Management and Production Engineering Review
Volume 10 • Number 1 • March 2019 • pp. 69–82
DOI: 10.24425/mper.2019.129570

A HYBRID FSIR-TOPSIS APPROACH FOR SELECTING OF MANUFACTURING LEVERS

Mehdi Ajalli[1], Mohammad Mahdi Mozaffari[2], Ali Asgharisarem[3]

[1] *Faculty of Management, University of Tehran, Iran*
[2] *Faculty of Social Science, Imam Khomeini International University (IKIU), Iran*
[3] *Faculty of Management and Accounting, Bu-Ali Sina University, Iran*

Corresponding author:
Mehdi Ajalli
Faculty of Management
University of Tehran
Tehran, Iran
phone: 0098-9126410243
e-mail: ajalli@ut.ac.ir

Received: 6 December 2017
Accepted: 18 February 2019

Abstract

One of the strategic decisions of any organization is decision making about manufacturing strategy. Manufacturing strategy is a perspective distinguishing a company from other present companies in that industry and creates a kind of stability in decisions and gives a special direction to organizational activities. SIR (SUPERIORITY& INFERIORITY Ranking) method and their applications have attracted much attention from academics and practitioners. FSIR proves to be a very useful method for multiple criteria decision making in fuzzy environments, which has found substantial applications in recent years. This paper proposes a FSIR approach based methodology for TOPSIS, which using MILTENBURG Strategy Worksheet in order to analyzing of the status of strategy of the Gas Company. Then formulates the priorities of a fuzzy pair-wise comparison matrix as a linear programming and derives crisp priorities from fuzzy pair-wise comparison matrices

Manufacturing levers (Alternatives) are examined and analyzed as the main elements of manufacturing strategy. Also, manufacturing outputs (Criteria are identified that are competitive priorities of production of any organization. Next, using a hybrid approach of FSIR and TOPSIS, alternatives (manufacturing levers) are ranked. So dealing with the selected manufacturing levers and promoting them, an organization makes customers satisfied with the least cost and time.

Keywords

strategy, Miltenburg's worksheet, Fuzzy Superiority & Inferiority Ranking (FSIR), TOPSIS, manufacturing levers, manufacturing outputs.

Introduction

There is many studies on manufacturing strategy (MS). For the first time Skinner (1969) [1] introduced manufacturing strategy to exploit certain properties of the manufacturing function to achieve competitive advantages. Manufacturing strategy is defined as a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system in order to meet a set of manufacturing objectives that fit with the overall business objectives. Skinner's approach have led to a predominant hierarchical process model starting from corporate strategy forming the context for the business strategy which in turn forms the context for each functional strategy including manufacturing. Skinner also has described the importance of a strategic alignment of the manufacturing function; manufacturing strategy has become one of the most discussed issues in the field of operations management. [2] provides a tool for the assessment of manufacturing's strategic role, and introduce product/process matrix. [3] proposed a framework for generic manufacturing strategies which is derived from [4, 5] approach of generic strategies and Hayes and Wheelwright's product-process matrix. [6] and [7] have made empirical observation of the strategy formulation and implementation process, and find that the process is essentially hierarchical, which is consistent with Skinner's approach. In a preliminary study of the ?rst HPM data set (High-Performance Manufacturing Project), Anderson & Schroeder (1999) [8] evaluated the process of manufacturing strategy empirically with a sample of 53 respondents. The paper focuses on the link between business strategy and manufacturing strategy and provides first insights how these strategy levels affect each other. The literature in the area of management strategy contains an excellent set of conceptualizations. In business and academic journals there exist plenty of articles telling industry what to do. The manufacturing industry, for instance, is told to integrate its financial, marketing and production strategies, develop an operational focus, and match its processing system to its product design and mix, and a host of other things. According to the Hill's point of view [9], manufacturing strategy should be supportive to the achievement of a company's competitive priorities. Hill also proposes a five-step procedure to link manufacturing strategy to order winners in order to achieve the congruence between them. Miltenburg [10] proposed an overall framework with three steps for performing an analysis of a company's manufacturing strategy in terms of congruence with the production system, its products, and its capabilities. In a study, Bates et al. [11] analyze the relationship between manufacturing strategy and organizational culture in 41 US plants and stress the link between the business strategy and the manufacturing strategy as well. At present, most research focuses on strategy content. However, research on manufacturing strategy development is relatively limited. Safsten et al. [12] investigate the usability of Miltenburg's framework in small and medium sized manufacturing companies, and further suggest some changes of the model. Lee et al. [13] propose a framework for a decision-support system to support the formulation of a manufacturing strategy which consists of manufacturing system modeling and analyzing performance measures. The proposed decision-support system enables the formulation of manufacturing strategy using what-if analysis against dynamic manufacturing environments. Quezada et al. [14] developed a methodology for the development of a manufacturing strategy by means of exploiting the concepts of the analytic hierarchy process. In terms of this methodology, a manufacturing strategy can be formulated by creating a five level hierarchy: focus, company objectives, strategic business units, critical success factors and manufacturing decision areas. This methodology also allows a strategic diagnosis of the current manufacturing system and the generation and evaluation of action plans to improve the company competitiveness. Slack et al. [15] give some indications on how to assess the support from the operations function. According to Slack view, manufacturing strategy is part of a manufacturing company's total strategy. It contains the pattern of strategic decisions and actions which set the role, objectives and activities of the manufacturing in a manufacturing company. Just as with any type of strategy, we can consider its content and process separately. The content of manufacturing strategy comprises the specific decisions and actions which set the manufacturing role, objectives and activities. Platts et al. [16] proposed a three stage procedure of developing manufacturing strategy. The procedure uses profiles of market requirements and achieved performance to show up the gaps which the manufacturing strategy must address. The literature Operation Management (OM) describe six indicators for plant competitive performance such as unit cost of manufacturing, standard product quality, on-time delivery, fast delivery, flexibility in changing the product mix and flexibility in changing volume, etc. [17]. Karacapilidis et al. [18] develop a computerized knowledge management system for the collaborative development of manufacturing strategy. The system is used to capture the strategists' rationale and stimulates knowledge elicitation, and it can support the social and knowledge processes of collaborative strategy development by integrating a domain specific modeling formalism.

Many publications offer conceptual frameworks, give empirical evidence, etc. concerning the use of a manufacturing strategy. While extensive literature on manufacturing strategy has been written since the 1960s, still some research questions remain unanswered. Today, manufacturing companies are forced to stand up to competitors in the light of a highly competitive environment. This can be achieved by a specific alignment of the manufacturing function. Through the formulation of a manufacturing strategy, the strategic potential of the manufacturing function can be realized, leading to superior competitiveness. Despite the fact that manufacturing strategy is commonly accepted as an important approach, there is still a lack of empirical work, especially regarding the use of manufacturing strategies in a broad international context [19].

Arafa et al. [20] has discussed the manufacturing strategy and enterprise dynamic capability. The typical strategic planning process for industrial enterprises starts by defining the business strategy that the firm will utilize. According to the selected type of strategy, firms have to generate a portfolio of capabilities that will determine the contribution of the manufacturing function to overall business performance. By analyzing different scenarios using a system dynamic simulation approach and considering market competitive dynamics, this study explores the volume flexibility measure considering both the operating environment and the simultaneous strategic behavior of the competing firms.

Jia et al. [21] proposed an approach for manufacturing strategy development based on fuzzy-QFD. The study starts by analyzing the process of manufacturing strategy development and the features of QFD. In this research, the proposed methodology for developing manufacturing strategy uses QFD as a transforming device to link competitive factors with manufacturing decision categories such as structural decision categories and infrastructural categories, and uses HOQ as a main tool in different stages of manufacturing strategy development process.

Zahirul and Maybelle [22], discovered how the strategic change following a corporate takeover impacted the nature and extent of use of the firm's management control systems (MCS), in particular its performance measurement system (PMS). They used Michael Porter's theory of competitive advantage and Robert Simons' levers of control framework to illustrate and interpret changes in the PMS within an Australian multinational subsidiary following its takeover by an overseas corporation. To provide empirical evidence on this issue, face-to-face interviews and archival data are used.

Pradip et al. [23] investigated the employment of manufacturing strategy in packaging industry of Indian company by three constructs manufacturing as competitive force, functional integration of manufacturing, strategic planning and communication. The final purpose of this paper is proposing a framework for linking and exploring the pattern of manufacturing strategy implementation, differences in manufacturing decisions/levers, manufacturing outputs and business performance of a firm. This is applied by grouping the equipment in four class based on the increasing level of manufacturing strategy implementation using cluster analysis.

