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RESEARCH PAPER

Selection of Computer-Integrated Manufacturing Technologies Using A Combined Fuzzy Analytic Hierarchy Process and Fuzzy TOPSIS

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ABSTRACT

In today's world, manufacturing companies are required to integrate their sources with manufacturing systems and use novel technologies in order to survive in the competitive world market. In this context, computer integrated manufacturing (CIM) and its related technologies are taken as novel and efficient schemes; therefore, selecting the best technology among them has been a challenging issue. Such an investment decision is, in nature, a multi-attribute problem. In fact, manufacturing technologies have various advantages and disadvantages which need to be considered in order to choose the best one. In this paper, we briefly study the structure and goals of computer integrated manufacturing systems, the role of different sectors in traditional and modern manufacturing systems, and the effect of information communication on them. Then, various options regarding the implementation of an integrated computer manufacturing technology are introduced and a combined model of the fuzzy analytical hierarchy process and fuzzy TOPSIS is proposed to handle the above-mentioned multiple criteria decision making problem. Finally, the considered options for manufacturing technologies are ranked using a numerical example.

KEYWORDS: *Multi-objective decision making (MODM); Computer-integrated manufacturing (CIM); Fuzzy analytic hierarchy process (FAHP); Fuzzy TOPSIS.*

1. Introduction

In today's world, manufacturing institutes are faced to numerous challenges for survival. In one hand, they need to consider customers various needs and try to satisfy them, and on the other hand, reach international competitive market, and these are possible through using modern technologies for more and better production, higher quality, lower practical expenses, flexible manufacturing, and globalization. Customers' needs are getting more and more constantly. In new markets, customers are not limited to a specific geographical location as manufacturers and customers around the world are connected through Information Communication Technology. In such markets, customers can order and buy regarding their needs, without being physically present in the shop or institute. So, manufacturing institutes face a global competition to gain more customers by using new technologies in their production and services. Regarding the above points, traditional based organizations are neither able to increase their production nor be accessible around the world, so they cannot compete in modern markets [1]. Therefore, the existence of manufacturing companies in today's global competence relies on technological innovation [2]. They have to realize the importance of available Computer-Integrated Manufacturing (CIM) technologies having wider range of performance capabilities to produce the products faster, cheaper, and flexible and more effectively [3]. Hence, global competition, leads manufacturing organizations through using integrated manufacturing systems. Application of this technology in big manufacturing industries appears as computer integrated manufacturing [1]. The beginning and appearance of mass production, manufacturing technologies has gone under a great change. However, to achieve mass production, transfer lines and fixed automation were needed. This need resulted in the development of programmable automation [4]. At

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first, the peace of manufacturing process went higher and the products became more qualitative and automation could answer the needs of customers' quick demands. There was a great leap in manufacturing industry by the appearance of computer and computer aided design (CAD) [5]. Computer Integrated Manufacturing was first used by Joseph Harrington (1973) in a book published by the name "Computer Integrated Manufacturing" [6]. In his primary definitions, he considered CIM as a controlling and communicative structure for integrating manufacturing system. He emphasized that CIM did not mean an automated factory and asserted that people are very much involved at all leaves [5].

The meaning of CIM is integrated use of computer technology in manufacturing, in order to reach company's goals. CIM refers to any computer based technology used in design, manufacturing, and logistics operations [7]. The integration process starts from designing the product, and continues to distribution to customers and their satisfaction. The aim of CIM is to create a computerized information center, which includes production, designing, and sales process (like buying, distribution, accounting, and budget control) in an integrated system. It is obvious that CIM will affect the production, assembly, raw material, supply management, and maintenance, and some other important functions such as product design, quality control, cost control, and customer service; As a result, computer integrated manufacturing will reduce design and manufacturing lead times, is often cited as creating greater market share and improved [8]. CIM technologies can be obtained from Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), industrial robotics, automatic material handling systems, group technology, rapid prototyping processes, flexible manufacturing systems, and computer numerically controlled (CNC) machines [3].

Manufacturing organizations sharply compete to produce products of the highest quality, lowest production cost, and best customer service. They responded to this situation by adopting computer integrated manufacturing technologies in order to produce top-quality, low-cost products delivered at the right time. Applying successful computer integrated manufacturing in manufacturing organizations needs high investigation and responsibility, hence, installing and running these systems in organization needs to be done through design, planning, and decision-making process [3]. With respect to the high expenses of applying CIM in organizations, managers of manufacturing organizations usually use decision making instruments to choose CIM technologies, so that the best strategy can be chosen in line with the organization's needs [7]. The budget of manufacturing organizations is limited and the implementation of integrated computer manufacturing in each organization is costly, the prioritization and selection of technologies in the manufacturing sector are important. Therefore, investing in top technologies will be the solution for implementing CIM in manufacturing organizations.

Unlike what most people think, CIM doesn't mean an automatic company. Computer integrated manufacturing is a kind of technology that can be applied to any industry and be controlled by that industry. In other words, each industry creates specific circumstances for computer integrated manufacturing, regarding its experiences, needs, and specific situations. It should be considered that the basis of computer integrated manufacturing is its communication networks [9]. In CIM systems, all functional and informational processes, from getting order to delivery and installation is done through computers, and there is an information connection between them; there is actually an information connection between activities that lead to manufacturing. The main core that connects different parts of a manufacturing organization is information (figure 1).

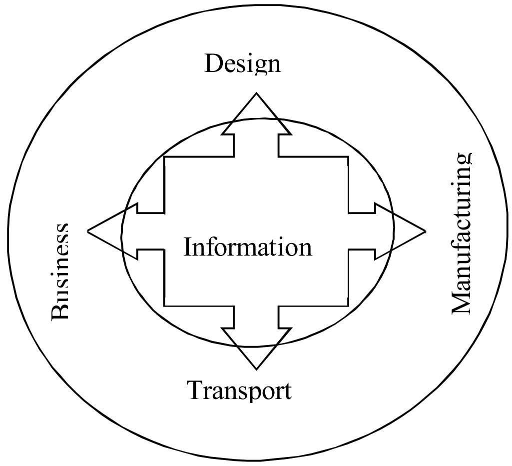

Fig. 1. Relationship between parts of CIM.

