AN EXTENDED APPROACH FOR MANUFACTURING STRATEGY PROCESS BASE ON ORGANIZATION PERFORMANCE THROUGH FUZZY QFD

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Abstract. This paper provides an extended model base on the Quality function deployment (QFD) framework to develop a manufacturing strategy process through linking manufacturing competitive factors with organization performance. Performance factors will guarantee alignment between manufacturing strategy and organization strategy. Performance analysis using entropy methods and the improvement ratio in all stages of this model is an advantage. A further advantage of model is the quantity control of correlation between manufacturing competitive factors, which causes factors to achieve higher rank such that their development will proceed the development of other competitive factors and increase the values of selected performance factors; similarly, quantity control of the correlation between manufacturing strategy decisions will increase effectiveness of this model in prioritizing manufacturing strategy development. The proposed model in this paper is implemented in an automotive rubber profile manufacturer in Iran. The results of application of the model are provided at the end of the article.

1. Introduction

In recent years, considerable attention has been devoted to strategic planning and its effects on firm performance. In manufacturing firms, to achieve competitive priorities, manufacturing strategy should be defined as a part of firm strategy and be in alignment with it. The effect of this alignment should always be observed in firm performance factors, which means a defined manufacturing strategy should create competitive priorities and obtained competitive priorities should improve performance factors. In this regard, manufacturing strategies, competitive priorities, organizational performance and organization strategy should be associated with each other in one alignment, which is not really executed in firms. The main reason for that is the lack of use of quantitative models in firms' decision making, mainly because of complexity, time consumption and no consideration of the various effects of variables on manufacturing strategy development in most of the current models. In the executive area, managers always try to develop a manufacturing strategy based on their experience in the firm, market and some learned theoretical concepts from manufacturing strategy content, which include such disadvantages as inattention to all effective variables, inconsistency between variables, mis-

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alignment between manufacturing and firm strategies, inattention to performance analysis, further qualitative analysis and the absence of a procedure to trace back and review data of decisions that made such developments. Therefore, there is still a need for qualitative and academic models that are understandable, easy to work with, not time consuming and able to consider most main effective parameters in manufacturing strategy development. Manufacturing strategy comprises a series of structural and infrastructural decisions that provide the necessary support for the relevant order of winners and qualifiers of the different market segments of a company [21]. From Hill's point of view, manufacturing strategy should be supportive of the achievement of a company's competitive priorities. In his research, through a five-step procedure, manufacturing strategy was linked to order winners to achieve congruence between them [19]. Hayes and Wheelwright [18] provide a tool for the assessment of manufacturing's strategic role and introduce the product/process matrix. Skinner proposes a hierarchical process model, starting from corporate strategy and forming the content of the business strategy, which in turn forms the content of functional strategies, including manufacturing. Lee *et al.* [25] propose a framework that consists of manufacturing system modeling and the analysis of performance measures based on a decision-support system. Quezada *et al.* [32] propose a methodology for the development of a manufacturing strategy by means of the analytic hierarchy process, in which a manufacturing strategy is formulated in a five level hierarchy. Tan and Platts [35] developed Burbidge's connectance model and propose a TAPS model to achieve a final decision by prioritizing available options. Hallgren and Olhager [17] create a framework and methodology for quantitative modeling for manufacturing strategy with the aim of providing a structure that can aid in improving the capabilities to meet market requirements. Lee and Kai [26] proposes a decision model for manufacturing best practice adoption by linking practices to competitive strategies. In the research of Pooya and Azar [31], they propose a five step model for formulating a manufacturing strategy. In this model, manufacturing objectives are adopted with environmental factors that affect manufacturing strategy by using the AHP approach. A study on previous manufacturing strategy development research efforts shows that a large number of studies have been conducted on this subject and that many different methodologies have been suggested; dominant models are related to the concept, not to the process, of manufacturing strategy [17].

Quality Function Deployment (QFD) was conceived in Japan in the late 1960s for new product development. QFD has been used by many companies to save design time and development time, to focus on the satisfaction of customer, and to improve communication at all levels of the organization [13]. In fact, it was required to provide a link between customers' requirements and the abilities of the system to fulfill the customers' requirements [2]. QFD makes it possible to rank "hows" in terms of their efficiency to reach the required "whats" by assessing how each "how" impacts each "what". Therefore, it is a viable tool for organizing and carrying out manufacturing strategy development quantitatively, has the capability of assessing the supportive degree of manufacturing strategy to competitive priorities and helps in assessing the congruence among various decisions of manufacturing strategy [21].

Crowe and Cheng [12] developed a new methodology for manufacturing strategic planning based on QFD in four stages: business strategies, functional level strategies, manufacturing priorities and action plans. Bottani [7] provided a fuzzy QFD approach to achieve agility with the aim of identifying the most appropriate enablers to be implemented by companies through linking competitive priorities, agile attributes and agile enablers with competitive characteristics of the related market. Jia and Bai [21] proposed a two stage Fuzzy QFD approach for manufacturing development; the first stage identifies competitive factors based on customer requirements and, in the second stage, manufacturing strategies are prioritized in terms of their efficiency to reach the adopted competitive factors. Barad and Gien [5] proposed a methodology that uses QFD to apply a contingency oriented approach to improvement priorities. They use two QFD matrices to make a structured relation between manufacturing strategy and operational improvement action through manufacturing competitive priorities. In summary, QFD was used in different scales of its capabilities in the manufacturing strategy process. However, there are still some limitations in the existing research and therefore further research is needed.

Organizational performance is the most important criterion in evaluating organization goals, decisions and actions. Organizational performance encompasses three specific areas of firm outcomes: (1) financial performance (profits, return on assets, return on investment, etc.); (2) market performance (sales, market share, etc.); and (3)

shareholder return (total shareholder return, economic value added, etc.) [33]. Studies show that there is a significant relationship between organizational performance and manufacturing strategy. Pooya [30] studied Iranian manufacturing systems and their business performance, using the cluster analyses. The results of his research show that there are significant differences between a manufacturing system's performance factors. Amoako-Gyampah and Acquah [3] proposed a model that examines the relationship between manufacturing strategy and competitive strategy as well as their influence on firm performance. The model implementation result shows that there is a significant and positive relationship between competitive strategy and the manufacturing strategies. Papke-shields and Malhotra [29] examine the role of both influence and the involvement of a manufacturing executive in achieving better business performance through alignment between the organizational and manufacturing strategies rather than directly. Their experiments have shown that both influence and involvement affect performance, but more effect on performance is related to the alignment between organizational and manufacturing strategies. Kazan *et al.* [22] investigate the effect of manufacturing strategies on financial performance. Their study results show that 55% of the changes in financial performance are dependent on manufacturing strategies.

Based on this conclusion on the content of previous research efforts, this paper proposes a conceptual model for manufacturing development based on QFD and tries to resolve leakages in existing models by using the maximum capabilities of the QFD method. In this model, manufacturing strategies will be developed through manufacturing competitive priorities and organization performance factors. The significant points of the integrated QFD model proposed in this paper are: first, manufacturing strategies will be aligned with organizational strategies by using two quality houses (HOQ) in QFD because these two HOQ manufacturing decisions relate to the organization performance factors. This alignment, in Skinner's [34] and Crowe and Cheng's [12] proposed model, was made by applying organization strategies in the model directly, and in Barad and Gien's [5] proposed model, was made by applying the origination competitive operation. Second, the quantitative effect of correlation between competitive priorities in HOQ1 are considered in the competitive priorities ranking formula; third, the quantitative effect of correlation between manufacturing decisions in HOQ2 are also considered in the manufacturing decisions ranking formula; fourth, quantitative performance analyses of the organization performance factors and manufacturing competitive priorities in HOQ1 and HOQ2 are applied to the manufacturing decision priority formula; performance analysis includes stakeholders' competitive analysis, which is quantified by the Entropy Shannon method, performance improvement ratio and performance goals. Fifth, the Fuzzy-AHP method is used to fulfill the "whats" and "hows", two relationship matrixes, to gain confidence concerning consistency in answers and the decisions' results. The similarities of this paper's proposed model with previous studies' existent models are, specifically, in using manufacturing competitive priorities and manufacturing decisions and relating them to each other; on the other hand, the significant difference between this model and previous existent models is the consideration of the quantitative effect of competitive analysis and the performance improvement ratio in a manufacturing strategy's development process. In previous models, such as Hallgren and Olhager [17], performance analysis is conducted after identifying manufacturing decisions to investigate whether selected decisions will lead the company to achieve its manufacturing goals. In the proposed model by Jia and Bai [21], performance analysis is only shown in the model as supplemented data in the experts' decision making and used qualitatively in manufacturing strategy development. Another main difference between this paper's proposed model and previous existent models is the application of the quantitative effect of correlation between pairs of manufacturing decisions and also between pairs of manufacturing competitive priorities in the manufacturing decision priority formula; a few models showed the effect of correlations between "hows", such as Jia and Bai [21]. Crowe and Cheng [12] proposed models, but in those models, the quantitative effect of correlations were not applied to formulas and were only considered by experts in the final decision making on manufacturing strategy adoption. Of the studied existent models, only Bottani [7] proposed a model that applied the quantitative effect of correlation between "hows" in its calculations.

TABLE 1. Decision categories and associated policy areas [17].