Fantino Giorgio [24] in a doctoral dissertation focused on workers skills as a competitive asset in world. In this context, the new actors have to understand and measure the advantage of investing in distinguished skills of their workers and translate this investment into competitive advantage.

Luqman et al. [25] used AHP approach for selecting of manufacturing process of Composite Bicycle's Crank Arm. The master purpose of this paper is investigating the potential type of manufacturing process to fabricate composite bicycle crank arm in order to help manufacturing in identification the best process to be applied in manufacturing of composite bicycle crank arm to decrease the manufacturing cost.

Undoubtedly, formulating the manufacturing strategy and the way of achieving it is one of the most important factors of business planning process of an organization, but in many cases, no attention is paid to it and there is not enough knowledge about it. To respond to this lack, a research is conducted in an industrial unit that is one of the great component makers of the country. The main purposes of this research are as follows;

- ranking manufacturing strategies;
- ranking manufacturing levers and assigning them optimally to support from manufacturing strategy.

For achieving these objectives, this paper proposes Miltenburg's strategy worksheet, and a Fuzzy Superiority & Inferiority Ranking (FSIR), based TOPSIS methodology which formulates the priorities of a fuzzy pair-wise comparison matrix as a linear programming and derives crisp priorities from fuzzy pair-wise comparison matrices.

The Superiority & Inferiority Ranking (FSIR) method is one of the new and relative complex Multi Criteria Decision Making methods. There are preference functions in this method such as PROMETHEE, which after calculating the preference of each alternative to the criteria, and finding the paired preference functions of alternatives due to the criteria, superiority and inferiority matrix must be formed. At the next step weighted flow matrix is formed such as SAW and TOPSIS techniques, and alternatives can be ranked by calculating the flows.

The fuzzy set theory approaches could resemble human reasoning in use of approximate information and uncertainty to generate decisions. Furthermore, fuzzy logic has been integrated with MCDM to deal with vagueness and imprecision of human judgment.

This paper outlines the theoretical basis of manufacturing strategy and Miltenburg's worksheet. Fuzzy logic that is the basis for this research analysis has been thoroughly explored and then the research methodology is discussed. Superiority and Inferiority ranking (SIR) techniques and subsequently expression of this technique in the fuzzy space are shaping the next phase of this article. Using fuzzy SIR techniques in strategy analysis – that is one of the innovations of this study – and its implementation in a typical sample and then expression of conclusions from findings form the final stages of this research.

Fuzzy SIR uses fuzzy set theory to express the uncertain comparison judgments as a fuzzy numbers.

The reminder of this paper is organized as follows: Sec. 2, Introduces the research area (Abzarsazi Industries of Iran); Sec. 3, describes manufacturing strategy (Manufacturing outputs as Criteria's and Manufacturing levers as Alternatives); Sec. 4, reviews the literature of TOPSIS, Fuzzy TOPSIS and Fuzzy TOPSIS stepwise procedure; Sec. 5, gives a brief review of Fuzzy SIR; in Sec. 6, case study of this research is presented; and finally in Sec. 7, is the conclusion of this paper.

Research area (Abzarsazi industries of Iran)

Abzarsazi Industries produces metal components that tries to improve its quality, safety and occupational hygiene performance constantly by establishing quality management systems, safety and occupational hygiene based on ISO 9001:2008 and OHSAS 18001:2007 for achieving its strategic aims. At present, having efficient human resource and equipped and advanced shop floors and also various processes of production such as machining, thermal operations, forging, founding, die making, etc. this industry is one of pioneer component maker companies in the country.

Production managers always want to offer a better and more diversified and cheaper product. On the other hand, Demands of customers increases and competitors offer more products, but what do producers offer to customers? According to Miltenburg's strategy worksheet there are six important outputs including in time delivery, cost, quality, performance, flexibility and innovation [26].

Applying a competitive strategy requires using a suitable production system and applying a production system also needs supplying an acceptable level of manufacturing levers. Manufacturing levers or manufacturing factors are human resources, organizational structures & controls, production planning & control, sourcing, process technology and facilities. Also existing limitations for organization is budget and time (Management and Employment).

Certainly, supplying the above manufacturing levers makes the organization reach ideal conditions, but do the existing limitations allow realizing this vision? According to the existing limitations, investing for improving which manufacturing lever(s) can be better effective in implementing suitable production systems and achieving the competitive advantages of the organization? It is better for producing companies to follow policies to meet expectations of customers in long term, to prevent from making sketchy decision and temporal improvements. Then the main question of the research is as follows:

According to limitation of resources in Abzarsazi Industries such as budget and time(Employments and Managers), and considering the Criteria's (Delivery, Cost, Quality, Performance, Flexibility, Innovativeness), improvement of which Manufacturing levers including human resources, organizational structure, substructures, production planning, process technology or supply resources can cover criteria of evaluating customers of Abzarsazi Industries?

The power of organizations in response to rapid changes of the environment and accountability to demands of customers in current competition conditions are the most important advantages. Doing the present research and finding suitable manufacturing levers according to demands of customers are necessary to achieve this aim. The results of solving this problem are: ranking manufacturing strategies, choosing a suitable production system, choosing manufacturing levers and allocating resources optimally to support from manufacturing levers. Implementing procedures of the research increases customers' satisfactions, production share relative to competitors and develops the organization more.

Manufacturing strategy

Organizations compete with each other to survive and achieve success and use a strategy to be better to survive and guarantee their success in long term. The nature of strategy is selection of different implementation of activities compared to competitors, so that it brings a unique value situation. According to Porter, a stable strategic situation is the result of a system of activities that any of them enhances the other. In strategy planning, three levels are defined for strategy: Corporate strategy, of Business strategy and functional strategy. The level of corporate strategy includes macro decisions of the company. The business strategy notes the way of competition at any business. According to the general direction of corporate strategy, business managers make decisions about competitive advantage of any business. Finally, functional strategies are designed for supporting function sectors of the company from corporate strategy and business strategy. [27] define the manufacturing strategy as a consistent model of decisions in production that is related to business strategy. According to this definition, manufacturing strategy is a body whose contents are decisions related to production and its two features are consistency of decisions with each other and their relations with business strategy [27]. Hill thinks the manufacturing strategy is the way of coordination for achieving consistency among production capabilities and success requirements [28].

Strategies show the way achieving the goals, so selecting correct and effective ways is critical. One of the suitable analytical models in manufacturing strategy and production system is Miltenburg strategy worksheet. Combining models and tools presented by other researchers, Miltenburg has presented a general framework for analyzing the manufacturing strategy of a company due to its convergence with production system and its capabilities [26].

Manufacturing outputs (Criteria's)

Production competitive priorities are one of the contextual elements of manufacturing strategy. In this element, the importance of any competitive priorities in production system is identified. The study of previous researches (to 1990s) about manufacturing strategy shows that there is a general agreement on four priorities of cost, quality, delivery and flexibility. Almost most theoreticians believe that in manufacturing strategy, the importance and priority of any of these four factors must be determined. Skinner believes that the emphasis of any of these priorities is a guideline for designing and planning a production system. For example, if in a production system, reduction of cost is chosen as the first priority, it shows that in production planning, cost reduction plans must be paid more attention. There are two views about competitive priorities:

- the view of exchanging competitive priorities,
- the view of high class global companies.

Advocates of the first view believe that producing companies are not able to simultaneously achieve all competitive priorities and as a result, there is a king of exchange between selection of competitive priorities and more attention to one of competitive priorities leads to less attention to other priorities. However, advocates of the second view believe that producing companies established today and famous as high class global producers retract this rule and apply competitive priorities including cost, quality, flexibility and quick delivery simultaneously on their production system.

Managers always try to offer a better and more diversified product more quickly. An organization being a pioneer in one or more of such cases can guarantee its victory against competitors. Industry offers six manufacturing outputs to the customers (Table 1). These six outputs are the result of Miltenburg's classification and match of eleven variables estimated in the study of Miltenburg [26].

Table 1
Manufacturing outputs [26].

