International Journal of Business and Economics, 2012, Vol. 11, No. 2, 105-126

Fuzzy Rule-Based Analysis of Industrial Service Flexibility in Collaborative Networks

Wen-Hsiang Lai*

Graduate Institute of Management of Technology, Feng Chia University, Taiwan

Abstract

The focus of this study is to analyze the factors influencing industrial service flexibility (SF) in Taiwan's manufacturing industry (TMI). This study develops a rule-based decision-support mechanism using fuzzy set theory and an analytic hierarchy process to evaluate SF in TMI. This study finds that the external collaborative network makes a greater contribution to SF than the internal collaborative network. Also, government support does not significantly improve SF because companies in TMI need core competencies and collaborative networks to integrate vertical and horizontal collaborations and maximize the effectiveness of SF.

Key words: fuzzy rule-based analysis; service flexibility; collaborative networks

JEL classification: L16; L80; L64

1. Introduction

Because the competitive environment is becoming more and more complex, "a firm's ability to quickly change directions and reconfigure strategically becomes crucial if it is to succeed and achieve sustainable competitive advantage" (Johnson et al., 2003, p. 74). Therefore, the traditional approach of emphasizing autonomy and independent operation may no longer fit effectively into the present industrial situation. Instead, an emphasis on cross-organizational collaboration and integration has begun to appear and plays an important role in modern industries. To attain mutual operational synergies, mutual symbiosis can be achieved by exerting core competencies to form a close and interactive relationship. Taiwan's enterprises consist mostly of small and medium-sized enterprises (SMEs) which exhibit agile flexibility and synergistic collaboration and which are highly acclaimed throughout the world. SMEs and intercompany service flexibility (SF) networks in particular represent the basic industrial structure and behavior of Taiwan's manufacturing industry (TMI) because to offer low costs, high quality, and on-time delivery to the

*Correspondence to: Graduate Institute of Management of Technology, Feng Chia University, Taiwan, 100, Wenhwa Rd., Seatwen, Taichung 40724, Taiwan. Email: whlai@fcu.edu.tw. The authors appreciate the financial support of Taiwan's National Science Council (project ID: NSC 99-2628-E-035 -048-).

cooperating owners, managers, and technicians, the development of two-way SF in the expanding TMI market makes upstream, midstream, and downstream companies establish unbreakable relationships and flexibilities. TMI has a small but substantial share of the global manufacturing industry, particularly in designing and manufacturing machines using SF with the principal objective of achieving success in global markets. TMI is a collaborative network made up of SMEs because Taiwan's industrial model is based mainly on relationships among individuals and family-run companies. Such relationship networks enable a company to obtain raw materials from the upstream end of its supply chains and to attract customers to the downstream end. Because SMEs are the main industrial force in Taiwan, intricate networks connecting all the SMEs in production and marketing relationships have been developed (e.g., contracting systems, satellite-factory systems, and marketing networks based on interpersonal relationships).

SF can be viewed as a multidimensional concept which can be divided into different types according to differences in the environmental uncertainties that TMI intends to change or to which it must respond. The CEO of Google, Eric Schmidt, has stated that "industrial service flexibility has a close relation with target-oriented enterprises' innovation activities" (*The New Yorker*, October 12, 2009, p. 46). Industrial SF offers a service to upstream and downstream partners in supply chains and to customers. Upton (1994, 1995) states that SF is the ability to plan and implement a directional change in manufacturing, including responding to dramatic environmental events with little penalty in time, effort, cost, or performance. The components of SF can be divided into internal manufacturing flexibility and connection of partners in external collaborative networks (Volberda and Rutges, 1999). External collaborative networks include linkages among corporate, marketing, and manufacturing strategies across networks of companies and provide an important source of support for enterprises facing challenges from environmental uncertainties. The formation of external collaborative networks involves enterprise resources, social relationships, and political and economic factors.

The creation and implementation of industrial SF strategies must focus on a core of services in collaborative intercompany networks of SMEs (Uzzi, 1997). SF is an important driving force for achieving high performance in TMI networks. However, even though many enterprises understand the benefits brought about by internal manufacturing flexibility and external collaborative networks, few of them truly understand the source and nature of these benefits. In-depth research into the behavior of such networks in TMI is essential to capture a clear understanding of SF's influence on company and intercompany performance. The contributions of this study include a hierarchical structure which can be used to implement SF in the real world and an understanding of how manufacturing flexibility and external collaborative networks in TMI influence a company's SF performance.

2. Literature Review

Traditionally, industries are divided into primary industry (i.e., agricultural, forestry, fisheries, animal husbandry, and mining industries), secondary industry (i.e., manufacturing and construction industries), and tertiary industry (i.e., service industries). These three kinds of industries seem to be entirely different in their industrial characteristics; however, they are all closely related to services. After the Industrial Revolution starting in the 18th century, changes in production tools and methods caused the original hand-labor economic system to be rapidly replaced by the machine-production economic system. Through a hundred years of continuous evolution in technological research and development, the marginal benefits brought by traditional technology to humans have gradually decreased, and management thinking has begun to focus on the dimensions of strategy and innovation in services. In this way, management thinking has returned to its original and intrinsic focus on serving people.

In the manufacturing industries, because simply modifying an existing production process serves merely to "alleviate the symptoms of an illness," it is more important to effect a permanent cure by developing people's concept of service and by pursuing SF in cooperation with various organizations in industry. SF provides services to customers and to upstream and downstream vendors throughout supply chains. To respond to rapid changes in market environments and customer needs, the manufacturing industry should introduce the concept of SF to satisfy the needs arising from various groups of customers. Thus, the industry not only satisfies external customers by flexibly receiving orders and manufacturing and delivering customized products, but also uses flexible combinations of integrated and collaborative vendors throughout its supply chains. Based on the work of Volberda and Rutges (1999), Sections 2.1 and 2.2 discuss SF in terms of manufacturing flexibility and collaborative networks.

2.1 Manufacturing Flexibility

Flexibility can extend a company's range of available products and can shorten the time that a company needs to respond to demand. Flexibility refers to the capability, willingness, and behavior of reacting to change requests in a flexible manner (Ivens, 2005). Although researchers and manufacturers understand the concept of flexibility, they struggle with its application to industry-wide standards (Gerwin, 1987; Sethi and Sethi, 1990). Newman et al. (1993) explain flexibility as a fundamental instrument for dealing with uncertainty. External uncertainty can stem from market demand or supply; internal uncertainty can arise from internal failures, lack of materials, and delays.

Turning to hierarchies of manufacturing flexibility in SF, Slack (1987) proposes a vertical (or hierarchical) concept of manufacturing flexibility, and similarly Gerwin (1987) analyzes manufacturing flexibility based on a four-level (low to high) hierarchy of machining plans, operational procedures, production resources, and production management. Gupta and Somers (1996) consider manufacturing flexibility at a company level from the viewpoints of business strategy, manufacturing, and organizational performance. Sethi and Sethi (1990) organize manufacturing flexibility in organizational structures into fundamental, systemic, and overall hierarchies, a structure which is similar to Upton's (1994) proposal of operational, tactical, and strategic hierarchical flexibilities and Volberda and Rutges's (1999) suggested classification of operational flexibility, structural flexibility, and strategic flexibility. Based on the classification proposed by Sethi and Sethi (1990), these three kinds of flexibilities can be viewed as manufacturing flexibilities and as capable of strengthening the organization's internal managerial capacity to respond to environmental changes and to influence the external environment by absorbing external information and combining external resources. Johnson et al. (2003) explain operational flexibility as the ability to shorten the time between planning and implementation within a company.

