

Full Length Research Paper

# Application of adaptive neuro fuzzy inference system in measurement of supply chain agility: Real case study of a manufacturing company

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In this paper we have developed an approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for measurement of agility in Supply Chain. An Agile Supply Chain (ASC) is frequently considered as a dominant competitive advantage. As complexity and vagueness of agility in global markets must be considered as one of the essential characteristics of an ASC system, we efficiently applied ANFIS in order to inject different and complicated agility capabilities (that is, flexibility, competency, cost, responsiveness and quickness) to the model in an ambiguous environment. Moreover, different potential attributes of ANFIS (that is, considering membership functions for each agility capabilities, training these functions through an adaptive procedure, using fuzzy concepts in order to model objective attributes) made the proposed approach meritorious for surveying real life problems. To our best knowledge such application has been never reported for ASC and ANFIS in literature. It has worth noting that application of the proposed procedure as a Decision Support System (DSS) helps managers to perform gap analysis between existent agility level and the desired one and also provides reliable information for decision making. The proposed procedure has efficiently been applied to a large scale automobile manufacturing company in Iran. Statistical analysis represent that there are no meaningful difference between experts' opinion and our proposed procedure for supply chain agility measurement.

**Key words:** Agile supply chain, adaptive neuro fuzzy inference system (anfis), supply chain management.

## INTRODUCTION

### Supply chain concepts

With an increasing global competition, at the beginning of the 21st century, companies have witnessed significant changes in the market, such as high degree of market volatility, shortened lifecycles, uncertain demand and unreliable supply. Mass markets are continuing to fragment as customers' demands and expectations rise. These developments have caused a major revision of business priorities and strategic vision (Sharifi and Zhang, 1999). The need to respond of volatile environment has been addressed in recent years by the concept of agility.

Companies have recognized that agility is crucial for their survival and competitiveness. Agility is defined as "the ability to cope with unexpected challenges as opportunities" (Sharifi and Zhang, 1999). Other related definitions of agility have been proposed since the construct is still in its initial stage of application to organizational phenomenon. Agility is "the ability to detect opportunities for innovation and seize those competitive market opportunities by assembling requisite assets, knowledge and relationships with speed and surprise" (Sambamurthy, 2003). Research works in this area have emphasized that firm's ability to respond is a key measure of agility (Dove, 2001; Overby et al., 2000).

While agility is accepted as a winning strategy for growth, even a basis for survival in certain business environments, the idea of creating agile supply chain have become a logical step for companies. Agility in sup-

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**Table 1.** Definition of agility.

Definition	Year	Authors
Agility is synthesized use of developed and well-known technologies and methods of manufacturing. That is, it is mutuality compatible with lean manufacturing, CIM, TQM, MRP, BPR, employee empowerment and OPT.	1994	Kidd
Agility means delivering value to customers, being ready for change, valuing human knowledge and skills and forming virtual partnership.	1995	Goldman, Negal
Agility is the capability of reaching unpredictable market changes in a cost-effective way, simultaneously prospering from the uncertainty.	1998	Gunasekaran
Agility means mobility in an organization's behavior towards the environment and can, therefore, understood an extensive answer to continually changing markets. Agile companies are in a process of constant re-determination, or self-organization, self-configuration and self-teaming.	1999	Bullinger
Agility is successful exploration of competence bases (speed, flexibility, innovation, proactively, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast-changing market environment.	1999	Yusuf et al.
Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a violate marketplace	1999	Naylor et al.
Agility is defined as the ability of an organization to respond rapidly to changes in demand both in terms of volume and variety.	2000	Christopher
Agility is all about customer responsiveness and market turbulence and requires specific capabilities that can be achieved using "lean thinking"	2001	Van Hoek
Innovative products and unstable demand typify agile supply drivers.	2003	Strattonand Warburton
Agility is a supply chain wide capability that aligns organizational structures, information systems, logistics processes and in particular, mindsets.	2005	Harrison and Van Hoak

ply chain is the ability of supply chain as a whole and its members to rapidly align the network and its operations to dynamic and turbulent requirements of the customers (Ismail and Sharifi, 2005). Agility has been defined as the ability of a supply chain to rapidly respond to changes in market and customers' demands (Sharp, 1999). The combination of Supply Chain Management (SCM) and agility is a significant source of competitiveness which has come to be named Agile Supply Chain (ASC).

The lack of systematic approach to agility does not allow companies to develop the necessary proficiency in change, a prerequisite for agility (Lin et al., 2006). ASC is seen as a winning strategy for companies wishing national and international leadership (Yusuf, 1999). However, the ability to build agile relationships has developed more slowly than anticipated and also little effort has been made to build ASC assessment methodology in recent years (Sharp et al., 1999).

An important question must be asked, after embracing

ASC. How companies can measure agility in supply chains? This measurement is essential for managers as it assists in achieving effectiveness of agility by performing gap analysis between existent agility level and the desired one. This also provides more informative and reliable information for decision making. Therefore, this study attempts to answer this question with a particular focus on measuring agility.

### Concepts of agile supply chain

In the 1990s, the researches interest had been focused on finding systematic ways for manufacturer to approach agility in their supply chains. Helping managers to attain a sustainable competitive advantage, numerous studies have discussed agility in organizations. Table 1 provides some definitions about agility.