Delivery	Time between taking orders and delivery to customers. How does a delay occur in most orders? How are delays?
Cost	Costs of materials, work force, overload and other resources used for producing a product
Quality	The extent of matching between materials and operations and demands and expectations of customers
Performance	The features of products and the extent in which features and design allow a product to do what other products can't do
Flexibility	The extent in which the volume of the existing products can increase or decrease to respond to demands of customers quickly
Innovativeness	The ability of introducing new products quickly by changing the design of the existing products

Manufacturing levers (alternatives)

Most big organizations have three levels of strategy as corporate strategy, Business strategy and Functional strategy. Main factors at business level are production, marketing, financial affairs and human relations. Each of these factors must perform inside certain limitations and these limitations will effect on strategies. At the third level of strategic planning orders (functional level), each of functional areas as marketing, production, financial affairs, etc. provide strategies for supporting from certain goals of the organization. Manufacturing strategy is composed of eight main components: production technology, capacity, facilities and deployment, process technology, human resources, operational decisions, integration of suppliers and quality (Fig. 1).

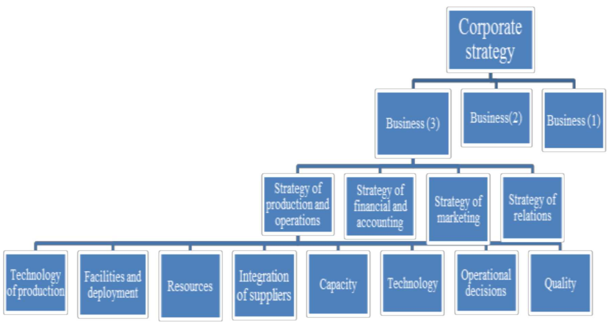

Fig. 1. Hierarchy of strategic planning in an organization.

Many authors have expanded lists of strategic decision aspects or production subsystems. In one of famous lists, six subsystems are slated for production. These subsystems are called Manufacturing levers (factors) and are: human resources, organizational structures & controls, production planning & control, sourcing, process technology and facilities (Table 2).

Table 2
Manufacturing levers.

Human resources	The level of skill, wage, educational policies and promotion, employment security and etc for all groups of staff
Organizational structures & controls	Formal communications between groups (queues) in production systems. The way of decision making, what is the dominant culture? Which system is used for evaluating performance and motivation?
Production planning & control	Rules and policies planning and controlling the following: flow of materials, activities of queued staff, operation of supporting from production and introducing new products
Sourcing	The amount of vertical integration, how does the production system manage that part of production and distribution system not owned? How are the relations with suppliers
Process technology	The type of equipment, the extent of automation, connection between production process parts
Facilities	The location, size and focus of individual shop floors, the type and time of variations in these shop floors

Any variation at the level of functional strategies of the organizations creates adjustments in manufacturing levers. Small variations in manufacturing levers improve the current production system and extensive modulations of manufacturing levers can result in variation of the production system. In other words, the combination of the six factors determines perfectly that whether the production system is job shop or batch flow, OPL[1], EPL[2], FMS[3], JIT[4] or continuous flow. When the existing production system changes to other system, wide modulations are required for all six factors.

Research methodology

The fuzzy TOPSIS

Decision-making is the procedure to find the best alternative among a set of feasible alternatives. Sometimes, decision-making problems considering several criteria are called multi-criteria decision-making (MCDM) problems [30, 31] and often require the decision makers to provide qualitative/quantitative assessments for determining the performance of each alternative with respect to each criterion, and the relative importance of evaluation criteria with respect to the overall objective of the problems. So, Multi-criteria decision making (MCDM) refers to screening, prioritizing, ranking, or selecting a set of alternatives (also referred to as "candidates" or "actions") under usually independent, incommensurate or conflicting criteria [32]. These problems will usually result in uncertain, imprecise, indefinite and subjective data being present, which makes the decision-making process complex and challenging. In other words, decision-making often occurs in a fuzzy environment where the information available is imprecise/ uncertain. Therefore, the application of fuzzy set theory to multi-criteria evaluation methods under the framework of utility theory has proven to be an effective approach [33]. The overall utility of the alternatives with respect to all criteria is often represented by a fuzzy number, which is named the fuzzy utility and is often referred to by fuzzy multi-criteria evaluation methods. The ranking of the alternatives is based on the comparison of their corresponding fuzzy utilities [34].

The TOPSIS is extended for group decision-making in a fuzzy environment [30] and incorporation the fuzzy set theory and the basic concepts of positive and negative ideal to expand multi-criteria decision-making in a fuzzy environment [31] and fuzzy pair-wise comparison and the basic concepts of positive ideal and negative ideal points to expand multi-criteria decision-making in a fuzzy environment [35]. A fuzzy multi-criteria decision-making method based on concepts of positive ideal and negative ideal points to evaluate bus companies' performance is also proposed [36].

Many ranking methods based on the fuzzy concepts have been proposed to solve the multiple criteria decision-making(MCDM) problems, e.g. [35, 37–48] etc. However, to efficiently resolve the ambiguity frequently arising in available information and do more justice to the essential fuzziness in human judgment and preference, the fuzzy set theory [49], has been used to establish a fuzzy TOPSIS problem [30, 37–39, 43, 47, 49–51].

Fuzzy TOPSIS uses fuzzy set theory to express the uncertain comparison judgments as a fuzzy numbers. The main steps of fuzzy TOPSIS are as follows:

Step 1: Construct the decision matrix as below:

[1]Operator – Paced Line Flow
[2]Equipment – Paced Line Flow
[3]Flexible Manufacturing System
[4]Just in Time

	C_1	C_2	$\ldots$	C_n
A_1	$\widetilde{X}_{11}$	$\widetilde{X}_{12}$	$\ldots$	$\widetilde{X}_{1n}$
A_2	$\widetilde{X}_{21}$	$\widetilde{X}_{22}$	$\ldots$	$\widetilde{X}_{2n}$
$\vdots$			$\vdots$	
A_m	$\widetilde{X}_{m1}$	$\widetilde{X}_{m2}$	$\ldots$	$\widetilde{X}_{mn}$
W_j	$\widetilde{W}_1$	$\widetilde{W}_2$	$\ldots$	$\widetilde{W}_n$

That: $\widetilde{X}_{ij} = (x_{ij}^l,\, x_{ij}^m x_{ij}^u)$, $\widetilde{W}_j = (w_j^l,\, w_j^m w_j^u)$.

If there is multi decision maker, we should calculate the simple mean for all of decision makers.

Step 2: Normalize the DM as below:

For C_j^+ ($j \in$ Benefit) $\Longrightarrow$ Max $x_{ij}^u = p \Longrightarrow x_{ij}^N = \left(\frac{x_{ij}^l}{P}, \frac{x_{ij}^m}{P}, \frac{x_{ij}^u}{P}\right)$

For C_j^- ($j \in$ Cost) $\Longrightarrow$ Min $x_{ij}^l = \emptyset \Longrightarrow x_{ij}^N = \left(\frac{\emptyset}{x_{ij}^u}, \frac{\emptyset}{x_{ij}^m}, \frac{\emptyset}{x_{ij}^l}\right)$

$\widetilde{u} \Longrightarrow$ Normalize $\widetilde{x}$

Step 3: Constructing weighted Normalized DM as below:

$$\widetilde{V} = \widetilde{u} \otimes \widetilde{w}$$

	C_1	C_2	$\ldots$	C_n
A_1	$\widetilde{V}_{11}$	$\widetilde{V}_{12}$	$\ldots$	$\widetilde{V}_{1n}$
A_2	$\widetilde{V}_{21}$	$\widetilde{V}_{22}$	$\ldots$	$\widetilde{V}_{2n}$
$\vdots$			$\vdots$	
A_m	$\widetilde{V}_{m1}$	$\widetilde{V}_{m2}$	$\ldots$	$\widetilde{V}_{mn}$

$$\widetilde{V}_{ij} = \widetilde{u}_{ij} \otimes \widetilde{w}_j = (w_{ij}^l,\, w_{ij}^m w_{ij}^u)$$
$$= (u_{ij}^l \times w_j^l,\, u_{ij}^m \times w_j^m u_{ij}^u \times w_j^u)$$