From the fundamental operational flexibility viewpoint, Koste and Malhotra (1999) explain that machine flexibility is the quantity and variety of operations that a machine can execute without incurring high transition costs or large changes in performance outcomes. Koste and Malhotra (1999) further point out that material-handling flexibility can be considered as the ability to transport different work pieces between various processing centers over multiple paths economically and effectively, thus achieving operational flexibility. Labor flexibility is the ability to provide labor and to guarantee performance even when demand becomes unstable; labor flexibility has good uniformity if it can maintain quality and efficiency across a variety of jobs (Hyun and Ahn, 1992; Upton, 1994). From the system structural flexibility viewpoint, routing flexibility uses alternate routes to whatever extent is judged necessary to deliver performance economically and effectively (Koste and Malhotra, 1999). Sethi and Sethi (1990) indicate that expansion flexibility should be considered while dealing with organizational system structure; the term *expansion flexibility* refers to the consolidation of system outputs and the intensification of their product or technology qualities. Delivery flexibility is the ability to change the content of the order or the delivery date (Dixon et al., 1990). From the overall strategic flexibility viewpoint, Aprile et al. (2005) state that process flexibility is the ability to handle logistics flexibly with respect to the possible connections among suppliers, assemblers, and markets. Hua et al. (2008) indicate that any company that expands its size or scope must develop its capability for intercompany SF, and that a key issue in such a company's manufacturing strategy is to respond to increased intercompany SF requirements by multipurpose production flexibility. Production flexibility is the ability to operate economically and effectively at various batch sizes or at different production output levels (Gerwin, 1987). Narasimhan et al. (2004) state that new product flexibility refers to the capability which exists in manufacturing equipment and how it is used to adapt quickly to new machine elements and products.

Based on the above discussions, this study divides manufacturing flexibility into three level 3 subfactors: fundamental operations, system structures, and overall strategies. Furthermore, these level 3 subfactors are classified into nine level 4 subfactors: machine flexibility, labor flexibility, material flexibility, expansion flexibility, delivery flexibility, routing flexibility, new product flexibility, production flexibility, and process flexibility.

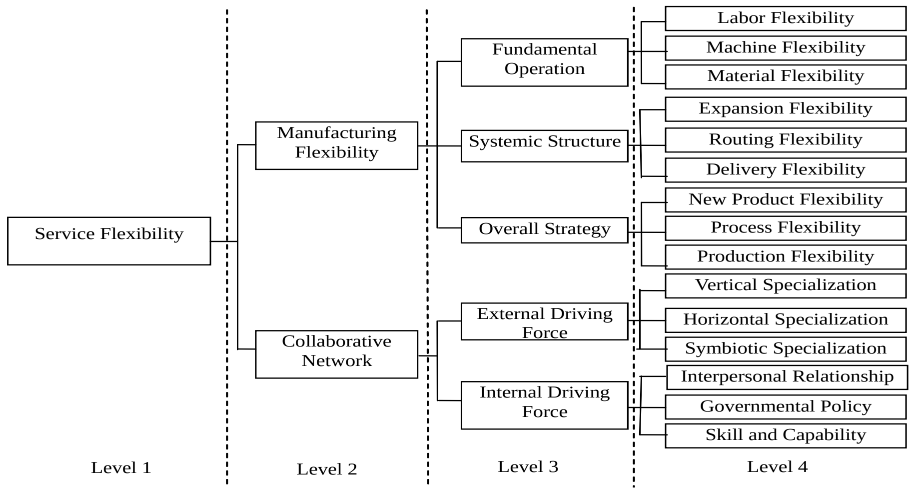
2.2 Collaborative Networks

The concept of "network" is originally derived from sociology and is used to describe interactive interpersonal relationships. Anderson (1994) and Harrison (1991) indicate that companies within close geographic proximity rely on an interactive and collaborative relationship as a necessary condition. Marshall (1920) discusses a concept of industrial district collaborations and addresses that the regionalization of industry is associated with gathering companies not only to mix external economic factors, but also to share the factors of production. Marshall (1920) believes that collaborative networks (i.e. clusters) are caused by the external economy, and Weber (1929) illustrates how collaborative networks can be divided into two stages, with company expansion leading to an industrial collaborative network as the first stage, and industrial agglomeration being caused by the mutual linkage of larger companies as the second stage. Collaborative networks are groups of inter-related companies that drive wealth creation and collaboration to raise the industry value in certain areas. The purpose of creating a collaborative network is to identify the area of the economy in which a region has a comparative advantage and develop short and long-term strategies to enlarge that regional economy.

The core of regional economic behavior is rooted in social exchange relationships, which are a cross-organizational process aimed at achieving mutual benefits, information exchange, initiation of activities, resource sharing, and enhanced capabilities. Achrol (1997) states that because of the industrial reconstruction resulting from large-scale downsizing, vertical disaggregation, outsourcing, and elimination of management layers in companies, collaborative networks have been rising to prominence. To achieve various goals related to business success, collaborative networks are used to perform various types of organizational tasks and to create or search for solutions under circumstances of limited resources. Himmelman (1996) states that a collaborative network not only shares resources and responsibilities, but also encompasses the collective benefit and value arising from mutual relationships. Similar opinions were expressed in the study by Johnson (1999), which indicates that a crucial issue in intercompany relationships is the presence of a strategic orientation in each company's thinking about and approach to intercompany relationships and management. Liu (1999) indicates that the collaborative network in TMI consists of six components: production relationships, regional combinations, profit-seeking and profit-sharing arrangements, high degree of coordination, technology sharing, and interpersonal networking.

With regard to the external driving forces of a collaborative network, Battat (1996) distinguish three types of collaborative networks. The first is a peripheral network of producer companies that supply parts, components, and services to a central company for further processing and assembly. The second is a peripheral network of consumer companies that process the raw or semi-finished outputs of a central producer company. The third is a horizontal collaborative network in which cooperative companies provide finished products to a central company, which in turn markets them or uses them for its own turnkey projects. Accordingly, the production and collaborative networks in TMI are divided into three types of collaborative specializations: vertical, horizontal, and symbiotic systems. "Horizontal" means cooperation among identical or similar industries; "vertical" means cooperation between upstream and downstream entities and also cooperation among vendors in a single product domain ranging from raw materials, parts, and semi-manufactured goods to finished products; "symbiotic" systems are also called "cross-industrial cooperation," which refers to horizontal or vertical collaborations among vendors in different product domains. With regard to the internal driving forces of collaborative networks, because of interpersonal relationships, sharing and exchange of ideas shape each individual's thinking not only within the individual, but also within intercompany collaborations (Berger and Luckmann, 1966). Kiong and Kee (1998) further indicate that interpersonal relationships are particularly emphasized in Chinese business society and become a crucial and decisive issue in pursuing successful business collaborations. Laumann and Knoke (1986) and Sullivan and Skelcher (2002) state that it is important for both collaboration parties to have similar or complementary technological skills and capabilities. Additionally, governments often promulgate regulations and policies to encourage industrial integration and collaboration.