Decision category	Policy areas
Structural	*Policy area*
Process technology	Process choice, technology, integration
Facilities	Size, location, specialization/focus
Capacity	Amount, timing, increment size
Vertical integration (VI)	Direction, extent, balance
Infrastructural	
Organization	Design, human resources, competence development
Manufacturing planning and control (MPC)	System design, decision support, systems integration
Quality	Definition, role, tools
New product introduction (NPI)	Rate of innovation, product design, industrialization

2. MANUFACTURING STRATEGY

Skinner [34] is a pioneer in defining manufacturing strategy; in his point of view, manufacturing strategy is a specific characteristic of manufacturing functionality and a company's competitive weapon. Cox and Blackstone [11] defined manufacturing strategy as "a collective pattern of decisions that acts upon the formulation and deployment of manufacturing resources. To be most effective, the manufacturing strategy should act in support of the overall strategic directions of the business and provide for competitive advantages". Manufacturing strategy content includes competitive priorities and decision areas in the Leong *et al.* [27] proposed model. Competitive priorities, defined as a consistent set of goals for manufacturing, and a review of the literature reveals a level of agreement on the following five competitive priorities: Quality, Delivery, Flexibility, Cost, and Innovativeness [27]. Specific decisions categories related to the content of manufacturing strategy are divided into structural strategic decisions and infrastructural strategic decisions [14]. Structural and infrastructural strategic decisions are associated through policy areas; Table 1 specifies the policy area of the main decision categories [17].

The process of manufacturing strategy development is here regarded as the procedures that are used to develop those manufacturing strategies to enhance the manufacturing function's capabilities. Thus far, different methodologies concerning the development of manufacturing strategy have been developed. Among them, four perspectives emerge, including the top-down perspective, bottom-up perspective, market requirements perspective, and manufacturing resources perspective [21].

The methodologies described here are representatives of those available. However, none of them reflects all of the four perspectives described above, and none of them includes all the various points that are addressed by manufacturing strategy development procedures. In spite of this, there are some common elements that exist in these methodologies, including:

– A process that links business strategy to manufacturing decisions by means of using organization performance factors as a translation device.
– A process that is market-based and includes judging the relative importance of the various competitive factors in terms of a customer's preferences.
– A process that includes assessing current achieved performance in terms of competitor performance levels and performance goals.
– A process that includes judging the correlation between various competitive factors and also between various manufacturing decisions in terms of considering manufacturing resources in the development of each manufacturing decision. These common elements are the basis of the new methodology of manufacturing strategy development that is developed in this paper.
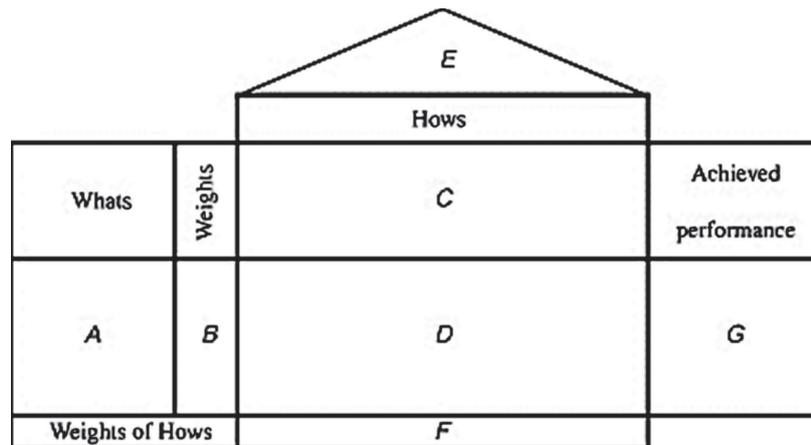
FIGURE 1. The steps for constructing HOQ.

3. QUALITY FUNCTION DEPLOYMENT

QFD (quality function deployment) is defined as a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase [1]. Form King's [24] point of view is that QFD will help companies to be proactive rather than reactive in product design. There are four phases in a QFD exercise: design, detail, process and production [16]. The first phase of QFD, usually called house of quality (HOQ), is of fundamental and strategic importance in the QFD system; the structures and analyzing methods of the other three QFD phases are essentially the same as the first one [10].

HOQ is a formal articulation of how a company sees the relationship between the requirements of the customer and the design characteristics of the new or improved product. The HOQ can be built in 6 steps, suggested by Brown [8] and Griffin and Hauser [15], through these steps matrix A to matrix G which shown in Figure 1 will be identified respectively.

When QFD is used in strategic planning, there will be a different perception of these concepts. The customers' requirements can be interpreted as the corporate or business requirements. They are internal customers rather than external customers. The team members in QFD exercises should be mostly top managers and all other functional level managers in the strategy formulation stage, as well as implementation engineers for action plan formulation. The decision attributes are sometimes strategic objectives or tactical policies rather than specific target values of the product design variables. It is therefore more difficult to quantify and develop a mathematical model for evaluation [24].

4. MANUFACTURING STRATEGY DEVELOPMENT BASED ON QFD AND FUZZY AHP

4.1. The characteristics of manufacturing strategy development based on QFD and Fuzzy AHP

Based on the analysis of the existing methodology related to the development of manufacturing strategy, we suggest a methodology of manufacturing strategy development, which is based on the HOQ.

The characteristics of this methodology are illustrated as follows:

– Use Business performance factors identified by business strategic objectives to keep manufacturing strategy in alignment with business strategy. These factors also represent a stakeholder's preferences.

– Use competitive factors as links between organization strategy, market requirement and manufacturing strategy.
– Judge the relative importance of the various competitive factors in terms of the stakeholder's preferences.
– Assess the current achieved performance on organization performance factors in terms of competitor performance levels and the expected performance level.
– Use HOQ as a translating device to link organization performance factors with competitive factors and competitive factors with manufacturing decision categories, such as structural decision categories and infrastructural categories, and use HOQ as the main tool in different stages of the manufacturing strategy development process.
– Assess correlation between competitive factors and between manufacturing objectives regarding the manufacturing resources perspective.
– Keep consistency in relative judgments by using the analytic hierarchy process method.

4.2. The stages of manufacturing strategy development based on QFD and Fuzzy AHP

Following a survey of the literature, the proposed conceptual model in this paper for manufacturing strategy deployment based on the QFD method is shown in Figure 2. At the first stage, organization performance factors and competitive factors are identified, respectively, and then the impact of each competitive factor on each performance factor is measured by using HOQ. At the second stage, competitive factors are used as "whats" in the HOQ matrix and manufacturing decision categories are identified and used as "hows" in the HOQ matrix. Then, the "how"–"what" relation scores are determined and the "hows" are weighted. The result of the matrix is the ranking of "hows" in descending order of importance (weights); this rank indicates what the key structural and infrastructural decisions are and also indicates to the key manufacturing-related tasks.

4.2.1. Quantitative method

In this paper we propose a fuzzy AHP-QFD methodology for the determination of manufacturing strategic decisions, and illustrate how to use it. We opted to follow the approach described by Ho *et al.* [20], who made a Fuzzy AHP method. The chosen method is use a triangular fuzzy number to transfer AHP to Fuzzy AHP. The main reasons of using fuzzy numbers are as follows, first, manufacturing strategic decisions, second, QFD method and third, decision makers. The determination of manufacturing strategic decision involves both qualitative and quantitative factors. Quantitative techniques based on purely mathematical data have some drawbacks when they are used to consider qualitative factors. In QFD the relation between "whats" and "hows" are often vague or imprecise and this is because of there is no a formal mechanisms for translating "whats"(which are generally qualitative) into "hows" (which are usually quantitative) in QFD model [6,23]. Also the decision-maker is unable or unwilling to express his/her preferences precisely, and the evaluations or opinions are expressed in linguistic terms. To address this type of uncertainty correctly, AHP method as a multiple criteria decision making methods and fuzzy logic are used in this paper to have more accurate evaluation and keep consistency in responses and decision results.

4.2.2. Stage 1: Determining competitive factors in terms of market requirements

This stage is undertaken to identify and rank competitive factors, which have more effect on the achievement of organization performance factors, according to the eight steps illustrated in Figure 3.