The main configuration parts in CIM that have the most information exchange are Computer Aided Design (CAD), Computer Aided Manufacturing (CAM). Designing and manufacturing were two separate phases in traditional systems which means that designing was done first and the product was made after that. This made a gap between these two processes and in most cases the expected criteria in the final product were not met, and the product was not acceptable to the customer. The problem exists no more in modern manufacturing systems like CIM, and the two processes are connected through information connection, and the final product is desirable. CAD and CAM were connected by Computer Aided Process Planning (CAPP).

CIM's concern is mostly inter-organizational and focuses on processes in the organization. In order to be integrated globally, manufacturing organizations must have an equal informational structure as well as inter-organizational integration to be connected to each other. VCIM is an improved approach of the traditional system of CIM. A global integrated manufacturing goes beyond the borders of a traditional system [1]. A lot of researchers have introduced various models for VCIM. It is obvious that in VCIM there is not a huge company to make each part, but every institute can do a part of job. The best product regarding cost, pace, and quality, is made based n the customer's order. Small to medium sized manufacturing institutes are connected in VCIM system [1].

The paper is organized as follows: In Section 2, literature review. In Section 3, the structure of CIM and VCIM systems. In Sections 4, Decision making model. In Section 5, present how we adopt the methodology, fuzzy AHP and fuzzy TOPSIS in real world. In Sections 6, proposed model are shown. In Sections 7, Numerical examples are illustrated. In Section 8, the conclusions are presented.

2. Literature Review

Lin (1976) claimed that the future of engineering is inextricably bound with the application of computer-integrated technology. He suggested that implementing advanced and integrated technologies would be an effective approach in solving problems such as decreased productivity, relative labor costs and consequent rise in unit costs, which are still plaguing present day manufacturers [5]. In 1984 Harington developed his previous model and said that manufacturing science structure is the same for different products. [1]. Yeomans in 1985 introduced a model that is mostly rooted in advanced industrial practices. He believes that CIM is a system that contains a lot of sub-systems with different structures [10]. Miller et al, recognized three integrations (technical integration, process integration, goal integration) to do so [10]. In the last two decades, CIM explanation from computer based working cells, macro automation, CAD / CAM, are changed. Lin in 1997 introduced a new integration concept in the form of virtual CIM [1]. After that, a lot of researchers tried to design the agent-based architectures in a VCIM circumstance. Maturana et al. in 1999 introduced a multi-agency structure named meta-morph in order to integrate manufacturing sources distributed for smart manufacturing systems, in which design, marketing, and distribution, timing, and supply agencies were grouped [11]. Peng et al. in 1999 proposed built an agent-based framework to integrate enterprise resources in order to timely plan and re-plan manufacturing processes [12]. Nahm and Ishikawa in 2005 introduced a multi-agent architecture consisting of hybrid agent architecture and hybrid network architecture for enterprise resources integration and collaboration which were connected through internet [13]. Wang et al. in 2007 proposed a functional model of multi-agent structure. This model makes VCIM system capable of dynamic and flexible information process, and also gives them the ability to have a mass production [1]. Historical process of this Evolution is shown in figure 2.

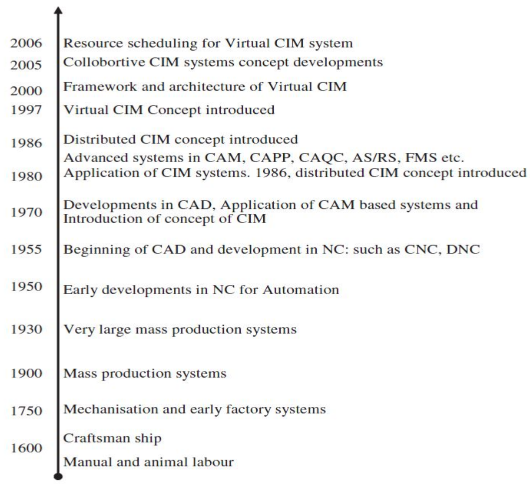

Fig. 2. Evolution in manufacturing technology [5].

Today, Computer Integrated Manufacturing has a prominent role in the manufacturing industry due to the growth and influence of information technology. Many researches have been done to develop CIM since the 1970s. Fig. 3, the historical Evolution and development of the CIM, are illustrated.

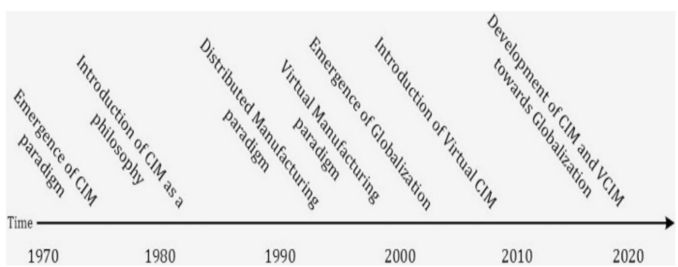

Fig. 3. Evolution and development of the CIM [14].

A lot of researches have been done regarding recognizing and ordering the most suitable computer integrated manufacturing technologies. These researches use decision making models, and we point some of them. Luong (1998) selected computer-integrated manufacturing technologies using a decision support system [7]. The method he used for decision making was based on mixing the analytical hierarchy process (AHP) and database technology. His objectives were: Reduction manufacturing lead time (MLT), Increased productivity (PRO), Reduced inventory and work in progress (WIP), Increased quality including reduced scraps and rework (QUA), Increased flexibility (FLEX), Increased integration in the company (INT), and available manufacturing technologies to choose were: Computer-aided design (CAD), Group technology (GT), Computer numerically controlled machines (CNC), Flexible manufacturing systems (FMS), Robotics (ROB), Automated material handling system (AMH), Material requirements planning (MRP), Computer-aided process planning (CAPP). Results a Case study (textile industry) shows that increase flexibility is considered the most important objective and CAPP have the highest weight [7].

