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# Align Agile Drivers, Capabilities and Providers to Achieve Agility: a Fuzzy-Logic QFD Approach

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## 1. Introduction

At the beginning of the twenty-first century, the world faces profound changes in many aspects, especially marketing competition, technological innovations and customer demands. A world-wide dispersion of education and technology has led to intense and increasingly global competition and an accelerated rate of change in the marketplace and innovation. There is a continuing fragmentation of mass markets into niche markets, as customers become more demanding with their increasing expectations. This critical situation has led to major revisions in business priorities, strategic vision, and the viability of conventional and even relatively contemporary models and methods developed thus far [1]. To cope with these changing competitive markets, as well as the ability to meet customer demands for increasingly shorter delivery times, and to ensure that the supply can be synchronized to meet the peaks and troughs of the demand are obviously of critical importance [2, 3]. Hence, companies now require a high level of maneuverability encompassing the entire spectrum of activities within an organization. Consequently, agility in addressing new ways to manage enterprises for quick and effective reaction to changing markets, driven by customer-designed products and services, has become the dominant vehicle for competition [4].

Generally, agility benefits can mass customization, increase market share, satisfy customer requirements, facilitate rapid introduction of new products, eliminate non-value-added activities, reduce product costs and increase the competitiveness of enterprises. Accordingly, agility has been advocated as the business paradigm of the 21<sup>st</sup> century, being considered the winning strategy for becoming a global leader in an increasingly competitive market of quickly changing customer requirements [5-7]. However, the ability to build agility has not developed as rapidly as anticipated, because the development of technology to manage an agile enterprise is still in progress [4, 6, 8]. Thus, in embracing agility, many important questions must be asked, such as: Precisely what is agility, and how can it be measured? How will companies know when they possess this attribute since no simple metrics or

Source: Supply Chain, Theory and Applications, Book edited by: Vedran Kordic, ISBN 978-3-902613-22-6, pp. 558, February 2008, I-Tech Education and Publishing, Vienna, Austria

indices are available? How and to what degree do the attributes of an enterprise affect its business performance? How does one compare agility with a competitive enterprise? To improve entrepreneurial agility, how does one identify the principal unfavorable factors? How can one assist in more effectively achieving agility [8-10]? Answers to such questions are critical to practitioners and the theory of agile entrepreneurial design. Therefore, the purpose of this research is to seek solutions to some of these problems, with a particular focus on agile strategic planning and measurement, as well as identifying the principal obstacles to improvement of agility.

Actually, the purpose of agile strategic planning is to unite the resources of an enterprise and to create business value. Agile enterprises are concerned with change, uncertainty and unpredictability within their business environment and making an appropriate response; therefore, these enterprises require a number of distinguishing attributes to promptly deal with the changes within their environment. Such attributes consist of four principal elements [7, 8]: responsiveness, competency, flexibility/adaptability and quickness/speed. Furthermore, the foundation for agility is comprised of the integration of information technologies, personnel, business process organization, innovation and facilities into strategic competitive attributes. To be truly agile, an enterprise must logically integrate and deploy a number of distinguishing providers with drivers and good capabilities, being finally transformed into strategic competitive edges [11].

Many theoretical models have been proposed for agile enterprise planning [1, 12-15]; however, only a few provide integrated methodologies suitable for adoption to enhance by identifying providers, beginning with the competitive bases of the enterprise. The relationship matrix in the quality function deployment (QFD) method provides an excellent tool for aligning important concepts and linking processes. Moreover, fuzzy logic is a useful tool for capturing the ambiguity and multiplicity of meanings of the linguistic judgments required to express both relationships and rates of agility attributes. To assist managers in more efficiently achieving agility, a systematic methodology, based on fuzzy logic and the relationship matrix in the QFD is devised to provide a means for linking the perspectives from agility drivers with their corresponding capabilities and providers, thereby measuring the agility of an enterprise as well as identifying the principal obstacles to improvement.

The remainder of this report is organized as follows. In Section II the related research is reviewed. In section III a conceptual model of an agile enterprise is described in detail for the development of a systematic evaluative methodology in Section IV. The development of a practical case is presented illustrated in Section V. Finally, Section VI a concluding discussion.

## **2. Review of related research**

### **A. Methodology**

Numerous studies for developing methodologies have been proposed to assist managers in the implementation of strategic planning for achieving agility. For example, to promote a new understanding of cooperation as a vital means of survival and prosperity in the new business era, Preiss et al. [12] proffered a generic model for approaching agility. This model consists of certain steps that can assist an enterprise in understanding its business environment and the changes occurring there, the attributes enabling the infrastructure, and the business processes that should be recognized in the subsequent actions of the organization to sustain its competitive advantage. The first integrated framework to achieve

agility was proposed by Gunasekaran [15]. The framework explains how the major capabilities of agile manufacturing should be supported and integrated with appropriate providers to develop an adaptable organization. Seeking to exploit the concept and practices of agility, two research teams [1, 10] have developed a three-step methodology for achieving agility. This methodology provides manufacturing companies with a tool for understanding the total concept of agility, assessing their current positions, determining their need for agility and the capabilities required for achievement, as well as adopting relevant practices which can induce these capabilities. A three-step model was also suggested by Jackson and Johansson [14] to analyze the agility of production systems. Their methodology begins with an assessment of the degree of market turbulence, to determine the relevance of agility in a specific context. Then, the strategic view of the company is examined, with a particular focus on potentials to enhance flexibility and change competencies as viable strategies to achieve a competitive advantage.

Although structured frameworks to formulate agility have been identified, most of them for strategic formulation are structural in nature. Thus, to assure that the providers can satisfy the strategic direction of an enterprise, an integrated methodology suitable for adoption to enhance agility by identifying its providers, beginning with competitive bases of the enterprise, is critical to both practitioners and the theory of agile enterprise design.

### **B. Measurement**

Many approaches to the measurement of agility have been proposed to assist managers in assessment; however, most of these methods assess only the capabilities of agility. Some authors [10, 16, 17] have defined an agility index as a combination of measurement of the intensity levels of enabling attributes; whereas, other measuring methods [18,19] have been developed on the basis of the logical concept of an analytical hierarchical process (AHP). An evaluation index for a mass-customization product manufacturing agility was devised by Yang and Li [20]. Furthermore, to overcome the vagueness of agility assessment, Tsourveloudis and Valavanis [21] designed some IF-THEN rules based on fuzzy logic; moreover, Lin et al. [6] developed a fuzzy agility index (FAI) based on providers using fuzzy logic. Each of these techniques, however, with the exception of the agility providers, seems to address only a limited aspect of a very complicated problem. Although each technique contributes to an understanding of the problem, each - functioning alone - is insufficient for handling the problem in its entirety because the selection of the provider and the assessment should be linked with the drivers and the capabilities [22]. It is therefore necessary to examine the problem from a broader perspective.

### **C. QFD Relationship Matrix**

The QFD method was designed to emphasize detailed pre-planning to meet customer needs and requirements for new product development. It employs several charts, called house of quality (HOQ), to translate the desires of the customer into the design or engineering characteristics of the product and subsequently into the characteristics of the parts, process plan and production requirements related to its manufacture. Phase I translates the voice of the customer into corresponding engineering characteristics; phase II moves one step backward in the design process by translating the engineering characteristics into characteristics of the parts; phase III identifies the critical process parameters and operations; and finally, phase IV identifies the detailed production requirements. The basic format of the HOQ consists of seven different major components: (1) customer requirements (CRs), (2) importance of customers' requirements, (3) design requirements (DRs), (4)

relationship matrix for CRs and DRs, (5) correlation among DRs (6) competitive analysis of competitors, and (7) prioritization of design requirements, as shown in Figure 1.

Although QFD has been proposed for customer-driven product development and delivery methodology, an enterprise can achieve various corporate strategic goals such as a reduction in customer complaints, improvement in design reliability and customer satisfaction, easier design change, a reduction in product-development-cycle time, and organizational efficiency by using this method [23, 24]. Similarly, QFD can be extended for aligning drivers with providers to achieve agility and make priority decisions concerning the specific provider improvements that should be made for enhancing the agility level of an enterprise. A simplified form of the HOQ matrix, in which the importance of customers' requirements, correlation analyses among DRs are removed, is utilized in this study. This simplified form is called a relationship matrix, wherein CRs are represented on the left side. Identifying the relative importance of the various CRs is an important step in discerning those that are critical and also helps in prioritizing the design effort. DRs are represented on the upper portion of the relationship matrix. The relative importance of the DRs can be calculated by using the relative importance of the CRs and the level assigned to the relationships between CRs and DRs, presented in the main body of the matrix, which can be represented in symbolic or numerical form. The level of the relationships is typically assessed by an evaluation team in a subjective manner.

#### **D. Fuzzy Logic**

A fuzzy set can be defined mathematically by assigning a value to each possible member in a universe representing its grade of membership. Membership in the fuzzy set, to a greater or lesser degree, is indicated by a larger or smaller membership grade. Fuzzy-set methods allow uncertain and imprecise systems of the real world to be captured through the use of linguistic terms so that computers can emulate human thought processes. Thus, fuzzy logic is a very powerful tool capable of dealing with decisions involving complex, ambiguous and vague phenomena that can be assessed only by linguistic values rather than by numerical terms. Fuzzy logic enables one to effectively and efficiently quantify imprecise information, perform reasoning processes and make decisions based on vague and incomplete data [25]. On the basis of previous study [26], the experts can make a significant measurement of the possibility of an event when it is known; however, in uncertain situations characterized by either a lack of evidence or the inability of the experts to make a significant measurement when available information is scarce, managers often react very incompetently. Fuzzy logic, by making no global assumptions about the independence, exhaustiveness, or exclusiveness of the underlying evidence, tolerates a blurred boundary in definitions [25]. Thus, fuzzy logic brings the hope of incorporating qualitative factors into decision-making.