Step 4: Determining the Fuzzy Positive & Negative Ideal Solution as below:

$$I^+ = \left(\widetilde{I}_1^+, \widetilde{I}_2^+, \ldots, \widetilde{I}_n^+\right)$$
$$= \left(\mathrm{Max}\widetilde{V}_{i1}, \mathrm{Max}\widetilde{V}_{i2}, \ldots, \mathrm{Max}\widetilde{V}_{in}\right)$$
$$I^- = \left(\widetilde{I}_1^-, \widetilde{I}_2^-, \ldots, \widetilde{I}_n^-\right)$$
$$= \left(\mathrm{Min}\widetilde{V}_{i1}, \mathrm{Min}\widetilde{V}_{i2}, \ldots, \mathrm{Min}\widetilde{V}_{in}\right)$$

Step 5: Calculating Distance between each Alternative & Fuzzy Positive & Negative Ideal Solution as below:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left\{ \left[V_{ij}^m - I_j^{+m}\right]^2 + a^* + b^* \right\}}$$

where

$$a^* = \left[(V_{ij}^m - I_j^{+m}) - (V_{ij}^l - I_j^{+l})\right]^2,$$
$$b^* = \left[(V_{ij}^m - I_j^{+m}) - (V_{ij}^u - I_j^{+u})\right]^2$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left\{ \left[V_{ij}^m - I_j^{-m}\right]^2 + c^* + d^* \right\}}$$

where

$$c^* = \left[(V_{ij}^m - I_j^{-m}) - (V_{ij}^l - I_j^{-l})\right]^2$$
$$d^* = \left[(V_{ij}^m - I_j^{-m}) - (V_{ij}^u - I_j^{-u})\right]^2$$

Step 6: Ranking with relation below:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}$$

So that the alternative with less CC_i is the better alternative.

SIR Method

This method (Similarity & Inferiority Ranking: SIR) is one of the new and relative complex Multi Criteria Decision Making methods. There are preference functions in this method such as PROMETHEE, which after calculating the preference of each alternative to the criteria, and finding the paired preference functions of alternatives due to the criteria, superiority and inferiority matrix must be formed. At the next step weighted flow matrix is formed such as SAW and TOPSIS techniques, and alternatives can be ranked by calculating the flows.

In SIR method we use such scores that these scores are obtained by comparing values of criteria. Assume that we have two alternatives A and A'. To calculate the scores for these ordinal data with respect to criterion g (to be maximized), we use the preference structure $\{P, I\}$ as follows:

$$APA'(A \text{ is preferred to } A') \text{ iff } g(A) > g(A'),$$
$$AIA'(A \text{ is indifferent to } A') \text{ iff } g(A) = g(A'),$$

where $g(A)$ and $g(A')$ are the criteria values for A and A' on criterion g.

First we must form a decision matrix. In any multi-criteria decision making method, the decision maker determines a number of criteria. Let A_1, $A_2, \ldots, Am$ be m alternative and $(g_1,\, g_2, \ldots, g_n)$ be n cardinal criteria. $g_j(A_i)$ is the performance of the i-th alternative A_i with respect to the j-th criteriong $_j$. $g_j(.)$ Is a real-valued function ($i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$)

$$D \begin{bmatrix} g_1(A_1) & g_2(A_1) & g_3(A_1) & g_n(A_1) \\ g_1(A_2) & g_2(A_2) & \cdots & g_n(A_2) \\ \vdots & . & \ddots & \vdots \\ g_1(A_m) & g_2(A_m) & \cdots & g_n(A_m) \end{bmatrix}.$$

Then we weight each criterion. In this step we can use some method like AHP or Shannon entropy. Now we can compare the criteria value on each criterion [52]. The generalized criterion is calculated using the elements of the decision matrix. The differences between criteria values are used to estimate the intensity of the preference of A over A' as per equation (1):

$$P(A, A') = f(d) = f(g(A) - g(A')),\quad P(A, A') \text{ is the preference of } A \text{ over } A'. \tag{1}$$

Brans [53] proposed six generalized criterion types which can be used to capture the characteristics of functions that represent the specified criteria. According to the attitude towards the preference structure and intensity of preference, the decision maker selects the generalized criteria (along with its associated parameter). Table 3 lists the types of generalized criteria. It should be noted that the intensity of preference for Types 3, 5, and 6 changes gradually from 0 to 1.

In this research, Criterion with linear preference and indifference area has been used. For each alternative A_i, the superiority index $S_j(A_i)$ and inferiority index $I_j(A_i)$ with respect to the j-th criterion are calculated as follows:

$$S_j(A)_i = \sum_{k=1}^{m} P(A_i, A_k) = \sum_{k=1}^{m} f_j(g_j(A_i) - g_j(A_k)), \tag{2}$$

$$I_j(A)_i = \sum_{k=1}^{m} P(A_k, A_i) = \sum_{k=1}^{m} f_j(g_j(A_k) - g_j(A_i)). \tag{3}$$

The superiority and inferiority indexes are used to form superiority matrix (S-matrix) and inferiority matrix (I-matrix). S-matrix provides information about the intensity of superiority of each alternative on each criterion, whereas, I-matrix provides information about the intensity of inferiority:

The superiority matrix (S-matrix)

$$\mathrm{S} \begin{bmatrix} S_1(A_1) & S_2(A_1) & S_3(A_1) & S_n(A_1) \\ S_1(A_2) & S_2(A_2) & \cdots & S_n(A_2) \\ \vdots & & \ddots & \vdots \\ S_1(A_m) & S_2(A_m) & \cdots & S_n(A_m) \end{bmatrix}.$$

The inferiority matrix (I-matrix)

$$\mathrm{I} \begin{bmatrix} I_1(A_1) & I_2(A_1) & I_3(A_1) & I_n(A_1) \\ I_1(A_2) & I_2(A_2) & \cdots & I_n(A_2) \\ \vdots & & \ddots & \vdots \\ I_1(A_m) & I_2(A_m) & \cdots & I_n(A_m) \end{bmatrix}.$$

The superiority and inferiority indexes (arranged in S- and I-matrix, respectively) are aggregated into two types of global preference indexes: superiority flow (S-flow) $\varphi^{\succ}$ (.) and inferiority flow (I-flow) $\varphi^{\prec}$(.). The S- and I-flows are basically the intensity of each alternative. The former flow measures how an alternative is globally superior to (or outranks) all the others, whereas, the latter flow measures how an alternative is globally inferior to (or outranked by) all the others.

Table 3
Generalized criteria.

Criterion	Criterion	Criterion
Type 1: True Criterion with linear preference	Type 2: Quasi criterion	Type 3: Criterion with linear preference
$f(d) = \begin{cases} 1 & \text{if } d \geq 0 \\ 0 & \text{if } d < 0 \end{cases}$	$f(d) = \begin{cases} 1 & \text{if } d \geq q \\ 0 & \text{if } d < q \end{cases}$	$f(d) = \begin{cases} 1 & \text{if } d \geq p \\ \frac{d}{p} & \text{if } 0 < d \leq p \\ 0 & \text{if } d \leq 0 \end{cases}$
Type 4: Level Criterion	Type 5: Criterion with linear preference and indifference area	Type 6: Gaussian criterion
$f(d) = \begin{cases} 1 & \text{if } d \geq p \\ \frac{1}{2} & \text{if } q < d \leq p \\ 0 & \text{if } d \leq q \end{cases}$	$f(d) = \begin{cases} 1 & \text{if } d \geq p \\ \frac{d-q}{p-q} & \text{if } q < d \leq p \\ 0 & \text{if } d \leq q \end{cases}$	$f(d) = \begin{cases} 1 - e^{\left(\frac{-d^2}{\sigma^2}\right)} & \text{if } d \geq 0 \\ 0 & \text{if } d < 0 \end{cases}$

There are two aggregation procedures which are used to obtain S- and I-flows. These are SAW and TOPSIS procedures. The SAW is considered the simplest and clearest procedure. It is usually used as a benchmark to compare the results obtained from other procedures. The TOPSIS is considered very logical way of approaching the discrete MCDM problems. However, it is computationally more complex than SAW [54]. The following sub-sections describe the structures of SAW and TOPSIS procedures.

