Full Length Research Paper

Determination of manufacturing strategy using interpretive structural modeling

Mehdi Abbasi¹, Mohsen Akbarpour Shirazi²* and Mir Bahador Aryanezjad³

¹Department of Industrial Engineering, Science and Research Branch, Islamic Azad University (IAU), Iran. ²Department of Industrial Engineering, Amirkabir University of Technology, Tehran, Iran. ³Department of Industrial Engineering, University of Science and Technology, Tehran, Iran.

Accepted 27 September, 2011

The interpretive structural modeling (ISM) methodology was applied as a tool for determination of optimal manufacturing strategy. For this purpose, a group of experts who had agreement to each other in their objectives and decisions about manufacturing strategy determination was selected and an algorithm containing seven steps was proposed. In the first step, improvable manufacturing capabilities of company (elements) were recognized. Then we made contextual relationships between the elements using the experts' opinions. In the next step, the reachability matrix was developed and driving and dependence powers of each element were calculated. After that, the reachability matrix was partitioned into different levels. Then related digraph was drawn, the ISM-based model extracted and related cluster of each element determined by drawing driving-dependence power diagram. The required time for performing each task was estimated by experts and the alternatives of action plans for improving elements were created using proposed rule related to each cluster. Finally, the related cluster of each element and the alternatives of action plans for improving elements were explained for experts. When the experts found desirable action plan and accepted the results, the algorithm was completed; otherwise, afore steps had to be repeated. We applied the algorithm for a case study.

Key words: Manufacturing strategy, manufacturing capabilities, manufacturing competitive priorities, interpretive structural modeling.

INTRODUCTION

The competencies that a company develops around its operational functions are referred to as manufacturing strategy. Manufacturing strategy is strongly integrated with company’s business strategies or also one of the components of company’s business strategies (Anderson et al., 1989). A good review was given about manufacturing strategy (Minor et al., 1994). A distinction is considerable between the process to formulate the manufacturing strategy and the content of manufacturing strategy (Platts et al., 1998; Barnes, 2002; Papke-Shields et al., 2002; Jia and Bai, 2010). The specific actions and decisions, which set the manufacturing roles, activities and objectives, are included in the content of manufacturing strategy. The procedures which can be used to develop manufacturing strategies are included in the process of manufacturing strategy (Jia and Bai, 2010; Slack et al., 2004). Following a seminal work in 1969, the concept of manufacturing strategy began to gain attention of researchers. In this report, manufacturing did not have the proper role in corporate strategy development; and instead of this, it gained an important role in corporate strategy (Skinner, 1969).

According to another description, manufacturing strategy consists of a sequence of decisions that over time enables a business unit to achieve a desired manufacturing infrastructure, structure and set of specific capabilities (Hayes and Wheelwright, 1984). An applicable definition of manufacturing strategy was
developed as a pattern of decisions (both infrastructural and structural) in 1998. These decisions determine the capability of a manufacturing system and specify how it will operate for meeting a set of manufacturing objectives that are consistent with the overall business objectives (Platts et al., 1998). With the association of these infrastructural and structural decisions, related policy areas have been presented (Jia and Bai, 2010; Hallgren and Olhager, 2006).

The principle research that related to development of manufacturing strategy has specified and described strategy development process and as a result, many different related methodologies to strategy development have been offered. Many prescriptive processes and the manufacturing strategy domain that has being dominated by conceptual models have been proposed in the big part of literature. In addition, for quantitative modeling of manufacturing strategy based on seven steps a methodology was developed that it could improve the capabilities to meet market requirements (Hallgren and Olhager, 2006). An excellent review about various processes to formulate manufacturing strategy and a new developed model was also given (Pun, 2004). Manufacturing capabilities were described as strengths in key manufacturing performance according to literature. Some dimensions of these capabilities are quality, cost, time, delivery, speed, dependability and product flexibility (Skinner, 1969; Skinner, 1974; White, 1996; Safizadeh et al., 2000). One of the important concerns in manufacturing firms is to obtain competitive advantages using appropriate manufacturing capabilities. There were little theories that could help manufacturing firms to choose the appropriate manufacturing capabilities for their situations (Leung and Lee, 2004). Therefore, using a suitable tool for recognition of appropriate manufacturing capabilities is useful. Appropriate manufacturing capabilities can be recognized using the interpretive structural modeling (ISM) methodology by considering experts opinions.