Fuzzy logic is currently being used extensively in many industrial applications as well as in managerial decision making. For example, it has been used in multi-attribute decision-making situations to select R&D project evaluation [27]. Ben Ghalia et al. [28] used fuzzy-logic inference for estimating hotel-room demand by eliciting knowledge from hotel managers and building fuzzy IF-THEN rules. Lin and Chen [29] devised a fuzzy-possible-success-rating for evaluating go/no-go decisions for new-product screening based on the product-marketing competitive advantages, superiority, technological suitability and risk. Chen and Chiou [30] devised a fuzzy credit rating for commercial loans. Hui et al. [31] obtained data from experienced supervisors to create a fuzzy-rule-based system for balance control of assembly lines in apparel manufacturing. Organizational transformations have



been widely adopted by firms to improve competitive advantage. Chu et al. [32] uses a nonadditive fuzzy integral to develop a framework to assess performance of organization transformation.

### 3. Conceptual model of agile enterprise

The goal of an agile enterprise is to enrich/satisfy customers and employees. An enterprise essentially possesses a set of capabilities for making appropriate responses to changes occurring in its business environment. However, the business conditions in which many companies find themselves are characterized by volatile and unpredictable demand; thus, there is an increasing urgency for pursuing agility. Agility might, therefore, be defined as the capability of an enterprise to respond rapidly to changes in the market and customers' demands. To be truly agile, an enterprise should possess a number of distinguishing agility-providers. From a review of the relevant literature [1, 4, 6, 12, 14], the author has developed a conceptual model of an agile enterprise, as shown in Figure 2.

The main driving force behind agility is change. There is nothing new about change; however, change is currently occurring at a much faster rate than ever before. Turbulence and uncertainty in the business environment have become the main causes of failures in enterprises. The number of changes and their type, specification or characteristics cannot be easily determined and probably is indefinite. Different enterprises with dissimilar characteristics and circumstances experience various changes that are specific and perhaps unique to themselves. However, there are some common characteristics in changes that occur, which can produce a general consequence for all enterprises. By summarizing previous studies [1, 4, 7, 8], the general areas of change in a business environment can be categorized as (1) market volatility caused by growth of the market niche, increasing introduction of new product and shrinkage of product life; (2) intense competition caused by rapidly changing markets, pressure from increasing costs, international competitiveness, Internet usage and a short development time for new products; (3) changes in customer requirements caused by demands for customization, increased expectations for quality and quicker delivery time; (4) accelerating technological changes caused by the introduction of new and efficient production facilities and system integration; and (5) changes in social factors caused by environmental protection, workforce/workplace expectations and legal pressure.

Agile enterprises are concerned with change, uncertainty and unpredictability within their business environment and making appropriate responses. Therefore, such enterprises require a number of distinguishing capabilities, or "fitness," to deal with these concerns. These capabilities consist of four principal elements [7, 8]: (1) responsiveness, the ability to see/identify changes, to respond quickly, reactively or proactively, and to recover; (2) competency, the efficiency and effectiveness of an enterprise in reaching its goals; (3) flexibility/adaptability, the ability to implement different processes and achieve different goals with the same facilities; and (4) quickness/speed, the ability to culminate an activity in the shortest possible time.

Achieving agility requires responsiveness in strategies, technologies, personnel, business processes and facilities. Agility-providers should exhibit agile characteristics as well as make available and determine the agility capabilities and behavior of an enterprise. Numerous studies dedicated to identifying agility-providers from which organization leaders can select items appropriate to their own strategies, organizational business processes and information

systems have been conducted. For example, Kumar and Motwani [33] identified twenty-three factors that influence a firm's agility. Goldman et al. [34] suggested that agility has four underlying components: (1) delivering value to customers, (2) being ready for change, (3) valuing human knowledge and skills, and (4) forming virtual partnerships. The "next generation manufacturing" project identified six attributes for agility: (1) customers, (2) physical plant and equipment, (3) human resources, (4) global markets, (5) core competency, and (6) practices and cultures [35]. Moreover, Yusuf et al. [36] proffered a set of thirty-two agile attributes grouped into four dimensions: (1) core competency management, (2) virtual enterprise, (3) capability for reconfiguration, and (4) knowledge-driven enterprises. These attributes, representing most aspects of agility, determine the entire behavior of an enterprise. Most recently, Ren et al. [37], following the work of Yusuf et al. [36] based on a survey circulated among UK enterprises, conducted principal component analysis to confirm the correlations between the thirty-two attributes. Finally, six principal components encompassing fifteen attributes were identified as critical agility-enabling-attributes: (1) human knowledge and skills, (2) customization, (3) partnership and change, (4) technology, (5) integration and competence, and (6) team-building. From this review we can see that different researchers provide certain insights into different aspects of agility providers. It is highly probable that there is no single set of agility providers reflecting all aspects.

Although several researchers [1, 12-15] have accepted a conceptual model for achieve agility, the purpose of agile strategic planning is to unite the resources of an enterprise to compete with the change in environment and to create business value, which according to some studies [4, 22] can be maximized and the competitive threat minimized only by selecting agile providers for investments aligned to the company's business strategy and competitive bases in the market. Thus, the first priority should be to understand the relationships among the specific market field requirement, as well as the agility capabilities and providers, to deploy and integrate both capabilities and providers, and to transform them into a competitive edge.

To assist managers in more efficiently achieving agility, on the basis of the conceptual model of an agile enterprise, and by using the relationship matrix in the QFD approach, a systematic model for linking and integrating agility drivers, capabilities and providers, can be constructed as shown in Figure 3. Specifically, this model can be described as follows:

- Analysis of agile strategy: to identify the degree of the agile abilities that can provide the required strength for responding to changes and searching for competitive advantage by maintaining alignment between agility drivers and agile abilities.
- Identification of agile providers: to find agility providers constituting the means by which the so-called needs of an enterprise relation to capabilities can be achieved by linking between abilities and providers.

#### 4. A fuzzy QFD-based algorithm for evaluation of agility

As mentioned in the previous section, the deployment and integration of agility drivers, capabilities and providers, and their transformation into a competitive edge is critical for achieving agility. Due to an either "imprecise" or "vague" definition of agile attributes and relationships, the deploying and integrating evaluation process is associated with uncertainty and complexity. Managers must make a decision by considering agile attributes and relationships which might have non-numerical values. All attributes must be integrated within the evaluation decision although none of them may exactly satisfy the ideals of the

enterprises. Conventional "crisp" evaluation approaches cannot handle such decisions suitably or effectively. Since humans have the capability of understanding and analyzing obscure or imprecise events which are not easily incorporated into existing analytical methods, the corporate strategic planning decision is made primarily on the basis of the opinions of experts. On the basis of previous research [38], in situations where evaluators are unable to make a significant assessment, linguistic expressions are used to estimate ambiguous events. Linguistic terms usually have vague meanings. One way to capture the meanings of linguistic terms is to use the fuzzy-logic approach to associate each term with a possibility distribution [39].

To assist managers in more efficiently achieving agility by using the relationship matrix in the QFD approach and fuzzy logic, an evaluation algorithm composed of four major parts (as shown in Figure 4) was devised for development and evaluation. First, identify the agility drivers on the basis of a survey of the business operation environment, determine the agility-level needs and identify the requirements for measuring the capabilities, and select the required providers for assessment. Second, apply the relationship matrix to link and analyze the fuzzy average relation-weight of the capabilities and providers. Third, synthesize the fuzzy ratings and average relation-weights of the capabilities to obtain the fuzzy-agility-index (FAI) of the enterprise and match the FAI with an appropriate linguistic term to label the agility level. Fourth, synthesize the fuzzy ratings and average relation-weights of the providers to obtain the fuzzy merit-relation-value index for each and rank them to identify the major barriers to enable managerial proactive implementation of appropriate ameliorating measures, a stepwise procedure for which follows.

1. Form a self-assessment committee.
2. Collect and survey data or information to identify the agility drivers, determine the needed capabilities and select the required providers for assessment.
3. Select the preference scale for measurement.
4. Apply the relationship matrix and use linguistic measurement to evaluate the agility attributes, relationship-levels and prepare a translation.
5. Analyze the fuzzy average relation-weights of the capabilities and providers.
6. Aggregate the fuzzy ratings and average relation-weights of capabilities into an FAI.
7. Match the FAI with an appropriate linguistic agility level.
8. Analyze the agility and offer suggestions.

#### A. Self-Assessment Committee

The essentials of an agile enterprise consist of integration of strategies, personnel, processes, networks and information systems. For knowledge acquisition to be successful, it is important that a variety of experts from different functions be chosen. Such a selection ensures that not only the complete domain is covered, but also that no single aspect of the business receives a greater emphasis within the final system.

#### B. Preparation for Assessment

Before assessing, the committee must survey the changes in the business operation environment and examine the organization's capability. On the basis of the external environmental survey and internal capability assessment, the committee can identify the main drivers, determine the level of agility needed and the capabilities of the enterprise in response to unpredictable changes, and select the agility-enabled attributes that are the means by which the so-called capabilities can be achieved.