Bozdag and et al. (2003) uses four methods of fuzzy multi-criteria decision making (group decision making of Blin, fuzzy synthetic evaluation, Yager's weighted goals method, and fuzzy analytic hierarchy process) taking into account both intangible and tangible factors, chooses the best CIM technologies; They suggested using fuzzy TOPSIS and fuzzy hierarchy methods for selection [8]. Yurdakul (2004) combined analytic hierarchy process and goal programming model selected computer-integrated manufacturing technologies; His research was done in a large manufacturing company in Turkey. He performed CIM in the company, and his goals were increase in the variety of products, reduction of manufacturing time, reduction of order size, integration between company's branches and costumers, and reduction of waste. The advisor company had many suggestions for engineering and designing units. These suggestions, integrated the designing systems and product data management, using computers [15]. In 2012, Tansel Ic, mentioned the problems of selection of CIM technologies, and selected the suitable technologies, using multi-aspect decision making (MADM); He uses Design of Experiment (DoE) and TOPSIS methods in his paper. Finally he suggested that broader features can be considered and a suitable technology can be selected through this method. Considering these criteria, the problem can be solved through other methods [3]. Jenab and et al. in 2015 uses method i-DEMATEL selected integrated manufacturing technology; Their finding showed CIM technology include CNC/DNC technology is the most suitable for the Laboratory [16]. Yu et al. (2015), in a study, examined the relationships, similarity, and differences between Computer-Integrated Manufacturing, Cyber-Physical Systems, and Cloud Manufacturin [17]. Delaram and Valilai (2018) presented An architectural view to computer integrated manufacturing systems based on Axiomatic Design Theory, n their research presented five critical aspects of a CIM system by layers, this architecture Included Physical, Functional, Managerial, Informational, and Control aspects [14].

If managers make a good decision with respect to their resources and limits, they can guarantee organization's future and its success. Multiple attributes decision making (MADM) has a great use in complex decision making, when there are several and sometimes opposite criteria. Extreme power of these techniques and their ability to lessening the complexity, using both numeric and qualitative criteria simultaneously, making a structure for decision making issues, and ease of use make it a useful tool for different decision making aspects. Multi attributes decision making models are in two types: multi criteria decision making (MCDM) and multi objectives decision making (MODM). MCDM is normally used for choosing the best option from existing option with regard to the posed criteria (criteria may oppose each other). MODM is used when we want to minimize or maximize some objectives which may oppose each other simultaneously [18]. MADM focuses on relative supremacy and relationship between objectives and criteria [19].

The literature survey shows that there is a need for a study that considers various phases of the CIM selection problem and integrates them with a simple way within a multi-level practical and flexible structure that fulfills differing task requirements for the decision-makers. To help the decision makers, there is a need for easy-to-use, adaptable, systematical, modifiable and logical scientific method or mathematical tools that can consider a large number of selection attributes and alternatives. In a decision making problem, the attributes must be measureable and their outcomes can be measured for every decision alternative. Therefore, MADM methods seem to be an appropriate tool for selecting one CIM alternatives from a set of available options based on multiple attributes. Although, a lot of MADM models is currently available to deal with CIM selection applications [3].

Choosing the best CIM technologies counts as an important and vital decision for big manufacturing organizations. Various options make it difficult to choose the best technology. Multi-dimensional decision making models have a great use in choosing suitable CIM technology. An MADM model orders the decisions, and the highest rank decision is introduced to the user as the best. Some techniques used in multi-dimensional decision making are [3]: Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW), Analytical Hierarchy Process (AHP), Data Envelopment Analysis (DEA), and Grey Relational Analysis (GRA), ELECTRE (Elimination and Et Choice Translating Reality), VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje), PROMETHEE and Multi-Objective Optimization on the basis of Ratio Analysis (MOORA).

In recent decades, Fuzzy MADM approaches are proposed for decision making problems where uncertainties are involved in the literature. There are various applications that incorporated fuzzy logic into MADM models; It is observed from the literature that in comparison to traditional MADM models, the fuzzy versions of the

MADM applications are very complex to comprehend and difficult to implement. As this fuzzy MADM approaches involves too much mathematical calculations, which may be impracticable and ineffective to the decision makers, who may not have a strong capability in mathematics; Hence, because of its maximum computational requirements, the computation time of the fuzzy MADM approaches would obviously be more [3].

In this research selected suitable CIM technologies via the proposed fuzzy AHP and fuzzy TOPSIS techniques with MCDM. The Fuzzy AHP method is used to determine the weight of the criteria (CIM technology). In this method, the decision maker begins by setting up the decision tree hierarchy. This tree shows the criteria and decision options. Then a series of pairwise comparisons is performed. In the other part of the study, fuzzy TOPSIS method is used to initialize strategies. The fuzzy TOPSIS to improve the gaps of alternatives between real performance values and pursuing aspired levels in each dimension and criterion and find out the best alternatives for achieving the objectives levels based on eight manufacturing technologies.

3. Methodology

3. 1. The proposed algorithm

This model for the CIM technology selection problem, composed of fuzzy AHP and fuzzy TOPSIS methods, consists of three basic stages: (1) identify the criteria to be used in the model by literature and experts, (2) Fuzzy AHP computations to …, (3) fuzzy TOPSIS to evaluate alternatives and determine the final rank.

In the first stage, alternative CIM technology and the objectives which will be used in their evaluation are determined and the decision hierarchy is formed. AHP model is structured such that the Best CIM technology is in the first level, objectives are in the second level and alternative (CIM technology) are on the third level. In the last step of the first stage, the decision hierarchy is approved by literatures and experts.

After the approval of decision hierarchy, objective used in CIM technology selection are assigned weights using fuzzy AHP in the second stage. In this phase, pairwise comparison matrices are formed to determine the criteria weights. The experts determine the values of the elements of pairwise comparison matrices. Computing the geometric mean of the values obtained from individual evaluations, a final pairwise comparison matrix on which there is a consensus is found. The weights of the criteria are calculated based on this final comparison matrix. In the last step of this phase, calculated weights of the objectives are approved by experts.