Figure 1. Hierarchy Structure of Influential Factors of SF



Based on the above discussions, this study divides the "collaborative network" factor into two level 3 subfactors representing external and internal driving forces. Furthermore, these level 3 subfactors are classified into six level 4 subfactors: vertical specialization, horizontal specialization, symbiotic specialization, interpersonal relationships, government policies, and skills and capabilities. Figure 1 shows the hierarchy structure of influential factors of SF used in this study.

3. Research Method

The fuzzy rule base consists of many fuzzy IF-THEN rules which are the other components to be determined. Traditionally, domain experts define the input criteria manually and subjectively. The process of determining the values of input criteria is time-consuming; especially while establishing the knowledge base, it is arduous to check for conflicts among different rules. The task is even more difficult during knowledge maintenance when rules need to be added or deleted. Therefore, fuzzy logic researchers have been seeking to develop an automatic process for determining the values of input criteria.

3.1 Expert Interviews and the First-Stage AHP Questionnaire

This study classifies the influencing factors and subfactors obtained from literature review and expert interviews into the AHP research framework to evaluate SF. This study includes interviewing managers in TMI confirmed to be direct participants in the decision-making that drives the manufacturing process. The data collection process included attempts to confirm or refute information from direct and hearsay informants without mentioning the sources of information when conducting interviews. Hearsay informants are persons providing beliefs and evaluations of process decisions and implementation stages who did not engage directly in the decisions and implementation stages. In the initial round of interviews, interviewees described their roles and personal SF experiences in the firms. In the second round of interviews, the interviewees were asked questions of influential factors of SF in the collaborative network.

After the second round of interviews was finished, this study constructed a draft hierarchy structure of influential factors of SF and showed the hierarchy structured diagram in the third round of interviews (with interviewees different from those in the first and second rounds of interviews) to demonstrate and verify the correctness and appropriateness of the hierarchy structure of influential factors of SF. Table 1 lists the backgrounds of 10 interviewees in this study. Figure 1 shows the resulting hierarchy tree structure of SF influential factors. There are four levels: level 1 is the target level, which will be given a value after level 2 has been calculated; level 2 consists of the two major factors of manufacturing flexibility and collaborative networks; level 3 contains five subfactors of each major factor in level 2; and level 4 contains three subfactors of each subfactor in level 3.

The purpose of the first-stage questionnaire is to determine the state of SF in TMI using the AHP method. All the chosen experts serve in the SMEs of TMI and have more than 10 years of seniority. 30 questionnaires were sent out, and 27 questionnaires were retrieved (90% retrieval rate). On the basis of a consistency index (C.I.) test from Expert Choice 2000, the researchers deleted unqualified questionnaires, leaving 22 valid questionnaires (73% validity rate).

Table 1. Backgrounds of 10 Interviewees

No.	Company type	Title	Experience
First and second round of interviews			
1	Precision Machinery Industry	General Manager	20
2	Hand Tool Industry	Inventory Manager	8
3	Machine Tool Industry	General Manager	19
4	Machine Tool Industry	General Manager	21
5	Precision Machinery Industry	Project Manager	23
Third round of interviews			
6	Precision Machinery Industry	Inventory Manager	7
7	Machine Tool Industry	CEO	16
8	Plastics and Rubber machinery	General Manager	27
9	Hand Tool Industry	Inventory Manager	13
10	Hand Tool Industry	General Manager	18

3.2 Fuzzy Set Theory

The term *fuzzy logic* emerged during the development of fuzzy set theory by Zadeh (1965). Formally, fuzzy logic is a structured and model-free estimator that approximates a function through linguistic input/output associations. Fuzzy rule-based systems apply fuzzy methods to solve many types of "real-world" problems, especially in cases where a system is difficult to model, is controlled by a human operator or expert, or where ambiguity or vagueness is common. A typical fuzzy system consists of an inference system, a membership function, and rule bases. In the last decade, research in fuzzy set theory has been extended to the field of fuzzy logic decision systems, which are used especially for management decision-making (Yoshino, 1995). Based on Lai and Tsai's (2009) fuzzy rule-based procedures and the MATLAB fuzzy toolbox, this study obtains the inference system described by Mamdani, a membership function, and a set of IF-THEN rules, as shown in Figures 2 and 3 and Tables 2 and 3.

Ragin (2000) states that, compared to conventional procedures, fuzzy analysis provides a much closer fit between theory and data. This study builds IF-THEN rules using high (H), moderate high (MH), moderate middle (MM), moderate low (ML), and low (L) values of input and output criteria, including individual main factors and subfactors, as shown in Table 2. Some IF-THEN values relate subfactors with a single major factor, while other IF-THEN rules relate major factors to each other. Each of the 15 level 4 subfactors, five level 3 subfactors, and two major factors can be used as a rule input. First, the IF-THEN rules for major factors are described, followed by rules involving subfactors. All rules have a unique output defined for every possible set of inputs. For example, the IF-THEN rules involving the main factors in SF performance must accommodate every combination of the two main factors, namely "manufacturing flexibility" and "collaborative network." Because each of these factors can take on five values, there are 5×5=25 rules. Table

3 shows an example of fuzzy rule-based calculations for the main factors influencing SF performance.

Figure 2. Mamdani Inference

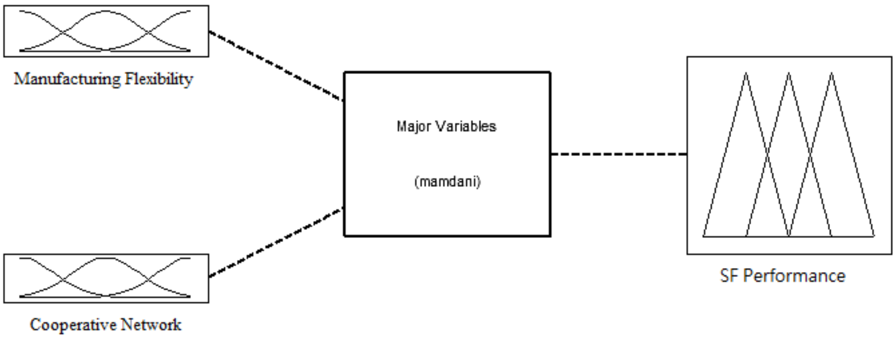
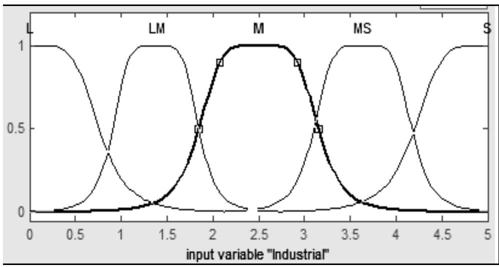


Figure 3. Membership Function and Output Interval Ranges



Ranges of *Y*	Linguistic term	Abbr.
$2.6 < Y \leqq 3$	High	H
$2.2 < Y \leqq 2.6$	Moderate High	MH
$1.8 < Y \leqq 2.2$	Moderate Middle	MM
$1.4 < Y \leqq 1.8$	Moderate Low	ML
$1 \leqq Y \leqq 1.4$	Low	L

3.3 Second-Stage Statistical Analysis

To verify the results obtained from the fuzzy AHP analysis, a five-point Likert scale was used as the design basis of the second-stage questionnaire. In the second-stage questionnaire, SPSS 12.0 and EXCEL were used to analyze the data. The samples in the second-stage statistical analysis were randomly selected from 1648 SMEs of TMI in Taichung City, Taiwan. The questionnaires were delivered to managers or senior engineers who had had more than 10 years of experience dealing with collaborative network relationships. 200 questionnaires were distributed by mail and e-mail, 131 questionnaires were retrieved (66% retrieval rate), and 123 questionnaires were valid (62% validity rate).