### C. Preference Scale System

Due to impreciseness and ambiguity in the criteria, which exist in the evaluation of agility, a precision-based evaluation may not be practical. Thus, the ratings of the attributes and the relationship-level assessment are frequently measured in linguistic terms rather than numerical ones.

The ad hoc usage of linguistic terms and corresponding membership functions is characteristic of fuzzy logic. It is notable that many popular linguistic terms and corresponding membership functions have been proposed for assessment [38, 40]. For the sake of convenience and in lieu of elicitation from the assessors, linguistic terms and corresponding membership functions were obtained directly from previous studies, or, on the basis of the needs of cognitive perspectives and available data characteristics, data from previous studies were used as the foundation for modification to meet individual situations and requirements, the results for which more satisfactorily fit users' needs. Furthermore, it is generally suggested that linguistic levels not exceed nine levels representing the limits of absolute human discrimination [41].

### D. Relationship-Matrix Application, Linguistic Measurement, and Translation

In preparation for evaluating agility, the assessors must survey and study the related data or information concerning implementation to gain an understanding of what will be considered in the evaluation.

After studying the data, on the basis of the experts' experience and knowledge, the assessors can directly use the aforementioned linguistic terms to assess the rating which characterizes the merit level of the various factors. Furthermore, the linguistic terms can be used to assess interrelationship level located in the central portion of the relationship matrix, indicating the experts' perceptions regarding relationships between drivers, capabilities and providers, implemented by direct assignment or indirect pair comparisons.

After the factors are rated and the interrelationship-level evaluated, the fuzzy numbers such as those listed in Table I are used to approximate the linguistic values.

### E. Analysis of Fuzzy Average Relation-Weights

Aggregation of the different experts' opinions in group decision-making is important, wherein many methods such as the arithmetical mean, median, and mode can be used. Since the median operation is more robust in a small sample, this method is recommended for aggregating these assessments.

On the basis of the traditional QFD methodology [42] and the definition of the fuzzy weighted average [43], the fuzzy average relation-weight representing the total relationship-levels between a particular column item and the entire list of row items can then be calculated as

$$FARWAC_j = \sum_{i=1}^m (FRLADAC_{ij} \otimes FLCAD_i) / \sum_{i=1}^m FLCAD_i \quad (1)$$

where  $FARWAC_j$  denotes the fuzzy average relation-weight of the  $j^{\text{th}}$  agility capability to all the agility drivers;  $FLCAD_i$  denotes the fuzzy level in change of the  $i^{\text{th}}$  drivers;  $FRLADAC_{ij}$  denotes the fuzzy relationship-level between driver  $i$  and capability  $j$ .

$$FARWAP_k = \sum_{j=1}^n (FRLACAP_{jk} \otimes FARWAC_j) / \sum_{j=1}^n FARWAC_j \quad (2)$$

where  $FARWAP_k$  denotes the fuzzy average relation-weight of  $k^{\text{th}}$  providers to all the agility capabilities;  $FARWAC_j$  denotes the fuzzy average relation-weight of the  $j^{\text{th}}$  capability

derived from Eq (1);  $FRLACAP_{jk}$  denotes the fuzzy relation-level between capability  $j$  and provider  $k$ .

The calculation of the membership function of a fuzzy weighted average is tedious, as indicated in [44, 45].

#### F. Aggregation of Fuzzy Ratings and Average Relation-Weights into Fuzzy-Agility Index

Representing the composite agility level of an enterprise, the fuzzy-agility index ( $FAI$ ) constitutes a fusion of information, i.e., a consolidation of the fuzzy merit of agility capabilities with the fuzzy average relation-weight of the drivers. The higher the  $FAI$  of an enterprise is, the higher its agility.

According to the fuzzy weighted average operation [43], the  $FAI$  is defined as

$$FAI = \sum_{j=1}^n (FMAC_j \otimes FARWAC_j) / \sum_{i=1}^m FARWAC_j \quad (3)$$

where  $FMAC_j$  denotes the fuzzy merit of the  $j^{\text{th}}$  agility capability and  $FARWAC_j$  denotes the fuzzy average relation-weight of the  $j^{\text{th}}$  capability derived from Eq (1).

#### G. Matching FAI with an Appropriate Linguistic Level

Once the  $FAI$  has been compiled, one can further approximate a linguistic label whose meaning is the same as (or closest to) the meaning of the  $FAI$  from the natural-language expression set of an agility label ( $AL$ ).

Several methods for matching the membership function with linguistic terms have been proposed. Three basic techniques include (1) Euclidean distance, (2) successive approximation, and (3) piecewise decomposition. The Euclidean distance method is most frequently utilized because it is the most intuitive form of human perception of proximity [46].

The Euclidean method consists of calculating the Euclidean distance from the given membership function to each functions representing the natural-language agility level expression set. Suppose that the natural-language agility level expression set is  $AL$ ,  $U_{FAI}$  and  $U_{ALi}$  are the membership functions of  $FAI$  and the natural-language agility level expression, respectively. Then, the distance between the fuzzy number  $FAI$  and each fuzzy-number  $AL_i \in AL$  can be calculated as

$$d(FAI, AL_i) = \left\{ \sum_{x \in p} (U_{FAI}(x) - U_{AL_i}(x))^2 \right\}^{1/2} \quad (4)$$

where  $p = \{x_0, x_1, \dots, x_m\} \subset [0, 1]$  so that  $0 = x_0 < x_1 < \dots < x_m = 1.0$ . To simplify, let  $p = \{0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1\}$ . Then, the distance from the  $FAI$  to each of the members in the set  $AL$  can be calculated and the closest natural expression with the minimum distance identified.

#### H. Analysis and Suggestions

As mentioned in the previous section, an evaluation of agility not only determines the agility of an enterprise but also, most importantly, helps managers identify the principal adverse factors for implementing an appropriate plan to enhance the agility level.

Agility-enabling attributes are supposed to provide and determine the entire agile behavior of an enterprise. To identify the principal obstacles to enhancing the agility level, a fuzzy agility-provider merit-relation-value index ( $FAPMRVI$ ) combining the merit ratings and the

average relation-weights of providers derived from Eq (2) is defined. The lower the  $FAPMRVI$  of a factor is, the lower the degree of contribution for the factor.

If the fuzzy average relation-weight is used to calculate  $FAPMRVI_k$  directly, the high value obtained neutralizes the low merit ratings in the calculation of  $FAPMRVI$ ; therefore, the actual principal obstacles (low merit rating and high average relation-weight) cannot be identified. If a high value is given to  $FARWAP_k$ , then  $[(1, 1, 1) \ominus FARWAP_k]$  becomes a low value. Hence, to elicit the factor with the lowest merit rating and the highest average-relation-weight for each agility provider  $k$ , the fuzzy index for  $FAPMRVI_k$  is defined as

$$FAPMRVI_k = FMAP_k \otimes FARVAP'_k \quad (5)$$

where  $FARVAP'_k = [(1, 1, 1) \ominus FARWAP_k]$ ;  $FMAP_k$  denotes the fuzzy merit of the  $k^{\text{th}}$  agility provider.

Since fuzzy numbers do not always yield a totally ordered set as real numbers do, all the  $FAPMRVI_k$  must be ranked. Many methods have been developed to rank fuzzy numbers [40, 47]. Here, the ranking of the fuzzy numbers is based on Chen and Hwang's left-and-right fuzzy-ranking method [40] since it not only preserves the ranking order but also considers the absolute location of each fuzzy number. The shortcoming of this method is that the ranking score depends on the definition of their fuzzy maximizing and minimizing sets.

In the left-and-right fuzzy-ranking method, the fuzzy maximizing and minimizing sets are, respectively, defined as

$$U_{\max}(x) = \begin{cases} x, & 0 \leq x \leq 1 \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

$$U_{\min}(x) = \begin{cases} 1-x, & 0 \leq x \leq 1 \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

When a triangular fuzzy number is given, the  $FAPMRVI$  defined as  $U_{FAPMRVI} R \rightarrow [0, 1]$  with a triangular membership function. Thus, the right-and-left scores of the  $FAPMRVI$  can be obtained, respectively, as

$$U_R(FAPMRVI) = \sup_x [U_{FAPMRVI}(x) \wedge U_{\max}(x)] \quad (8)$$

$$U_L(FAPMRVI) = \sup_x [U_{FAPMRVI}(x) \wedge U_{\min}(x)]. \quad (9)$$

Finally, the total score of the  $FAPMRVI$  can be obtained by combining the left and right scores, being defined as

$$U_T(FAPMRVI) = [U_R(FAPMRVI) + 1 - U_L(FAPMRVI)]/2. \quad (10)$$

## 5. A practical case study

In this section, an agility development project of an international IT products-and-services enterprise in Taiwan is cited to demonstrate the evaluation procedure for this approach.

### A. Subject of Case Study

“Enterprise A” is an internationally recognized IT products-and-services company, particularly noted for PCs and notebooks, earning an annual revenue of about US \$6.2 billion in 2005. This enterprise employs marketing and service operations across the Asia-Pacific Rim, Europe, the Middle East, and the Americas, supporting dealers and distributors in more than 100 nations. In the 1990’s, the markets for IT products matured; moreover, low-cost production in developing nations grew, thus prompting large multinational firms to simultaneously provide local responsiveness and global integration to in reaction to an uncertain business environment. Such changes profoundly challenged the enterprise. To achieve and sustain global success and satisfy new small-niche markets, this enterprise strived to become a major global supplier to enrich its customers, reduce to-market time, reduce the total cost of ownership, and enhance overall competitiveness.

