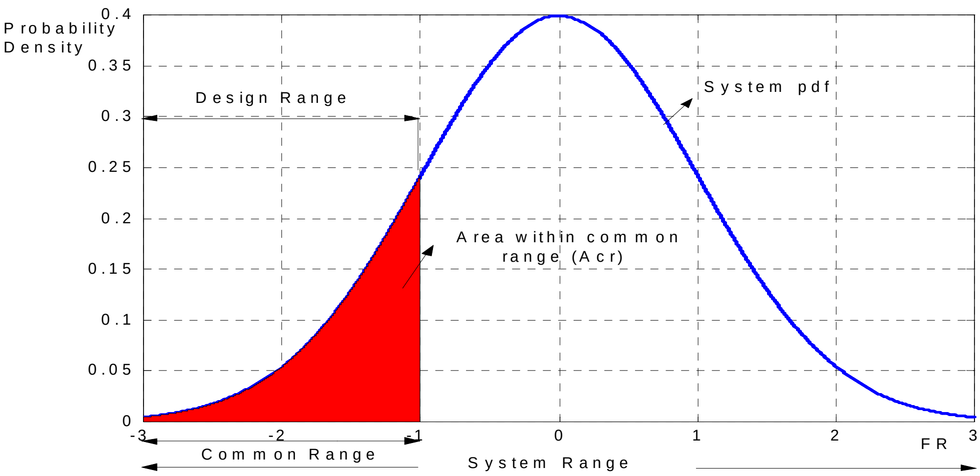

Figure 3. Design Range, System Range, Common Range and Probability Density Function of a FR

Therefore, the information content is equal to

$$I = \log_2\left(\frac{1}{A_{cr}}\right) \quad (5)$$

4. FUZZY INFORMATION AXIOM APPROACH

The fuzzy data can be linguistic terms, fuzzy sets, or fuzzy numbers. If the fuzzy data are linguistic terms, they are transformed into fuzzy numbers first. Then all the fuzzy numbers (or fuzzy sets) are assigned crisp scores.

The following numerical approximation systems are proposed to systematically convert linguistic terms to their corresponding fuzzy numbers. The system contains five conversion scales (Figure 4 and Figure 5).