4.2.2.1. *Step 1: Identify the "whats" – measuring organization performance factors.* This step identifies the organization performance factors, which are identified by stakeholders' requirements, such as ROI, ROA, Sales increase, Profit increase, etc. that the manufacturing will be required to increase. In manufacturer companies, the manufacturing strategy has a main share in the growth of organization performance factors. These organization performance factors are used as "whats" in the QFD matrix.
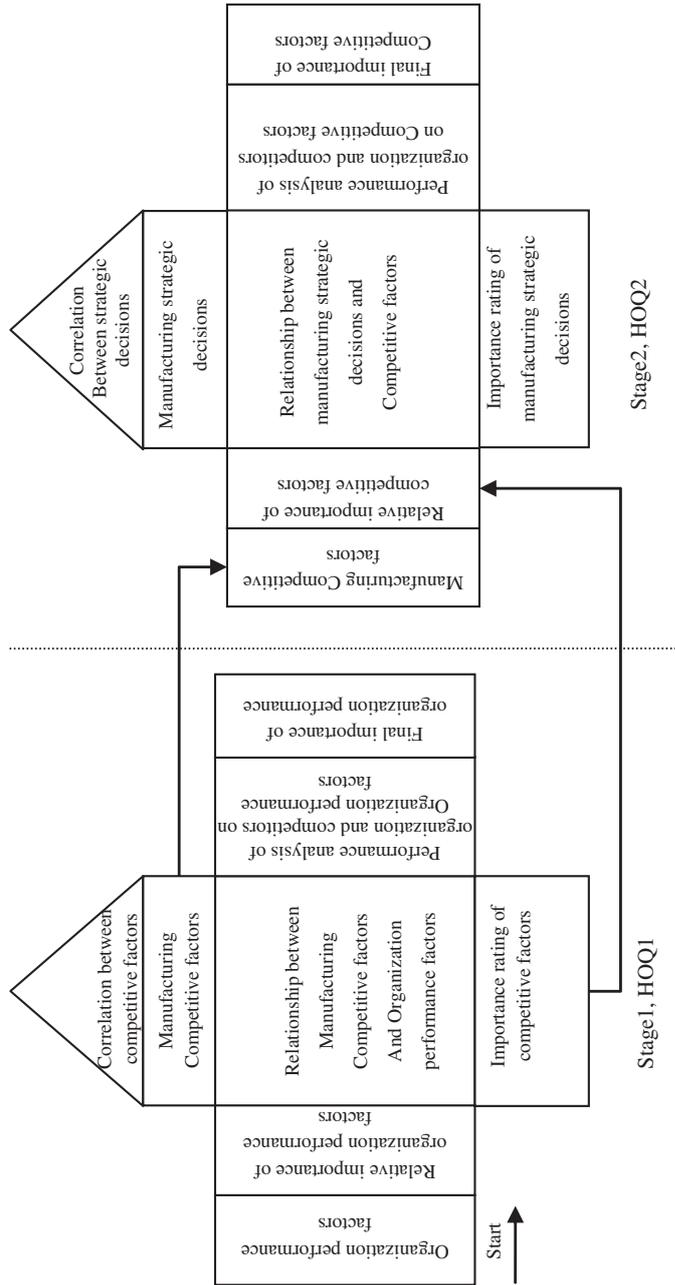
FIGURE 2. Current study's proposed model for manufacturing strategy development.

4.2.2.2. *Step 2: Determine the relative importance ratings of organization performance factors.* Stakeholders' requirements ("Whats") are usually in different degrees of importance, and it is common practice for a company to focus more on the important "Whats". The relative importance of the "Whats" is usually expressed as a set of ratings that can be determined by letting the stakeholders reveal their perceptions on the relative importance of the "Whats" and then averaging their perceptions. The appropriate way of obtaining their perceptions is by conducting individual interviews. Suppose that, for performance factor W_i in comparison with W_j, stakeholder k supplies a relative importance rating $\tilde{d}_{ij}^k$ to it; then, the resulting average relative importance rating G_i for W_i is computed by

$$\overline{\overline{\widetilde{D}}}_{ij} = \left[\prod_{k=1}^{\mathrm{ND}} \widetilde{d}_{ij}^{(K)} \right]^{\frac{1}{\mathrm{ND}}} \tag{4.1}$$

$$i = 1, 2, \ldots m \quad j = 1, 2, \ldots m$$

ND = number of Stakeholders

$$\widetilde{D} = \begin{bmatrix} \dfrac{\overline{\overline{d}}_{11}}{\sum_{i \in M} \overline{\overline{d}}_{i1}} & \dfrac{\overline{\overline{d}}_{12}}{\sum_{i \in M} \overline{\overline{d}}_{i2}} & \cdots & \dfrac{\overline{\overline{d}}_{1m}}{\sum_{i \in M} \overline{\overline{d}}_{im}} \\ \dfrac{\overline{\overline{d}}_{21}}{\sum_{i \in M} \overline{\overline{d}}_{i1}} & \dfrac{\overline{\overline{d}}_{22}}{\sum_{i \in M} \overline{\overline{d}}_{i2}} & \cdots & \dfrac{\overline{\overline{d}}_{2m}}{\sum_{i \in M} \overline{\overline{d}}_{im}} \\ \vdots & \vdots & \ddots & \vdots \\ \dfrac{\overline{\overline{d}}_{m1}}{\sum_{i \in M} \overline{\overline{d}}_{i1}} & \dfrac{\overline{\overline{d}}_{m2}}{\sum_{i \in M} \overline{\overline{d}}_{i2}} & \cdots & \dfrac{\overline{\overline{d}}_{mm}}{\sum_{i \in M} \overline{\overline{d}}_{im}} \end{bmatrix} \tag{4.2}$$

$$\widetilde{G} = \begin{bmatrix} \sum_{i=1}^{M} \widetilde{d}_{1i}/m \\ \sum_{i=1}^{M} \widetilde{d}_{2i}/m \\ \vdots \\ \sum_{i=1}^{M} \widetilde{d}_{mi}/m \end{bmatrix} \tag{4.3}$$

4.2.2.3. *Step 3: Identify competitors and conduct organization experts' competitive analysis (Performance Analysis).* Competitors who produce similar products should be identified by the company under study. Knowing the company's strengths and constraints in all aspects of related subjects to manufacturing and in comparison with its main competitors is essential for a company if it wishes to improve its competitiveness in the relevant markets. This type of information can be obtained by asking the organization experts to rate the relative performance of the company and its competitors on each "What" and then aggregate the organization experts' ratings. A useful way of conducting this type of comparison analysis is through individual interviews.

Denote the company in question with C_1. Suppose that $L - 1$ competitors are identified, denoted as $C_2, C_3, \ldots, C_L$. Then, the K organization experts are requested to provide their perceptions on the relative performance of these L companies' similar performance in terms of the M organization performance factors. Suppose that expert K supplies a rating X_{mlk} on company C_l's performance in terms of W_m by using the scale shown in Table 2, where X_{mlk} is one of the nine crisp numbers shown in Table 1; then, the performance rating of company C_l on customer need W_m is given as

$$X_{ml} = (x_{ml1} + x_{ml2} + \ldots + x_{mlk})/K$$
$$= \sum_{k=1}^{K} x_{mlk}/K$$
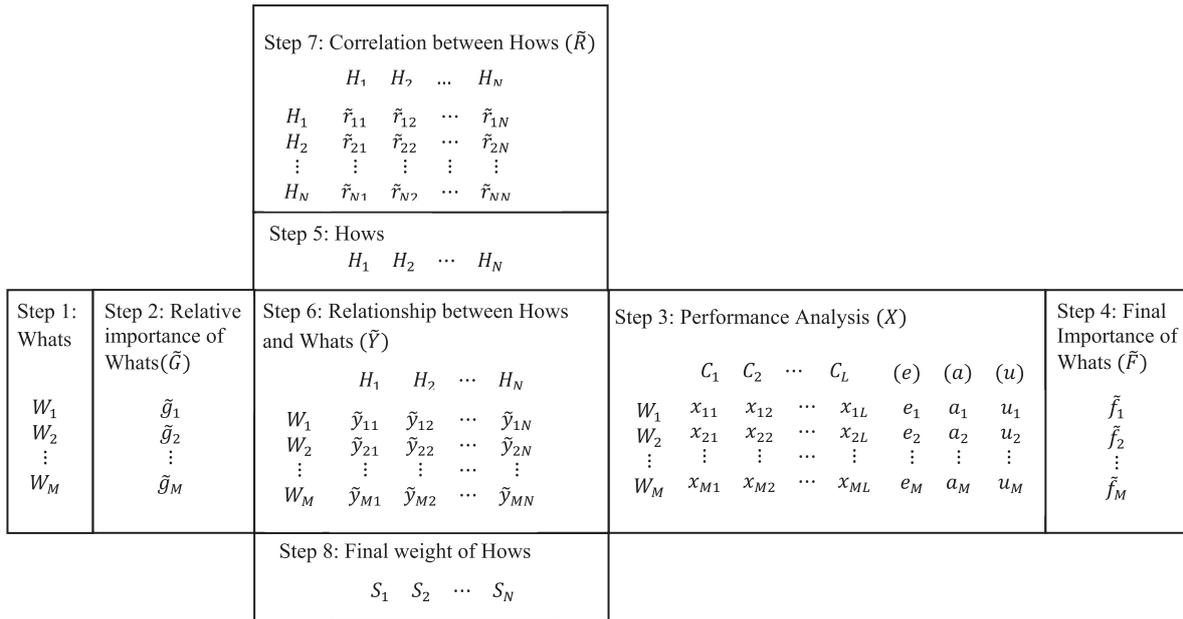$$m = 1, 2, \ldots, M \; l = 1, 2, \ldots, L \tag{4.4}$$

Step 7: Correlation between Hows ($\tilde{R}$)

	H_1	H_2	...	H_N
H_1	$\tilde{r}_{11}$	$\tilde{r}_{12}$	$\cdots$	$\tilde{r}_{1N}$
H_2	$\tilde{r}_{21}$	$\tilde{r}_{22}$	$\cdots$	$\tilde{r}_{2N}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
H_N	$\tilde{r}_{N1}$	$\tilde{r}_{N2}$	$\cdots$	$\tilde{r}_{NN}$

Step 5: Hows
H_1 H_2 $\cdots$ H_N

Step 1: Whats

W_1
W_2
$\vdots$
W_M

Step 2: Relative importance of Whats($\tilde{G}$)

$\tilde{g}_1$
$\tilde{g}_2$
$\vdots$
$\tilde{g}_M$

Step 6: Relationship between Hows and Whats ($\tilde{Y}$)

	H_1	H_2	$\cdots$	H_N
W_1	$\tilde{y}_{11}$	$\tilde{y}_{12}$	$\cdots$	$\tilde{y}_{1N}$
W_2	$\tilde{y}_{21}$	$\tilde{y}_{22}$	$\cdots$	$\tilde{y}_{2N}$
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$
W_M	$\tilde{y}_{M1}$	$\tilde{y}_{M2}$	$\cdots$	$\tilde{y}_{MN}$

Step 3: Performance Analysis (X)

	C_1	C_2	$\cdots$	C_L	(e)	(a)	(u)
W_1	x_{11}	x_{12}	$\cdots$	x_{1L}	e_1	a_1	u_1
W_2	x_{21}	x_{22}	$\cdots$	x_{2L}	e_2	a_2	u_2
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
W_M	x_{M1}	x_{M2}	$\cdots$	x_{ML}	e_M	a_M	u_M

Step 4: Final Importance of Whats ($\tilde{F}$)

$\tilde{f}_1$
$\tilde{f}_2$
$\vdots$
$\tilde{f}_M$

Step 8: Final weight of Hows
S_1 S_2 $\cdots$ S_N

FIGURE 3. HOQ constructing steps.