Since an enterprise has been advocated as the 21<sup>st</sup>-century operation paradigm, and being perceived as a winning strategy for becoming national and international leader, the corporate management team (executive team) concluded that it wished to achieve an extremely agile enterprise through continuous improvement processes. Thus, an assessment team led by the executive vice president was organized. This team was selected from the most knowledgeable personnel who had mastered the principles of an agile enterprise and whose job it was to investigate and correct problems. The team membership encompassed the vice president of marketing, the general auditor, the global manufacturing manager, the director of human resources, a senior project manager and two consultants for business strategy. Each member brought particular concerns and desires into the decision, which had to be reconciled by consensus, a necessary procedure since all parties would contribute to the success or failure of the project.

### B. Commitments of Project

The aim of agility evaluation is to produce a good set of results, from which an agility index is determined for perceptions of the current situation, and another index for the goals toward increasing the agility of the enterprise. Since top-level commitment is essential, specific objectives for the development project were agreed on by the CEO:

- To implement an enterprise-wide self-assessment for establishing a baseline;
- To identify the strengths of the enterprise and areas needing improvement for feedback to the management team;
- To feed opportunities for improvement into the business planning cycle, including corporate objectives; and
- To develop the process of self-assessment by using the agile enterprise model as an annual component of the business cycle.

### C. Evaluation by Fuzzy QFD-Based Algorithm

When enterprise A sets the goal to implement an agile enterprise, the committee had several questions, such as: Precisely what is agility, and how can it be measured? How can both analytical and intuitive understandings of agility be developed in a particular business environment? How can the agility of enterprise A be improved? Answering these questions requires knowledge of what to measure, how to measure it and how to evaluate the results. Moreover, how to integrate drivers, capabilities and providers into alignment must be taken into account if the enterprise is to implement agility. Although important concepts and steps for development formulation have previously been identified, there is still no systematic tool to integrate these concepts. Furthermore, due to the existing ill-defined and ambiguous

elements concerning agility factors and their interrelationships, experts can easily differentiate between high, medium, and low; however, it is difficult to judge whether a value (e.g., 0.2) is low or another value (e.g., 0.3) is also low. Therefore, it is easier to use linguistic terms to measure ambiguous events. Since linguistic variables contain ambiguity and a multiplicity of meanings and the information obtained can be expressed as a range in a fuzzy set instead of a single value as in traditional methods, fuzzy logic may be applied in this evaluation context. On the basis of the procedures of the fuzzy QFD-based algorithm, the agility development evaluation was implemented and the goal achieved. The deliberations concerning how to initiate agility development are summarized below:

1) Identify agility drivers, determine capabilities and select providers for assessment. To accurately elicit assessment criteria reflecting the entire set of features of an agile enterprise within a period of ten days, the committee made a series of business-environment changes, as well as trend surveying and analysis, the major content of which included changes in the marketplace, competitive circumstances and criteria; technological innovations and applications; changes in customer requirements; and changes in social factors. Moreover, to facilitate the experts' holistic understanding of the current situation, two review meetings were held to discuss a series of activities, the major content of which included

- Enterprise characteristics: enterprise priorities (quality, cost, time, customers satisfaction, etc.), perceived quickness, responsiveness, core business and competencies, as well as specific enterprise problems;
- Policy and strategy: the key factors prompting the enterprise to change and the strategies adopted;
- Business structure: organization, process, personnel, information technology and innovative structures providing the capability for achieving agility;
- Practices: those performed in response to change

On the basis of discussion results, the committee further referred to the factors proposed in previous studies [1, 4, 7, 8, 10, 16-18]. The agility drivers were identified and the capabilities and providers for assessment selected, as shown in Table II. (This Table presents merely what the author assessed to be the most prevalent and meaningful factors for this case study).

2) Determine the preference scale for measurement. This is based on the needs for cognitive perspectives and available data characteristics and also considers the linguistic terms used in previous studies and modified to incorporate enterprise A situations. Furthermore, after two days of discussion based on a long-standing recognition of the meaning of linguistic values, ultimately the committee selected for assessment the linguistic terms and associated fuzzy numbers listed in Table I.

3) Apply the relationship matrix and use linguistic terms to assess agility attributes and relationship-levels, and translate the linguistic terms into fuzzy numbers. Within a period of six days, a series of brainstorming sessions was held to identify the relationships among the variables. For this, the experts were asked about the mutual relationships among variables (e.g., how a particular variable helps to achieve the others). By using the conclusions in the review meetings and brainstorming session, and on the basis of their experience, knowledge and judgment, the committee members applied the relationship matrix (as shown in Tables III and IV) and used the level scale  $W = \{\text{Extremely Low [EL]}, \text{Very Low [VL]}, \text{Low [L]}, \text{Fair [F]}, \text{High [H]}, \text{Very High [VH]}, \text{Extremely High [EH]}\}$  to measure the degree of change in the agility drivers. They used the value scale  $RS = \{\text{Very Low [VL]}, \text{Low [L]}, \text{Fair [F]}, \text{High [H]},$



Very High [VH]] to evaluate extent of the relationships between agility drivers and capabilities, as well as the relationship-levels between capabilities and providers; moreover, they used the rating scale  $R = \{\text{Worst [W]}, \text{Very Poor [VP]}, \text{Poor [P]}, \text{Fair [F]}, \text{Good [G]}, \text{Very Good [VG]}, \text{Excellent [E]}\}$  to assess the merit ratings of the capabilities and providers. A sample of the linguistic assignment is shown in Tables III and IV. Furthermore, on the basis of the associated relations shown in Table I, fuzzy numbers approximating the linguistic terms and linguistic assignments were translated into fuzzy numbers.

4) Analyze the fuzzy average relation-weight in the relationship matrix. Before this analysis, the committee used the median operation to integrate the different assignments under the same factors given by different experts. Furthermore, by applying Eqs. (1)-(2), the fuzzy average relation-weights of the agility capabilities and providers can be calculated, respectively. The results are listed in Table V.

5) Aggregate the fuzzy ratings and fuzzy average relation-weights into an FAI. By applying Eq (3), the FAI for enterprise A was obtained as

$$FAI = (0.37, 0.56, 0.75).$$

6) Match the FAI with an appropriate linguistic level. Once the FAI was obtained, to identify the agility level, the committee further approximated a linguistic label whose meaning is the same as (or closest to) the meaning of the FAI from the natural-language agility-level (AL) expression set. In this case, the set  $AL = \{\text{Definitely Agile [DA]}, \text{Extremely Agile [EA]}, \text{Very Agile [VA]}, \text{Highly Agile [HA]}, \text{Agile [A]}, \text{Slightly Agile [SA]}, \text{Fairly [F]}, \text{Slightly Slow [SS]}, \text{Slowly [S]}\}$  was selected for labeling, the linguistics and corresponding membership functions of which are shown in Figure 5. Then, by using Eq (4), the Euclidean distance  $D$  from the FAI to each member in set AL was calculated:

$$D(FAI, DA) = 2.0094, \quad D(FAI, EA) = 2.0094, \quad D(FAI, VA) = 1.7277,$$

$$D(FAI, HA) = 0.9924, \quad D(FAI, A) = 1.1405, \quad D(FAI, SA) = 1.8168,$$

$$D(FAI, F) = 2.0094, \quad D(FAI, SS) = 2.0094, \quad D(FAI, S) = 2.0094$$

Thus, by matching a linguistic label with the minimum  $D$ , the agility level of enterprise A can be labeled as "Highly Agile", as shown in Figure 5.

7) Analyze and suggest. Since the agility index of enterprise A is "Highly Agile" (according to the evaluation), far from the "Extremely Agile" objective, obstacles within the organization can stop or impact the achievement of the company. Agility providers are supposed to enable and determine the entire agile behavior of an enterprise. By applying Eq (5), the fourteen fuzzy agility-provider merit-relation-value indexes (FAPMRVIs) listed in Table VI were obtained.

Moreover, by applying Eqs (6)-(10), the FAPMRVIs were defuzzified, as listed in Table V. These indices represent the effect of each provider contributing to the agility level of enterprise A. On the basis of the Pareto principle, the committee decided to focus their resources on a few critical factors and sets a scale of 0.2 as the management's threshold for identifying the factors for improvement. Subsequently, as shown in Table VI, four providers performed lower than the threshold, namely (1) first-time right design, (2) multi-skilled and flexible personnel, (3) response to changing market requirements, and (4) cross-functional teams. These providers represent the most significant contributions for enhancing the agility of the enterprise. In connection with the weakest providers within the organization, the committee suggested that an action plan be implemented to improve the adverse providers and to enhance the agility level of the company.

After five years and ten cycles of continuous implemented improvement, the agility index of enterprise A has risen close to the “Extremely Agile” level; moreover, the managers are able to capture information on demand immediately from all over the world to make rapid and appropriate decisions to respond more efficiently and effectively to customers. The tangible benefits are the mean lead-time for responding to customers’ demands reduced by approximately 37% under the same inventory level; sales-average increased by 11%, 23%, 27%, 17% and 19% during the five years; an ascent from ninth of fourth position in the world market, especially boosted by becoming the leading brand of PCs and notebooks in the European market.