Table 2. Main Influential Factors and Subfactors of SF

Main Factors (Level 2)	Subfactors (Level 3)	Subfactors (Level 4)	Linguistic terms	Values
Manufacturing Flexibility	Fundamental Operations		High	3
		Labor Flexibility	Moderate – High	2.5
		Machine Flexibility	Moderate – Middle	2
		Material Flexibility	Moderate – Low	1.5
			Low	1
	System Structure		High	3
		Expansion Flexibility	Moderate – High	2.5
		Routing Flexibility	Moderate – Middle	2
		Delivery Flexibility	Moderate – Low	1.5
			Low	1
	Overall Strategy		High	3
		New Product Flexibility	Moderate – High	2.5
		Process Flexibility	Moderate – Middle	2
		Production Flexibility	Moderate – Low	1.5
			Low	1
Collaborative Network	External Driving Force		High	3
		Vertical Specialization	Moderate – High	2.5
		Horizontal Specialization	Moderate – Middle	2
		Symbiotic Specialization	Moderate – Low	1.5
			Low	1
	Internal Driving Force		High	3
		Interpersonal Relationships	Moderate – High	2.5
		Government Policies	Moderate – Middle	2
		Skills and Capabilities	Moderate – Low	1.5
			Low	1

Table 3. An Example of Fuzzy Rule-Based Calculations Involving the Main Influencing Factors

IF Scenario		Manufacturing Flexibility (w=0.428)	Collaborative Network (w=0.572)	Output Value	Linguistic Term
1	if	H	H	3	H
2	if	H	MH	2.714	H
3	if	H	M	2.428	MH
			…		
23	if	L	M	1.572	ML
24	if	L	ML	1.286	L
25	if	L	L	1	L

4. Analysis of Results

4.1 First-Stage AHP Questionnaire

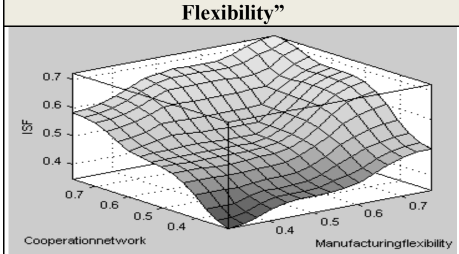
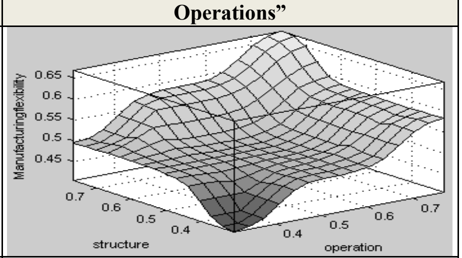
In the first stage, the AHP questionnaire was designed and distributed to experts in the SMEs of TMI. After examining the AHP questionnaire, the C.I. was found to be less than 0.1, which satisfies the requirements of AHP. Table 4 shows the results of the AHP analysis performed in this study.

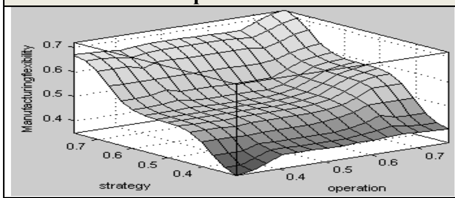
Table 4. AHP Analysis of SF

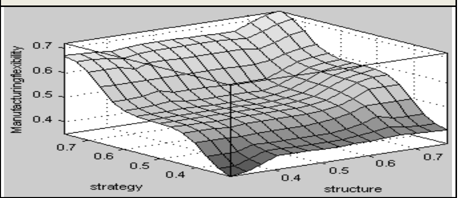
Main Factor (Level 2)	Subfactors (Level 3)	Subfactors (Level 4)	*w* (Weighting)
Manufacturing Flexibility (*w*=0.428)	Fundamental Operation (*w*=0.223)	Labor Flexibility	0.283
		Machine Flexibility	0.452
		Material Flexibility	0.265
	System Structure (*w*=0.184)	Expansion Flexibility	0.102
		Routing Flexibility	0.467
		Delivery Flexibility	0.431
	Overall Strategy (*w*=0.593)	New Product Flexibility	0.332
		Process Flexibility	0.558
		Production Flexibility	0.110
Collaborative Network (*w*=0.572)	External Driving Force (*w*=0.343)	Vertical Specialization	0.216
		Horizontal Specialization	0.138
		Symbiotic Specialization	0.646
	Internal Driving Force (*w*=0.657)	Interpersonal Relationships	0.427
		Government Policies	0.143
		Skills and Capabilities	0.430

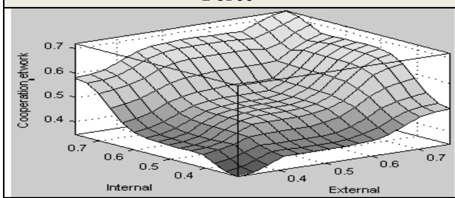
After editing the fuzzy rule bases and assuming the AHP weightings, 20 fuzzy surfaces were generated. Based on each 3D plot, analyses of the observed phenomena are shown in Table 5.

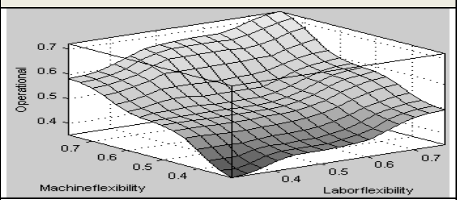
Table 5. 3D Fuzzy Surfaces and Explanations

"Collaborative Network" vs. "Manufacturing Flexibility"	"System Structure" vs. "Fundamental Operations"
	
● "Collaborative Network" has a greater influence	● "Fundamental Operations" has a greater

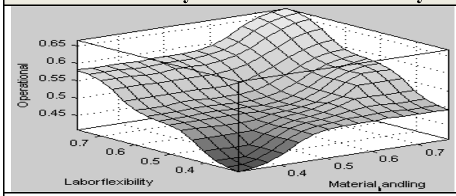
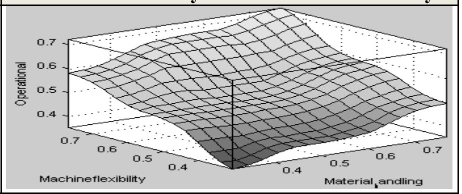
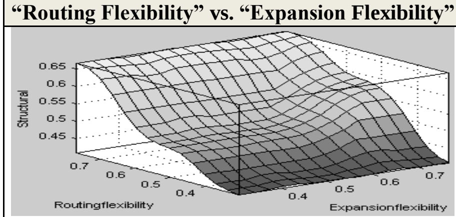
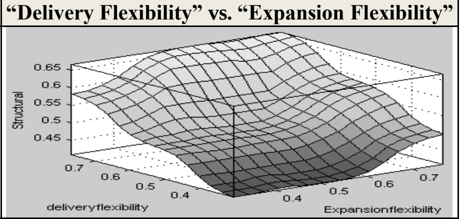
<table>
<tr>
<td>on SF than “Manufacturing Flexibility.”
● When the two factors cooperate with each other, the best “Manufacturing Flexibility” can occur.
● When the two factors reach ML strength, their influences on SF stagnate, and they will not rise until the MH level is exceeded.</td>
<td>influence on “Manufacturing Flexibility” than does “System Structure.”
● When the two factors cooperate with each other, the best “Manufacturing Flexibility” can occur.
● At the ML level, the two factors have a largely similar influence on “Manufacturing Flexibility.”
● At the ML level, “System Structure” does not increase its influence on “Manufacturing Flexibility.” However, the influence of “Fundamental Operations” stagnates at this stage, but it begins to rise again after the MH level has been exceeded.</td>
</tr>
<tr>
<th>“Overall Strategy” vs. “Fundamental Operations”</th>
<th>“Overall Strategy” vs. “System Structure”</th>
</tr>
<tr>
<td>