TABLE 2. Scale of measuring the companies'.

Very poor		Poor		Neutral		Good		Very good
1		2	3	4	5	6	7	8	9

current and goal performance in terms of WHATs.

Thus, the companies' performance ratings of the organization performance factors can be denoted by a $M \times L$ matrix, called a customer comparison matrix:

$$X = \begin{array}{c} \\ W_1 \\ W_2 \\ \vdots \\ W_M \end{array} \begin{array}{cccc} C_1 & C_2 & \cdots & C_l \\ \left[\begin{array}{cccc} x_{11} & x_{12} & \cdots & x_{1l} \\ x_{21} & x_{22} & \cdots & x_{2l} \\ \vdots & \vdots & \ddots & \vdots \\ x_{M1} & x_{M2} & \cdots & x_{Ml} \end{array} \right] \end{array}. \tag{4.5}$$

Based on this X information, experts' competitive priority ratings of the WHATs for the producing company C_1 can be obtained as $e = (e_1, e_2, \ldots, e_m)$, where e_m is company C_l's priority rating on organization performance factors W_m. This set of priority ratings can be derived by the more objective entropy method.

According to company C_l's current performance on the WHATs in relation to its competitors' performance, performance goals for the WHATs can be set for the company. These goals should be set competitively and realistically by the company, which is a highly strategic activity involving many considerations from the relevant management. Assume that, for organization performance factors W_m, a proper performance goal a_m has been set according to the scale shown in Table 2. Thus, the company has a goal performance vector in terms of the organization performance factors, denoted as $a = (a_1, a_2, \ldots, a_m)$. In most cases, each goal performance level should not be lower than the current performance level, implying the need or desire for further improvement.

From this, we can also set the company's improvement ratio for W_m as $U_m = a_m/x_{ml}$. It is obvious that the higher the improvement ratio, the more the company should work on the WHAT. Thus, the improvement ratio identifies the areas where current manufacturing capabilities must improve and further instructs manufacturing to take actions to close the gap between current performance and the goal.

4.2.2.4. *Step 4: Determine the final importance rating of organization performance factors.* Organization performance factors with higher relative importance, as perceived by stakeholders, and higher competitive priorities and improvement ratios should receive higher attention. Thus, the final importance rating of organization performance factors W_m's for the company is determined jointly by its relative importance g_m, expert competitive priority e_m and improvement ratio u_m as

$$f_m = u_m \times g_m \times e_m$$
$$m = 1, 2, \ldots, M. \tag{4.6}$$

WHATs with high final ratings indicate both their importance and potential business benefit to the company. Of course, a (weighted) sum of u_m, g_m and e_m can also produce a reasonable f_m, if preferred. In any case, we will denote the final importance ratings for the organization performance factors as a vector, $f = (f_1, f_2, \ldots, f_m)$.

4.2.2.5. *Step 5: Identify the competitive factors – "hows".* This step translates organization performance factors into competitive factors, which links market requirements and manufacturing strategy to each other. Many competitive factors have a market requirements perspective; for instance, quality, delivery, cost, innovation, and protecting the environment are all customers' requirements. Many competitive factors also have a direct correspondence internally to manufacturing. Hill [19] has formally identified competitive factors as the key link between the marketing and manufacturing aspects of strategy development. For instance, delivery speed and reliability are dependent on both production lead times and flexibility, and product range, customization and innovativeness are based on internal flexibility [8].

4.2.2.6. *Step 6: Link organization performance factors with competitive factors.* This step determines the correlation scores of organization performance factors and competitive factors. The correlation scores between a HOW and a WHAT are usually determined by analyzing to what extent the HOW could technically relates to and influences the WHAT. Correlation scores can be derived by different methods; in this paper, we use the fuzzy AHP method, which was provided by Ho *et al.* [20], in step 6.1 to step 6.7:

– *Construct a fuzzy pair wise comparison matrix*:

$$\widetilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \cdots & \cdots & \ddots & \cdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix}. \tag{4.7}$$

Where n denotes the number of elements (*i.e.*, number of competitive factors) and $\tilde{a}_{ij}$ refers to the geometric mean of the organization experts' fuzzy comparison of element i to element j with respect to each criterion. The 9-point scale shown in Table 3 can be used to determine which element is more important and by how much.

– *Fuzzy-based AHP synthesization*: Divide each entry $(\tilde{a}_{ij})$ in each column of matrix $\widetilde{A}$ by its column total. The matrix now becomes a normalized pair wise comparison matrix:

$$\widetilde{A} = \begin{bmatrix} \frac{\tilde{a}_{11}}{\sum_{i \in N} \tilde{a}_{i1}} & \frac{\tilde{a}_{12}}{\sum_{i \in N} \tilde{a}_{i2}} & \cdots & \frac{\tilde{a}_{1n}}{\sum_{i \in N} \tilde{a}_{in}} \\ \frac{\tilde{a}_{21}}{\sum_{i \in N} \tilde{a}_{i1}} & \frac{\tilde{a}_{22}}{\sum_{i \in N} \tilde{a}_{i2}} & \cdots & \frac{\tilde{a}_{2n}}{\sum_{i \in N} \tilde{a}_{in}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\tilde{a}_{n1}}{\sum_{i \in N} \tilde{a}_{i1}} & \frac{\tilde{a}_{n2}}{\sum_{i \in N} \tilde{a}_{i2}} & \cdots & \frac{\tilde{a}_{nn}}{\sum_{i \in N} \tilde{a}_{in}} \end{bmatrix}. \tag{4.8}$$

TABLE 3. Scales in pair wise comparisons between hows and whats.

Verbal judgment of preference	Intensity of importance	Fuzzy number
Equally important	1	(1,1,3)
Moderate importance	3	(1,3,5)
Strong importance	5	(3,5,7)
Extreme importance	7	(5,7,9)
Extremely more important	9	(7,9,9)

Where N denotes the set of competitive factors, that is, $N = \{1, 2, \ldots, n\}$.

– *Compute the average of the entries in each row of matrix $\widetilde{A}$ to yield column vector*:

$$\widetilde{C} = \begin{bmatrix} \tilde{c}_{1k} \\ \vdots \\ \tilde{c}_{nk} \end{bmatrix} = \begin{bmatrix} \frac{\frac{\tilde{a}_{11}}{\sum_{i \in N} \tilde{a}_{i1}} + \frac{\tilde{a}_{12}}{\sum_{i \in N} \tilde{a}_{i2}} + \cdots + \frac{\tilde{a}_{1n}}{\sum_{i \in N} \tilde{a}_{in}}}{n} \\ \vdots \\ \frac{\frac{\tilde{a}_{n1}}{\sum_{i \in N} \tilde{a}_{i1}} + \frac{\tilde{a}_{n2}}{\sum_{i \in N} \tilde{a}_{i2}} + \cdots + \frac{\tilde{a}_{nn}}{\sum_{i \in N} \tilde{a}_{in}}}{n} \end{bmatrix}. \tag{4.9}$$

Where $\tilde{c}_{ik}$ denotes the importance ratings of competitive factor i. Column vector elements are row elements of correlation organization performance factors, and competitive factors matrix $(\widetilde{Y})$

$$\widetilde{Y} = (\tilde{c}_{k1}, \tilde{c}_{k2}, \ldots, \tilde{c}_{kn}). \tag{4.10}$$

– *Fuzzy-based AHP consistency verification*: Multiply each entry in column i of matrix $\tilde{A}$ by $\tilde{c}_{ik}$. Then, divide the summation of values in row i by $\tilde{c}_{ik}$ to yield another column vector:

$$\overline{\overline{C}} = \begin{bmatrix} \bar{\bar{c}}_{1k} \\ \vdots \\ \bar{\bar{c}}_{nk} \end{bmatrix} = \begin{bmatrix} \frac{\tilde{c}_{1k}\tilde{a}_{11} + \tilde{c}_{2k}\tilde{a}_{12} + \cdots + \tilde{c}_{nk}\tilde{a}_{1n}}{\tilde{c}_{1k}} \\ \vdots \\ \frac{\tilde{c}_{1k}\tilde{a}_{n1} + \tilde{c}_{2k}\tilde{a}_{n2} + \cdots + \tilde{c}_{nk}\tilde{a}_{nn}}{\tilde{c}_{nk}} \end{bmatrix}. \tag{4.11}$$

Where $\overline{\overline{C}}$ refers to a weighted sum vector. For the next steps, $\overline{\overline{C}}$ should be de-fuzzified to be displayed as the $\bar{C}$ vector. In the approach proposed, the Yager ranking de-fuzzification formula is used [7]:

$$F = \frac{a + 2b + c}{4}. \tag{4.12}$$

– *Compute the averages of values in vector $\bar{C}$ to yield the maximum eigenvalue of matrix $\tilde{A}$*:

$$\lambda_{\max} = \frac{\sum_{i \in N} \bar{C}_{ik}}{n}. \tag{4.13}$$

– *Compute the consistency index*:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{4.14}$$

– *Compute the consistency ratio*:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}(n)}. \tag{4.15}$$

Where $\mathrm{RI}(n)$ is a random index of which the value is dependent on the value of n, as shown in Table 4. If CR is greater than 0.10, then go to step 6.1. Otherwise, go to step 7.