## 6. Discussion and conclusions

The agility of an enterprise is perceived as the dominant competitive vehicle. This report has highlighted the following questions: How close is the enterprise to becoming agile? How can the enterprise effectively improve its agility? Deploying and integrating agility providers, capabilities and drivers and transforming them into strategic competitive edges are critical for an enterprise to achieve agility. Although important concepts and steps for achieving agility have been identified, there is still no systematic tool for integrating these steps. Most of the existing approaches for agility development are structural in nature. Also, conventional (crisp) evaluation approaches which are unsuitable and ineffective for handling situations which by nature lead to complexity and vagueness have been evaluated. To compensate for these limitations, a QFD-based framework to logically integrate the agility provider, capability and driver has been proposed. The methodology provides a systematic structure for translating the agility drivers in the business environment into capabilities needed and subsequently for determining the requirements of agility-enabled attributes. In addition a fuzzy agility index (FAI) composed of agility capability ratings and its relation-weights with drivers has been developed for agility measurement in an enterprise. This report has also described how the proposed approach was applied to develop agility in a Taiwanese PC enterprise. Through development and evaluation, it has been shown that the proposed framework and procedures can enhance the agility of an enterprise, as well as ensure a competitive edge.

This method has been developed from the QFD concept and adapted for a PC enterprise which served as an initial case study for validating the model and approach. The enterprise and managers involved in the case study were generally pleased with the approach. This work provides potential value to practitioners by offering a rational structure to logically integrate different elements at various stages of strategic planning. The uncertainty and vagueness of assessment of each attribute and relationship have been addressed to assure relatively realistic information. An unprecedented application of the QFD and fuzzy logic has been demonstrated to researchers.

Since the case study has demonstrated the usefulness of the model for business strategic planning, it is hoped that more managers will be encouraged to adopt this method. However, neither a single case study nor several necessarily provide a true measure of the relative performance and success of this model. Further research should be done to bring this method to maturity and to compare the efficiency of the method in different types of planning (such as information-strategy, marketing, product-roadmap, knowledge-management, etc.). Moreover, this approach does not focus on finding an optimal deployment but merely addresses prioritizing agility providers. For further research, a goal-

programming model can be developed to select in greater detail the combination of agility capabilities and providers which results in optimal levels of agility, subject to cost and other enterprise constraints.

It is acknowledged that the evaluation levels and members involved in any particular implementation will be different, depending on the firm involved. The agility drivers and entrepreneurial objectives and strategies vary from firm to firm. For example, enterprises in high-tech industries, stressing competitive advantage through innovation, may have decided on agility capabilities and providers differently from firms in traditional industries seeking to compete in flexibility, global sourcing and low-cost providers.

Furthermore, according to the comments from the previous case, this approach resolves some of the problems in traditional methods of strategic business planning, having several advantages when compared to previous methods:

1. This method provides a structured procedure for identifying the agility drivers in a business environment, thereby deploying capabilities needed to finally determine the providers that will support or enhance the agility of the enterprise. Furthermore, the case study demonstrated that having providers align with strategy and drivers ensures that the providers can cope with strategic direction and provide a competitive edge for the enterprise.
2. This method gives the analyst more convincing and reliable results. The FAI was expressed in a range of values, providing an overall description of the agility of an enterprise and ensuring that the decision made in the evaluation is not biased. As an example, an agility index having a fuzzy value (0.37, 0.56, 0.75) indicates that the agility level is closer to "Highly Agile," but also not far away from "Agile."
3. This method provides a guiding, dynamic document linking the business strategy of a firm with its environment and outlines details for implementation through continuous process improvement and total quality management.
4. This method provides a first step in preventing a majority of inappropriate assessments and also expedites the eventual financial analysis by highlighting the most important benefits and drawbacks for formulating a comprehensive plan for improvement.

Finally, there are some limitations to the fuzzy-logic approach. The membership function of natural language expression depends on the managerial perspective of the experts, who must be at a strategic level in the enterprise to evaluate the importance of all aspects such as strategy, marketing and technology. Furthermore, competitive situations and requirements vary from one enterprise or industry to another; hence, a company must establish its unique membership function appropriate to its own specific environment and considerations. Moreover, the computation of a fuzzy weighted average is still complicated and not easily appreciated by managers. Fortunately, this calculation has been computerized to increase accuracy while reducing both computation time and the possibility of errors.

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| Levels of change    |                   | Merit ratings       |                   | Relationship-levels |                  |
|---------------------|-------------------|---------------------|-------------------|---------------------|------------------|
| Linguistic variable | Fuzzy number      | Linguistic variable | Fuzzy number      | Linguistic variable | Fuzzy number     |
| Extremely Low (EL)  | (0, 0.05, 0.15)   | Worst (W)           | (0, 0.05, 0.15)   | Very Low (VL)       | (0, 0.1, 0.2)    |
| Very Low (VL)       | (0.1, 0.2, 0.3)   | Very Poor (VP)      | (0.1, 0.2, 0.3)   | Low (L)             | (0.1, 0.25, 0.4) |
| Low (L)             | (0.2, 0.35, 0.5)  | Poor (P)            | (0.2, 0.35, 0.5)  | Fair (F)            | (0.3, 0.5, 0.7)  |
| Fair (F)            | (0.3, 0.5, 0.7)   | Fair (F)            | (0.3, 0.5, 0.7)   | High (H)            | (0.6, 0.75, 0.9) |
| High (H)            | (0.5, 0.65, 0.8)  | Good (G)            | (0.5, 0.65, 0.8)  | Very High (VH)      | (0.8, 0.9, 1.0)  |
| Very High (VH)      | (0.7, 0.8, 0.9)   | Very Good (VG)      | (0.7, 0.8, 0.9)   |                     |                  |
| Extremely High (EH) | (0.85, 0.95, 1.0) | Excellent (E)       | (0.85, 0.95, 1.0) |                     |                  |

Table 1.Fuzzy numbers to approximate linguistic variable values

| Drivers   | Capabilities   | Providers   |
|---|--|---|
| Growth of niche market (A D <sub>1</sub> )  | Sensing /Identifying changes and fast response (AC <sub>1</sub> )              | Multi-skilled and flexible personnel (AP <sub>1</sub> )           |
| Increasing rate of change in product models (A D <sub>2</sub> )                   | Strategic vision (AC <sub>2</sub> )  | Workforce skill upgrade (AP <sub>2</sub> )                        |
| Product lifetime shrinkage (A D <sub>3</sub> )                                    | Technological ability and appropriate product introduction (AC <sub>3</sub> ). | Quick new product introduction (AP <sub>3</sub> )                 |
| Rapidly changing market (A D <sub>4</sub> )                                       | Cost-effectiveness (AC <sub>4</sub> )  | Response to changing market requirements (AP <sub>4</sub> )       |
| Increasing pressure on cost (A D <sub>5</sub> )                                   | Cooperation and operation efficiency and effectiveness (AC <sub>5</sub> )      | Products with substantial value-addition (AP <sub>5</sub> )       |
| Increasing pressure of global market competition (A D <sub>6</sub> )              | Product volume/model flexibility (AC <sub>6</sub> )                            | First-time right design (AP <sub>6</sub> )                        |
| Decreasing new products time to market (A D <sub>7</sub> )                        | Organization/personnel flexibility (AC <sub>7</sub> )                          | Trust-based relations with customers/suppliers (AP <sub>7</sub> ) |
| Quicker delivery time and time to market (A D <sub>8</sub> )                      | Product/service design, delivery alacrity and timeliness (AC <sub>8</sub> )    | Technology awareness (AP <sub>8</sub> )                           |
| Increasing quality expectation (A D <sub>9</sub> )                                | Fast operation time (AC <sub>9</sub> )   | Skill and knowledge enhancement (AP <sub>9</sub> )                |
| Introduction of new soft technologies (software and methods) (A D <sub>10</sub> ) |  | Concurrent execution of activities (AP <sub>10</sub> )            |
| Environmental pressures (A D <sub>11</sub> )                                      |  | Information technology and communication (AP <sub>11</sub> )      |
|   |  | Empowerment and decentralized decision-making (AP <sub>12</sub> ) |
|   |  | Cross-functional team (AP <sub>13</sub> )                         |
|   |  | Culture of change (AP <sub>14</sub> )                             |