SAW procedure; S- and I-flows are calculated based on the weight of criteria (w_j) as follows:

$$\varphi^{\succ}(A_i) = \sum_{j=1}^{n} W_j S_j(A_i), \tag{4}$$

$$\varphi^{\prec}(A_i) = \sum_{j=1}^{n} W_j I_j(A_i), \tag{5}$$

where

$$\sum_{i=1}^{n} W_j = 1\,(W_j \geq 0).$$

TOPSIS procedure; S-flow is calculated based on ideal solution A_{S+} and negative-ideal solution A_{S-} for the superiority matrix (S-matrix) as follows:

$$\varphi^{\succ}(A_i) = \frac{S_i^{-}(A_i)}{S_i^{-}(A_i) - S_i^{+}(A_i)}, \tag{6}$$

$$S_i^{+}(A_i) = \left\{ \sum_{j=1}^{n} \left| W_j \left(S_j(A_i) - S_j^{+} \right) \right|^{\lambda} \right\}^{1/\lambda} \quad (0 \leq \lambda \leq \infty), \tag{7}$$

$$S_i^{-}(A_i) = \left\{ \sum_{j=1}^{n} \left| W_j \left(S_j(A_i) - S_j^{-} \right) \right|^{\lambda} \right\}^{1/\lambda} \quad (0 \leq \lambda \leq \infty), \tag{8}$$

$$A_S^{+} = \left(\max_i S_1(A_i), ..., \max_i S_n(A_i) \right) = (S_1^{+}, ..., S_n^{+}), \tag{9}$$

$$A_S^{-} = \left(\min_i S_1(A_i), ..., \min_i S_n(A_i) \right) = (S_1^{-}, ..., S_n^{-}). \tag{10}$$

I-flow is calculated based on ideal solution I_S^{+} and negative-ideal solution I_S^{-} for the inferiority matrix (I-matrix) as follows:

$$\varphi^{\prec}(A_i) = \frac{I_i^{+}(A_i)}{I_i^{-}(A_i) - I_i^{+}(A_i)}, \tag{11}$$

$$I_i^{+}(A_i) = \left\{ \sum_{j=1}^{n} \left| W_j \left(I_j(A_i) - I_j^{+} \right) \right|^{\lambda} \right\}^{1/\lambda} \quad (0 \leq \lambda \leq \infty), \tag{12}$$

$$I_i^{-}(A_i) = \left\{ \sum_{j=1}^{n} \left| W_j \left(I_j(A_i) - I_j^{-} \right) \right|^{\lambda} \right\}^{1/\lambda} \quad (0 \leq \lambda \leq \infty), \tag{13}$$

$$A_I^{+} = \left(\min_i I_1(A_i), ..., \min_i I_n(A_i) \right) = (I_1^{+}, ..., I_n^{+}), \tag{14}$$

$$A_I^{-} = \left(\max_i I_1(A_i), ..., \max_i I_n(A_i) \right) = (I_1^{-}, ..., I_n^{-}). \tag{15}$$

Net and relative flows; Net flow (n-flow) and relative flows (r-flow) are calculated utilizing S- and I-flows as per equations (8) and (9):

$$\varphi_n(A_i) = \varphi^{\succ}(A_i) - \varphi^{\prec}(A_i), \tag{16}$$

$$\varphi_r(A_i) = \frac{\varphi^{\succ}(A_i)}{(\varphi^{\succ}(A_i) - \varphi^{\prec}(A_i))}. \tag{17}$$

Four complete ranking are obtained from S-, I-, n- and r-flows. These are S-ranking $(\Re_{>})$, I-ranking $(\Re_{<})$, n-ranking $(\Re_n)$, and r-ranking $(\Re_r)$. The S-ranking $\Re_{>} = \{P_{>}, I_{>}\}$, is obtained based on the descending order of $\varphi^{\succ}(A_i)$ as follows:

$$A_i P > A_k \quad \text{iff} \quad \varphi^{\succ}(A_i) > \varphi^{\succ}(A_k), \tag{18}$$

$$A_i I > A_k \quad \text{iff} \quad \varphi^{\succ}(A_i) > \varphi^{\prec}(A_k). \tag{19}$$

The I-ranking $\Re_{<} = \{P_{<}, I_{<}\}$, obtained based on the ascending order of $\varphi^{\prec}(A_i)$ as follows:

$$A_i P < A_k \quad \text{iff} \quad \varphi^{\prec}(A_i) > \varphi^{\prec}(A_k), \tag{20}$$

$$A_i I < A_k \quad \text{iff} \quad \varphi^{\prec}(A_i) = \varphi^{\prec}(A_k). \tag{21}$$

The n-ranking and r-ranking are obtained based on the descending order of n- and r-flows, respectively.

Partial ranking $(\Re)$ is obtained by combining S-ranking $\Re_{>}$, and I-ranking $\Re_{<}$, in a partial ranking structure as follows:

$$\Re = \{P, I, R\} = \Re_{>} \cap \Re_{<}. \tag{22}$$

The intersection principle, proposed by Brans et al. (1986) and Roy et al. (1992), is adopted to compare any two alternatives as follows:

Preference relation P:

$$\begin{aligned} APA' \quad &\text{iff} \quad (AP > A' \quad \text{and} \quad AP < A') \\ &\text{or} \quad (AP < A' \quad \text{and} \quad AI > A') \\ &\text{or} \quad (AI > A' \quad \text{and} \quad AP < A'). \end{aligned} \tag{23}$$

Indifference relation I:

$$\begin{aligned} AIA' \quad &\text{iff} \quad AI > A' \\ &\text{and} \quad AI < A'. \end{aligned} \tag{24}$$

www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

Incomparability relation R:

$$ARA' \quad \text{iff} \quad (AP > A' \quad \text{and} \quad A'P < A) \quad \text{or} \quad (A'P < A \quad \text{and} \quad AP > A'). \tag{25}$$

Fuzzy SIR stepwise procedure

Step 1: Construct the Decision Matrix as below:

	C_1	C_2	$\ldots$	C_n
A_1	$\widetilde{X}_{11}$	$\widetilde{X}_{12}$	$\ldots$	$\widetilde{X}_{1n}$
A_2	$\widetilde{X}_{21}$	$\widetilde{X}_{22}$	$\ldots$	$\widetilde{X}_{2n}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_m	$\widetilde{X}_{m1}$	$\widetilde{X}_{m2}$	$\ldots$	$\widetilde{X}_{mn}$
W_j	$\widetilde{W}_1$	$\widetilde{W}_2$	$\ldots$	$\widetilde{W}_n$

That: $\widetilde{X}_{ij} = (x_{ij}^l,\ x_{ij}^m x_{ij}^u)$, $\widetilde{W}_j = (w_j^l,\ w_j^m w_j^u)$
If there is multi decision maker, we should calculate the simple mean or weighted mean for all of decision makers.

Step 2: Construct the Pair-wise Matrix as below:

C_1	A_1	A_2	$\ldots$	A_m
A_1	$\acute{\widetilde{X}}_{11}$	$\acute{\widetilde{X}}_{12}$	$\ldots$	$\acute{\widetilde{X}}_{1m}$
A_2	$\acute{\widetilde{X}}_{21}$	$\acute{\widetilde{X}}_{22}$	$\ldots$	$\acute{\widetilde{X}}_{2m}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_m	$\acute{\widetilde{X}}_{m1}$	$\acute{\widetilde{X}}_{m2}$	$\ldots$	$\acute{\widetilde{X}}_{mm}$

That: $\acute{\widetilde{X}}_{ij} = (\acute{x}_{ij}^l \acute{x}_{ij}^m \acute{x}_{ij}^u)$

$$\acute{x}_{pq}^l = \begin{cases} x_{pj}^l - x_{iq}^l; & \frac{x_{pj}^l + x_{pj}^m + x_{pj}^u}{3} > \frac{x_{iq}^l + x_{iq}^m + x_{iq}^u}{3} \\ 0; & \text{otherwise} \end{cases} \tag{26}$$

$$\acute{x}_{pq}^m = \begin{cases} x_{pj}^m - x_{iq}^m; & \frac{x_{pj}^l + x_{pj}^m + x_{pj}^u}{3} > \frac{x_{iq}^l + x_{iq}^m + x_{iq}^u}{3} \\ 0; & \text{otherwise} \end{cases} \tag{27}$$

$$\acute{x}_{pq}^u = \begin{cases} x_{pj}^u - x_{iq}^u; & \frac{x_{pj}^l + x_{pj}^m + x_{pj}^u}{3} > \frac{x_{iq}^l + x_{iq}^m + x_{iq}^u}{3} \\ 0; & \text{otherwise} \end{cases} \tag{28}$$

Step 3: Construct a Superiority & Inferiority Matrix as below:

S	C_1	C_2	$\ldots$	C_n	$\widetilde{\varphi}^+$
A_1	$\widetilde{S}_{11} = \sum \widetilde{s}_{1j}^1$		$\ldots$	$\widetilde{S}_{1n} = \sum \widetilde{s}_{1j}^n$	$\sum\limits_k \widetilde{w}_k \sum\limits_j \widetilde{s}_{1j}^k$
A_2	$\widetilde{S}_{ij} = \sum \widetilde{s}_{ij}^k$				
$\vdots$					
A_m					
W_j	$\widetilde{W}_1$	$\widetilde{W}_2$	$\ldots$	$\widetilde{W}_n$	
I	C_1	C_2	$\ldots$	C_n	$\widetilde{\varphi}^+$
A_1	$\widetilde{I}_{11} = \sum \widetilde{I}_{i1}^1$		$\ldots$	$\widetilde{I}_{1n} = \sum \widetilde{I}_{in}^n$	$\sum\limits_k \widetilde{w}_k \sum\limits_j \widetilde{s}_{1j}^k$
A_2	$\widetilde{I}_{ij} = \sum \widetilde{I}_{ij}^k$				
$\vdots$					
A_m					
W_j	$\widetilde{W}_1$	$\widetilde{W}_2$	$\ldots$	$\widetilde{W}_n$	

Step 4: Combining the TOPSIS approach with FSIR in step3 and ranking by TOPSIS as below:

S	
w_j	
$\mathbf{A}^+$	
$\mathbf{A}^-$	
I	
w_j	
$\mathbf{A}^+$	
$\mathbf{A}^-$	

$$\mathbf{I}^+\mathbf{I}^-, \quad \varphi^- = \frac{I^-}{I^+ + I^-} \tag{29}$$

Step 5: Ranking by FSIR as below:

5.1.

	$\varphi^+ \oplus \varphi^-$	$\frac{1}{\varphi^+ \oplus \varphi^-}$	Ratio Flow (Doubis & Prade) $\frac{\varphi^+}{\varphi^+ \oplus \varphi^-}$	Doubis & Prade Method
A_1	$\widetilde{a}_i = (a_i^l, a_i^m a_i^u)$	$\widetilde{b}_i = (b_i^l, b_i^m b_i^u)$	$\widetilde{c}_i = (c_i^l, c_i^m c_i^u)$	
A_2				
$\vdots$				
A_m				

5.2.

	φ^+	φ^-	Net-Flow	
A_1	$\widetilde{\varphi}_1^+$	$\widetilde{\varphi}_1^-$	$\widetilde{\varphi}_1^n = \widetilde{\varphi}_1^+ \ominus \widetilde{\varphi}_1^-$	Yager Method
A_2	$\widetilde{\varphi}_2^+$	$\widetilde{\varphi}_2^-$	$\widetilde{\varphi}_2^n = \widetilde{\varphi}_2^+ \ominus \widetilde{\varphi}_2^-$	
$\vdots$	$\vdots$	$\vdots$	$\vdots$	
A_m	$\widetilde{\varphi}_m^+$	$\widetilde{\varphi}_m^-$	$\widetilde{\varphi}_m^n = \widetilde{\varphi}_m^+ \ominus \widetilde{\varphi}_m^-$	

$$b_i^m = \frac{1}{a_i^m},$$

$$b_i^l = \frac{1}{a_i^m} - \frac{a_i^u - a_i^m}{a_i^{m2}}, \tag{30}$$

$$b_i^u = \frac{1}{a_i^m} - \frac{a_i^m - a_i^l}{a_i^{m2}},$$

$$c_i^m = \varphi_i^{+m}.b_i^m,$$

$$c_i^l = c_i^m - [(b_i^m - b_i^l).\varphi_i^{+m} + (\varphi_i^{+m} - \varphi_i^{+l}).b_i^m],$$

$$c_i^u = c_i^m - [(b_i^u - b_i^m).\varphi_i^{+m} + (\varphi_i^{+u} - \varphi_i^{+m}).b_i^m]. \tag{31}$$

Case study (Evaluation and Selecting of Manufacturing Levers)

Step 1: Now we use Fuzzy SIR to evaluate the Manufacturing Levers. We will use a numerical illustration to show our method. In first, set up the fuzzy decision making matrix of Manufacturing Levers evaluation according to opinions of five experts in Abzarsazi Industries of Iran with fuzzy linguistic variables. On the other hand, in this step, a questionnaire prepared and five experts in Abzarsazi Industries completed it with linguistic variables. To convert the fuzzy linguistic variables to fuzzy number can use the Table 4.

Table 4
Linguistic variables for paired comparison criteria.

VL (Very low)	0	0.5	2
L (Low)	1	2	3
ML (Medium Low)	2	3.5	4
M (Medium)	4	5	6
MH (Medium High)	5	6.5	8
H (High)	7	8	9
VH (Very High)	8	9.5	10

So, the fuzzy decision making matrix of Manufacturing Levers evaluation according to opinions of five experts in Abzarsazi Industries of Iran with fuzzy number will extracted, and finally, the Integrated Fuzzy Decision Matrix will be as Fig. 2.

Step 2: Construct the Pair-Wise Matrices according to all of criteria's.

Step 3: Construct a Superiority & Inferiority Matrix as Figs 3 and 4.

That for example the number (−15.24152) in column $\varphi+$ is calculated as below:

$$\begin{gathered}-15.24152 = (-0.40594 * 0.9375) \\ +(0 * 6.0625) + (0.29631 * 5.875) \\ +(-0.76563 * 4.9375) + (-1.1875 * 5.5625) \\ +(-0.625 * 4.375).\end{gathered}$$

That for example the numbers (−0.13312, 0.062514, 0.649049) in table above are calculated as below:

$$-0.13312 = \left(-\frac{-0.40594}{e^*}\right) * 0.9375,$$

$$0.062514 = \left(-\frac{0.09375}{e^*}\right) * 1.90625,$$

$$0.649049 = \left(\frac{0.59375}{e^*}\right) * 3.125$$

where

$$e^* = \max(0.59375,\ 2.85875, 1.96825, 1.030938, 0, 2.187).$$

And the number (0.339273) in column $\varphi+$ is calculated as

$$0.339273 = \frac{16.17266}{31.49575 + 16.17253}.$$

That $A+$, $A-$ are maximum and minimum of column numbers.

Step 4: Combining the TOPSIS approach with FSIR in Step 3 and ranking by TOPSIS as Fig. 5.

Step 5: Ranking by FSIR as Fig. 6.

Conclusion

In this paper, Manufacturing levers (Alternatives) are examined and analyzed as the main elements of manufacturing strategy. Also, manufacturing outputs (Criteria's) are identified that are competitive priorities of production of any organization. Next, using a hybrid approach of FSIR and TOPSIS, alternatives (manufacturing levers) are ranked. Generally, evaluation and selecting of Manufacturing Levers and its problems as well as subjective judgment of appraiser are vague and uncertain, and so fuzzy set theory helps to convert DM preferences and judgments into meaningful results by applying linguistic values to measure each criterion with respect to every levers. In this paper, a multi-criteria group decision making model has been developed based on fuzzy set theory to efficiently deal with the ambiguity of the decision making problems in practical cases to evaluate the levers and comparing them. Fuzzy SIR is a helpful tool in multi-criteria decision making, in this method two superiority and inferiority flows show that an alternative how can be preferred to another alternatives. Other flows (n-flow and r-flow) in this method show that which of superiority or inferiority flow is more powerful than another. It makes decision making process more reliable. So dealing with the selected manufacturing levers and promoting them, an organization makes customers satisfied with the least cost and time.

Attachments:

C1	A1			A2			A3			A4			A5			A6		
A1	0	0	0	0	0	0	0	0	0	0	0	0	-0.4059375	0.09375	0.59375	0	0	0
A2	-0.09375	0.40625	0.6559375	0	0	0	-0.25	0.21875	0.46875	-0.0625	0.34375	0.5623125	0	0.5	0.75	-0.1875	0.171875	0.42175
A3	-0.3125	0.1875	0.6559375	0	0	0	0	0	0	-0.28125	0.125	0.5623125	-0.21875	0.28125	0.75	0	0	0
A4	-0.4060625	0.0625	0.4684375	0	0	0	0	0	0	0	0	0	-0.3123125	0.15625	0.5625	0	0	0
A5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A6	-0.2655	0.234375	0.5934375	0	0	0	-0.42175	0.046875	0.40625	-0.23425	0.171875	0.4998125	-0.17175	0.328125	0.6875	0	0	0
SUM	-1.0778125	0.890625	2.37375	0	0	0	-0.67175	0.265625	0.875	-0.578	0.640625	1.6244375	-1.10875	1.359375	3.34375	-0.1875	0.171875	0.42175

Fig. 2. The Integrated Fuzzy Decision Matrix.