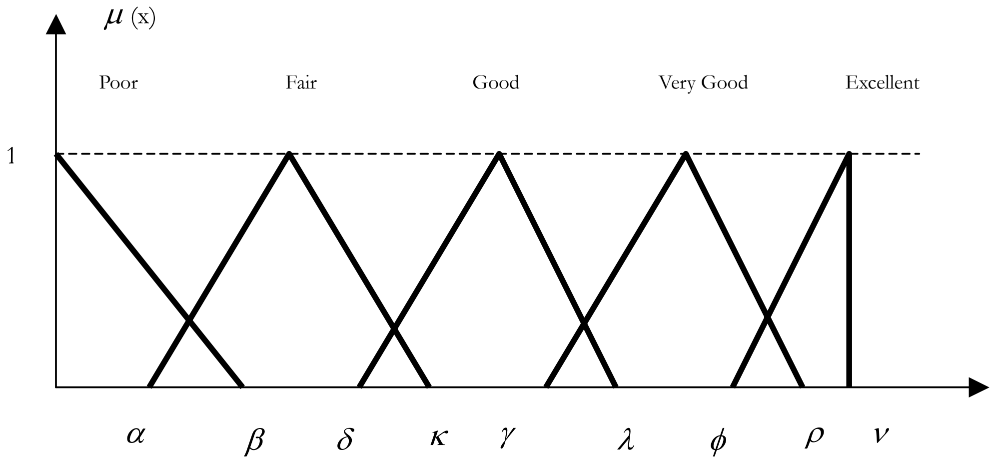

Figure 4. The Numerical Approximation System for Intangible Factors

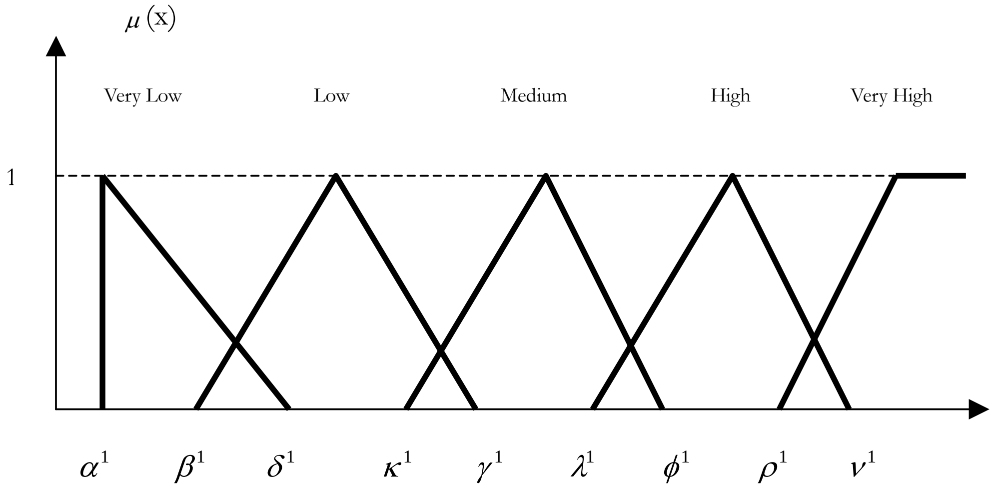

Figure 5. The Numerical Approximation System for Tangible Factors

In the fuzzy case, we have incomplete information about the system and design ranges. The system and design range for a certain criterion will be expressed by using 'over a number', 'around a number' or 'between two numbers'. Triangular or trapezoidal fuzzy numbers can represent these kinds of expressions. We now have a membership function of triangular or trapezoidal fuzzy number whereas we have a probability density function in the crisp case. So, the common area is the intersection area of triangular or trapezoidal fuzzy numbers. The common area between design range and system range is shown in Figure 6.

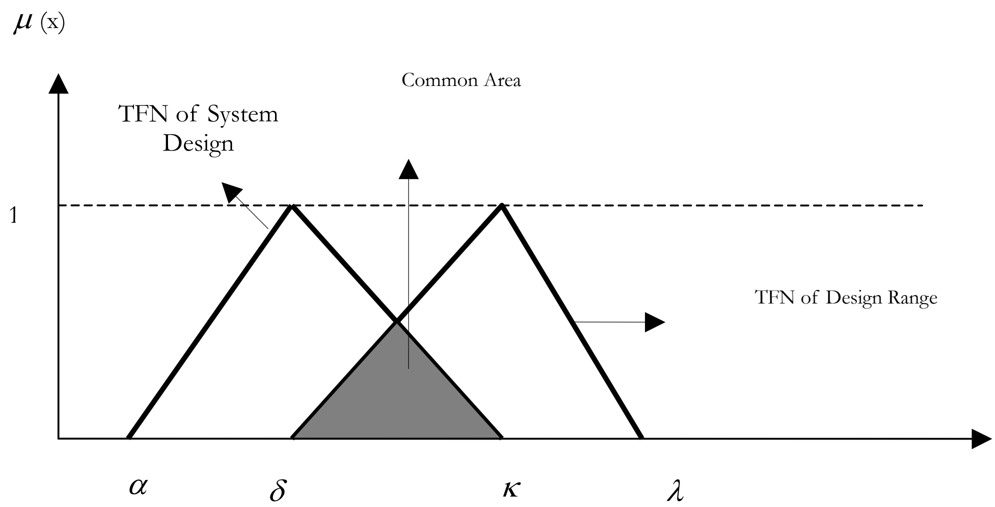

Figure 6. The Common Area of System and Design Ranges

Therefore, information content is equal to

$$I = \log_2 \left(\frac{TFN\ of\ System\ Design}{Common\ Area} \right) \qquad (6)$$

In the following, the numerical application of multi-attribute Information axiom approach including both crisp and fuzzy criteria to select the most suitable material handling equipment is given.

5. A NUMERICAL APPLICATION OF MULTI-ATTRIBUTE INFORMATION AXIOM APPROACH

A textile company needs to handle the materials effectively for decreasing lead times. The plain chain conveyor as a most proper equipment has been proposed by MHAD with respect to the database for manufacturing requirements. In this section, the designer make the final decision for the most proper equipment among the alternatives of the same type using the multi-attribute decision-making module. Therefore, the designer has determined four possible plain chain conveyors. The criteria considered in the selection process are categorized into the groups of costs and technical characteristics. The group of costs includes fixed costs per hour and variable costs per hour. The group of technical characteristics includes speed of conveyor, item width, item weight and flexibility. Maximum conveyor lenght is excluded since the values of these criteria are the same for each candidate.

The criteria in the group of costs are linguistic variables. The flexibility in the group of technical characteristics is also a linguistic variable. The company's design ranges which mean that what a designer wants to achieve for the above criteria are as follows:

FR_{FC} = Fixed costs per hour (FC) must be low

FR_{VC} = Variable costs per hour (VC) must be low

FR_{S} = Speed of conveyor (S) must be in the range of 8 to 10

FR_{W} = Item width (W) must be in the range of 10 to 20

FR_{IW} = Item weight (IW) must be in the range of 0 to 10

FR_{F} = Flexibility (F) must be excellent

Alternative conveyors' costs and performance scores evaluated by the company's managers with respect to criteria are given in Table 3. The data for design ranges and the data for system ranges are entered into the software-MHAD. The calculated results below are obtained by MHAD. The data for speed of conveyor, item width and item weight given in Table 3 are arranged to include the minimum and maximum performance values supplied by the conveyors. The managers produce the system range data and use the linguistic expressions about costs and flexibility as in Table 3, too. Figure 6 shows the membership functions of the linguistic expressions about flexibility. For example in Figure 6, the decision-maker subjectively evaluates the alternatives with the linguistic term "poor" if these two criteria are assigned a score of (0, 0, 6) over 20; "fair" with a score of (4, 7, 10) over 20; "good" with a score of (8, 11, 14) over 20; "very good" with a score of (12, 15, 18) over 20; "excellent" with a score of (16, 20, 20) over 20. In the same way the decision-maker subjectively evaluates the alternatives with the membership function of the linguistic expressions about fixed costs per hour and variable costs per hour. Alternatives with the linguistic term "very low" if these two criteria are assigned a score of (3/2, 3/2, 7/4); "low" with a score of (3/2, 7/4, 2); "medium" with a score of (7/4, 2, 9/4); "high" with a score of (2, 9/4, 5/2); "very high" with a score of (9/4, 5/2, 5/2) for fixed costs per hour (Euro/hour) is evaluated. The decision-maker also evaluates the alternatives with the linguistic term "very low" if these two criteria are assigned a score of (0.400, 0.400, 0.420); "low" with a score of (0.400, 0.420, 0.440); "medium" with a score of (0.420, 0.440, 0.460); "high" with a score of (0.440, 0.460, 0.480); "very high" with a score of (0.460, 0.480, 0.480) for variable costs per hour (Euro/hour).

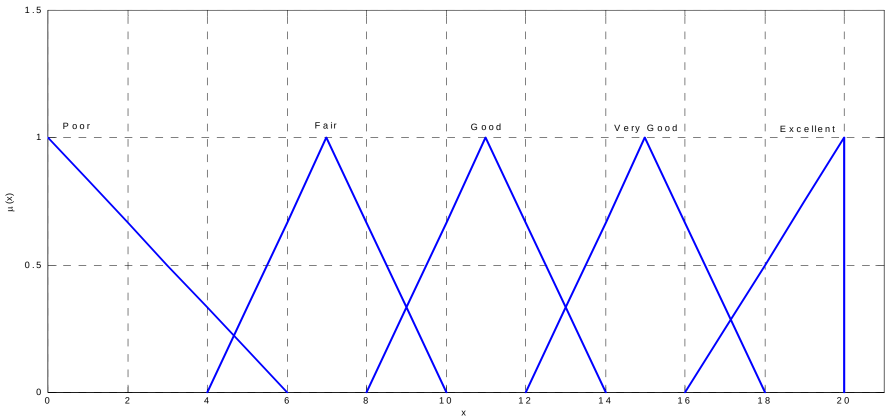

Figure 6. TFNs for Intangible Factors (Flexibility)

Table 3. The system range data for conveyor costs and technical characteristics

Alternatives	**Criteria**					
	Fixed costs per hour (Euro/hour)	**Variable costs per hour (Euro/hour)**	**Speed of conveyor (meter/min)**	**Item width (cm)**	**Item weight (kg)**	**Flexibility**
C1	Low	Low	8 to 12	2 to 15	0 to 10	Very Good
C2	Medium	Low	9 to 13	2 to 20	0 to 10	Excellent
C3	Medium	Medium	7 to 11	3 to 30	0 to 20	Excellent
C4	High	medium	6 to 10	3 to 25	0 to 15	Very Good

The information content for conveyors can be computed using Equation (3) and Equation (6) using the system ranges in Table 3 and the design ranges. The results of Information content in Table 4 are obtained.

Table 4. The results of Suh's Information Content for conveyors

Alternatives	**Information Content**						
	I_{FC}	I_{VC}	I_S	I_W	I_{IW}	I_F	$\sum I_i$
C1	0.000	0.000	1.000	1.379	0.000	3.391	5.770
C2	2.000	0.000	2.000	0.848	0.000	0.000	4.848*
C3	2.000	2.000	1.000	1.433	1.000	0.000	7.433
C4	Infinite	2.000	1.000	1.138	0.585	3.391	Infinite

The information contents for the criteria with respect to the alternatives are given in Table 4. As the conveyor with minimum information content is the most suitable alternative with respect to the designer's requirements, C2 is selected.

6. CONCLUSION

An intelligent system called MHAD which considers both technical and economic criteria in material handling equipment selection process is presented at this paper. MHAD System is developed by the integration of an expert system and the multi-attribute decision-making modules. The rule-based system module provides rules which are utilized by inference engine for determining the most proper material handling equipment type such as conveyor. Ultimately, a final decision is made for the most proper equipment among the alternatives of the same type using the information axiom of axiomatic design principles.

Crisp multi-attribute decision-making (MADM) methods solve problems in which all decision data are assumed to be known and must be represented by crisp numbers. The methods are to effectively aggregate performance scores. Fuzzy MADM methods have difficulty in judging the preferred alternatives because all aggregated scores are fuzzy data. A multi-attribute Information axiom approach including both crisp and fuzzy criteria is proposed in the multi-attribute decision-making module.

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