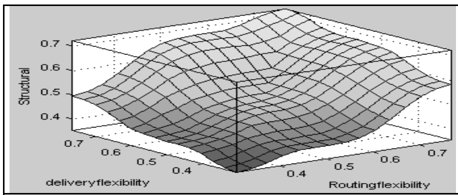
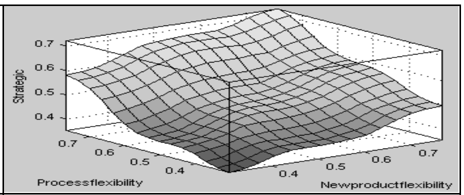
</td>
<td>


</td>
</tr>
<tr>
<td>● “Overall Strategy” has greater influence on “Manufacturing Flexibility” than does “Fundamental Operations.”
● After exceeding the ML level, “Fundamental Operations” does not exert a positive influence on “Manufacturing Flexibility.”
● After exceeding the MH level, “Fundamental Operations” combines with “Overall Strategy” to exert a strong influence on “Manufacturing Flexibility.”</td>
<td>● “Overall Strategy” has greater influence on “Manufacturing Flexibility” than does “System Structure.”
● After exceeding the ML level, “System Structure” does not exert a positive influence on “Manufacturing Flexibility.”
● After exceeding the MH level, “System Structure” combines with “Overall Strategy” to exert a strong influence on “Manufacturing Flexibility.”</td>
</tr>
<tr>
<th>“Internal Driving Force” vs. “External Driving Force”</th>
<th>“Machine Flexibility” vs. “Labor Flexibility”</th>
</tr>
<tr>
<td>


</td>
<td>


</td>
</tr>
<tr>
<td>● “Internal Driving Force” and “External Driving Force” within “Collaborative Network” had a largely similar degree of influence on “Collaborative Network.”
● After reaching the MH level, the two factors exert a significant and increasing influence on</td>
<td>● “Machine Flexibility” has a greater influence on “Fundamental Operations” than does “Labor Flexibility.”
● When the two factors cooperate with each other, the best effect can be obtained on “Fundamental Operations.”</td>
</tr>
</table>

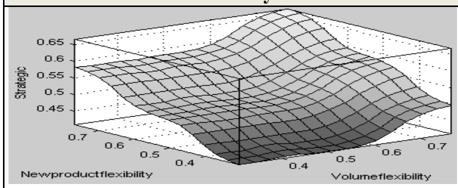
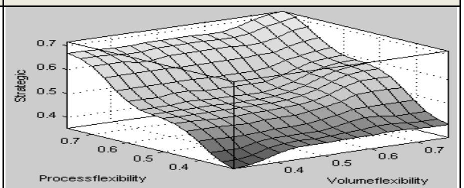
"Collaborative Network," in which "Internal Driving Force" is the most outstanding factor.	● After exceeding the MH level, "Labor Flexibility" has an increasing influence on "Fundamental Operations."
"Labor Flexibility" vs. "Material Flexibility"	**"Machine Flexibility" vs. "Material Flexibility"**
	
● "Labor Flexibility" has a greater influence on "Fundamental Operations" than does "Material Flexibility." ● After reaching the M level, "Material Flexibility" does not increase its influence on "Fundamental Operations." ● At the M and MH levels, inflection points occur in "Labor Flexibility."	● "Machine Flexibility" has a greater influence on "Fundamental Operations" than on "System Structure." ● After exceeding the ML level, "System Structure" does not exert a positive influence on "Manufacturing Flexibility." ● After exceeding the MH level, "System Structure" combines with "Overall Strategy" to continue to have a strong influence on "Manufacturing Flexibility."
"Routing Flexibility" vs. "Expansion Flexibility"	**"Delivery Flexibility" vs. "Expansion Flexibility"**
	
● "Routing Flexibility" has a far greater influence on "System Structure" than does "Expansion Flexibility." ● "Expansion Flexibility" has little influence on "System Structure." ● Although "Expansion Flexibility" has almost zero influence on "System Structure," the combination of high levels of "Expansion Flexibility" and "Routing Flexibility" still exerts a significant influence on "System Structure."	● "Delivery Flexibility" has a greater influence on "System Structure" than does "Expansion Flexibility." ● Only when "Expansion Flexibility" reaches a value greater than MH does it begin to exert a significant influence on "System Structure." ● The combination of "Delivery Flexibility" and M-level-stage "Expansion Flexibility" exerts the greatest influence on "System Structure."
"Delivery Flexibility" vs. "Routing Flexibility"	**"Process Flexibility" vs. "New Product Flexibility"**

<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>

- “Routing Flexibility” has a greater influence on “System Structure” than does “Delivery Flexibility.”
- When the two factors collaborate with each other, the greatest influence on “System Structure” occurs.
- Before reaching the MH level, the two factors have almost the same influence on “System Structure.” However, after “Routing Flexibility” reaches the MH level, its influence increases substantially.

</td>
<td>

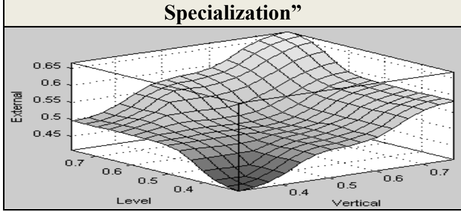
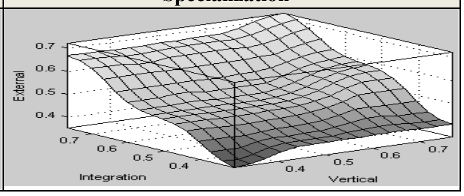
- “Process Flexibility” has a greater influence on “Overall Strategy” than does “New Product Flexibility.”
- After reaching the MH level, “Process Flexibility” tends to have an increasing influence.