S	**Criteria 1**			**Criteria 2**			**Criteria 3**		
Alternative 1	-0.40594	0.09375	0.59375	0	0	0	-0.29631	0.125	0.452938
Alternative 2	-0.59375	1.640625	2.85875	0.015625	0.453125	0.71825	0	0	0
Alternative 3	-0.8125	0.59375	1.96825	-0.203125	0.921875	1.624375	-0.28125	1.109375	2.421
Alternative 4	-0.71838	0.21875	1.030938	-0.015375	0.828125	1.2495	-0.125	1.734375	2.76475
Alternative 5	0	0	0	-0.359375	1.046875	2.030625	-0.32813	1.8125	3.20225
Alternative 6	-1.09325	0.78125	2.187	-0.359375	0.78125	2.030625	-0.156	1.0625	1.68675
Weight	0.9375	1.90625	3.125	5.0625	6.0625	21.9375	5.875	6.90625	32.25

Criteria 4			**Criteria 5**			**Criteria 6**			**φ+**		
-0.76563	1.46875	3.34125	-1.1875	0.546875	2.014813	-0.625	6.46875	12.8125	-15.24152	46.65576	169.9718
0	0	0	-0.39	0.046875	0.437313	3.125	10.84375	20.0625	11.024961	62.0791	155.8958
-0.71875	0.21875	1.217188	-1.32813	0.859375	2.624188	-2.75	2.25	6.5	-26.41016	32.64746	201.7618
-0.8425	1	2.560313	-0.8125	0.171875	1.202313	9.25	19.4375	30.1875	30.303688	124.7402	364.6989
-1.12313	0.3125	1.529688	-0.51563	0.171875	0.811688	0	0	2.125	-12.16066	21.81787	193.4137
-0.37431	0.09375	0.561625	0	0	0	-1.625	0.5625	2.5	-12.7183	17.0293	131.2289
4.9375	6.03125	16.9375	5.5625	6.21875	7.5625	4.375	5.15625	6.375			

Fig. 3. The Superiority Matrix.

NWS	**Criteria 1**			**Criteria 2**			**Criteria 3**		
Alternative 1	-0.30219	0.59388	2.594829	0.875434	6.726539	32.5945	0.184541	3.900918	28.57086
Alternative 2	0	0	0	-0.558544	1.921868	13.66897	0.669308	0.615673	3.983438
Alternative 3	-0.18834	0.177122	0.956493	-0.595939	0.132543	4.79613	-0.89874	0.070267	0.90625
Alternative 4	-0.16206	0.427177	1.77573	-0.819416	0.331357	7.670931	-0.39176	0.003346	0.3125
Alternative 5	-0.31086	0.906448	3.655171	0	0	0	0	0	0
Alternative 6	-0.05257	0.114608	0.46103	0	0	0	-1.31354	0.080305	1.7965
A+	0	0.906448	3.655171	0.875434	6.726539	32.5945	0.669308	3.900918	28.57086
A-	-0.31086	0	0	-0.819416	0	0	-1.31354	0	0

Criteria 4			**Criteria 5**			**Criteria 6**			**S+**	**S-**	**φ-**
0	0	0	-0.92131	0.164801	1.553183	0.020637	0.76006	2.074882	16.14591	37.21393	0.697415
-1.59243	2.226375	16.9375	-2.98504	1.318405	6.956257	-0.06191	0.334427	0.872052	27.30936	20.49962	0.428782
-1.41117	0.946209	8.518768	0	0	0	0.268278	1.580926	3.743809	34.757586	9.985688	0.223177
-0.43287	0.166978	2.343052	-1.40039	0.659202	2.905956	0	0	0	35.045522	8.318639	0.191832
-0.54633	0.779231	6.011593	-1.80577	0.659202	3.757702	0.484965	2.784861	6.375	38.523356	8.695461	0.184152
-1.59343	1.391484	12.2564	-2.87301	1.936407	7.5625	0.505601	2.237618	4.78125	36.420339	13.36785	0.268494
0	2.226375	16.9375	0	1.936407	7.5625	0.505601	2.784861	6.375			
-1.59343	0	0	-2.98504	0	0	-0.06191	0	0			

Fig. 4. The Inferiority Matrix.

Alternatives	φ+	Rank	φ-	Rank	π (net Flow)=(φ+)-(φ-)	Rank	Ratio flow= (φ+)/ (φ+ + φ-)	Rank
A1	0.339273	**5**	0.697415	**1**	-0.35814199	**6**	0.327266	**5**
A2	0.186807	**6**	0.428782	**2**	-0.24197523	**5**	0.30346	**6**
A3	0.690126	**3**	0.223177	**4**	0.466948474	**3**	0.755637	**3**
A4	0.748671	**2**	0.191832	**5**	0.556839153	**2**	0.796033	**2**
A5	0.780367	**1**	0.184152	**6**	0.596214161	**1**	0.809073	**1**
A6	0.559889	**4**	0.268494	**3**	0.291394225	**4**	0.675881	**4**

Fig. 5. Combining the TOPSIS approach with FSIR in step3 and ranking by TOPSIS.

-13.4244	103.6523	443.027
-2.75434	106.9395	420.3077
-30.8204	80.89746	375.4913
19.95224	129.1367	416.5703
-6.45736	102.4014	402.0195
-16.8996	88.52246	376.5261

-0.02194	0.009647635	0.020545
-0.01805	0.009351086	0.018943
-0.03265	0.012361327	0.029432
-0.00949	0.007743731	0.014291
-0.01881	0.009765495	0.020147
-0.02546	0.011296568	0.02475

Yager		
-15.2415	46.65576	169.9718
11.02496	62.0791	155.8958
-26.4102	32.64746	201.7618
30.30369	124.7402	364.6989
-12.1607	21.81787	193.4137
-12.7183	17.0293	131.2289

Ratio Flow (Doubis-Prade)			Deffuzification	Rank		Net Flow			Deffuzification	Rank
-1.6208	0.450118	2.148241	0.356918098	**5**		-288.297	-10.3408	168.1547	-35.20590723	**4**
-1.59798	0.580507	2.053254	0.404070968	**4**		-253.387	17.21875	169.6751	-12.31858496	**3**
-1.79608	0.403566	3.051361	0.515603524	**2**		-200.14	-15.6025	206.1721	-6.293161133	**2**
-1.91537	0.965955	3.64084	0.914345741	**1**		-21.5678	120.3438	375.0503	148.5425146	**1**
-0.74216	0.213062	2.115279	0.449811323	**3**		-220.766	-58.7656	187.7104	-37.64681348	**5**
-0.76955	0.192373	1.711535	0.331682879	**6**		-258.015	-54.4639	135.4103	-57.88322363	**6**

Fig. 6. Final ranking using FSIR.

References

[1] Skinner W., *Manufacturing-missing link in corporate strategy*, Harvard Business Review, 136–145, 1969.

[2] Hayes R.H., Wheelwright S.C., *Restoring our Competitive Edge*, Free Press, New York, 1984.

[3] Kotha S., Orne D., *Generic manufacturing strategies: A conceptual synthesis*, Strategic Management Journal 10, 211–231, 1989.

[4] Porter M.E., *The technological dimension of competitive strategy*, [in:] Rosenbloom, R.S. [Ed.], Research on Technological Innovation, Management and Policy, Jai, Greenwich, CT, pp. 1–33, 1983.

[5] Porter M.E., *Competitive Advantage – Creating and Sustaining Superior Performance*, [in:] Powell, Olson, David L., Flores, Benito E. [Eds], 1997, Proceedings Decision Science Institute, Vol. 3, POM – Manufacturing, San Diego, FreePress, New York, pp. 1171–1173, 1985.

[6] Voss C.A., *Empirical observation of the process of manufacturing strategy formulation and implementation*, Paper presented at the Int. Conference on Production Economics, Igls. Austria, 1990.

[7] Marucheck A., Pannesi R., Anderson C., *An explanatory study of the manufacturing strategy process in practice*, Journal of Operation Management, 9(1), 101–123, 1990.