According to previous report (Skinner, 1969), trade-offs exist between high levels of performance along manufacturing dimensions. Sarmiento et al. (2007) prepare a selective bibliography on reported empirical evidence considering the compatibility/trade-offs relationships among delivery reliability and other manufacturing capabilities. Using a suitable tool for recognition of appropriate trade-offs among manufacturing capabilities is useful. Recognition of mentioned relationships can be done using ISM methodology by considering expert(s) opinions. Competitive priorities were defined for key manufacturing capabilities and achieving them (Noble, 1995; Ward et al., 1998; Kathuria, 2000; Boyer and Lewis, 2002). Cost, delivery, quality, and flexibility are four widely accepted competitive priorities. Different groups of manufacturers, even within an industry (Kathuria, 2000), emphasize the different sets of competitive priorities. Therefore, competitive priorities should be carefully defined because it determines the adaptation direction of various processes or management practices (Singh et al., 2008). The shared understanding of strategic priorities between managers at operating, middle or/and top levels of the organization is defined as strategic consensus (Kellermanns et al., 2006).

Sarmiento et al. proposed a new approach to study strategic consensus and its effect on manufacturing performance. They assumed that competitive priorities and their trade-offs had been given. By considering these assumptions, this approach incorporates the trade-off compatibility relationships between each pair of competitive priorities into the measurement of consensus and agreement on manufacturing competitive priorities (Sarmiento et al., 2008).

This method was based on supposed appropriate competitive priorities and relationships between them. Introducing a method for obtaining reliable manufacturing competitive priorities and their relationships (without mentioned assumptions) is desirable when these assumptions for creating manufacturing capability network were not being reliable.

Interpretive structural modeling (ISM) methodology is a computer-assisted methodology to understand and construct the fundamental of relationships among criteria in complicated systems or situations.

The ISM theory is based on discrete mathematics, group decision-making, graph theory, computer assistance, and social sciences (Warfield, 1974a, b, 1976; Huang et al., 2005). The ISM procedures are implemented through individual or group mental models for obtaining binary matrices, also called relation matrices, to present the relations of the criteria (Huang et al., 2005).

The ISM methodology was used for conserving energy in Indian Cement Industry (Saxena and Sushil, 1992), for analyzing some important vendor selection criteria (Mandal and Deshmukh, 1994), for establishing a hierarchy of actions to achieve the Indian objective of waste management (Sharma et al., 1995), for studying the knowledge management in some manufacturing industries (Singh et al., 2003), for exploring the barriers to reverse logistics (Ravi and Shankar, 2005), for studying the influence of IT on the supply chain (Jharkaria and Shankar, 2005), for identifying the major barriers hindering the application of bio-energy (McCormick and Ka berger, 2007), for choosing the reverse logistics provider (Kannan et al., 2009), for selecting locations of high technology manufacturing centers in China (Feng et al., 2010), for gaining an evolution framework for technology transfer of new equipment in high technology industry (Lee et al., 2010), for creating the system framework in fatal construction industry occupational accidents (Chen et al., 2010), and for developing a novel hybrid multiple criteria decision making approach to outsource vendor selection (Ya-Ti et al., 2010). The ISM methodology was performed in the following steps:
1. Considered criteria (sub-criteria) of the problem are listed, and each criterion (sub-criterion) is defined as \( x_i \), \( i = 1, 2, 3, ..., n \).

2. Adjacency (relation) matrix that shows the relationship between the criteria (sub-criteria) is developed from the identified criteria (sub-criteria) in step 1.

3. Reachability matrix is developed. By adding obtained matrix to the identity matrix, the initial reachability matrix is calculated (Warfield, 1973, 1974a, b, 1976; Huang et al., 2005; Lee et al., 2010, Ya-Ti et al., 2010; Malone, 1975; Sage, 1977; Yang et al., 2008). By incorporating the transitive relationships in initial one, the final reachability matrix is obtained (Wang et al., 2008).

4. To create the structural models, the elements are decomposed into different levels. This is an algorithm-based process that depends on interrelationships between elements, categorizes them into different levels. This provides a multilevel ISM that the relationships between elements are clarified (Chen et al., 2010).

5. A directed graph (digraph) is drawn based on the given relationships in the reachability matrix, and the transitive links are removed. The resultant digraph is changed to an ISM model by replacing variable nodes with statements.

6. The developed ISM model is checked for conceptual inconsistency and necessary modifications made (Ravi and Shankar, 2005).