CIM technologies ranks are determined by using fuzzy TOPSIS method in the third stage. Linguistic values are used for evaluation of alternative CIM technologies in this step. Schematic diagram of the proposed model for CIM technologies selection is provided in Fig. 4.

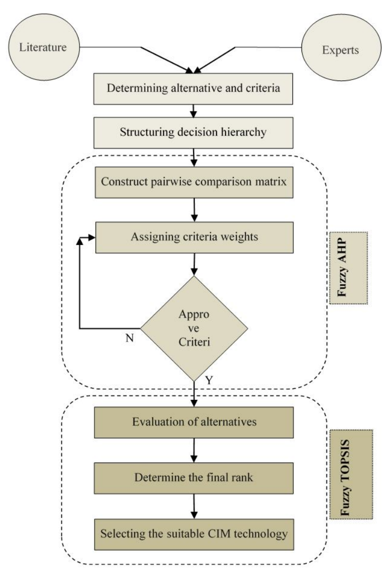

Fig. 4. Schematic diagram of the proposed model for CIM technology selection.

3.2. Fuzzy sets theory and analytic hierarchy process method

Analytic hierarchy process (AHP) developed by Saaty (1980) is a powerful method to solve complex decision problems [20]. Any complex problem can be decomposed into several sub-problems using AHP in terms of hierarchical levels where each level represents a set of criteria or attributes relative to each sub-problem [21]. The AHP is a multi-attribute decision tool that allows financial and non-financial, quantitative and qualitative measures to be considered and trade-offs among them to be addressed. The AHP is aimed at integrating different measures into a single overall score for ranking decision alternatives. Its main characteristic is that it is based on pair-wise comparison judgments [22]. The AHP method is based on three principles: first, structure of the model; second, comparative judgment of the alternatives and the criteria; third, synthesis of the priorities [23].

Although the purpose of AHP is to capture the expert's knowledge, the traditional AHP still cannot really reflect the human thinking style [24]. The traditional AHP method is problematic in that it uses an exact value to express the decision maker's opinion in a comparison of alternatives [25]. And AHP method is often criticized, due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair wise comparison process [26]. To overcome all these shortcomings, fuzzy analytical hierarchy process was developed for solving the hierarchical problems. Decision-makers usually find that it is more accurate to give interval judgments than fixed value judgments. This is because usually he/she is unable to make his/her preference explicitly about the fuzzy nature of the comparison process [24]. Hence, Buckley (1985) used the evolutionary algorithm to calculate the weights with the trapezoidal fuzzy numbers; The fuzzy AHP based on the fuzzy interval arithmetic with triangular fuzzy numbers and confidence index a with interval mean approach to determine the weights for evaluative elements [21].

3.2.1. Establishing fuzzy numbers

Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets have been introduced by Zadeh (1965) as an extension of the classical notion of set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition – an element either belongs or does not belong to the set [21]. It is possible to use different fuzzy numbers according to the situation. In applications it is often convenient to work with triangular fuzzy numbers (TFNs) because of their computational simplicity, and they are useful in promoting representation and information processing in a fuzzy environment [27].

Triangular fuzzy numbers can be defined as a triplet $\tilde{A}$= (l, m, u). The parameters l, m, and u. respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. A triangular fuzzy number M is shown in Fig. 5 [28].

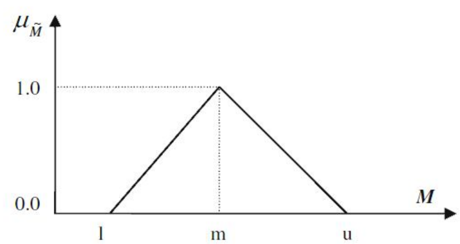

Fig. 5. Triangular fuzzy number

A fuzzy number $\tilde{A}$ on R to be a TFN if its membership functions $\mu(x)$: R →[0, 1] is equal to following Equation (1):

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-l}{m-l}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0, & otherwise \end{cases} \quad (1)$$

If we define two positive triangular fuzzy numbers (l1, m1, u1) and (l2, m2, u2) then important operations are:

Addition of the fuzzy number

$$(l1, m1, u1) + (l2, m2, u2) = (l1 + l2, m1 + m2, u1 + u2) \quad (2)$$

Multiplication of the fuzzy number

(l1, m1, u1).(l2, m2, u2) = (l1 . l2, m1 . m2, u1 . u2) (3)

Subtraction of the fuzzy number
(l1, m1, u1) - (l2, m2, u2) = (l1 - u2, m1 - m2, u1 - l2) (4)

Reciprocal of the fuzzy number
(l1, m1, u1)-1 = (1/u1, 1/m1, 1/ l1) (5)

Vertex method is define to calculate the distance between two triangular fuzzy numbers

$$d(\tilde{m},\tilde{n}) = \sqrt{\frac{1}{3}[(l_1-l_2)^2+(m_1-m_2)^2+(u_1-u_2)^2]} \quad (6)$$

3.2.2. Linguistic variables

Linguistic variables take on values defined in its term set: its set of linguistic terms. Linguistic terms are subjective categories for the linguistic variable. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language. This paper used linguistic variable to express reasonably situation that difficult to define. Table 1 shows membership function of linguistic scales.

Tab. 1. Membership functions of linguistic scale.