TABLE 4. List of random index value [28].

N	2	3	4	5	6	7	8	9	10
(n) RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

TABLE 5. Correlation graphic symbols and corresponding fuzzy numbers.

Degree of correlation	Fuzzy number	Graphic symbol
Strong positive	●	$(0.3 : 0.5 : 0.7)$
Positive	○	$(0 : 0.3 : 0.5)$
Negative	□	$(-0.3 : -0.5 : 0)$
Strong negative	■	$(-0.7 : -0.5 : -0.3)$

4.2.2.7. *Step 7: Correlation between competitive factors (HOWs).* This step in the construction of the HOQ allows for keeping track of pairs of "hows" needing parallel improvements or comprising "hows" those are inconsistent with each other. The generic entry of the roof of correlations, referred to as $\widetilde{R}$, expresses the correlation between the jth and $\acute{j}$th $(j\acute{j} = 1, 2, \ldots, n, j \neq \acute{j})$ competitive factors. Specifically, the correlation matrix is assumed as the incremental changes of the degree of attainment of the j-th how when the attainment of the $\acute{j}$th one is unitary increased. Correlations are usually expressed by graphic symbols following a 4-level scale, ranging from "strong negative" to "strong positive". As in the case of relationships, in the approach proposed, symbols are translated into triangular fuzzy numbers according to the correspondence shown in Table 5 [7]:

4.2.2.8. *Step 8: Determine the final weights of competitive factors.* Weights of competitive factors are determined based on formula (4.17).

$$\widetilde{\text{RI}}_j = \sum_{i=1}^{M} \tilde{F}_i \otimes \tilde{Y}_{ij} \qquad j = 1, 2, \ldots, N \tag{4.16}$$

$$\tilde{s}_j = \sum_{j=1}^{N} \tilde{R}_{j\acute{j}} \otimes \widetilde{RI}_{\acute{j}} \qquad j = 1, 2, \ldots, N \tag{4.17}$$

$$\tilde{S} = (\tilde{s}_1, \tilde{s}_2, \cdots, \tilde{s}_n) \tag{4.18}$$

In formula (4.16), the vector $\widetilde{F}$ indicates the whats' final importance weights and $\widetilde{Y}$ is the whats and hows relation matrix. Matrix $\widetilde{R}$ in formula (4.17) is the hows' correlation.

4.2.3. Stage 2: Determine strategic manufacturing decision categories

As described before, the content of manufacturing strategy comprises structural and infrastructural strategic decision categories. At this stage, manufacturing decision categories are identified and used as "hows" in the QFD matrix to illustrate in what order they can fulfill the competitive factors determined and measured in the first stage. The competitive factors are used as "whats" in the second QFD matrix. Stage 2 is comprised of eight steps, as shown in Figure 3. All calculation methods in step 3 to step 8 in HOQ1 and HOQ2 are exactly the same. Note that, in HOQ2, the index M in formulas denotes the set of competitive factors and index N denotes the set of manufacturing strategic decisions.

4.2.3.1. *Step 1: Use the competitive factors as the "whats".* The competitive factors determined in stage 1 are used as the "whats" in the QFD matrix in this step.

4.2.3.2. *Step 2: Determine the relative importance ratings of whats.* The final weights of the competitive factors determined in stage 1 are used as the relative importance of the competitive factors in this step.

4.2.3.3. *Step 3: Identify competitors and conduct organization experts' competitive analysis (Performance Analysis).* Competitors in this step are similar with those identified in stage 1. The calculation method is similar to step 3 in stage 1.

4.2.3.4. *Step 4: Determine the final importance rating of competitive factors.* The calculation method is similar to step 4 in stage 1.

4.2.3.5. *Step 5: Identify manufacturing strategic decisions – "hows".* In this step, manufacturing decision categories, which can be divided into structural strategic decisions and infrastructural decisions, are established. Actions within these two decision categories normally have direct impact on the fulfillment of competitive factors. For instance, improvement in flexibility may accelerate the speed to market of a new product and also may enhance the cost reduction.

4.2.3.6. *Step 6: Link competitive factors with manufacturing strategic decisions.* This step determines the correlation scores of competitive factors and manufacturing strategic decisions. The method is used to find correlation scores is the fuzzy AHP method, which is explained in step 6.1 to step 6.7 of stage 1.

4.2.3.7. *Step 7: Correlation between manufacturing strategic decisions (HOWs).* This step measures the correlation between the manufacturing decision categories ("hows") that are contained in the "roof" of the HOQ2. The correlations between pairs of "hows" are expressed with a 4-level scale, which is explained in stage 1.

4.2.3.8. *Step 8: Determine the final weights of manufacturing strategic decisions.* The weight of each manufacturing decision indicates the importance of each manufacturing decision and effectiveness of their investment in achieving manufacturing competitive factors. Then, by determining the final weights of manufacturing decisions, they can be ranked. Based on the obtained ranking and available sources, one or more manufacturing strategic decisions can be developed and key-related tasks can be identified. The final weights of manufacturing decisions are determined using equation (4.16) and then, to include ease and perceptible comparison of the final weights, they are de-fuzzified according to the Yager ranking de-fuzzification formula (4.14).

5. Case study

To ensure that the model is usable and applicable and that it provides genuine decision support to the decision maker it has been conducted in the biggest extrusion rubber manufacturer in the Middle East and Iran. The company was established in 2004 in Iran to produce various types of rubber and plastic based on different grades, such as EPDM, SBR, NBR, TPV, TPE, CR, PVC and NBRPVC. The approximate production capacity of this company in the auto profiles scope is 2 000 000 per year. The auto industry is the main customer of this company, in which more than 200 types of rubber profiles are produced for auto manufacturers. The company also has good experiences in regards to the export of its auto production to France, Russia, Romania, Egypt, Azerbaijan, Kazakhstan and Syria.

There were some factors, such as the willingness of auto manufacturers to optimize auto parts, auto manufacturers' production ramp up, more active participation of competitors, economic instability caused by sanctions and increasing rate of environmental changes that led the company under study to develop its manufacturing strategy based on new conditions.

The company does not apply a specific method or model to develop its manufacturing strategy further the Senior manager required to apply a model which consider both qualitative and quantitative data in manufacturing strategy decisions to lead the company proactively in promising condition of Automotive industry. Therefore, to eliminate this deficiency, a model was proposed for manufacturing strategy development aimed firstly at relating organization performance factors to manufacturing competitive priorities and secondly at relating manufacturing competitive priorities to both structural and infrastructural manufacturing decisions. Then, to investigate the efficiency of the proposed model, it was applied to the company under study.

In the studied company, experts who affected manufacturing strategy development included the vice president, plant manager and managers of engineering, production, and primitive maintenance, industrial and commercial

TABLE 6. Organization performance factors.

Performance factors	Reference
Sales increase	
ROA	[9, 30]
Profit increase	

TABLE 7. Organization performance factors' relative importance.

Performance factors	Relative importance
Sales increase	(0.25, 0.24, 0.25)
ROA	(0.41, 0.41, 0.42)
Profit increase	(0.34, 0.34, 0.33)

departments. They had either a bachelor's or master's degree in their specialty with over 12 years of experience in their field of work; their specialties were relevant to the scope under their supervision. The decision and QFD exercise team was made up of eight members who were present during the research, The entire procedure of manufacturing strategy development was characterized by the proposed steps in stage 1 and stage 2, explained to team members individually in order to answer to their all questions.

5.1. Identifying organization performance factors ("whats")

In this step, the organization performance factors were used as the "whats" in the QFD matrix, and the relative importance of the various organization performance factors was determined by means of measuring stakeholders' needs. A meeting was held to discuss organization performance factors and to determine their relative importance. The participants of the meeting included stakeholders and all the company's experts who had influence on the manufacturing strategy. We presented to the participants various organization performance factors that had emerged from a careful review of the literature. Because organizational performance can be judged by many different constituencies, resulting in many different interpretations of "successful performance", this study necessarily examines organizational performance from a single constituency perspective, namely, that of the common stockholder in for-profit organizations. From this perspective, successful organizational performance can be equated with successful value creation for stockholders. According to Carton [9], this perspective typically equates value creation with organizational financial performance; accordingly, this study addresses the organizational financial performance. Following survey of the literature and discussions, the group arrived at a consensus on the final list of three organization performance factors.

5.2. Determining the relative importance of "whats"

After the determination of the organization performance factors, each of the company's stakeholders and organization experts established the level of importance of each "what" by means of a linguistic variable. The linguistic variable was quantified using triangular fuzzy numbers (Tab. 3).The fuzzy pair wise importance comparison matrixes assigned by each participant were aggregated by using the geometric mean average operator, as described by equation (4.1); the resulting matrix was then normalized according to equation (4.2). Based on the normalized matrix, a column vector showing the importance rating of organization performance factors (Tab. 7) was constructed as described by equation (4.3).

TABLE 8. Performance Analysis matrix X in HOQ1.