[8] Anderson J.C., Schroeder, R.G., *The process of manufacturing strategy: Some empirical observations and conclusions*, International Journal of Operations & Production Management, 11(3), 86–110, 1991.

[9] Hill T., *Manufacturing strategies*, England: Macmillan, 1995.

[10] Miltenburg J., *How to formulate and implement a winning plan*, Portland: Productivity Press, 1995.

[11] Bates K., Amundson S., Morris W., Schroeder R.G., *The crucial interrelationship between manufacturing strategy and organizational culture*, Management Science, 41(10), 1565–1580, 1995.

[12] Safsten K., Winroth M., *Analysis of the congruence between manufacturing strategy and production system in SMME*, Computers in Industry, 49(1), 91–106, 2002.

[13] Lee K., Jeong H.N., Park C., Park J., *Development of a decision-support system for the formulation of manufacturing strategy*, International Journal of Production Research, 40(15), 3913–3930, 2002.

[14] Quezada L.E., Cordova F.M., O'Brien C., *Application of the analytic hierarchy process in manufacturing strategy formulation*, International Journal of Industrial Engineering – Theory Applications and Practice, 10(3), 204–212, 2003.

[15] Slack N., Chambers S., Johnston R., *Operation management*, England: Prentice Hall, 2004.

[16] Platts K.W., Gregory M.J., *Manufacturing audit in the process of strategy formulation*, International Journal of Operations and Production Management, 10(9), 47–65, 2004.

[17] Schroeder R.G., Flynn B. [Eds], John Wiley & Sons, Inc., New York, 2001.

[18] Karacapilidis N., Adamides E., Evangelou C., *A computerized knowledge management system for the manufacturing strategy process*, Computers in Industry, 57(2), 178–188, 2006.

[19] Jorn H.T., *Empirical analysis of manufacturing strategy implementation*, International Journal of Production Economics, 113, 370–382, 2008.

[20] Arafa A., ElMaraghy W.H., *Manufacturing strategy and enterprise dynamic capability*, CIRP Annals – Manufacturing Technology, 60, 507–510, 2011.

[21] Jia G.Z., Bai M., *An approach for manufacturing strategy development based on fuzzy-QFD*, Computers & Industrial Engineering, 60, 445–454, 2011.

[22] Zahirul Hoque, Maybelle Chia, *Competitive forces and the levers of control framework in a manufacturing setting: A tale of a multinational subsidiary*, Qualitative Research in Accounting & Management, 9, 2, 123–145, 2012.

[23] Pradip P. Patil, Narkhede B.E., Milind M. Akarte, *Pattern of manufacturing strategy implementation and implications on manufacturing levers and manufacturing outputs and business performance*, International Journal of Indian Culture and Business Management, 10(2), 157–177, 2015.

[24] Fantino G., Miragliotta G., Supervisor, Mariano Corso: Tutor, Paolo Trucco: The Chair of the Doctoral Program (2017), Extreme Manufacturing Flexibility: Organizational levers to cope with extreme planning, volume and mix flexibility requirements, Doctoral Dissertation of: Giorgio Fantino.

[25] Luqman M., Rosli M.U., Khor C.Y., Shayfull Zambree, Jahidi H., *Manufacturing Process Selection of Composite Bicycle's Crank Arm using Analytical Hierarchy Process (AHP)*, IOP Conference Series: Materials Science and Engineering 2018.

[26] Miltenburg J., *Manufacturing strategy*, 2nd ed. New York: Productivity Press, 2005.

[27] Hayes R.H., Wheelwright S.C., *Restoring our Competitive Edge*, Free Press, New York, 1984.

[28] Hill T., *Manufacturing Strategy, Text and Cases*, 2end Edition, Palgrave, 2000.

[29] Chen C.T., *A fuzzy approach to select the location of the distribution center*, Fuzzy Sets and Systems, 118(1), 65–73, 2001.

[30] Wang Y.J., Lee H.-S., *Generalizing TOPSIS for fuzzy multiple-criteria group decision-making*, Computers and Mathematics with Applications, 53, 1762–1772, 2007.

[31] Fenton N., Wang W., *Risk and confidence analysis for fuzzy multi-criteria decision making*, Knowledge-Based Systems, 19, 430–437, 2006.

[32] Kuo M.S., Tzeng G.H., Huang W.C., *Group decision-making based on concepts of ideal and anti-ideal points in a fuzzy environment*, Mathematical and Computer Modeling, 45, 324–339, 2007.

[33] Chen S.J., Hwang C.L., *Fuzzy Multiple Attribute Decision Making Methods and Applications*, Springer, Berlin, 1992.

[34] Wang T.-C., Chang T.-H., *Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment*, Expert Systems with Applications, 33, 870–880, 2007.

[35] Yeh C.H., Deng H., Chang Y.H., *Fuzzy multi-criteria analysis for performance evaluation of bus companies*, European Journal of Operational Research, 126(3), 459–473, 2000.

[36] BallıS., Korukoğlu S., *Operating system selection using fuzzy AHP and TOPSIS methods*, Mathematical and Computational Applications, 14(2), 119–130, 2009.

[37] Büyüközkan G., Feyzioğlu O., Nebol E., *Selection of the strategic alliance partner in logistics value chain*, International Journal of Production Economics, 113(1), 148–158, 2008.

[38] Chen C.T., *A fuzzy approach to select the location of the distribution center*, Fuzzy Sets and Systems, 118(1), 65–73, 2001.

[39] Chou C.C., *A fuzzy MADM method for solving A/R collection instruments selection problem*, Journal of Marine Science and Technology, 15(2), 115–122, 2007.

[40] Chou T.Y., Liang G.S., *Application of a fuzzy multi-criteria decision-making model for shipping company performance evaluation*, Maritime Policy and Management, 28(4), 375–392, 2001.

[41] Ding J.F., *Partner selection of strategic alliance for a liner shipping company using extent analysis method of fuzzy AHP*, Journal of Marine Science and Technology, 17(2), 97–105, 2009.

[42] Ertuğrul İ., Karakaşoğlu N., *Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection*, The International Journal of Advanced Manufacturing Technology, 39(7–8), 783–795, 2008.

[43] Lee H.S., Chou M.T., *A fuzzy multiple criteria decision making model for airline competitiveness evaluation*, Lecture Notes in Computer Science, No. 4252, 902–909, 2006.

[44] Liang G.S., *Fuzzy MCDM based on ideal and anti-ideal concepts*, European Journal of Operational Research, 112(3), 682–691, 1999.

[45] Tsaur S.H., Chang T.Y., Yen C.H., *The evaluation of airline service quality by fuzzy MCDM*, Tourism Management, 23(2), 107–115, 2002.

[46] Valls A., Vicenc T., *Using classification as an aggregation tool in MCDM*, Fuzzy Sets and Systems, 115(1), 159–168, 2000.

[47] Wang Y.J., Lee H.S., Lin K., *Fuzzy TOPSIS for multi-criteria decision-making*, International Mathematical Journal, 3(4), 367–379, 2003.

[48] Zadeh L.A., *Fuzzy sets*, Information and Control, 8(1965), 338–353, 1965.

[49] Zadeh L.A., *The concept of a linguistic variable and its application to approximate reasoning*, Information Sciences, Part I: 8, 199–249; Part II: 8, 301–357; Part III: 9, 43–80, 1975.

[50] Zadeh L.A., *The concept of a linguistic variable and its application to approximate reasoning*, Part 1, 2 and 3, Information Sciences, 8, 3, 199–249, 1975; 8, 4, 301–357, 1975; 9, 1, 43–80, 1976.

[51] Xu X., *The SIR method: A superiority and inferiority ranking method for multi criteria decision making*, European Journal of Operation Research, 131, 587–602, 2001.

[52] Brans J.P., Vincke Ph., Mareschal B., *How to select and how to rank projects: The PROMETHEE method*, European Journal of Operational Research, 24, 228–238, 1986.

[53] Janic M., Reggiani A., *An Application of the Multiple Criteria Decision Making (MCDM) Analysis to the Selection of a New Hub Airport*, EJTIR, 2, 2, 113–142, 2002.

[54] Bates K., Amundson S., Morris W., Schroeder R.G., *The crucial interrelationship between manufacturing strategy and organizational culture*, Management Science, 41(10), 1565–1580, 1995.