Table 2. Agility-related factors

|                 |                  | Agility capabilities           |                 |                 |                 |                 |                 |                 |                 |                 |                 |
|-----------------|------------------|--------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 |                  |                                |                 |                 |                 |                 |                 |                 |                 |                 |                 |
|                 |                  | Merits of agility capabilities | AC <sub>1</sub> | AC <sub>2</sub> | AC <sub>3</sub> | AC <sub>4</sub> | AC <sub>5</sub> | AC <sub>6</sub> | AC <sub>7</sub> | AC <sub>8</sub> | AC <sub>9</sub> |
| Level of change |                  |                                | G               | G               | G               | F               | F               | VG              | F               | P               | F               |
| Agility drivers | AD <sub>1</sub>  | VH                             | VH              | H               | H               | F               | F               | VH              | H               | H               | VH              |
|                 | AD <sub>2</sub>  | VH                             | H               | H               | VH              | H               | H               | H               | VH              | H               | VH              |
|                 | AD <sub>3</sub>  | VH                             | H               | H               | VH              | H               | H               | F               | H               | H               | VH              |
|                 | AD <sub>4</sub>  | VH                             | H               | VH              | H               | H               | H               | VH              | H               | VH              | VH              |
|                 | AD <sub>5</sub>  | EH                             | H               | F               | H               | VH              | H               | H               | F               | H               | H               |
|                 | AD <sub>6</sub>  | VH                             | H               | VH              | H               | VH              | VH              | H               | VH              | VH              | VH              |
|                 | AD <sub>7</sub>  | VH                             | VH              | H               | H               | F               | H               | H               | H               | VH              | VH              |
|                 | AD <sub>8</sub>  | VH                             | VH              | H               | H               | F               | H               | H               | H               | VH              | VH              |
|                 | AD <sub>9</sub>  | H                              | H               | F               | H               | F               | VH              | F               | F               | H               | F               |
|                 | AD <sub>10</sub> | H                              | H               | H               | H               | H               | F               | H               | H               | H               | H               |
|                 | AD <sub>11</sub> | H                              | F               | H               | F               | L               | F               | L               | F               | F               | L               |

Table 3. Agility capability related to drivers: agile strategies analysis matrix (assigned by general auditor)

|                             |                 | Agility providers |                 |                 |                 |                 |                 |                 |                 |                 |                  |                  |                  |                  |                  |
|-----------------------------|-----------------|-------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|------------------|------------------|------------------|------------------|
|                             |                 | AP <sub>1</sub>   | AP <sub>2</sub> | AP <sub>3</sub> | AP <sub>4</sub> | AP <sub>5</sub> | AP <sub>6</sub> | AP <sub>7</sub> | AP <sub>8</sub> | AP <sub>9</sub> | AP <sub>10</sub> | AP <sub>11</sub> | AP <sub>12</sub> | AP <sub>13</sub> | AP <sub>14</sub> |
| Merits of agility providers |                 | VG                | G               | VG              | F               | G               | G               | G               | VG              | VG              | G                | G                | E                | F                | G                |
| Agility capabilities        | AC <sub>1</sub> | H                 | H               | VH              | H               | H               | H               | L               | H               | H               | F                | H                | VH               | H                | H                |
|                             | AC <sub>2</sub> | H                 | F               | H               | H               | H               | H               | VH              | H               | F               | H                | H                | H                | F                | VH               |
|                             | AC <sub>3</sub> | VH                | VH              | VH              | H               | H               | VH              | F               | H               | H               | H                | VH               | F                | H                | H                |
|                             | AC <sub>4</sub> | H                 | H               | H               | H               | H               | H               | VH              | H               | H               | H                | H                | F                | F                | H                |
|                             | AC <sub>5</sub> | H                 | H               | H               | VH              | H               | VH              | H               | H               | H               | VH               | H                | H                | VH               | H                |
|                             | AC <sub>6</sub> | VH                | H               | H               | VH              | H               | H               | H               | H               | H               | H                | H                | H                | H                | F                |
|                             | AC <sub>7</sub> | VH                | H               | H               | VH              | H               | H               | H               | H               | H               | VH               | H                | VH               | H                | H                |
|                             | AC <sub>8</sub> | H                 | H               | H               | VH              | H               | VH              | H               | H               | H               | VH               | H                | H                | H                | H                |
|                             | AC <sub>9</sub> | VH                | H               | H               | VH              | H               | VH              | H               | H               | H               | VH               | H                | H                | VH               | H                |

Table 4. Agility providers related to capabilities: principle obstacle identification matrix (assigned by general auditor)

| Agility capability  | Fuzzy average relation-weights | Agility providers   | Fuzzy average relation-weights |
|---|--------------------------------|---|--------------------------------|
| Sensing /Identifying changes and responding (AC <sub>1</sub> ).             | (0.61, 0.76, 0.92)             | Multi-skilled and flexible personnel (AP <sub>1</sub> )           | (0.60, 0.74, 0.90)             |
| Strategic vision (AC <sub>2</sub> ).  | (0.60, 0.76, 0.91)             | Workforce skill upgrade (AP <sub>2</sub> )                        | (0.55, 0.72, 0.88)             |
| Technological ability and appropriate product introduction (AC).            | (0.65, 0.79, 0.93)             | Quick new product introduction (AP <sub>3</sub> )                 | (0.60, 0.76, 0.91)             |
| Cost-effectiveness (AC <sub>4</sub> ).                                      | (0.61, 0.77, 0.92)             | Response to changing market requirements (AP <sub>4</sub> )       | (0.63, 0.78, 0.93)             |
| Cooperation and operations efficiency and effectiveness (AC <sub>5</sub> ). | (0.58, 0.75, 0.91)             | Products with substantial value-addition (AP <sub>5</sub> )       | (0.52, 0.70, 0.87)             |
| Product volume/model flexibility (AC <sub>6</sub> )                         | (0.54, 0.73, 0.89)             | First-time right design (AP <sub>6</sub> )                        | (0.62, 0.77, 0.93)             |
| Organization/personnel flexibility (AC <sub>7</sub> )                       | (0.46, 0.63, 0.76)             | Trust-based relations with customers/suppliers (AP <sub>7</sub> ) | (0.55, 0.73, 0.89)             |
| Product/service design, delivery alacrity and timeliness (AC <sub>8</sub> ) | (0.67, 0.82, 0.96)             | Technology awareness (AP <sub>8</sub> )                           | (0.54, 0.72, 0.88)             |
| Fast operation time (AC <sub>9</sub> )                                      | (0.65, 0.81, 0.95)             | Skill and knowledge enhancement (AP <sub>9</sub> )                | (0.60, 0.75, 0.9)              |
|   |                                | Concurrent execution of activities (AP <sub>10</sub> )            | (0.60, 0.76, 0.91)             |
|   |                                | Information technology and communication (AP <sub>11</sub> )      | (0.60, 0.75, 0.9)              |
|   |                                | Empowerment and decentralized decision-making (AP <sub>12</sub> ) | (0.52, 0.71, 0.88)             |
|   |                                | Cross-functional team (AP <sub>13</sub> )                         | (0.55, 0.73, 0.89)             |
|   |                                | Culture of change (AP <sub>14</sub> )                             | (0.37, 0.58, 0.78)             |

Table 5. Fuzzy average relation-weights of agility capabilities and providers

| Agility providers | Merits of agility provider | (1.0, 1.0, 1.0) (-)<br>$FARWAP_i$ | Fuzzy relation-value indexes | Ranking scores |
|-------------------|----------------------------|-----------------------------------|------------------------------|----------------|
| AP <sub>1</sub>   | (0.3, 0.5, 0.7)            | (0.1, 0.26, 0.4)                  | (0.03, 0.13, 0.28)           | 0.1808         |
| AP <sub>2</sub>   | (0.5, 0.65, 0.8)           | (0.12, 0.28, 0.45)                | (0.06, 0.182, 0.36)          | 0.2339         |
| AP <sub>3</sub>   | (0.7, 0.8, 0.9)            | (0.09, 0.24, 0.4)                 | (0.063, 0.192, 0.36)         | 0.2391         |
| AP <sub>4</sub>   | (0.5, 0.65, 0.8)           | (0.07, 0.22, 0.37)                | (0.035, 0.143, 0.296)        | 0.1929         |
| AP <sub>5</sub>   | (0.5, 0.65, 0.8)           | (0.13, 0.3, 0.48)                 | (0.065, 0.195, 0.384)        | 0.2478         |
| AP <sub>6</sub>   | (0.3, 0.5, 0.7)            | (0.07, 0.23, 0.38)                | (0.021, 0.115, 0.266)        | 0.1681         |
| AP <sub>7</sub>   | (0.5, 0.65, 0.8)           | (0.11, 0.27, 0.45)                | (0.055, 0.176, 0.36)         | 0.2305         |
| AP <sub>8</sub>   | (0.7, 0.8, 0.9)            | (0.12, 0.28, 0.46)                | (0.084, 0.224, 0.414)        | 0.2722         |
| AP <sub>9</sub>   | (0.5, 0.65, 0.8)           | (0.1, 0.25, 0.4)                  | (0.05, 0.163, 0.32)          | 0.2115         |
| AP <sub>10</sub>  | (0.5, 0.65, 0.8)           | (0.09, 0.24, 0.4)                 | (0.045, 0.156, 0.32)         | 0.2077         |
| AP <sub>11</sub>  | (0.5, 0.65, 0.8)           | (0.1, 0.25, 0.4)                  | (0.05, 0.163, 0.32)          | 0.2115         |
| AP <sub>12</sub>  | (0.5, 0.65, 0.8)           | (0.12, 0.29, 0.48)                | (0.06, 0.189, 0.384)         | 0.2444         |
| AP <sub>13</sub>  | (0.3, 0.5, 0.7)            | (0.11, 0.27, 0.45)                | (0.033, 0.135, 0.315)        | 0.1947         |
| AP <sub>14</sub>  | (0.3, 0.5, 0.7)            | (0.22, 0.42, 0.63)                | (0.066, 0.21, 0.441)         | 0.2709         |