Cross impact matrix-multiplication applied to classification or Matrice d'Impacts Croises-Multiplication Appliance a un Classement (MICMAC), a French term, was developed (Duperrin and Godet, 1973) to study the diffusion of impacts through reaction paths and loops for developing hierarchies for members of an element set. MICMAC analysis can be used to identify and analyze the elements in a complicated system (Warfield, 1990). Analyzing the dependence and driving powers of the variables is the objective of the MICMAC analysis (Mandal and Deshmukh, 1994). Generally, according to the dependence and driving powers of all elements, the elements are classified into four clusters (Ravi and Shankar, 2005).

For constructing a network, as suggested method by Sarmiento et al. (2008) was based on them, the recognition of competitive priorities (Singh et al., 2008) and their relationships is desirable. To the best of our knowledge, determination of manufacturing strategy by using ISM methodology has not been reported. The methodology provides a platform for decision-makers or expert(s) to identify elements and to determine their relationships in order to make related digraph. The expert(s) can easily understand the ISM methodology and it provides a participating platform for them to develop manufacturing strategy. Therefore, applying the ISM methodology to create an activity-oriented manufacturing capability network after identifying competitive priorities and their relationships is one of the contributions in this paper. The elements are categorized in four clusters using the MICMAC analysis, that it is beneficial to make action plans for improving manufacturing capabilities. We suggested a rule for each cluster made by MICMAC analysis, to make the alternatives of action plans. It is another contribution of this paper. It is noticeable that in large-scale problems, elements scheduling can be done using CPM according to their cluster of MICMAC analysis.

**PROPOSED ALGORITHM FOR DETERMINATION OF MANUFACTURING STRATEGY**

The ISM methodology can be used to determine manufacturing strategy. For this purpose, a group of expert(s) who have agreement in their objectives and decisions about manufacturing strategy determination was(were) selected. Then, seven steps of proposed algorithm are shown as follows:

Step 1: We recognize the improvable manufacturing capabilities of company (elements) using expert(s) opinions.

Step 2: We make contextual relationships between the elements using expert(s) opinions. For understanding the interrelationships among these elements, a contextual connection “prefer to” is chosen. This means that one element is preferred to another. All relationships between each two elements \( i \) and \( j \) are determined and structural self-interaction matrix (SSIM) is created. It has to be mentioned that four symbols V, A, X, and O are used in SSIM as reported in the literature. Then the adjacency matrix is made by using SSIM.

Step 3: Initial and final reachability matrix are developed. After this, driving and dependence power of each element are calculated.

Step 4: We partition the obtained reachability matrix into different levels.

Step 5: A digraph based on the relationships in the reachability matrix is drawn and the transitive links are removed. Then we convert the resultant digraph into an ISM by replacing variable nodes with statements.

Step 6: Driving–dependence power diagram is obtained based on the calculated driving and dependence power of each element.

Step 7: We estimate the duration of each task performing according to experts’ opinions. After that, action plan alternatives for improving elements according to cluster of each element are made.

Suggested rules for obtained clusters by MICMAC analysis to make the alternatives of action plans are:

(a) Independent elements should be performed at the beginning time of the action plans.

(b) Dependent elements should be performed at the end of the action plans.

(c) Linkage elements should be performed at the middle of action plans (after finishing independent elements and before starting dependent ones). We prefer to schedule these elements without increase in total time with considering the manufacturing ability of company for doing simultaneous improvements. The manufacturing ability of company for doing simultaneous improvements can be calculated as reported in the literature (Miltonburg, 2005).

(d) We schedule autonomous elements based on the manufacturing ability of company for doing simultaneous improvements.

Then, we explain about the related cluster of elements and the alternatives of action plans for experts. They may find desirable action plan and confirm the results or decide to modify them. The mentioned steps are repeated until experts confirm the results.
**RESULTS AND DISCUSSION**

Consider a company that we want to determine its manufacturing strategy. At first, three experts who have agreement to each other in their objectives and decisions about manufacturing strategy determination were chosen. Then proposed algorithm was applied as follow:

**Step 1:** Elements were recognized by using experts' opinions. These elements were making things right (the quality advantage), changing what is made (the flexibility advantage), making things fast (the delivery advantage) and making things cheap (the cost advantage). We show these elements by numbers 1 to 4, respectively.