	C1	C2	C3	C4		P_{il}			$E(W_i)$	e_i	a_i	u_i
Sales increase	5	8	8	7	0.17	0.28	0.28	0.25	0.97	0.329	8	1.6
ROA	5	7	7	6	0.20	0.28	0.28	0.24	0.99	0.336	8	1.6
Profit increase	6	8	8	7	0.20	0.27	0.27	0.24	0.98	0.333	8	1.3

5.3. Identifying competitors, conducting organization experts' competitive analysis (Performance Analysis) and determining the final importance rating of organization performance factors

In this step, the competitors of the company under study (C1) were identified and the organization experts' competitive analysis was conducted. In the extrusion rubber sealing market, company C1 has three main competitors in Iran, called company C2, C3 and C4, each of which makes similar types of extrusion rubber profiles. To investigate the extrusion rubber sealing market and company C1's n Iran relative position in this market to find out priorities for further improvement, we asked experts to rate the relative performance of company C1's financial factors and three competitors' similar financial factors in terms of three WHATs by using the scale in Table 2. The experts' assessments are shown in Table 8 in crisp numbers. We did not consider using triangular fuzzy numbers to represent performance assessments because it is too complex to incorporate triangular fuzzy numbers into the following entropy computations. Applying the entropy method, company C1's competitive priority ratings of the stakeholders' needs (whats) based on the experts comparison matrix was obtained.

According column e_i of Table 8, we see that W2 is the highest competitive priority for company C1, followed by W_3 and W_1. After various considerations based on the resources available and the relative performance of the four companies on 3 WHATs, company C1 decided on the performance goals much higher than current performance levels to be competitive, shown in column a_i of Table 8. We did not consider setting goals in fuzzy triangular number form either because it would result in some computational and explanatory difficulties. Column u_i also shows company C1 improvement ratios on each WHATs.

According to each WHAT's relative importance rating, competitive priority rating and improvement ratio, the final importance rating of the WHATs was obtained. When the relative importance ratings are triangular fuzzy numbers, the final importance ratings are given as the following triangular fuzzy numbers:

$$f = (f_1, f_2, f_3) = [(0.131, 0.128, 0.132), (0.222, 0.223, 0.224), (0.151, 0.153, 0.148)].$$

5.4. Identifying competitive factors – "hows"

In this step, the competitive factors were used as the "Hows" in the QFD matrix. Meetings were held to discuss competitive factors. The participants included all organization experts who affect manufacturing strategy deployment. We presented the group of participants with various competitive factors that had emerged from a careful review of the manufacturing strategy literature. Following survey of the literature and discussions, the group agreed on the final list of competitive factors, shown in Table 9.

Quality, Delivery, Cost, Innovation, Service, and Protect environment are the customers' requirements; thus, many competitive factors have a market requirements perspective. Many competitive factors also have a direct correspondence internally to manufacturing. According to Hill [19], competitive factors are formally identified as the key link between the marketing and manufacturing aspects of strategy development. For instance, Delivery speed and reliability are dependent on both production lead times and flexibility, and product range, customization and innovativeness are based on internal flexibility [28].

TABLE 9. Manufacturing competitive factors.

Competitive factors	References
Quality (Performance, Conformance)	
Delivery (Speed, Dependability)	
Cost	
Flexibility (Volume, Product, Design)	[17, 26, 27, 30, 31]
Innovation (Production, Process)	
Service	
Protect environment	
Technology	

5.5. Linking organization performance factors with competitive factors

In this step, the relationship weightings between organization performance factors and competitive factors were determined. Fuzzy AHP was used to calculate the relationship weightings. The first step was to construct a fuzzy pair wise comparison matrix on competitive factors with respect to each organization performance factor; all 8 experts were asked to compare competitive factors with respect to each organization performance factor, and, in total, each organization performance factor had 8 compression matrixes that reduced to 1 after obtaining the geometric mean, *i.e.*, the final compression matrix with respect to the sales increase factor after obtaining the geometric mean. For synthesization, a normalized Fuzzy comparison matrix was constructed (Fig. 4). Based on matrix $\widetilde{A}$, a column vector showing the correlation scores of organization performance factors, *i.e.*, sales increase, and competitive factors was constructed (Fig. 5). To verify consistency, a fuzzy and crisp weighted sum vector was constructed (Figs. 6 and 7). Then, the maximum eigenvalues of matrix $\widetilde{A}$, the consistency index, and consistency ratio were computed. Because CR is less than 0.10, the fuzzy pairwise comparison is consistent:

$$\lambda_{\max} = \frac{8.89 + 9.02 + 8.86 + 8.95 + 8.92 + 8.86 + 8.76 + 8.87}{8} = 8.89$$

$$\text{CI} = \frac{8.89 - 8}{7} = 0.13$$

$$\text{CR} = \frac{0.13}{1.41} = 0.09$$

$$C = \begin{vmatrix} 0.12 & 0.10 & 0.11 \\ 0.24 & 0.24 & 0.24 \\ 0.11 & 0.11 & 0.11 \\ 0.16 & 0.16 & 0.17 \\ 0.13 & 0.14 & 0.14 \\ 0.09 & 0.10 & 0.09 \\ 0.05 & 0.05 & 0.04 \\ 0.10 & 0.12 & 0.10 \end{vmatrix} \quad \bar{C} = \begin{vmatrix} 6.18 & 8.15 & 13.08 \\ 6.23 & 8.20 & 13.45 \\ 6.11 & 8.12 & 13.09 \\ 6.19 & 8.17 & 13.28 \\ 6.19 & 8.16 & 13.15 \\ 6.21 & 8.14 & 12.93 \\ 6.12 & 8.12 & 12.70 \\ 6.14 & 8.14 & 13.06 \end{vmatrix} \quad \bar{C} = \begin{vmatrix} 8.89 \\ 9.02 \\ 8.86 \\ 8.95 \\ 8.92 \\ 8.86 \\ 8.76 \\ 8.87 \end{vmatrix}.$$

The obtained fuzzy column vector shows the relationship between W_1 and Hows:

$$\widetilde{Y_1} = [(0.12, 0.10, 0.11), (0.24, 0.24, 0.24), \ldots, (0.10, 0.12, 0.10)].$$

5.6. Correlation between competitive factors (HOWs)

In this step, correlations between competitive factors were identified to find which pairs had positive correlation and which had negative correlation. Competitive factors that had more positive correlation mean that

	Quality			Delivery			Cost			Flexibility			Innovation			Service			Environment			Technology		
A~	0.16	0.10	0.23	0.17	0.14	0.14	0.09	0.08	0.08	0.08	0.07	0.07	0.10	0.09	0.09	0.12	0.13	0.12	0.10	0.09	0.09	0.12	0.12	0.10
	0.15	0.17	0.13	0.30	0.23	0.39	0.31	0.31	0.30	0.27	0.27	0.25	0.19	0.22	0.18	0.27	0.27	0.28	0.22	0.23	0.22	0.18	0.19	0.15
	0.12	0.13	0.11	0.06	0.08	0.06	0.14	0.10	0.19	0.15	0.14	0.13	0.10	0.10	0.09	0.07	0.08	0.06	0.08	0.09	0.09	0.13	0.16	0.14
	0.21	0.22	0.20	0.11	0.13	0.10	0.10	0.11	0.09	0.21	0.15	0.28	0.23	0.20	0.24	0.18	0.18	0.16	0.14	0.14	0.14	0.13	0.12	0.14
	0.13	0.16	0.14	0.13	0.14	0.12	0.12	0.14	0.12	0.07	0.10	0.07	0.18	0.13	0.23	0.15	0.14	0.13	0.16	0.15	0.14	0.13	0.12	0.14
	0.07	0.07	0.07	0.05	0.07	0.05	0.11	0.12	0.10	0.07	0.07	0.05	0.07	0.08	0.06	0.10	0.09	0.15	0.16	0.15	0.15	0.11	0.11	0.08
	0.05	0.05	0.04	0.04	0.05	0.03	0.05	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.03	0.02	0.03	0.02	0.06	0.05	0.09	0.06	0.06	0.05
	0.11	0.10	0.09	0.14	0.15	0.11	0.07	0.08	0.07	0.10	0.15	0.11	0.09	0.14	0.09	0.08	0.09	0.07	0.08	0.10	0.08	0.15	0.12	0.20

FIGURE 4. Normalized Fuzzy Compression of competitive factors with respect to sales increase.

	Quality			Delivery			Cost			Flexibility			Innovation			Service			Environment			Technology		
Quality	0.3	0.5	0.7	0	0.3	0.5	0.3	0.5	0.7	0	0.3	0.5	0	0.3	0.5	0.3	0.5	0.7	0.3	0.5	0.7	0	0.3	0.5
Delivery	0	0.3	0.5	0.3	0.5	0.7	0.3	0.5	0.7	0	0.3	0.5	0	0.3	0.5	0.3	0.5	0.7	-0.5	-0.3	0	0	0.3	0.5
Cost	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	-0.5	-0.3	0	-0.7	-0.5	-0.3	-0.5	-0.3	0	-0.5	-0.3	0	-0.5	-0.3	0
Flexibility	0	0.3	0.5	0	0.3	0.5	-0.5	-0	0	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0	0.3	0.5	0	0.3	0.5
Innovation	0	0.3	0.5	0	0.3	0.5	-0.7	-0.5	-0	0.3	0.5	0.7	0.3	0.5	0.7	0	0.3	0.5	0	0.3	0.5	0.3	0.5	0.7
Service	0.3	0.5	0.7	0.3	0.5	0.7	-0.5	-0.3	0	0.3	0.5	0.7	0	0.3	0.5	0.3	0.5	0.7	0	0.3	0.5	0	0.3	0.5
Environment	0.3	0.5	0.7	-0.5	-0.3	0	-0.5	-0.3	0	0	0.3	0.5	0	0.3	0.5	0	0.3	0.5	0.3	0.5	0.7	0	0.3	0.5
Technology	0	0.3	0.5	0	0.3	0.5	-0.5	-0.3	0	0	0.3	0.5	0.3	0.5	0.7	0	0.3	0.5	0	0.3	0.5	0.3	0.5	0.7

FIGURE 5. Correlation between competitive factors.