Table 6. Fuzzy merit-relation-value indexes of agility providers

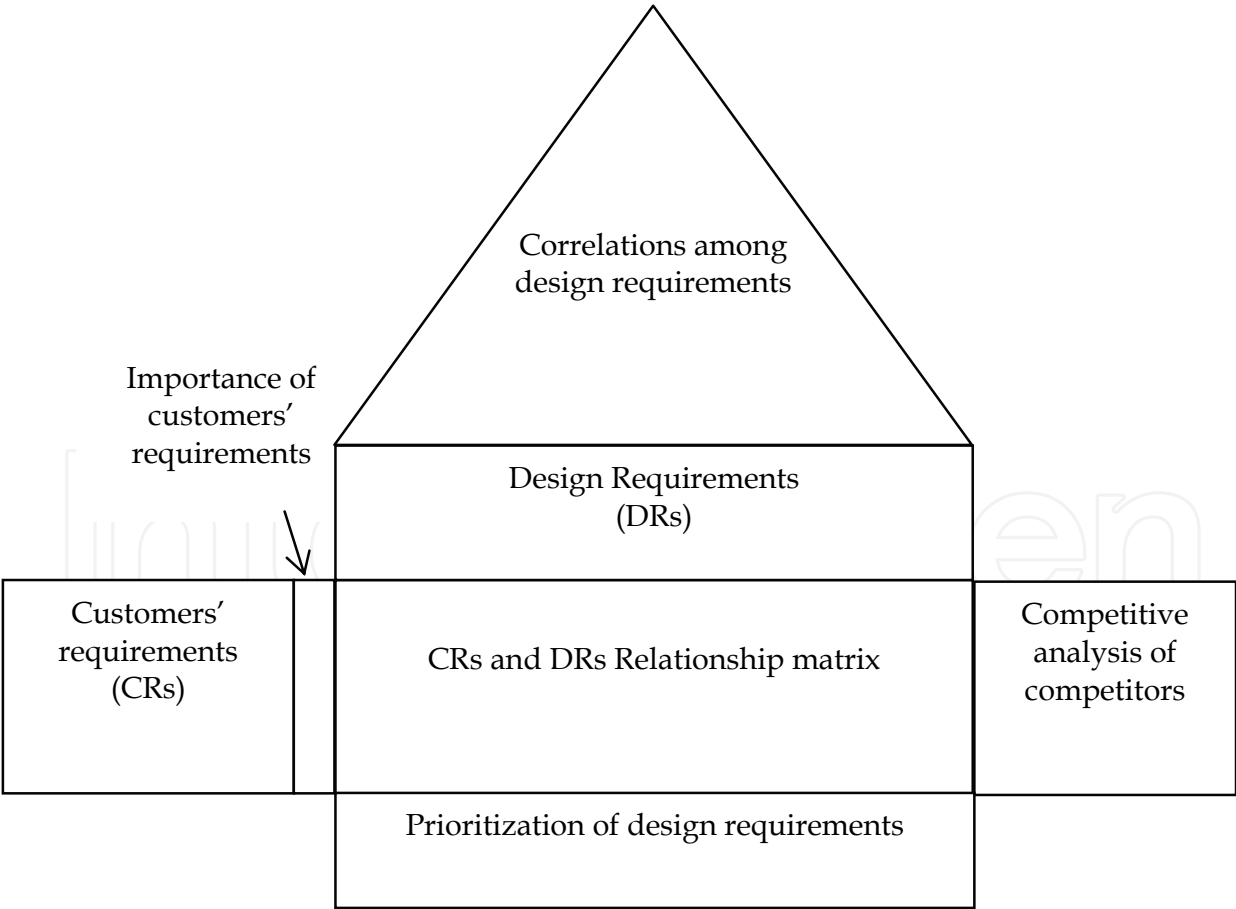


Figure 1. A basic house-of-quality (HOQ) matrix



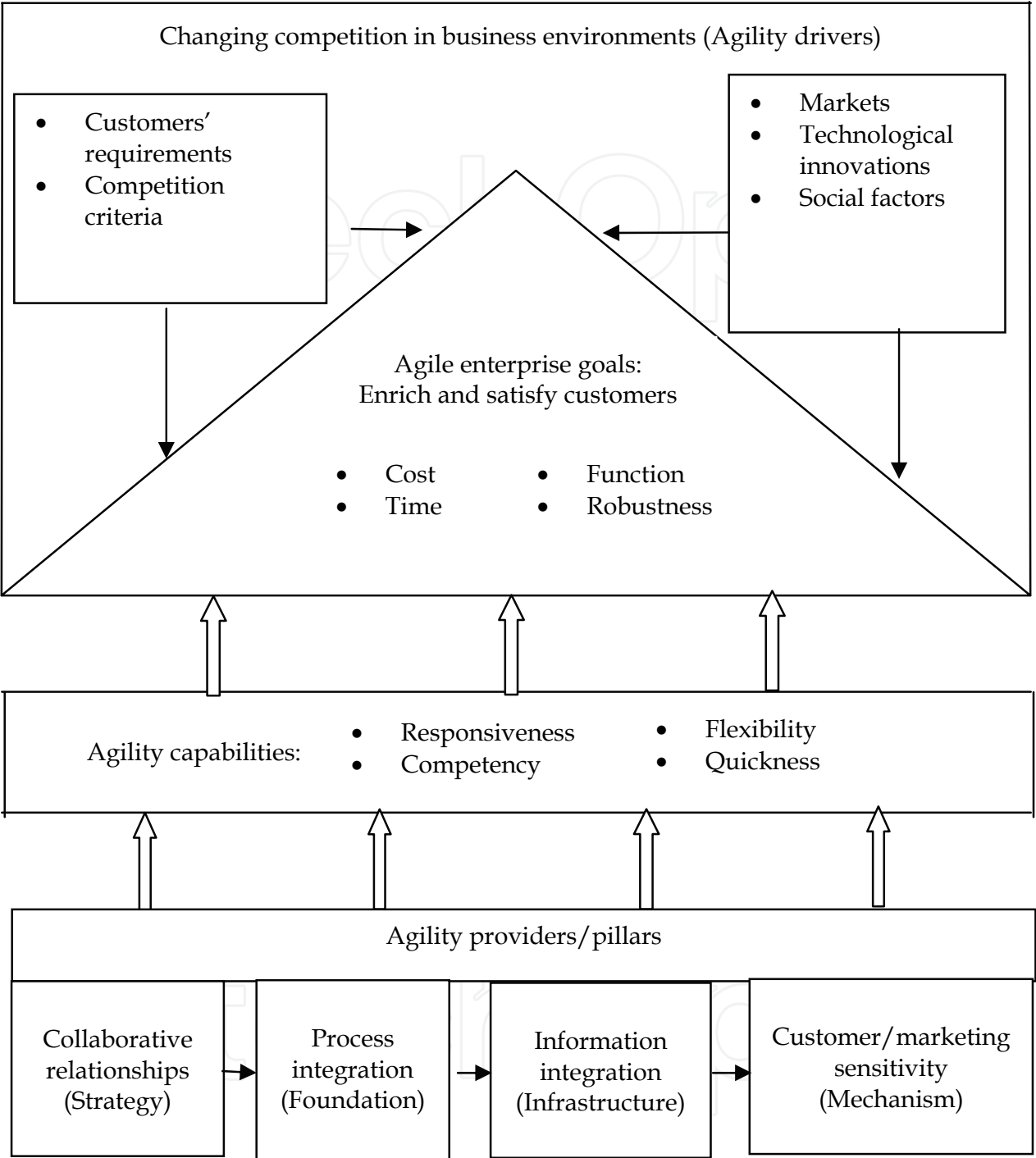
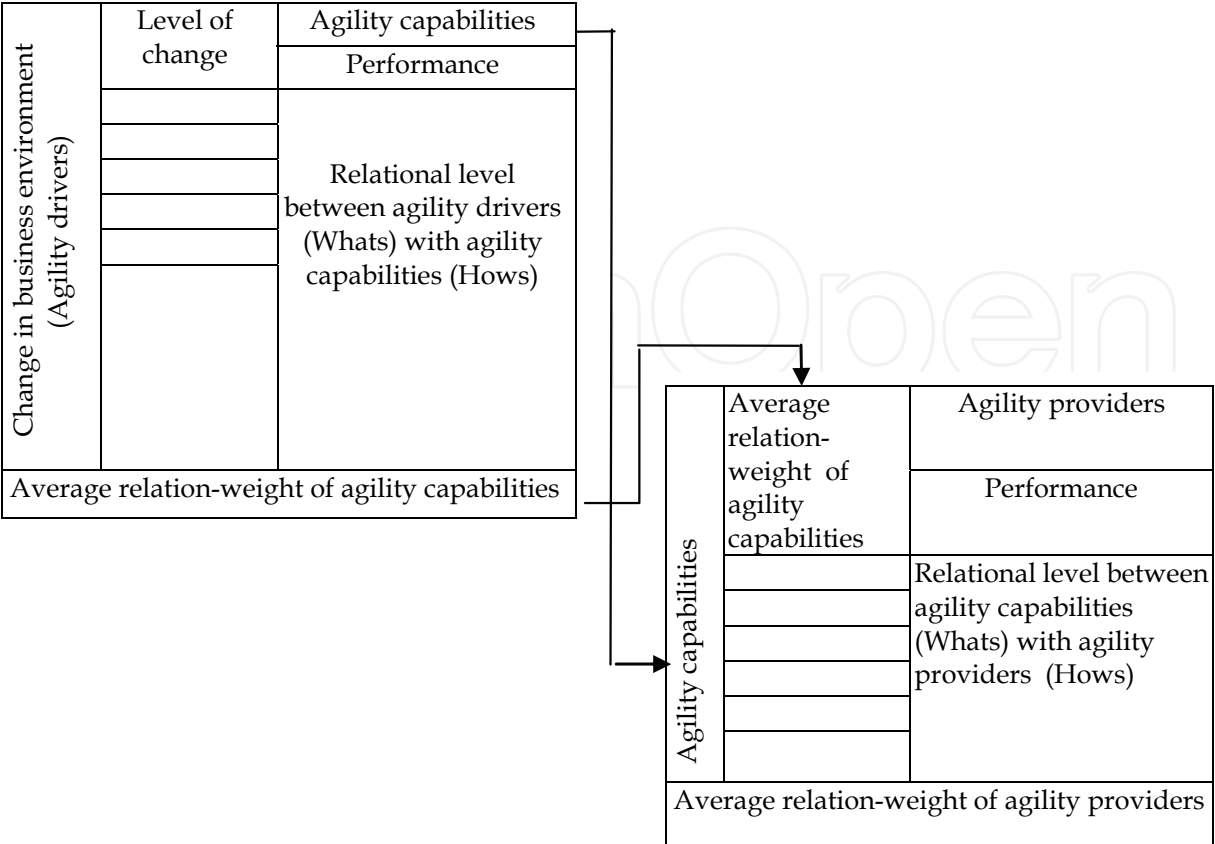