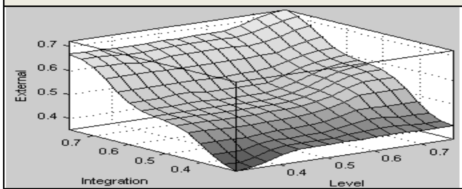
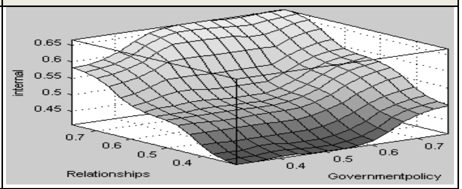
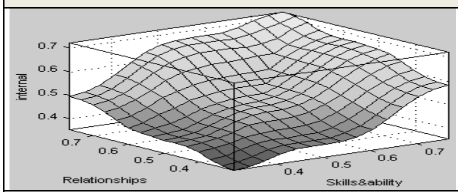
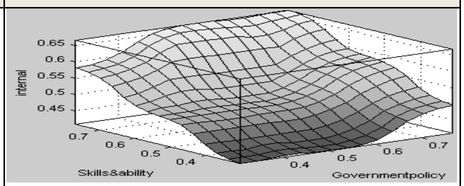
</td>
</tr>
<tr>
<td>“New Product Flexibility” vs. “Volume Flexibility”</td>
<td>“Process Flexibility” vs. “Volume Flexibility”</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>

- “New Product Flexibility” has greater influence on “Overall Strategy” than does “Volume Flexibility.”
- After reaching the MH level, “Volume Flexibility” tends to have an increasing influence.
- When “New Product Flexibility” and “Process Flexibility” both reach the MH level, their combination exerts a strong influence on “Overall Strategy.”

</td>
<td>

- “Process Flexibility” has a far greater influence on “Overall Strategy” than does “Volume Flexibility.”
- After exceeding the ML stage, “Process Flexibility” does not exert a further positive influence on “Overall Strategy.”
- After exceeding the MH level, “Process Flexibility” combines with “Overall Strategy” to exert a strong influence on “Manufacturing Flexibility.”

</td>
</tr>
<tr>
<td>“Horizontal Specialization” vs. “Vertical Specialization”</td>
<td>“Symbiotic Cooperation” vs. “Vertical Specialization”</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
</table>

● In the first stage, "Horizontal Specialization" exerts an influence on the external pattern of "Collaborative Network," but its influence does not grow after it reaches the ML level. ● "Vertical Specialization" has a greater influence on the external pattern of "Collaborative Network" than does "Horizontal Specialization."	● "Symbiotic Cooperation" has a far greater influence on the external pattern of "Collaborative Network" than does "Vertical Specialization." ● The best external pattern of "Collaborative Network" requires the contribution of "Vertical Specialization" at a level above MH.
"Symbiotic Cooperation" vs. "Horizontal Specialization"	**"Interpersonal Relationships" vs. "Government Policies"**
	
● "Symbiotic Cooperation" has a far greater influence on the external pattern of "Collaborative Network" than does "Horizontal Specialization." ● The best external pattern of "Collaborative Network" requires the contribution of "Horizontal Specialization" at a level above MH.	● "Interpersonal Relationships" has a greater influence on "Internal Driving Force" in "Collaborative Network" than does "Government Policies." ● In the first stage, "Government Policies" exerts little influence. ● The combination of "Government Policies" at a level above MH and "Interpersonal Relationships" results in the best influence on "Internal Driving Force" in "Collaborative Network."
"Interpersonal Relationships" vs. "Skills and Capabilities"	**"Skills and Capabilities" vs. "Government Policies"**
	
● "Skills and Capabilities" has a greater influence on "Internal Driving Force" in "Collaborative Network" than does "Interpersonal Relationships." ● When these two factors collaborate with each other, the best influence on "Internal Driving Force" in "Collaborative Network" occurs.	● "Skills and Capabilities" has a greater influence on "Internal Driving Force" in "Collaborative Network" than does "Government Policies." ● In the first stage, "Government Policies" exerts little influence. ● The combination of "Government Policies" at a level above MH and "Skills and Capabilities" results in the best influence on "Internal Driving Force" within "Collaborative Network."

Through a series of discussions with the third round interviewees and a review of various combinations of the 20 plots shown in Table 5, this study reaches 13 conclusions from the fuzzy surfaces with respect to the main factors and subfactors, as shown in Table 6. In Table 6, the basic principle of reaching 13 conclusions is based on the evaluation of sensibility and validity of the phenomena observed in Table 5. The sensibility and validity refer to the appropriateness and accuracy of the observed phenomena of SF in TMI, respectively.

Table 6. 13 Conclusions from 20 Fuzzy Surfaces

1	If an enterprise intends to achieve good SF in its operations, external collaboration is more important than internal collaboration.
2	Low-level managers are more influential than middle-level managers in dealing with the internal SF of manpower and materials handling and adjustment.
3	For internal manufacturing SF, the high-level managers who deal with the flexibilities of product, process, and production in response to environmental changes are more influential than the low-level managers who handle the adjustments of manpower, machines, and materials.
4	For internal manufacturing SF, the high-level managers who deal with the flexibilities of product, process, and production in response to environmental changes are more influential than the middle-level managers who handle the adjustments of production lines and delivery schedules.
5	To create SF, effective utilization and adjustment of manufacturing machines is more efficient than effective deployment of manpower.
6	To obtain better internal manufacturing SF, effective deployment of manpower is more efficient than effective utilization and adjustment of materials.
7	Expanding production lines, recruiting new employees, and introducing new technologies will not significantly influence manufacturing SF within an enterprise.
8.	Compared with changing the delivery time to fit customers' needs, adding different product lines to produce specific products will have more influence on the manufacturing SF within an enterprise.
9	To obtain substantial improvements, high-level managers are usually more willing to adjust manufacturing processes than to develop new products to fit market needs.
10	The operating factors of the collaborative network (e.g., personnel cooperation, partners' technical capabilities) are more important than any combination of patterns of the collaborative network (e.g., vertical, horizontal).
11	When building a cooperative network, the symbiotic relationship achieved by an integrated pattern of vertical and horizontal cooperation results in a greater effect than any one independent collaboration.
12	Laws or policies enacted by government are usually not helpful in encouraging collaboration among enterprises. Incentives are the main reasons for constructing mutual collaborations among enterprises.
13	Compared with persuasion through government policies and interpersonal relationships with vendors, an enterprise's possession of a good technical background exerts a greater influence on its collaborative network.

4.2 Second-Stage Questionnaire

Based on the second-stage questionnaire, the seniority levels of the respondents were more than 10 years (27%), 5–10 years (29%), 3–5 years (29%), and 1–3 years (16%). Moreover, 54% of the respondents were high-level managers, 32% were middle-level managers, and 15% were low-level managers. From a statistical analysis using SPSS, the average value of Cronbach's alpha was 0.817, which indicates good reliability. Table 7 lists the results of the reliability analysis and the values of Cronbach's α for each question.

Table 7. Reliability Analysis and Cronbach's Alpha (α)

Question	Alpha If Item Deleted	Question	Alpha If Item Deleted
1	0.806	8	0.810
2	0.803	9	0.792
3	0.811	10	0.814
4	0.809	11	0.800
5	0.808	12	0.803
6	0.787	13	0.802
7	0.809		

Notes: The sample size is N=123. The overall Cronbach's Alpha is 0.817.

Table 8 shows statistical results for each conclusion. Among these 13 conclusions, the smallest mean is for conclusion 7 (M=3.03), and the largest mean is for conclusion 11 (M=4.38). All 13 conclusions scored higher than the minimum average of 3 (score from 1 to 5 for each item) and passed the SPSS Cronbach's reliability test. Table 8 also shows the mean and P-value for each conclusion. Based on these results, conclusions 1, 2, 4, 7, 9, and 11 are the most significant, while conclusions 3, 8, 10, and 12 are less significant.