Since the introduction of agility paradigm, the potential

**Table 2.** Conceptual model based studies.

<b>The main points of conceptual model</b>	<b>Year</b>	<b>Authors</b>
4 key dimensions: strategies, Tec, people and system	1999	Gunasekaran
ASC's enablers	2000	Christopher
Agility audit in supply chains	2001	Van Hoak
Integrated model for enabling ASC: principles, programs, actions c	2001	Towill
Agile supply chain capabilities	2003	Yusuf
A conceptual model for assessing agility in supply chain	2005	Torang Lin
Identifying agility index in supply chain	2006	Agarval
A process approach to ASC	2006	Sowford
Conceptual model for assessing ASC, Agility drivers, enablers and outcomes	2007	Vazquez
Modeling and control of supply chain	2008	Gunasekaran

benefits of implementing it in companies were soon widely recognized by researchers and industries (Sun et al., 2005). The agility is recognized as a winning competitive advantage (Christopher, 2000; Christopher and Towill, 2001; Dove, 1994; Goldman et al., 1995; Goranson, 1999; Kidd, 1994; Naylor et al., 1999; Oleson, 1998; Sharif and Zhang, 2001; Swafford et al., 2000; Van Hoak et al., 2001; Yusuf et al., 2003; White et al., 2005).

Considering agility and SCM in a simultaneous way, led to introduction of an ASC (Christopher, 2000) . The idea of creating ASCs has become a logical step for companies, while agility is accepted as a winning strategy for growth or even a basis for survival in certain business environments. Agility in supply chain is the ability of supply chain as a whole and its members rapidly align the network and its operation to dynamics and turbulent requirements of the customers (Ismail and Sharif, 2005). It has been identified that ASC requires various distinguishing capabilities to respond changing environments (Christopher, 2000) . These capabilities include four main elements (Sharp et al., 1999; Christopher, 2000):

1. Responsiveness, which is the ability to identify changes and respond to them quickly, reactively or proactively and also to recover from them.
2. Competency, which is the ability to efficiently and effectively realize enterprise objectives.
3. Flexibility, which is the ability to implement different process and apply different facilities to achieve the same goal.
4. Quickness which is the ability to complete an activity as quickly as possible.

In the literature, frameworks based on other characteristics of supply chain agility have also been suggested. The research works can be classified in three main categories: a) Conceptual model, b) Empirical and c) Experts' judgments. Many researchers have provided conceptual over views, different reference and mature models of agility. For instance Lin et al. (2006) presented that to have a truly ASC some enablers like Collaborative

relationship as the supply chain strategy, Process integration as the foundation of supply chain, Information integration as the infrastructure of supply chain and finally Customer/ marketing sensitivity as the mechanism of supply chain, are required. Table 2 provides some conceptual models in this area.

Table 3 illustrates the comparison between empirical and expert judgment considering some main attributes (that is, simplicity, generalization, model sensitivity to sampling, type of data (fuzzy or crisp), type of variables and calculation speed.

To our best knowledge, existing approaches have not considered the impact of enablers in measuring agility in supply chains. Moreover, it has also worth to be mentioned that the scales used to aggregate the agility capabilities have main limitations as follow. Existing procedures do not consider about ambiguity and multi possibility associated with mapping of individual judgment to a number. The subjective judgment, selection and preference of evaluators have a significant influence on these methods. Due to the qualitative and ambiguous attributes linked to agility measurement, most measures are described subjectively using linguistic terms and cannot be handled effectively using conventional assessment approaches.

### **Concept of artificial neural network**

Artificial neural nets (ANNs) were designed as a simplified model of the biological neurons. In an attempt to capture "intelligence," it was theorized that since the human brain was constructed of a number of similarly constructed neural cells, a simulation constructed using these neural models should have similar capabilities. Using the mathematical model, a "neural network" can be designed by putting a number of these mathematical "neurons" together in various configurations.

On the other hand ANNs are, as their name indicates, computational networks which attempt to simulate, in a gross manner, the networks of nerve cell (neurons) of the

**Table 3.** Comparison of empirical and expert judgment based studies.

Author	Year	Description	Simplicity	Generalization	Model sensitivity to sampling	Data	Variable	Calculation speed	Study	
									Empirical	judgment based
Power	2001	CSFs in ASC using regression analysis	Low	–	High	Crisp	Continuum	Low		
Weber	2002	Agility assessment in virtual organization	Low	–	High	Crisp	Continuum	Low		
Yusuf	2003	Study the relation between Capabilities and objectives in ASC	medium	–	High	Crisp	Continuum	medium		
Avella	2007	Using structural equation to test conceptual model	medium	–	High	Crisp	Continuum	Medium		
Hessami	2008	Identifying effective factors on ASC	medium	–	High	Crisp	Continuum	Medium		
Ihu	2002	Evaluation model of ASC's performance	medium	medium	Low	Fuzzy	Linguistic term	Medium		
Torng	2005	Assessing agility using experts judgments	medium	medium	Low	Fuzzy	Linguistic term	Medium		
Agrawal	2005	Modeling the metrics of lean, agile and le-agile supply chain based on ANP model	Low	High	Low	Crisp	Continuum	Low		
Jain et al.	2008	Evaluating agility in supply chain based on rule mining	Low	–	High	fuzzy	Linguistic term	High		

biological (human or animal) central nervous system. This simulation is a gross cell-by-cell (neuron-by-neuron, element-by-element) simulation. It borrows from the neuro-physiological knowledge of biological neurons and of networks of such biological neurons. It thus differs from conventional (digital or analog) computing machines that serve to replace, enhance or speed-up human brain computation without regard to organization of the computing elements and of their networking. Still, we emphasize that the simulation afforded by neural networks is very gross.

A wide variety of application and several structures for ANNs in literature of engineering and management science.