**Step 2:** Experts' opinions make contextual relationships between the elements. For understanding the interrelationships between the elements, a contextual "prefer to" was selected. This means that one element was preferred to another. All relationships between each two elements (i and j) were studied and SSIM was created as it is shown in Table 1. It has to be mentioned that symbol V means element i prefers to element j but element j does not prefer to element i and symbol O means that there is no relationship between element i and j. Then the adjacency matrix was made by using SSIM (Table 2).

<table>
<thead>
<tr>
<th>Element</th>
<th>4</th>
<th>3</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>2</td>
<td>V</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

**Step 3:** The initial reachability matrix was calculated by adding obtained adjacency matrix to the identity matrix. The final reachability matrix was obtained by incorporating the transitive relationships in initial one. Then driving and dependence powers were calculated (Table 3). Transitive relationships did not exist and the initial and final reachability matrices were the same.

<table>
<thead>
<tr>
<th>Element</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Step 4:** The obtained reachability matrix was partitioned into different levels as it is shown in Tables 4 to 6.

**Step 5:** Based on the given relationships in the reachability matrix, a digraph was drawn and the transitive links were removed (Figure 1). We converted resultant digraph into an ISM-based model by replacing variable nodes with statements (Figure 2).

**Step 6:** As shown in Figure 3, driving–dependence power diagram was made based on the calculated driving and dependence power values.

**Step 7:** The experts estimated the required time for improving quality, flexibility, delivery, and cost to be 90, 70, 70 and 100 days, respectively. According to related rules for each obtained cluster by MICMAC analysis, three alternatives of action plans were created as shown in Tables 7 to 9.

It is mentionable that in proposed action plan 1, the company was able to improve the elements 2 and 3 simultaneously. In proposed action plans 2 and 3, just one element improving was possible in each definite time. Then related elements of each cluster in the driving-dependence power diagram were described for experts. The first cluster (I) contains autonomous elements that these elements have weak driving and dependence powers. These elements are approximately disconnected from the system. This cluster had no element. The second cluster (II) consists of dependent elements that have weak driving power but strong dependence power. Improving cost was the only element in this cluster. The third cluster (III) consists of linkage elements that have strong driving and dependence powers. As shown in Figure 3, improving delivery and flexibility were the elements of this cluster. The fourth cluster (IV) is a presentation of independent elements that has strong driving power but weak dependence power. Improving quality was the only member of this cluster. After that, the alternatives of action plans for improving elements were explained for experts, too. They selected action plan 1 as the desired action plan and confirmed the results. So, algorithm was finished.

**Conclusions**

In this article, we suggest an algorithm containing seven steps by using the ISM for determining manufacturing
Table 4. Interaction 1 of partitioning reachability matrix.

<table>
<thead>
<tr>
<th>Element</th>
<th>Reachability set</th>
<th>Antecedent set</th>
<th>Intersection set</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1,2,3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1,2</td>
<td>2,4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1,3</td>
<td>3,4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2,3,4</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5. Interaction 2 of partitioning reachability matrix.

<table>
<thead>
<tr>
<th>Element</th>
<th>Reachability set</th>
<th>Antecedent set</th>
<th>Intersection set</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1,2,3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1,2</td>
<td>2</td>
<td>2</td>
<td>II</td>
</tr>
<tr>
<td>3</td>
<td>1,3</td>
<td>3</td>
<td>3</td>
<td>II</td>
</tr>
</tbody>
</table>

Table 6. Interaction 3 of partitioning reachability matrix.

<table>
<thead>
<tr>
<th>Element</th>
<th>Reachability set</th>
<th>Antecedent set</th>
<th>Intersection set</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>III</td>
</tr>
</tbody>
</table>

Figure 1. Directed graph.

Figure 2. ISM-based model.
strategy. Before running algorithm, a group of experts was selected. These experts had agreement to each other in their objectives and decisions about manufacturing strategy determination. In this proposed algorithm, experts’ opinions were systematically applied through ISM to identify elements and their relationships. Then the elements were placed in four clusters (includes autonomous, dependent, linkage, and independent elements) using MICMAC analysis; after that, experts estimated the duration of each element performing. To improve the elements, the action plan alternatives were created using four proposed rules. Finally, the related cluster of elements and proposed action plans alternatives were described for experts. Confirming the results and finding desirable action plan by experts is the condition of algorithm finishing.

REFERENCES
Anderson JC, Cleveland G, Schroeder RG (1989). Operations strategy:
a literature review. J. Oper. Manage., 8: 133–158.