4.3 Discussion

According to the results of the AHP analysis, in the main factor dimension, "Manufacturing Flexibility" (*w*=0.572) is slightly more important than "Collaborative Networking" (*w*=0.428). This indicates that most of the SMEs in Taiwan emphasize external collaborative relationships with other enterprises. In the level 3 subfactor dimension, "Internal Driving Force" (*w*=0.657) is the most important factor, with the second most important being "Overall Strategy" (*w*=0.593). These observations reveal that, to achieve better external collaboration, it is essential to build solid internal core competencies by developing appropriate strategies within enterprises. In the level 4 subfactors dimension, "Machine Flexibility" (*w*=0.452), "Routing Flexibility" (*w*=0.467), "Process Flexibility" (*w*=.558), and "Symbiotic Specialization" (*w*=0.646) are relatively important within the level 3 subfactors of "Fundamental Operations," "System Structures," "Overall Strategies," and "External Driving Force" respectively. The level 4 subfactor "Government Policies" (*w*=0.143) is obviously insignificant within the level 3 subfactor "Internal Driving Force." These findings show that even though government policies are important for industrial development, Taiwan's SMEs in TMI focus more on their internal capabilities of machining, routing, and processing and on their external capabilities to build external symbiotic relationships.

Table 8. Statistical Results for 13 SF Conclusions (N=123)

Conclusion	M-value	Std. Dev.	Std. Error	T-value	P-value	Mean Diff.
1	3.80	0.732	0.066	−2.958	0.004***	−0.195
2	3.69	1.041	0.094	−3.291	0.001***	−0.309
3	3.90	0.814	0.073	−1.329	0.186	−0.098
4	3.78	0.825	0.074	−2.950	0.004***	−0.220
5	3.86	0.833	0.075	−1.840	0.068*	−0.138
6	3.85	0.897	0.081	−1.911	0.058*	−0.154
7	3.03	1.071	0.097	−10.021	0.000***	−0.967
8	3.95	0.756	0.068	−0.716	0.476	−0.049
9	3.66	0.838	0.076	−4.520	0.000***	−0.341
10	4.06	0.681	0.061	0.927	0.356	0.057
11	4.38	0.696	0.063	6.092	0.000***	0.382
12	4.10	0.740	0.067	1.462	0.146	0.098
13	4.14	0.750	0.068	2.043	0.043**	0.138

Notes: ***, **, and * denote significance at levels 0.01, 0.05, and 0.10, respectively.

Based on the statistical results for the 13 SF conclusions shown in Table 8, more than 70% of the experts participating in this survey agree with the conclusions of the first-stage questionnaire. In Table 8, the means for all but conclusion 7 ($M=3.03$) are above 3.6, which indicates that most of the conclusions obtained from the first-stage AHP fuzzy analysis are to a certain extent in agreement with the participants' opinions of the second-stage questionnaires. As for significance levels, leaving aside conclusions 3, 8, 10, and 12, the remaining conclusions (1, 2, 4, 5, 6, 7, 9, 11, and 13) have high levels of significance ($P < 0.01$ for conclusions 1, 2, 4, 7, 9, and 11, $P < 0.05$ for conclusion 13, and $P < 0.1$ for conclusions 5 and 6). Conclusions 1 and 2 ($M > 3.6$ and $P < 0.01$) indicate that external SF is more important than internal SF and that low-level managers are more influential than middle-level managers when dealing with the internal SF of manpower and materials handling adjustments. Conclusions 3 ($M = 3.9$, $P > 0.1$) and 4 ($M=3.78$, $P < 0.01$) indicate that high-level managers who deal with the SF of product, process, and production in response to environmental changes are not necessarily more influential than the low-level managers who handle the adjustments of production lines and delivery schedules, but that high-level managers are more important than the middle-level managers who handle adjustments of manpower, machine, and materials.

In the "Manufacturing Flexibility" dimension, there are two indications from conclusions 5 and 6 ($M > 3.8$, $P < 0.1$). First, an effective utilization and adjustment of manufacturing machines is more efficient than an effective deployment of manpower. Second, to achieve better internal manufacturing SF, an effective deployment of manpower is more efficient than an effective utilization and adjustment of materials. Based on these two indications, it is obvious that to create SF, the utilization and adjustment of manufacturing machines are more important than the deployment of manpower and the implementation of materials handling. Conclusions 7 ($M = 3.03$, $P < 0.01$) and 8 ($M = 3.95$, $P > 0.1$) within "System Structures" reveal that expanding production lines, recruiting new employees, and introducing new technologies can possibly increase manufacturing SF within an enterprise. Moreover, adding different product lines to produce specific products will possibly be more efficient than expanding production lines, recruiting new employees, and introducing new technologies. Conclusion 9 ($M = 3.66$, $P < 0.01$) of "Overall Strategies" indicates that instead of developing new products to fit market needs, high-level managers are usually more willing to adjust manufacturing processes to obtain substantial SF improvements.

In the "Collaborative Network" dimension, conclusion 10 ($M = 4.06$, $P > 0.1$) indicates that cooperation among personnel, partners' technical capabilities, and so on, are possibly more important than any vertical or horizontal combination of collaborative networks. Conclusion 11 ($M = 4.38$, $P < 0.01$) has the highest mean value and greatest significance and shows that compared to any one independent collaboration, the symbiotic relationship achieved by an integrated pattern of vertical and horizontal cooperation results in a greater effect when building collaborative networks. Conclusions 12 ($M = 4.1$, $P > 0.1$) and 13 ($M = 4.14$, $P < 0.05$) within "Internal Driving Force" indicate that laws or policies enacted by government are usually not helpful in encouraging collaborations among enterprises and that an enterprise's possession of a good technical background exerts a greater influence on the collaborative network.

5. Conclusions

Because the progress of science and technology is accelerating at an astonishing rate throughout the world, business uncertainty and risk are increasing in industry. Therefore, SF is more important than ever to help manufacturing industries deal with environmental uncertainties. This leads to an inevitable drive to increase SF in the production process. SMEs located in Taiwan's major towns and cities must acquire the ability to perform flexible ordering, production, and integration of their upstream and downstream industrial supply chain to support Taiwan's joint economic efforts. In recent years, the global trend in industry has been moving towards a service orientation, and the manufacturing sectors have also undergone an important service revolution. In recent years, thanks to SF, Taiwan has achieved many economic miracles and set records in business exports. Because most companies in TMI are SMEs, to cope with rapid environmental change, these SMEs need to improve their technology skills and pursue high manufacturing quality and productivity. This study provides a complete overview of SF performance with respect to manufacturing flexibility and collaborative network in TMI.

In the “Manufacturing Flexibility” dimension, in response to the environmental impact of customers’ requests, new products, modified products, volume, and delivery time are the elements that enterprises need to address to meet customers’ requirements. Adding different product lines to produce specific products will significantly increase manufacturing SF within an enterprise. “Manufacturing Flexibility” means a flexible operation controlled and managed internally by an enterprise. If an enterprise intends to achieve good SF performance, cooperation and effort at every level of employees and managers are indispensable. Moreover, it is not necessary to purchase additional machines or recruit new employees to optimize operational SF. It is better to take advantage of existing equipment and manpower to undertake enterprise changes and process reengineering, to cultivate multiskilled workforces through education and training, and to maximize existing enterprise resources. Taiwan’s SMEs have developed rapid-response capabilities to cope with these requirements and with uncertainty. After confirming their situation, enterprises need to deploy and distribute their resources based on their current internal manufacturing structures.