### Concepts of fuzzy

Our understanding of most physical processes is based largely on imprecise human reasoning. This imprecision (when compared to the precise quantities required by computers) is nonetheless a form of information that can be quite useful to humans. The ability to embed such reasoning in hitherto intractable and complex problems is the criterion by which the efficacy of fuzzy logic is judged. Undoubtedly this ability cannot solve problems that require precision - problems such as shooting precision laser beams over tens of kilometers in space; milling machine components to accuracies of parts per billion; or focusing a microscopic electron beam on a specimen the

size of a nanometer. The impact of fuzzy logic in these areas might be years away, if ever. But not many human problems require such precision-problems such as parking a car, backing up a trailer, navigating a car among others on a freeway, washing clothes, controlling traffic at intersections, judging beauty contestants and a preliminary understanding of a complex system (Ross, 2004).

However, the gradual evolution of the expression of uncertainty using probability theory was challenged, first in 1937 by Max Black, with his studies in vagueness, then with the introduction of fuzzy sets by Lotfi Zadeh in 1965. Zadeh's work [1965] had a profound influence on the thinking about uncertainty because it challenged not only

probability theory as the sole representation for uncertainty, but the very foundations upon which probability theory was based: classical binary (two-valued) logic (Ross, 2004).

Fuzzy logic provides an effective means of dealing with problems involving imprecise and vague phenomena. Fuzzy concepts enable assessors to use linguistic terms to assess indicators in natural language expressions and each linguistic term can be associated with a membership function. Furthermore, fuzzy logic has found significant applications in management sciences (Lin and Chen, 2004).

### **Novelties of proposed approach**

Lack of an efficient measuring tool for agility of supply chain system made us to develop a procedure with aforementioned functionality. The imprecise nature of attributes for associated concepts persuade us to apply fuzzy concepts and aggregate this powerful tool with ANNs concepts in favor of gaining ANFIS as an efficient tool for development and surveying of our novel procedure. Due to our best knowledge this combination has never been reported in literature before.

### **PROPOSED MODEL FOR MEASUREMENT OF SUPPLY CHAIN AGILITY**

To assist companies in better achieving an ASC, a fuzzy inference system (FIS) has been developed for mapping tangible and intangible input space to output space. The proposed FIS has been based on the experiences of experts to evaluate agility of supply chains.

To measure supply chain agility two main steps should be carried out. The first one is development of a conceptual model to identify measurement criteria. In this step capabilities of supply chain have been used to define supply chain agility in three basic segments (that is, sourcing, manufacturing and delivery) . Secondly, ANFIS architecture has been designed that can construct an input-output mapping based on both human knowledge in the form of fuzzy if-then rules with appropriate membership functions and stipulated input-output data based- for deriving agility in supply chains. These two parts are investigated in detail in following sections.

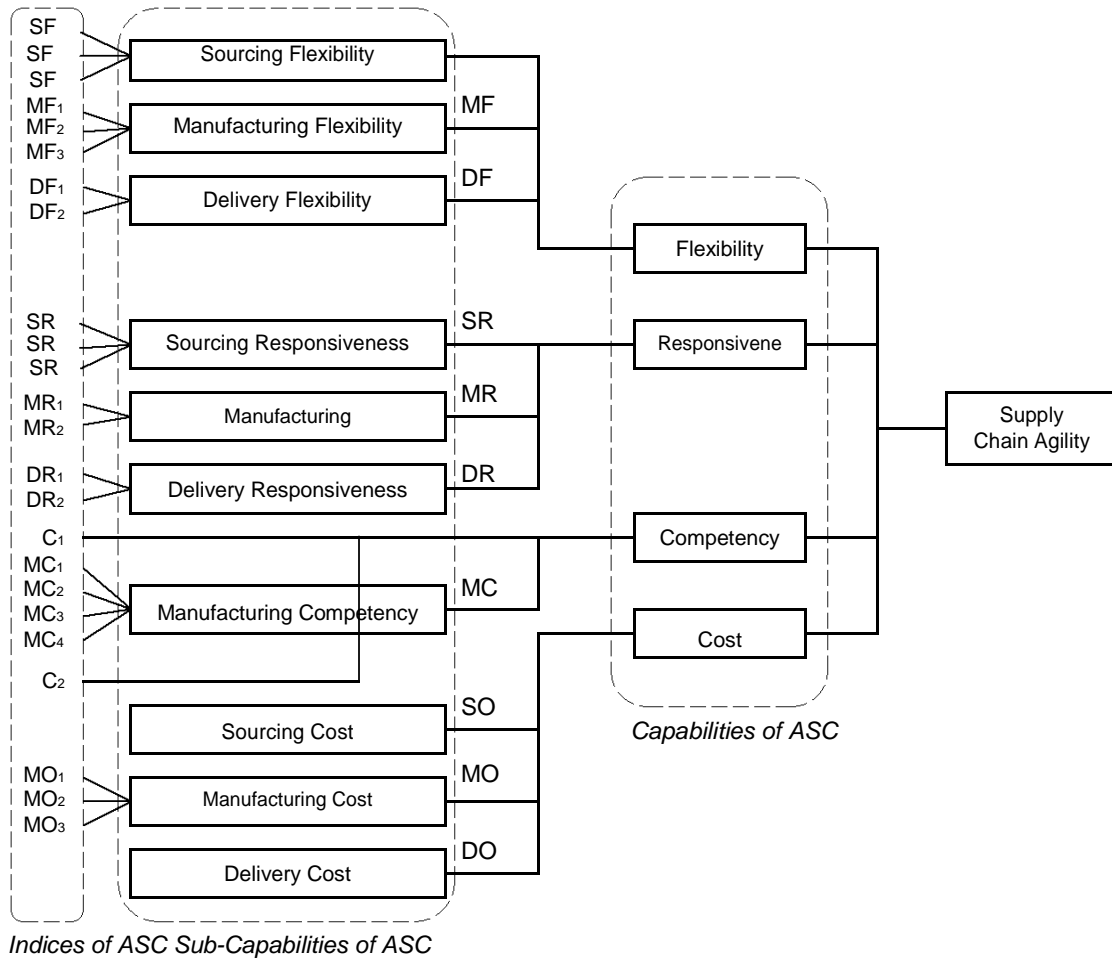
An ASC has various distinguishing capabilities. In order to develop the supply chain agility assessment model, a committee of decision-maker has been formed. The members of the committee are supply chain managers, strategic managers and finance managers as well as academic experts. Necessary brainstorming sessions have been carried out participating all members. In other word, rather than asking the same questions to individual members separately, only one response is received from the group and it is believed to represent the democratic