Fuzzy number	Linguistic scales	TFN
1	Equally important (Eq)	(1,1,3)
3	Weakly important (Wk)	(1,3,5)
5	Essentially important (Es)	(3,5,7)
7	Very strongly important (Vs)	(5,7,9)
9	Absolutely important (Ab)	(7,9,9)

3.2.3. Fuzzy AHP

In this study the extent fuzzy AHP is utilized, which was originally introduced by Chang [29]. In the following, first the outlines of the extent analysis method on fuzzy AHP are given and then the method is applied to a supplier selection problem. Let
X={x1, x2,…, xn }
Be an object set, and
G= {g1, g2,…, gn }
Be a goal set. Then, each object is taken and extent analysis for each goal is performed, respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, \ldots\ldots. M_{gi}^m \quad i=1,2,\ldots.,n \quad (7)$$

Where all the M_{gi}^j (j=1,2,…,m) are TFNs. The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i=\sum_{j=1}^{m} M_{gi}^j * \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \quad (8)$$

The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \mathrm{SUP}[\min(\mu M_1(x), \mu M_2(y)], \; x\geq y \quad (9)$$

When a pair (x,y) exists such that x ≥ y and μM1(x)=μM2(y), then we have $V(M_1 \geq M_2)=1$. Since M_1 and M_2 are convex fuzzy numbers we have that:

$$V(M1 \geq M2) = hgt(M1 \cap M2) = \mu M1(d) \quad (10)$$

When $M_1=(l_1,m_1,u_1)$ and $M_2=(l_2,m_2,u_2)$ the ordinate of D is given by Equation (11):

$$V(M1 \geq M2) = hgt(M1 \cap M2) = \begin{cases} 1, & if \quad m_1 \geq m_2 \\ 0, & if \quad l_2 \geq u_1 \\ \frac{l_2-u_1}{(m_1-u_1)-(m_2-l_2)}, & otherwise \end{cases} \quad (11)$$

To compare M1 and M2, we need both the values of V(M1 ≥M2) and V(M2 ≥M1).

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers Mi (i= 1,2,...,k) can be defined by:

V(M ≥ M1,M2,…,Mk)=V[(M ≥ M1) and (M ≥ M2)and …and (M ≥ Mk)]=min V(M ≥ Mi),i=1,2,…,k (12)

Assume that: d ′(Ai)=min V(Si ≥ Sk) (13)

For k =1,2,...,n; k ≠ i . Then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (14)$$

Where Ai (i= 1,2,...,n) are n elements. Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (15)$$

Where W is a non-fuzzy number.

3.3. The fuzzy TOPSIS method

TOPSIS is a widely used MADM technique because of its simple and programmable nature [30]. TOPSIS, developed by Hwang and Yoon (1981) is used to obtain ranking scores and rank the alternatives accordingly [31]. The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is a solution that maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria [32]. In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. However, under many conditions crisp data are inadequate to model real-life decision problems. Therefore, the fuzzy TOPSIS method is proposed where the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS [27].This method is particularly suitable for solving the group decision-making problem under fuzzy environment. The algorithm of this method can be described as follows:

Step 1: Determine the weighting of evaluation criteria. (This research employs fuzzy AHP to find the fuzzy preference weight.)

Step 2: Construct the fuzzy performance/decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria.

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_1 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array}, \quad (16)$$

$$i=1,2,\dots,m;\ j=1,2,\dots,n;\quad \tilde{x}_{ij} = \frac{\sum \tilde{x}^k_{ij}}{k}$$

Where $\tilde{x}^k_{ij}$ is the performance rating of alternative Ai with respect to criterion Cj evaluated by kth expert, and $\tilde{x}^k_{ij} = (l^k_{ij}, m^k_{ij}, u^k_{ij})$.

Step 3: Normalize the fuzzy-decision matrix. The normalized fuzzy-decision matrix denoted by $\tilde{R}$ is shown as following formula:

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n} \quad i = 1,2,\dots,m; j = 1,2,\dots,n \quad (17)$$

Then, the normalization process can be performed by following formula:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right), u_j^+ = max_i\{u_{ij} | i = 1,2,\dots,n\} \quad (18)$$

The normalized $\tilde{r}_{ij}$ is still triangular fuzzy numbers. The weighted fuzzy normalized decision matrix is shown as following matrix $\tilde{V}$:

$$\tilde{V} = [\tilde{v}_{ij}]_{mn}, i = 1,2,\dots,m; j = 1,2,\dots,n \quad (19)$$

Where $\tilde{v}_{ij} = \tilde{x}_{ij}.w_i$

Step 4: Identify positive ideal (A*) and negative ideal (A-) solutions. The fuzzy positive-ideal solution (FPIS, A*) and the fuzzy negative-ideal solution (FNIS, A-) are shown in the following equations:

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_i^*\} = \left\{\left(\max_j v_{ij} \middle| i\epsilon I'\right), \times \left(\min_j v_{ij} \middle| i\epsilon I''\right)\right\}, i = 1,2,\dots,n\ j = 1,2,\dots,J, \quad (20)$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_i^-\} = \left\{\left(\min_j v_{ij} \middle| i\epsilon I'\right), \times \left(\max_j v_{ij} \middle| i\epsilon I''\right)\right\}, i = 1,2,\dots,n\ j = 1,2,\dots,J, \quad (21)$$

Where I' is associated with benefit criteria and I'' is associated with cost criteria.
Step 5: Calculate the distance of each alternative from A* and A- using the following equations:

$$D_j^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^*) \quad j = 1,2,\ldots,J \tag{22}$$

$$D_j^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^-) \quad j = 1,2,\ldots,J \tag{23}$$

Step 6: Calculate similarities to ideal solution.

$$CC_j = \frac{D_j^-}{D_j^* + D_j^-} \qquad j = 1,2,\ldots,J. \tag{24}$$

Step 7: Rank preference order. Choose an alternative with maximum CC_j^* or rank alternatives according to CC_j^* in descending order.

4. Numerical Example

A numerical example is presented to illustrate the combined fuzzy AHP-TOPSIS application and validity of its results in the CIM selection problem. For the CIM selection problem, the factors are determined based on the Luong [3]. Luong considered the selection problem of the most suitable CIM technologies for textile industry. The CIM technology selection problem consists of six objectives and eight alternative CIM technologies, as shown in Table 2.

Tab. 2. CIM technologies and objectives suggested

CIM technology	Objectives
Computer-aided design (CAD)	Reduction manufacturing lead time (MLT)
Group technology (GT)	Increased productivity (PRO)
Computer numerically controlled machines (CNC)	Reduced inventory and work in progress (WIP)
Flexible manufacturing systems (FMS)	Increased quality including reduced scraps and rework (QUA)
Robotics (ROB)	
Automated material handling system (AMH)	Increased flexibility (FLEX)
Material requirements planning (MRP)	Increased integration in the company (INT)
Computer-aided process planning (CAPP)	

The hierarchical structure of this research is shown in Fig. 6. After the construction of the hierarchy, the different priority weights of each criteria, attributes and alternatives are calculated using the fuzzy AHP and fuzzy TOPSIS approaches. The comparison of the importance of one criterion, attribute (objective) or alternative over another can be done with the help of the questionnaire.