In the internal SF dimension, the utilization and management of company-level resources are the primary elements of flexibility in Taiwan. Company-level resources such as labor, machines, and materials provide a diversity of products and maintain an assurance of the product’s quality, price, and delivery time. In the collaborative network dimension, the collaborative network plays the important role of an intermediary to balance external and internal flexibilities. Because TMI tends to form clusters, it is clear that collaborative networks are popular in Taiwan. The collaborative network improves SMEs in TMI and perfects cooperation in TMI supply chains. Even though TMI owns the collaborative network, enterprises within TMI should focus more on internal SF by sharing their experiences with their partners in collaborative networks. To internalize external resources and strengthen internal core competencies to define better the mission, vision, and goals most suitable for the enterprise, managers (especially high-level managers) should integrate their own knowledge and decision-making concepts by collecting external information and learning from collaborative networks.

In Taiwan, peripheral industries strongly support central factories and satellite factories and give TMI a high level of SF and powerful production advantages. SMEs in TMI use their network relationships to cope with competitive market conditions, to benefit their international endeavors, and to enhance their managerial performance levels. SF is a core capability of manufacturing companies. Each company must achieve and sustain a high degree of flexibility to survive in the global economy.

References

Achrol, R. S., (1997), “Changes in the Theory of Interorganizational Relations in Marketing Paradigm,” *Journal of the Academy of Marketing Science*, 25(1), 56-71.

Anderson, G., (1994), "Industry Clustering for Economic Development," *Economic Development Review*, 12(2), 26-32.

Aprile, D., A. C. Garavelli, and I. Giannoccaro, (2005), "Operations Planning and Flexibility in a Supply Chain," *Production Planning & Control*, 16(1), 21-31.

Battat, J. Y., I. Frank, and X. Shen, (1996), *Suppliers to Multinationals: Linkage Programs to Strengthen Local Companies in Developing Countries*, Washington, DC: The International Corporation and the World Bank.

Berger, P. L. and T. Luckmann, (1966), *The Social Construction of Reality*, Garden City, N.Y.: Doubleday and Company, Inc.

Dixon, J. R., A. J. Nanni, and T. E. Vollmann, (1990), *The New Performance Challenge Measuring Operations for World-Class Competition*, Homewood, IL: Dow Jones-Irwin.

Harrison, B., (1991), "Industrial Districts: Old Wine in New Bottles," *Journal of Regional Studies*, 26(5), 469-483.

Himmelman, A. T., (1996), "On the Theory and Practice of Transformational Collaboration: From Social Service to Social Justice," in *Creating Collaborative Advantage*, C. Huxham ed., London: Sage.

Hua, Z., F. Huang, and B. Zhang, (2008), "Process Flexibility with Bill of Material Constraints," *International Journal of Production Research*, 46(6), 1567-1586.

Gerwin, D., (1987), "An Agenda for Research on the Flexibility of Manufacturing Processes," *International Journal of Operations & Production Management*, 7, 38-49.

Gupta, Y. P. and T. M. Somers, (1996), "Business Strategy, Manufacturing Flexibility, and Organizational Performance Relationships: A Path Analysis Approach," *Production and Operations Management*, 5(3), 204-233.

Hyun, J. H. and B. H. Ahn, (1992), "A Unifying Framework for Manufacturing Flexibility," *Manufacturing Review*, 5, 251-260.

Ivens, B. S., (2005), "Flexibility in Industrial Service Relationships: The Construct, Antecedents, and Performance Outcomes," *Industrial Marketing Management*, 34(6), 566-576.

Johnson, J. L., (1999), "Strategic Integration in Industrial Distribution Channels: Managing the Interfirm Relationship as a Strategic Asset," *Journal of the Academy of Marketing Science*, 27(1), 4-18.

Johnson, J. L., P. W. Lee, A. Saini, and B. Grohmann, (2003), "Market-Focused Strategic Flexibility: Conceptual Advances and an Integrative Model," *Journal of the Academy of Marketing Science*, 31(1), 74-89.

Kiong, T. C. and Y. P. Kee, (1998), "Guanxi Bases, Xinyong and Chinese Business Networks," *British Journal of Sociology*, 49(1), 75-96.

Koste, L. L. and M. K. Malhotra, (1999), "A Theoretical Framework for Analyzing the Dimensions of Manufacturing Flexibility," *Journal of Operations Management*, 18(1), 75-93.

Lai, W. H. and C. T. Tsai, (2009), "Fuzzy Rule-Based Analysis of Firm's Technology Transfer in Taiwan's Machinery Industry," *Expert Systems with Applications*, 36(10), 12012-12022.

Lambe, C. J. and R. E. Spekman, (1997), "Alliances, External Technology Acquisition, and Discontinuous Technological Change," *Journal of Product Innovation Management*, 14(2), 102-116.

Laumann, O. E. and D. Knoke, (1986), "Social Network Theory," in *Approaches to Social Theory*, L. Siegwart, J. S. Coleman and S. Nowak eds., New York: Russell Sage Foundation, 83-104.

Liu, R. J., (1999), *Network Division: Analysis of Taiwan's Machine Tool Industry Competitive Mystery*, Taiwan: Publisher.

Maloni, M. J. and W. C. Benton, (1997), "Supply Chain Partnerships: Opportunities for Operations Research," *European Journal of Operational Research*, 101(3), 419-429.

Marshall, A., (1920), "Industry and Trade—A Study of Industrial Technique and Business Organization and of Their Influences on the Condition of Various Classes and Nation," *The American Economic Review*, 86(3), 630-640.

Narasimhan, R., S. Talluri, and A. Das, (2004), "Exploring Flexibility and Execution Competencies of Manufacturing Firms," *Journal of Operations Management*, 22, 91-106.

Newman, W. R., M. Hanna, and M. J. Maffei, (1993), "Dealing with the Uncertainties of Manufacturing: Flexibility, Buffers and Integration," *International Journal of Operations and Production Management*, 13, 19-34.

Ragin, C. C., (2000), *Fuzzy-Set Social Science*, Chicago: The University of Chicago Press.

Slack, N., (1987), "The Flexibility of Manufacturing Systems," *International Journal of Operations and Production Management*, 7, 35-45.

Sethi, A. K. and S. P. Sethi, (1990), "Flexibility in Manufacturing: A Survey," *The International Journal of Flexible Manufacturing Systems*, 2, 289-328.

Sullivan, H. and C. Skelcher, (2002), Working across Boundaries: Collaboration in Public Service, NY: Palgrave Macmillan.

Upton, D. M., (1994), "The Management of Manufacturing Flexibility," *California Management Review*, 36(2), 72-89.

Upton, D. M., (1995), "Flexibility as Process Mobility: The Management of Plant Capabilities for Quick Response Manufacturing," *Journal of Operations Management*, 12, 205-224.

Uzzi, B., (1997), "Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness," *Administrative Science Quarterly*, 42(1), 35-67.

Volberda, H. W. and A. Rutges, (1999), "FARSYS: A Knowledge-Based System for Managing Strategic Change," *Decision Support Systems*, 26, 99-123.

Weber, A., (1929), *Theory of the Location of Industries*, Chicago: The University of Chicago Press.

Yoshino, M. Y., (1995), *Strategic Alliances: An Entrepreneurial Approach to Globalization*, Harvard College.

Zadeh, L. A., (1965), "Fuzzy Sets," *Information and Control*, 8(3), 338-353.