majority point of view of the group. A conceptual model which has been derived from expert's knowledge is shown in Figure 1. It consists of three main segments of supply chain (sourcing, manufacturing and delivery). As Prater (2001) mentioned the supply chain may be broken down into these three basic segments, the combination of these supply chain segments on the one hand and supply chain's capabilities on the other hand leads to the definition of supply chain agility. Four main attributes and twenty four sub-attributes which are the basis of the conceptual model have been represented in Tables 4 and 5, respectively.

### **DESIGNING ANFIS ARCHITECTURE**

Fuzzy set theory is a perfect mean for modeling uncertainty and imprecision arising from mental phenomena. These are neither random nor stochastic. In the field of artificial intelligence (machine intelligence) there are various ways to represent knowledge. Perhaps the most common way to represent human knowledge is to form it into natural language expressions of the type: IF antecedent, THEN consequence. The form in expression is commonly referred to as the IF-THEN rule-based form. This form generally is referred to as deductive form. It typically expresses an inference such that if we know a fact (premise, hypothesis, antecedent), then we can infer another fact called a conclusion. As this form of knowledge expresses human empirical and heuristic knowledge in our own language of communication which is characterized as shallow knowledge, is quite in the context of linguistics terms. FISs are one of the most applied and popular systems developed for fuzzy reasoning which use fuzzy logic for modeling uncertainty. Fuzzy reasoning, also known as approximate reasoning, is an inference procedure that derives conclusions from a set of fuzzy if-then rules and known facts. The FIS is a popular computing framework based on the concepts of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. It has been applied successfully in a wide range of science and engineering such as control, function approximation, signal processing, simulation, data clustering and data mining and decision support systems. In literature, we can find some other names such as fuzzy rule based system, fuzzy expert system, fuzzy model, fuzzy associative memory, fuzzy logic controller and simply (and ambiguously) fuzzy system. There is several inference techniques developed for fuzzy rule based systems in the literature (Mamdani, 1977; Takagi and Sugeno, 1985).

Mamdani FIS is the first inference methodology, in which inputs and outputs are represented by fuzzy relational equations in canonical rule-based form. In Sugeno FIS, output of the fuzzy rule is characterized by a crisp function. Typical representation of a fuzzy rule in a Sugeno FIS is given by:



**Figure 1.** The conceptual model.

**Table 4.** Attributes of the Conceptual Model

Attribute	Reference List
Flexibility	Sharp et al. 1999, Christopher 2000, Swafford et al. 2006, Sharifi and Zhang 1999; Lin et al., 2006.
Responsiveness and quickness	Sharifi and Zhang, 1999; Goldman et al., 1994; Kidd, 1999; Lin et al., 2006. Vickery and Calantone, 1999; Handfield and Pannesi, 1992; Vickery and Drog, 1999; Tersine and Himminbirg, 1995.
Competency	Lin et al., 2006; Sharif and Zhang, 1999.
Cost	Swafford et al., 2006; Sharifi and Zhang, 1999; Van Hoak et al., 2001. Cooper and Enllarm, 1993; Goldman et al., 1994; Crocitto and Yusuf, 2003.

**Table 5.** Sub-Attributes of the Conceptual Model.

Code	Sub-attributes	References
SF <sub>1</sub>	numerous available suppliers	Sharifi and Zhang, 1999; Goldman et al. 1994.
SF <sub>2</sub>	flexibility in volume	Sharifi and Zhang, 1999; Goldman et al., 1994.
SF <sub>3</sub>	flexibility in variety	Swafford, 2006.
MF <sub>1</sub>	flexible manufacturing system	Powar and Sohal, 2001.
MF <sub>2</sub>	CAM based manufacturing	Ismail and Sharifi, 2005; Towill, 2001.

**Table 5.** Contd.

MF <sub>3</sub>	variety and volume of productions	Sharifi and Zhang 1999
DF <sub>1</sub>	variety of supply schedules for meeting costumers' needs	Swafford, 2006.
DF <sub>2</sub>	flexibility in volume of product	Swafford, 2006.
SR <sub>1</sub>	Adaptability of deliver time by suppliers	Van Hoak, 2001.
SR <sub>2</sub>	suppliers' delivery time	Van Hoak, 2001.
SR <sub>3</sub>	supplier relation management	Copanico,1996; Coyle et al., 1996.
MR <sub>1</sub>	Time of establishment and changing parts	Sharifi and Zhang, 1999.
MR <sub>2</sub>	Responsiveness level to the market changes	Swafford, 2006; Goldman et al., 1994.
C <sub>1</sub>	cooperation and internal-external balance	Agrawal and Shankar, 2002; Lee et al., 1999.
MC <sub>1</sub>	new product introduce	Ismail and Sharifi, 2005.
MC <sub>2</sub>	quality of products or services	Swafford, 2006; Sharifi and Zhang, 1999.
MC <sub>3</sub>	Integration	Cristopher and Towill, 2001.
MC <sub>4</sub>	time of new product development	Goldman, 19994.
C <sub>2</sub>	capabilities of human resources	Willis, 1995; Sharifi and Zhang.
SO	Sourcing cost	Cooper, 1993; Goldman et al., 1994.
MO <sub>1</sub>	production cost	Swafford, 2006; Goldman et al., 1994.
MO <sub>2</sub>	establishment cost	Swafford, 2006; Goldman et al., 1994.
MO <sub>3</sub>	The cost of changing parts	Swafford, 2006; Goldman et al., 1994.
DO	delivery cost	Van Hoak, 2001; Sharifi and Zhang, 1999.