Organization Performance Factor (whats)	Relative Importance			Quality			Delivery			Cost			Flexibility			Innovation			Service			Environment			Technology			Priority Rating	Improve. Ratio	Final Importance Rating (whats)		
Sales increase	0.25	0.24	0.25	0.12	0.10	0.11	0.24	0.24	0.24	0.11	0.11	0.11	0.16	0.16	0.17	0.13	0.14	0.14	0.09	0.10	0.09	0.05	0.05	0.04	0.10	0.12	0.10	0.3299	1.6	0.13	0.13	0.13
ROA	0.41	0.41	0.42	0.09	0.09	0.09	0.16	0.16	0.17	0.17	0.17	0.17	0.16	0.15	0.16	0.17	0.18	0.17	0.09	0.09	0.09	0.05	0.05	0.05	0.11	0.11	0.11	0.3367	1.6	0.22	0.22	0.22
Profit increase	0.34	0.34	0.33	0.07	0.07	0.07	0.17	0.16	0.18	0.22	0.21	0.21	0.19	0.19	0.19	0.16	0.17	0.16	0.07	0.07	0.07	0.04	0.04	0.04	0.08	0.09	0.08	0.3333	1.33	0.15	0.15	0.15
Hows Final Importance (Fuzzy)	0.06	0.19	0.29	0.05	0.18	0.28	-0.09	0.01	0.13	0.02	0.14	0.25	0.00	0.13	0.23	0.04	0.15	0.26	-0.07	0.06	0.18	0.00	0.13	0.24								
Hows Final Importance (Crisp)		0.182			0.175			0.015			0.139			0.122			0.151			0.057			0.122								
Hows Rating		1			2			7.0			4			5.0			3			6.0			5.0								

FIGURE 6. HOQ1 Matrix.

these "hows" should be improved, and those that had negative correlation mean that their improvement may cause conflict between competitive factors; therefore, in executive area, these conflicts should be considered and resolved. In this case, all 8 experts were asked to determine how extending the improvement of the jth competitive factor would affect the attainment of the jth one according to the scale described in Table 3. Figure 5 shows the obtained fuzzy correlation between competitive factors in the company under study, and the symbolic view of correlation between competitive factors can be observed in HOQ1 in Figure 6.

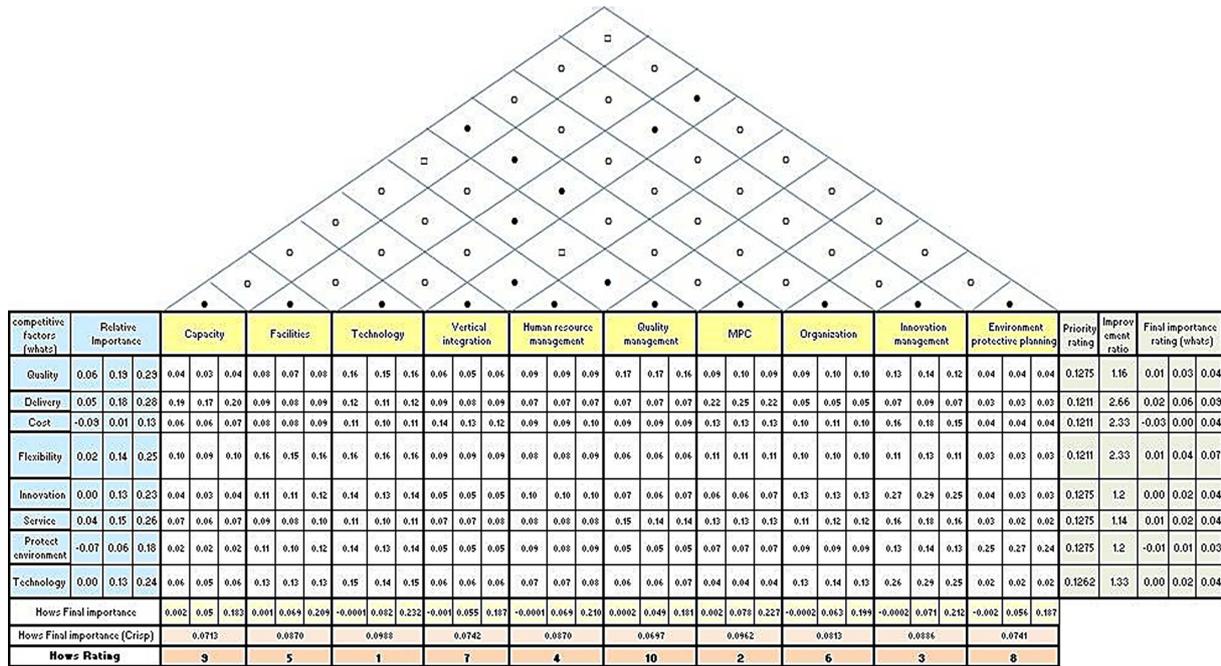	competitive factors (whats)	Relative Importance			Capacity			Facilities			Technology			Vertical integration			Human resource management			Quality management			MPC			Organization			Innovation management			Environment protective planning			Priority rating	Improvement ratio	Final importance rating (whats)		
Quality	0.06	0.13	0.23	0.04	0.03	0.04	0.08	0.07	0.08	0.16	0.15	0.16	0.06	0.05	0.06	0.09	0.09	0.09	0.17	0.17	0.16	0.09	0.10	0.09	0.09	0.10	0.10	0.13	0.14	0.12	0.04	0.04	0.04	0.1275	1.16	0.01	0.03	0.04
Delivery	0.05	0.18	0.28	0.19	0.17	0.20	0.09	0.08	0.09	0.12	0.11	0.12	0.09	0.08	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.22	0.25	0.22	0.05	0.05	0.05	0.07	0.09	0.07	0.03	0.03	0.03	0.1211	2.66	0.02	0.06	0.03
Cost	-0.03	0.01	0.13	0.06	0.06	0.07	0.08	0.08	0.09	0.11	0.10	0.11	0.14	0.13	0.12	0.09	0.09	0.10	0.09	0.09	0.09	0.13	0.13	0.13	0.10	0.11	0.10	0.16	0.18	0.15	0.04	0.04	0.04	0.1211	2.33	-0.03	0.00	0.04
Flexibility	0.02	0.14	0.25	0.10	0.09	0.10	0.16	0.15	0.16	0.16	0.16	0.16	0.09	0.09	0.09	0.08	0.08	0.09	0.06	0.06	0.06	0.11	0.11	0.11	0.10	0.10	0.10	0.11	0.13	0.11	0.03	0.03	0.03	0.1211	2.33	0.01	0.04	0.07
Innovation	0.00	0.13	0.23	0.04	0.03	0.04	0.11	0.11	0.12	0.14	0.13	0.14	0.05	0.05	0.05	0.10	0.10	0.10	0.07	0.06	0.07	0.06	0.06	0.07	0.13	0.13	0.13	0.27	0.29	0.25	0.04	0.03	0.03	0.1275	1.2	0.00	0.02	0.04
Service	0.04	0.15	0.26	0.07	0.06	0.07	0.09	0.08	0.10	0.11	0.10	0.11	0.07	0.07	0.08	0.08	0.08	0.08	0.15	0.14	0.14	0.13	0.13	0.13	0.11	0.12	0.12	0.16	0.18	0.16	0.03	0.02	0.02	0.1275	1.14	0.01	0.02	0.04
Protect environment	-0.07	0.06	0.18	0.02	0.02	0.02	0.11	0.10	0.12	0.14	0.13	0.14	0.05	0.05	0.05	0.09	0.08	0.09	0.05	0.05	0.05	0.07	0.07	0.07	0.09	0.09	0.09	0.13	0.14	0.13	0.25	0.27	0.24	0.1275	1.2	-0.01	0.01	0.03
Technology	0.00	0.13	0.24	0.06	0.05	0.06	0.13	0.13	0.13	0.15	0.14	0.15	0.06	0.06	0.06	0.07	0.07	0.08	0.06	0.06	0.07	0.04	0.04	0.04	0.13	0.14	0.13	0.26	0.29	0.25	0.02	0.02	0.02	0.1262	1.33	0.00	0.02	0.04
Hows Final importance				0.002	0.05	0.183	0.001	0.069	0.209	-0.0001	0.082	0.232	-0.001	0.055	0.187	-0.0001	0.069	0.210	0.0002	0.049	0.181	0.002	0.078	0.227	-0.0002	0.063	0.199	-0.0002	0.071	0.212	-0.002	0.056	0.187					
Hows Final importance (Crisp)		0.0713			0.0870			0.0988			0.0742			0.0870			0.0697			0.0962			0.0813			0.0886			0.0741								
Hows Rating		9			5			1			7			4			10			2			6			3			8								

FIGURE 7. HOQ2 Matrix.