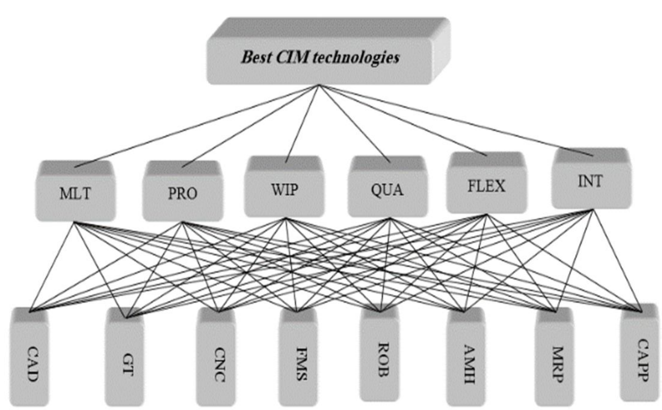

Fig. 6. Decision hierarchy of CIM technology selection.

The method of calculating priority weights of the different decision alternatives is discussed below.
Step 1(FAHP method): The weights of evaluation dimensions.

We adopt fuzzy AHP method to calculate the weights of different dimensions for the objectives and alternatives. Following the construction of the fuzzy AHP model, it is extremely important that experts fill the judgment matrix. To complete

the matrix, multiple academic members and students familiar with the subject were used. The following section demonstrates the computational procedure of the weights of dimensions.
According to The expert answers about the relative important of dimension, then the pairwise comparison matrices of dimensions will be obtained. We apply the fuzzy numbers defined in Table 1. We transfer the linguistic scales to the corresponding fuzzy numbers. therefore, the pairwise comparison matrices of the objectives will be constructed as follows matrix A:

$$A = \begin{array}{c} \\ MLT \\ PRO \\ WIP \\ QUA \\ FLEX \\ INT \end{array} \begin{array}{c} \begin{array}{cccccc} MLT & PRO & WIP & QUA & FLEX & INT \end{array} \\ \begin{bmatrix} (1,1,1) & (1,3,5) & (1,2,4) & (1,1,3) & (1,2,4) & (3,5,7) \\ (0.2,0.33,1) & (1,1,1) & (0.25,0.5,1) & (0.25,0.5,1) & (1,3,5) & (1,2,4) \\ (0.25,0.5,1) & (1,2,4) & (1,1,1) & (0.25,0.5,1) & (1,3,5) & (1,2,4) \\ (0.33,1,1) & (1,2,4) & (1,2,4) & (1,1,1) & (3,5,7) & (1,3,5) \\ (0.25,0.5,1) & (0.2,0.33,1) & (0.2,0.33,1) & (0.14,0.2,0.33) & (1,1,1) & (5,7,9) \\ (0.14,0.2,0.33) & (0.25,0.5,1) & (0.25,0.5,1) & (0.2,0.33,1) & (0.11,0.14,0.2) & (1,1,1) \end{bmatrix} \end{array}$$

To calculate the fuzzy weights of dimensions, the computational procedures are displayed as following parts:

$$\textstyle\sum_{j=1}^{m} M_{g1}^{j} = (1,1,1) + (1,3,5) + (1,2,4) + (1,1,3) + (1,2,4) + (3,5,7) = (8,14,24)$$

$$\sum_{j=1}^{m} M_{g2}^{j} = (3.7,7.33,13), \sum_{j=1}^{m} M_{g2}^{j} = (4.5,9,16), \sum_{j=1}^{m} M_{g2}^{j} = (7.33,14,22), \sum_{j=1}^{m} M_{g2}^{j} = (6.79,9.36,13.33), \sum_{j=1}^{m} M_{g2}^{j} = (1.95,2.67,4.53)$$

$$[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]^{-1} = [32.27,56.36,92.86]^{-1} = (0.0107,0.0177,0.0309)$$

$$s_1 = (0.086,0.248,0.743), s_2 = (0.039,0.130,0.402), s_3 = (0.048,0.159,0.495), s_4 = (0.078,0.248,0.681), s_5 = (0.073,0.166,0.413), s_6 = (0.020,0.047,0.140)$$

$$V(s_1 \geq s_2) = 1, V(s_1 \geq s_3) = 1, V(s_1 \geq s_4) = 1, V(s_1 \geq s_5) = 1, V(s_1 \geq s_6) = 1$$

$$V(s_2 \geq s_1) = \frac{0.402 - 0.086}{(0.402 - 0.086) + (0.248 - 0.130)} = 0.728$$

Similarly, we can obtain the remaining $V(s_i \geq s_k)$.

$$V(s_1 \geq s_2, s_3, s_4, s_5, s_6) = 1, V(s_2 \geq s_1, s_3, s_4, s_5, s_6) = 0.728, V(s_3 \geq s_1, s_2, s_4, s_5, s_6) = 0.822, V(s_4 \geq s_1, s_2, s_3, s_5, s_6) = 1, V(s_5 \geq s_1, s_2, s_3, s_4, s_6) = 0.798, V(s_6 \geq s_1, s_2, s_3, s_4, s_5) = 0.212$$

$$W' = (1,0.728,0.821,1,0.798,0.212), W = \frac{W_i'}{\sum W_i'} = (0.219,0.159,0.180,0.219,0.175,0.046)$$

We also can calculate the remaining W_i, there are:
$W_{CAD} = (0.029,0.173,0.214,0,0.104,0.048), W_{GT} = (0,0.197,0.187,0.134,0.018,0)$,
$W_{CNC} = (0.237,0,0.2,0,0.105,0.249)$, $W_{FMS} = (0,0.22,0.113,0.060,0,0)$,
$W_{ROB} = (0.089,0,0.156,0.044,0.170,0.271)$, $W_{AMH} = (0.063,0,0,0.178,0.172,0.271)$,
$W_{MRP} = (0.030,0.225,0.026,0.319,0.213,0.070)$,
$W_{CAPP} = (0.272,0.183,0.101,0.262,0.213,0.087)$,
$W_{objectives} = (0.219,0.159,0.180,0.219,0.175,0.046)$,
The final weight and ranking are shown in Table 3.