$$\text{IF } x_1 \text{ is } \tilde{A}_1 \text{ AND } x_2 \text{ is } \tilde{A}_2 \dots \text{ AND } x_n \text{ is } \tilde{A}_n \text{ then } y = f(x_1, x_2, \dots, x_n) \quad (1)$$

Where;  $\tilde{A}_i$  are fuzzy sets (fuzzy partitions of each input) and  $y$  is a crisp function. The output of a Sugeno type FIS with  $m$  rules is calculated as the weighted average of crisp functions as follow.

$$y = \frac{\sum_{j=1}^m y_j \prod_{i=1}^n \mu_{A_i}(x_i)}{\sum_{j=1}^m \prod_{i=1}^n \mu_{A_i}(x_i)} \quad (2)$$

Artificial neural networks (ANN) are another efficient tool of artificial intelligence. Fuzzy systems and ANNs have their own advantages and drawbacks. Fuzzy systems have the ability to represent comprehensive linguistic knowledge which is usually given by an expert. However, fuzzy systems do not provide a mechanism to automatically acquire and tune those rules. On the other hand ANNs are adaptive systems that can be trained and tuned from a set of samples. Once they are trained, ANNs can deal with new input data by generalizing the acquired knowledge. Nevertheless, it is very difficult to extract and understand that knowledge. In other words, fuzzy systems and ANNs are complementary paradigms. Neuro-fuzzy systems have been recently proposed to combine the advantages of fuzzy systems and ANNs. Neuro-fuzzy systems are fuzzy systems which use theory of ANNs in order to determine their properties through

processing of data samples. Neuro-fuzzy systems harness the power of the fuzzy logic and ANNs through utilizing the mathematical properties of ANNs in tuning rule-based fuzzy systems that approximate the way human's process information. ANFIS is one of the most popular techniques has been applied frequently in recent years (Jang, 1993) . The most common inference system used in ANFIS is a first order Sugeno-type FIS which is in the form of relation. During the training procedure, rule parameters including antecedent parameters and consequent parameters will be tuned to present more accurate outputs with the minimum error. Some training algorithms has been presented for tuning the ANFIS (Jang, 1993). Least square estimator is used to tune the consequent parameters as back propagation for antecedent parameters. Table 6 summarizes the learning procedure in ANFIS.

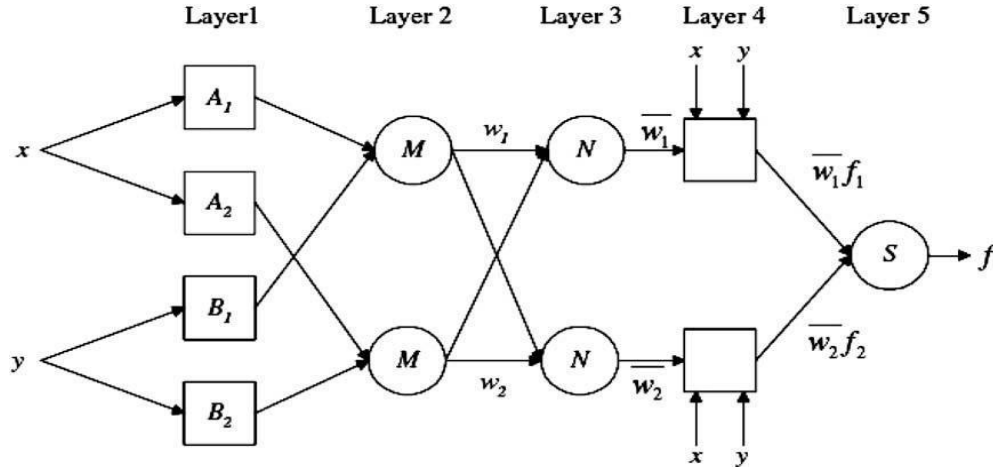
Making a better sense, we briefly describe the architecture of ANFIS applied in our proposed procedures.

Layer 1: All inputs are fuzzified through introducing fuzzy partitions in this layer. A wide range of fuzzy membership functions can be used in this layer. Applying a bell shaped membership function will result in following equation.

$$\mu_{A_i}^1(X) = \frac{1}{1 + \left( \frac{x - c_i}{a_i} \right)^{2b_i}} \quad (3)$$

**Table 6.** Learning procedure in ANFIS.

	<b>Forward pass</b>	<b>Backward pass</b>
Premise parameters	Fixed	Gradient descent
Consequent parameters	Least square estimate	Fixed
Signals	Node outputs	Error rates



**Figure 2.** Structure of ANFIS layers.

Layer 2: Differentiable T -Norms like product operator are used to derive the firing level of rules in the second layer as equation 4.

$$O^2 = w_i = \mu_{A_i}(X) \times \mu_{B_i}(Y) \quad (4)$$

Layer 3: Firing levels of rules are normalized in layer 3 as equation 5.

$$O^3 = \bar{w}_i = w_i / w \quad (5)$$

Layer 4: The output of each node in this layer is simply the product of the normalized firing strength and a first order polynomial (for a first order Sugeno type FIS). Thus, the outputs of this layer are given by equation 6.

$$O^4 = \bar{w}_i \times f_i \quad (6)$$

Layer 5: The final output of system is calculated as the weighted average of previous nodes as equation 7.

$$O^5 = \frac{\sum \bar{w}_i \times f_i}{\sum \bar{w}_i} \quad (7)$$

The schematic structure of our proposed ANFIS, has been represented in Figure 2.