5.7. Transferring competitive factors and their final importance to HOQ2

The competitive factors determined in 6.4 were used as the "whats" in HOQ2, and the final importance of competitive factors in HOQ1 were used as the relative importance of "whats" in HOQ2.

5.8. Identifying competitors, conducting organization experts' competitive analysis (Performance Analysis) and determining the final importance rating of competitive factors

Competitors in this step are similar to 6.3, and to compare C1's performance on competitive factors with the performances of C2, C3 and C4, step 5.2.2.3 was followed to determine the importance ratings of competitive factors for company C1. The final importance ratings of competitive factors were determined by following 5.2.4, performance analysis of the competitive factors were computed as shown in Table 10 and the final importance rating was computed in HOQ2, as shown in Figure 7.

5.9. Identifying manufacturing strategic decisions – "Hows"

In this step, meetings were held to discuss the manufacturing decision areas. The participants of the meetings included all organization experts who affected manufacturing strategy deployment. We presented the group of participants with structural and infrastructural strategic decisions that had emerged from a careful review of the manufacturing strategy literature. Following survey of the literature and discussions, the group agreed on the final list of manufacturing strategic decisions, which are shown in Table 11.

The selected list is focused on mostly strategic decisions because, after sanctions against Iran, the economic crisis affected various aspects of manufacturing; thus, the senior manager of the company preferred to have a comprehensive review of the company's situation and manufacturing decisions.

TABLE 10. Performance Analysis matrix X in HOQ2.

	C1	C2	C3	C4		P_{il}			$E(W_i)$	e_i	a_i	u_i
Quality	6	7	7	6	0.23	0.26	0.26	0.23	0.99	0.1275	7	1.16
Delivery	3	9	9	7	0.10	0.32	0.32	0.25	0.94	0.1211	8	2.66
Cost	3	9	9	7	0.10	0.32	0.32	0.25	0.94	0.1211	7	2.33
Flexibility	3	8	8	7	0.11	0.30	0.30	0.26	0.94	0.1211	7	2.33
Innovation	5	7	7	6	0.2	0.28	0.28	0.24	0.99	0.1275	6	1.2
Service	7	7	7	7	0.25	0.25	0.25	0.25	0.99	0.1275	8	1.14
Protect environment	5	5	5	5	0.25	0.25	0.25	0.25	0.99	0.1275	6	1.2
Technology	6	9	9	9	0.18	0.27	0.27	0.27	0.98	0.1262	8	1.33

TABLE 11. Manufacturing strategic decisions.

Decision categories	Decision areas	References
Structural	Capacity Facilities Technology (Process/Production) Vertical integration	[17, 18, 26, 30, 36]
Infrastructural	Human resource management Quality management Manufacturing planning and control (MPC) Organization Innovation management Environment protective planning	

5.10. Linking competitive factors with manufacturing strategic decisions

This step determines the correlation scores of competitive factors and manufacturing strategic decisions. The fuzzy AHP method was used. All 8 experts were asked to compare manufacturing strategic decisions with respect to each competitive factor. Then by applying related calculations (similar to stage 1) relationship between Whats and Hows were obtained.

5.11. Correlation between manufacturing strategic decisions (HOWs)

This step measures the correlation between the manufacturing strategic decisions ("Hows") that are contained in the "roof" of the HOQ2. The symbolic view of correlation between Hows can be observed in HOQ2 in Figure 7.

5.12. Determining the final weights and rank of manufacturing strategic decisions

In this last step, the final weight of manufacturing strategic decisions calculated according to equation (4.17) can be shown at the base of HOQ2. By determination of the weights of manufacturing decisions, manufacturing strategic decisions are ranked and therefore the key manufacturing-related tasks can be determined. In this case, in terms of final scores of Hows, manufacturing strategic decisions were ranked as: technology, manufacturing planning and control, Innovation management, Human resource management, facilities, Organization, Vertical integration, Environment protective planning, Capacity.

In order to achieve accurate result seventeen excel files were provided to aggregating data from questionnaires which formulated to transform experts linguistic answers to the fuzzy pair wise comparison and execute all formulas in stage 1 and stage 2.

Complete execution of the proposed model in the studied company shows: (1) How the QFD model relates stakeholders' requests in the form of organizational performance factors to manufacturing decisions through manufacturing competitive priorities. (2) How organizational performance factors influence manufacturing decisions priority by applying the final importance of organizational performance factors on the manufacturing competitive priorities importance ratio. (3) How competitive analyses and the performance improvement ratio affect the final importance weights of "Whats" in HOQ1 and HOQ2 to make their importance weights more real and make the selection of "Hows" more accurate to achieve improvements in organization performance. (4) How the correlation between "Hows" influence their final weight to develop those "Hows" that have the most positive effect on others' development. (5) In this company's expert's point of view concerning organization performance factors, return of asset (ROA) has the first rank, followed by profit increase and sales increase, respectively, in the second and third rank, which means that managers of this company seek more profit margin rather than only the increment rate of sales. (6) The main problem of this company was not only the cost but also not being proactive in setting manufacturing competitive priorities, especially in production technology, production facilities, flexibility and innovation, which means that the company's managers should not concentrate only on cost reduction solutions but also on executive programs, using new process technologies, satisfying customers' requests related to product improvements, keeping constituency in material supplying for on time delivery, etc. (7) This company did not notice its rivals and external environment signals, or if it had, it did not have rapid and appropriate reaction to them, meaning that it is essential for the company to create a team composed of the company's managers and external consultants to observe environmental signals and propose appropriate scenarios to encounter them.

The main limitations of company under study in model execution are listed as follows: (1) Rivals' financial performances were not explicitly available; therefore, to overcame this limitation, sales index and profit index were evaluated in comparison with the market share variations in the studied company, and ROA index was evaluated according to experts' knowledge relative to the size of their rivals, technology and history in the auto part industry. (2) Previous manufacturing decisions were not available to be used as a comparison base with results achieved from the model execution, and organization strategy alignment was also not explicit because the available organization strategy was too old and was not compatible with current situations; therefore, to overcome this limitation, all comparisons were performed according to the experts' subjective data.

The validation of all questionnaires factors that had emerged from a careful review of the literature and expert team approbation were rechecked and confirmed by academic experts. Most of all data were collected base on paired comparison to improve qualitative data gathering. Consistency verification on gathered data is also applied by a fuzzy and crisp weighted sum vector in the current model. Obtained results from complete execution of the proposed model were investigated in a meeting with expert team, results satisfied their expectation and decided to choose the obtained manufacturing strategic decisions as an organization priorities to revise the current manufacturing strategies in structural and infrastructural manufacturing subsystems to be in alignment with the manufacturing competitive priorities and organizational performance.

6. Conclusions

The aim of this paper was to provide an applicable model based on the quality function deployment (QFD) framework for manufacturing strategy development. In this model: (1) Organization performance factors were related to manufacturing decisions, which included both structural and infrastructural, and this relation remained until the completion of model execution. (2) Process oriented approach was used in manufacturing strategy development by using the HOQ matrix as a main tool in model execution to control and keep consistency between decisions that were made in each stage. (3) Organization performance analysis in comparison with rivals and future performance goals on organization performance factors and manufacturing competitive priorities were applied to keep coherence and continuity between previous and future decisions in manufacturing strategy development. (4) Correlations between manufacturing decisions were considered in the manufacturing decisions importance weight formula to make the prioritization and selection process more efficient than before.

(5) QFD created the possibility for group decision making, in which a company's experts' and main stakeholders' comments could be considered effectively and simultaneously with at least partiality and prejudice in the decision making process.

Some of the advantages and innovations of the model proposed in this paper, in comparison with other similar studies in the field of manufacturing strategy definition and development, are listed as follows: (1) In this model, manufacturing strategy was indirectly related to organization strategy through financial performance factors and HOQ as the main tool of the model. Then, in spite of most previous models, in which a direct relation between manufacturing strategy and organization strategy prevented them from being executable in companies that did not have organization strategy, this model will be executable in all companies due to the existence of financial performance factors in all companies. (2) Performance analysis was applied to the manufacturing decisions importance rating and prioritization through competitive analysis of organization performance factors and manufacturing competitive priorities by using the Entropy Shannon method and computing the performance improvement ratio on organization performance factors and manufacturing competitive priorities. (3) Manufacturing decision correlation effects were applied in manufacturing decision prioritization, whereas most previous studies did not apply them.

In the present study, among performance factors, only quantitative performance factors with financial perspective were considered in the model, and qualitative performance factors were not considered due to the lack of proper use of qualitative indicators among Iranian manufacturing companies; thus, to cover all aspects of organization performance in the manufacturing strategy development process, it is recommended that future research considers both quantitative and qualitative performance factors in the model. In this study, more detailed action plans for implementation were not considered in the model due to time limitations; thus, it is recommended that future research adds a third HOQ matrix to the model to relate the selected manufacturing strategy from the second stage to the proper action plans in the third stage. The advantages of this recommendation include being confident about the execution of selected manufacturing strategies and involving the executive layer's employees in strategic decision making to create organizational commitment to execute the adopted decisions. In this paper, manufacturing strategies were development based on manufacturing organization performance factors and competitive priorities, which are affected by some another items; for example, competitive priorities are affected by the manufacturing paradigm and production life cycle. However, in this model, the influence of the mentioned items due to time limitation was not considered for the identification of competitive priorities. Thus, to make a comprehensive model on manufacturing strategy development, it is suggested that the influence of these items be investigated in future studies.

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