Tab. 3. CIM technologies alternatives weights and ranking.

CIM Technology Alternatives	Weights	Rank
Computer-aided design (CAD)	0.093	7
Group technology (GT)	0.097	5
Computer numerically controlled machines (CNC)		
Flexible manufacturing systems (FMS)	0.118	3
Robotics (ROB)	0.068	8
Automated material handling system (AMH)	0.099	4
Material requirements planning (MRP)	0.095	6
Computer-aided process planning (CAPP)	0.157	2
	0.20	1

Step 2 (FTOPSIS method): Construct the fuzzy-decision matrix and choose the appropriate linguistic variables for the alternatives with respect to objectives. Linguistic variables are presented in Table 4.

Tab. 4. Linguistic variables for the objective weights [33].

Linguistic variables	Triangular fuzzy scale
Very low (VL)	(0,0.1,0.25)
Low (L)	(0.15,0.3,0.45)
Medium (M)	(0.35,0.5,0.65)
High (H)	(0.55,0.7,0.85)
Very high (VH)	(0.75,0.9,1)

The fuzzy-decision matrix is:

$$
\begin{array}{c}
\text{CAD} \\ \text{GT} \\ \text{CNC} \\ \text{FMS} \\ \text{ROB} \\ \text{AMH} \\ \text{MRP} \\ \text{CAPP}
\end{array}
\begin{bmatrix}
(0.15,0.3,0.45) & (0.15,0.3,0.45) & (0,0.1,0.25) & (0.55,0.7,0.85) & (0.35,0.5,0.65) & (0.35,0.5,0.65) \\
(0.55,0.7,0.85) & (0.35,0.5,0.65) & (0,0.1,0.25) & (0,0.1,0.25) & (0.55,0.7,0.85) & (0.15,0.3,0.45) \\
(0.55,0.7,0.85) & (0.35,0.5,0.65) & (0,0.1,0.25) & (0.15,0.3,0.45) & (0.35,0.5,0.65) & (0,0.1,0.25) \\
(0.35,0.5,0.65) & (0.35,0.5,0.65) & (0.35,0.5,0.65) & (0.35,0.5,0.65) & (0.75,0.9,1) & (0.75,0.9,1) \\
(0.75,0.9,1) & (0.55,0.7,0.85) & (0.15,0.3,0.45) & (0.55,0.7,0.85) & (0.35,0.5,0.65) & (0.35,0.5,0.65) \\
(0.55,0.7,0.85) & (0.55,0.7,0.85) & (0.55,0.7,0.85) & (0.15,0.3,0.45) & (0.35,0.5,0.65) & (0.15,0.3,0.45) \\
(0.35,0.5,0.65) & (0,0.1,0.25) & (0.55,0.7,0.85) & (0,0.1,0.25) & (0.15,0.3,0.45) & (0.15,0.3,0.45) \\
(0.35,0.5,0.65) & (0.15,0.3,0.45) & (0.35,0.5,0.65) & (0.15,0.3,0.45) & (0.15,0.3,0.45) & (0.15,0.3,0.45)
\end{bmatrix}
$$

Step 3: Calculate the weighted normalized fuzzy decision matrix. We can normalize the fuzzy-decision matrix using Eq. (18). The normalized fuzzy decision matrix is formed as in Table 5. Then weighted normalized fuzzy decision matrix is formed as in Table 6.

Tab. 5. Normalized fuzzy decision matrix

	MLT	PRO	WIP	QUA	FLEX	INT
CAD	(0.15,0.3,0.45)	(0.176,0.353,0.529)	(0,0.118,0.294)	(0.647,0.824,1)	(0.35,0.5,0.65)	(0.35,0.5,0.65)
GT	(0.55,0.7,0.85)	(0.412,0.588,0.765)	(0,0.118,0.294)	(0,0.118,0.294)	(0.55,0.7,0.85)	(0.15,0.3,0.45)
CNC	(0.55,0.7,0.85)	(0.412,0.588,0.765)	(0,0.118,0.294)	(0.176,0.353,0.529)	(0.35,0.5,0.65)	(0,0.1,0.25)
FMS	(0.35,0.5,0.65)	(0.412,0.588,0.765)	(0.412,0.588,0.765)	(0.412,0.588,0.765)	(0.750,0.9,1)	(0.75,0.9,1)
ROB	(0.75,0.9,1)	(0.647,0.824,1)	(0.176,0.353,0.529)	(0.647,0.824,1)	(0.35,0.5,0.65)	(0.35,0.5,0.65)
AMH	(0.55,0.7,0.85)	(0.647,0.824,1)	(0.647,0.824,1)	(0.176,0.353,0.529)	(0.35,0.5,0.65)	(0.15,0.3,0.45)
MRP	(0.35,0.5,0.65)	(0,0.118,0.294)	(0.647,0.824,1)	(0,0.118,0.294)	(0.15,0.3,0.45)	(0.15,0.3,0.45)
CAPP	(0.35,0.5,0.65)	(0.176,0.353,0.529)	(0.412,0.588,0.765)	(0.176,0.353,0.529)	(0.15,0.3,0.45)	(0.15,0.3,0.45)