## CASE STUDY DESCRIPTION

The proposed methodology has been applied to Iran Khodro spare parts and After-sale service co. (ISACO).

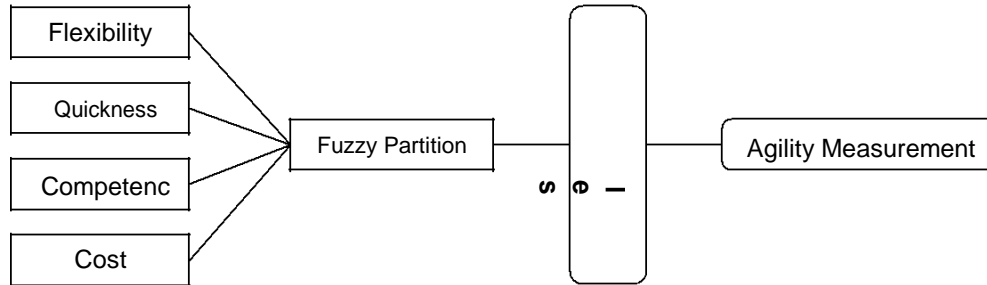
ISACO is an international trading company supplying a wide range of auto spare parts, the company is also distributor for imported brands. Company's domain of activity includes supply automotive parts and services, customer services, dealer and service network, parts sourcing, warranty sales and etc for all automobiles manufactured by Iran Khodro company, the largest automotive manufacturer in the Middle East. In order to carry out agility assessment procedure, a committee of experts have been formed. In this step we constructed the decision team including engineering manager, quality control and insurance manager, purchasing manager and financial manager, then they are requested to evaluate the agility factors that appear in our conceptual model using constructed questionnaire in the range of 0-10. The ANFIS output in our case study is calculated 4.58. Next section shows the implementation of the proposed methodology in our case study through three steps.

## MODEL IMPLEMENTATION

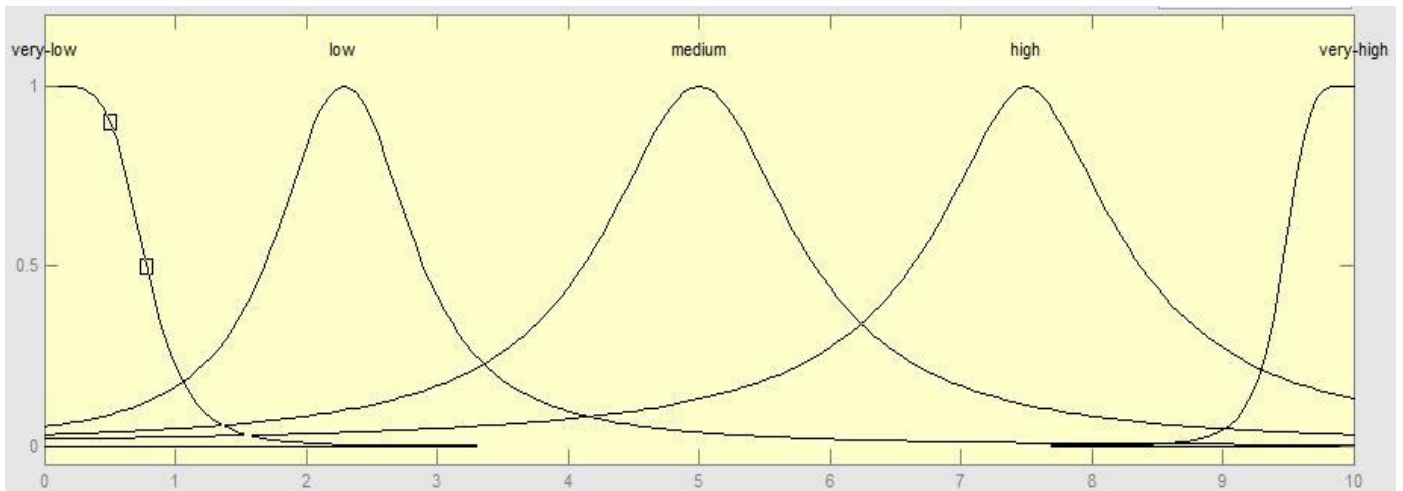
### Step 1. Rule generation

There are different ways for rule generation in ANFIS. The common way is grid partitioning which partitions the





**Figure 3.** Architecture of ANFIS for deriving supply chain agility.



**Figure 4.** Membership functions for output (Agility level).

input space and sets membership functions. Another way is deriving rules by experts and inserting rules to the system, if possible. This way can increase the speed of training and can train the FIS with fewer numbers of observations. Clustering the inputs is another efficient way for rule generation. Traditional K-means and fuzzy C-means are criticized because we should impose the number of clusters. Mountain clustering is an efficient clustering approach which approximates the center of clusters by using a density function called mountain function (Yager and Filev, 1994). This approach uses the grid points as alternatives of cluster centers. We can use data points as clusters center alternatives instead of grid points in mountain clustering. This method is called subtractive clustering (Chiu, 1994). In this paper, subtractive clustering has been used to generate the FIS. It has worth noting that the range of influence, the squash factor, the acceptance ratio and the rejection ratio were set at 0.5, 1.25, 0.5 and 0.15, respectively. Also, for we have used four distinctive ANFIS structure like Figure 2 in order to derive different ASC capabilities (that is, flexibility (FI), competency (Cm), cost (Co), quickness and responsiveness (Qu)). All of these procedures were accomplished

considering their sub criteria shown in Figure 1. The modified rules of trained ANFIS have been represented in the Appendix.