Figure 2. A conceptual framework of an agile enterprise



Matrix for analyzing agile strategies

Matrix for identifying obstacles to agility

Figure 3. A systematic agility-linking model

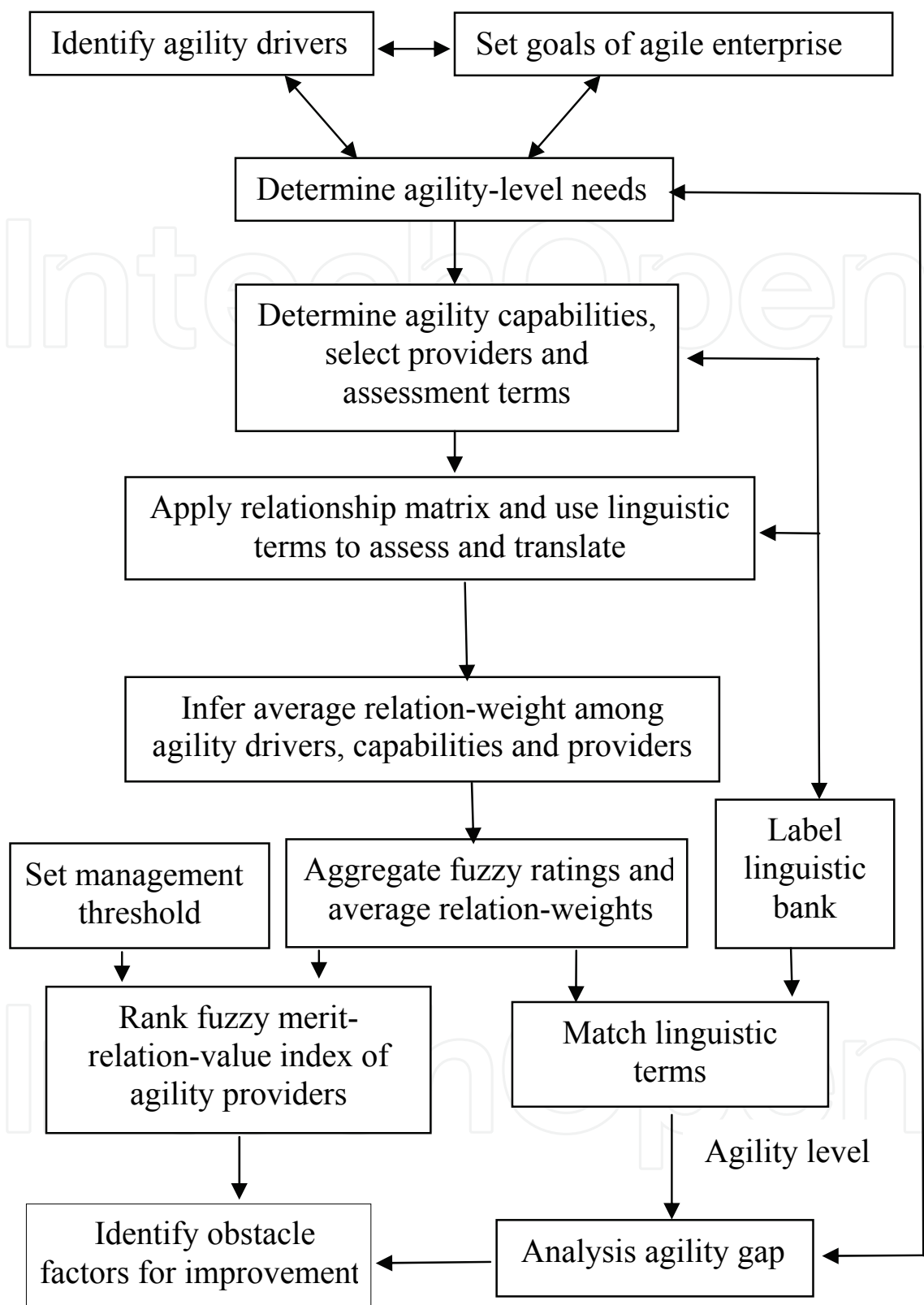


Figure 4. A method for evaluating and achieving agility

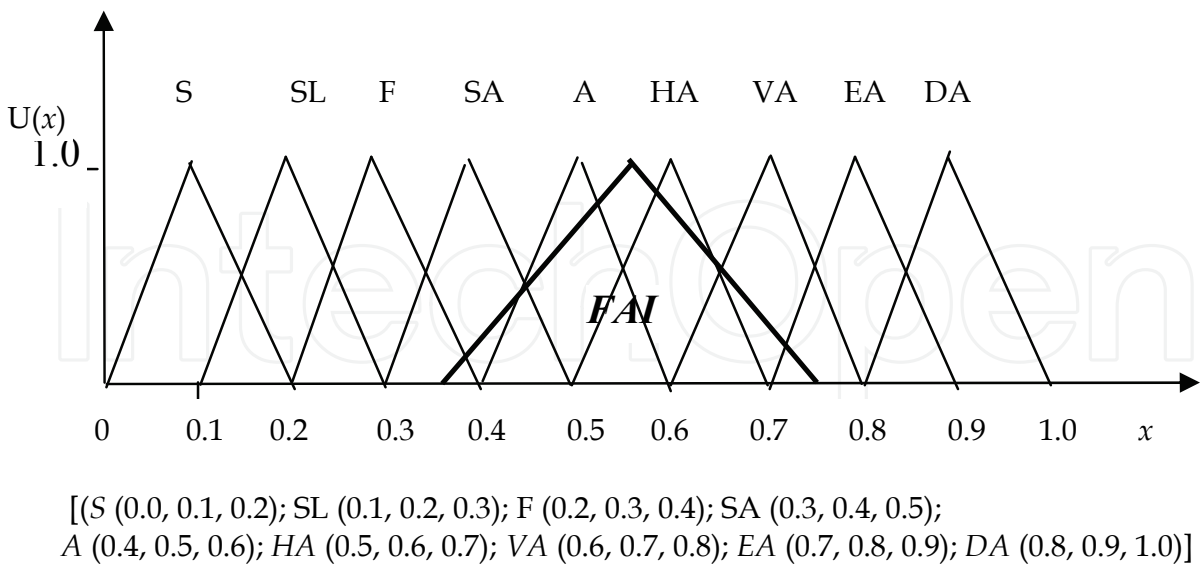


Figure 5. Matching fuzzy agility index with linguistic terms



## **Supply Chain**

Edited by Vedran Kordic

ISBN 978-3-902613-22-6

Hard cover, 568 pages

**Publisher** I-Tech Education and Publishing

**Published online** 01, February, 2008

**Published in print edition** February, 2008

Traditionally supply chain management has meant factories, assembly lines, warehouses, transportation vehicles, and time sheets. Modern supply chain management is a highly complex, multidimensional problem set with virtually endless number of variables for optimization. An Internet enabled supply chain may have just-in-time delivery, precise inventory visibility, and up-to-the-minute distribution-tracking capabilities. Technology advances have enabled supply chains to become strategic weapons that can help avoid disasters, lower costs, and make money. From internal enterprise processes to external business transactions with suppliers, transporters, channels and end-users marks the wide range of challenges researchers have to handle. The aim of this book is at revealing and illustrating this diversity in terms of scientific and theoretical fundamentals, prevailing concepts as well as current practical applications.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Chwei-Shyong Tsai, Chien-Wen Chen and Ching-Torng Lin (2008). Align Agile Drivers, Capabilities and Providers to Achieve Agility: a Fuzzy-Logic QFD Approach, Supply Chain, Vedran Kordic (Ed.), ISBN: 978-3-902613-22-6, InTech, Available from:

[http://www.intechopen.com/books/supply\\_chain/align\\_agile\\_drivers\\_\\_capabilities\\_and\\_providers\\_to\\_achieve\\_agility\\_\\_a\\_fuzzy-logic\\_qfd\\_approach](http://www.intechopen.com/books/supply_chain/align_agile_drivers__capabilities_and_providers_to_achieve_agility__a_fuzzy-logic_qfd_approach)

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