Tab. 6. Weighted normalized fuzzy decision matrix

	MLT	PRO	WIP	QUA	FLEX	INT
CAD	(0.014,0.028,0.042)	(0.016,0.033,0.049)	(0,0.011,0.027)	(0.060,0.076,0.093)	(0.032,0.046,0.060)	(0.032,0.046,0.060)
GT	(0.054,0.068,0.083)	(0.040,0.057,0.075)	(0,0.011,0.029)	(0,0.011,0.029)	(0.054,0.068,0.083)	(0.015,0.029,0.044)
CNC	(0.065,0.082,0.1)	(0.048,0.069,0.090)	(0,0.014,0.035)	(0.021,0.042,0.062)	(0.041,0.059,0.077)	(0,0.012,0.029)
FMS	(0.024,0.034,0.044)	(0.028,0.040,0.052)	(0.028,0.040,0.052)	(0.028,0.040,0.052)	(0.051,0.062,0.068)	(0.051,0.062,0.068)
ROB	(0.075,0.089,0.099)	(0.064,0.082,0.099)	(0.018,0.035,0.053)	(0.064,0.082,0.099)	(0.035,0.050,0.065)	(0.035,0.050,0.065)

AMH	(0.052,0.067,0.081)	(0.062,0.079,0.095)	(0.062,0.079,0.095)	(0.017,0.034,0.050)	(0.033,0.048,0.062)	(0.014,0.029,0.043)
MRP	(0.055,0.079,0.102)	(0,0.019,0.049)	(0.102,0.130,0.157)	(0,0.019,0.046)	(0.024,0.047,0.071)	(0.024,0.047,0.071)
CAPP	(0.072,0.103,0.134)	(0.036,0.073,0.109)	(0.085,0.121,0.157)	(0.036,0.073,0.109)	(0.031,0.062,0.092)	(0.031,0.062,0.092)

Step 4: Identify FPIS (A*) and FNIS (A-) solutions.
We can define the fuzzy positive-ideal solution (FPIS, A*) and the fuzzy negative-ideal solution (FNIS, A-) as $\tilde{v}_i^* = (1,1,1)\ and\ \tilde{v}_i^- = (0,0,0)$ for benefit criterion, and $\tilde{v}_i^* = (0,0,0)\ and\ \tilde{v}_i^- = (1,1,1)$ for cost criterion. In this study, all objectives are benefit. The distance of each alternative from D* and D- can be currently calculated using Eq. (6), Eq. (22) and Eq. (23).

$$D_1^* = \sqrt{\frac{1}{3}[(1-0.014)^2 + (1-0.028)^2 + (1-0.042)^2]} + \cdots + \sqrt{\frac{1}{3}[(1-0.032)^2 + (1-0.046)^2 + (1-0.060)^2]} = 5.757$$

$$D_1^- = \sqrt{\frac{1}{3}[(0-0.014)^2 + (0-0.028)^2 + (0-0.042)^2]} + \cdots + \sqrt{\frac{1}{3}[(0-0.032)^2 + (0-0.046)^2 + (0-0.060)^2]} = 0.255$$

Step 5: Calculate the CCj according Eq. 23.

$$CC_1 = \frac{D_1^-}{D_1^* + D_1^-} = \frac{0.255}{5.757 + 0.255} = 0.042$$

Similar calculations are done for the other alternatives and the results of fuzzy TOPSIS analyses are summarized in Table 7.

Tab. 7. Fuzzy TOPSIS results.

Alternatives	Dj*	Dj-	CCj
Computer-aided design (CAD)	5.757	0.255	0.042
Group technology (GT)	5.750	0.265	0.044
Computer numerically controlled machines	5.718	0.300	0.050
(CNC)	5.724	0.281	0.047
Flexible manufacturing systems (FMS)	5.614	0.395	0.066
Robotics (ROB)	5.666	0.343	0.057
Automated material handling system (AMH)	5.655	0.372	0.062
Material requirements planning (MRP)	5.510	0.520	0.086
Computer-aided process planning (CAPP)			

Based on CCj values, the ranking of the alternatives in descending order are CAPP, ROB, MRP, AMH, CNC, FMS, GT and CAD. Proposed model results indicate that CAPP is the best CIM Technology with CCj value of 0.086.

5. Conclusion

Today, manufacturing industries are facing new challenges. Innovative solutions will solve the problem [34]. In order to, CIM is an innovative and expansive concept to provide the solutions manufacturing industries are seeking to survive in the current competitive global market with sophisticated and demanding customers. In recent decade, computer-related technologies and ICT tools are improved for the betterment of manufacturing industries. For this purpose VCIM concept is generated. In this study first, architecture for a CIM and VCIM system is described, then CIM selection is presented.
Decisions in Manufacturing industries are very complex, because is investment. Decisions are made today in increasingly complex environments industrial. In more cases the use of experts in this field is necessary. One of the problems in this environment is to select the suitable CIM technologies. Selecting the right CIM technology will have many benefits for the

companies. Multi-attribute decisions-making or multi-objective decisions-making method should be used to justify this problem. The combined use of the AHP and Topsis approaches extended the use of an MADM or MODM approach. Since humans are unsuccessful in making quantitative predictions, where they are comparatively efficient in qualitative forecasting, fuzzy set theory is an excellent tool to handle qualitative assessments about these systems.

In this study, objectives in manufacturing and proposed CIM Technology Company according literature and experts are identified, CIM technology selection with fuzzy AHP and fuzzy TOPSIS method has been proposed. In this presented model objective including: Reduction manufacturing lead time (MLT), Increased productivity (PRO), Reduced inventory and work in progress (WIP), Increased quality including reduced scraps and rework (QUA), Increased flexibility (FLEX), Increased integration in the company (INT); and CIM Technology including: Computer-aided design (CAD), Group technology (GT), Computer numerically controlled machines (CNC), Flexible manufacturing systems (FMS), Robotics (ROB), Automated material handling system (AMH), Material requirements planning (MRP), Computer-aided process planning (CAPP).

Objectives are assigned weights using fuzzy AHP by using pairwise comparison matrices. CIM technologies ranks are determined by using fuzzy TOPSIS method. The importance of the dimensions is evaluated by experts, and the uncertainty of human decision-making is taken into account through the fuzzy concept in fuzzy environment. After implementing and computation the proposed model, results show that CAPP is the best CIM Technology .

In future studies, other multi-criteria methods like fuzzy PROMETHEE and ELECTRE can be used to CIM Technology selection problems. Application of the proposed method in this study in a wider range of selection problems, which have large number of attributes in manufacturing companies.

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