## Step 2. Data generation and training the ANFIS

A questionnaire was designed in order to collect the knowledge from experts in a leading manufacturing company. A set of data which contains 150 opinions were collected. A value equal to 80% of these data was used for training the ANFIS and the rest applied for checking and validation of the model. Figure 3 shows the architecture of the main ANFIS for deriving supply chain agility. The output space (that is, agility level) was partitioned by five membership functions as shown in Figure 4. By inserting ANFIS output to the system we can derive the agility level. Also, the results of an analysis about the trend of training error and checking error have been plotted in Figure 5. We continued the training process to 70 epochs because the trend of checking error started to increase afterward and over fitting occurred. The value of checking error by 70 epochs was 0.07 which

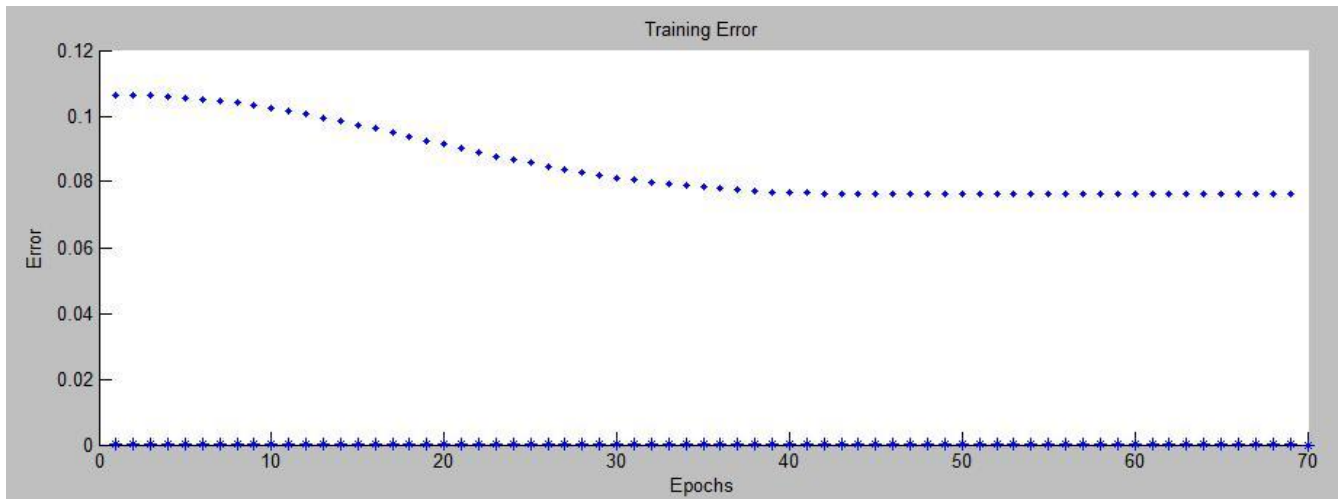


Figure 5. Trend of errors.

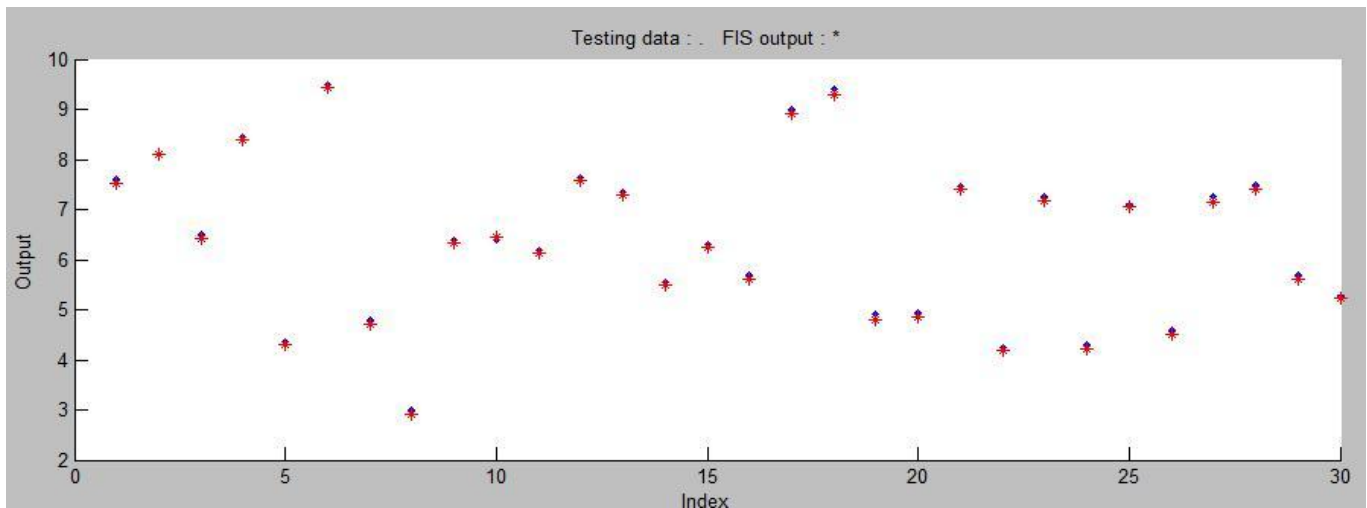


Figure 6. Comparison of ANFIS outputs and testing data.

is acceptable. Then, we derived the value of supply chain agility by a trained ANFIS. The ANFIS output in Iran-Khodro Co. which is a leading car manufacturing company in Iran is calculated 4.58. By matching the selected membership function for agility variable with associated crisp output (that is, 4.58) the supply chain of this company can be labeled "Medium agile". It has worth noting that it should be "High agile" according to experts' opinions.

### Step 3. Validation of the model

As we mentioned in step 2, after receiving experts' opinion about the agility level of supply chain to the set of inputs values, we divided them into two categories. We used a part of data set for training ANFIS (that is, 80%).

The remaining data have been used for validation purpose between ANFIS output and the score which experts have identified. The plot of ANFIS outputs and testing data has been shown in Figure 6. Training data appears at circles with the checking data, appearing as plus in this figure. As it is observed, they conform to each other.

In order to validate the accuracy of proposed ANFIS, we compared the model output with experts' knowledge about agility level which has not been used for training ANFIS. We used mean error and mean magnitude for validating the proposed ANFIS. The mean error between experts' knowledge and the output of model and Mean Magnitude of Relative Error (MMRE) were 0.07 and 0.012, respectively. These are acceptable amounts.

We have also chosen sign test for significant testing. The confidence level was set to 95% and the test statistic was Min ( $w^-$ ,  $w^+$ ). This test is a standard test to test dif-

ference between population means for two paired samples which are equal. We implement this test in MINITAB 15.0 software. The results imply that there is not enough evidence to reject the null hypothesis. Considering P-Value = 0.081 and = 0.05, there is no significant difference between two paired samples. It means our system behavior does not have significant difference with experts' knowledge.

## Conclusion

Since ASC is considered as a dominant competitive advantage in recent years, evaluating supply chain agility can be useful and applicable for managers to make more informative and reliable decisions in anticipated changes of volatile markets. As agility assessment is associated with vagueness and complexity, crisp evaluation are unsuitable and ineffective, so we have developed an ANFIS using ASC capabilities for deriving agility level in supply chain. FIS can be used when there is a shallow knowledge and can be operated with some experiences about the system. The objective of using ANFIS was to optimize the parameters of equivalent fuzzy inference system by applying a learning algorithm using input-output data sets. Fuzzy theory has been used to handle the imprecision and vagueness of ASC's attributes.

This study has been addressed the question of how to measure and improve supply chain agility as we cannot manage what we can not measure. We have implemented the proposed methodology in a leading car manufacturing company in Iran to prove the applicability of the model and the supply chain of this company is labeled "Medium agile" that, according to experts' opinions it should be "High agile".

This evaluation helps managers to perform gap analysis between an existent agility level (Medium) and the desired one (high). Gap analysis assists to identify obstacles within the organization that could block agility achievement. Furthermore, the proposed methodology facilitates a rapid decision making for managers and can also ease a systematic quality improvement as it provides the means for managers to devise an improvement plan. We used mean error and MMRE as criterion sets for validating approach. We also analyzed the proposed model behavior by comparing with experts' knowledge using the sign test and no significant difference was found between these two paired samples.

Further research is necessary to compare efficiency of different models for measuring agility in supply chain. Although this study has just been done in the Iranian manufacturing enterprises, different novelties of proposed procedure (that is, applying ANFIS and using different capabilities for an ASC) made it proper for surveying other real life cases. Considering enablers in agility evaluation and investigating the impact of them on capabilities could be studied in further researches. Also, finding the relations between enablers and capabilities

could be the focus of future research in order to design a dynamic system for ASC measurement.

## Appendix: Fuzzy rule base

1. If (FI is MF1) and (Qu is MF1) and (Cm is MF1) and (Co is MF1) then

$$Ca = 0.3938FI + 0.2314 Qu + 0.07149 Cm + 0.276 Co + 1.013$$

2. If (FI is MF2) and (Qu is MF2) and (Cm is MF2) and (Co is MF2) then

$$Ca = 0.3551 FI + 0.3041 Qu + 0.2337 Cm + 0.2771 Co + 0.6154$$

3. If (FI is MF3) and (Qu is MF3) and (Cm is MF3) and (Co is MF3) then

$$Ca = 0.4117 FI + 0.2206 Qu + 0.1157 Cm + 0.2256 Co + 1.444$$

4. If (FI is MF4) and (Qu is MF4) and (Cm is MF4) and (Co is MF4) then

$$Ca = 0.4425 FI + 0.1921 Qu + 0.1494 Cm + 0.2209 Co + 1.057$$

5. If (FI is MF5) and (Qu is MF5) and (Cm is MF5) and (Co is MF5) then

$$Ca = 0.49 FI + 0.3555 Qu + 0.05525 Cm + 0.2887 Co + 0.05678$$

6. If (FI is MF6) and (Qu is MF6) and (Cm is MF6) and (Co is MF6) then

$$Ca = 0.49 FI + 0.3555 Qu + 0.05525 Cm + 0.2887 Co + 0.05678$$

7. If (FI is MF7) and (Qu is MF7) and (Cm is MF7) and (Co is MF7) then

$$Ca = 0.4882 FI + 0.2391 Qu + 0.1863 Cm + 0.2554 Co + 0.2741$$

8. If (FI is MF8) and (Qu is MF8) and (Cm is MF8) and (Co is MF8) then

$$Ca = 0.4257 FI + 0.3333 Qu + 0.1036 Cm + 0.2566 Co + 0.1446$$

9. If (FI is MF9) and (Qu is MF9) and (Cm is MF9) and (Co is MF9) then

$$Ca = 0.3628 FI + 0.2521 Qu + 0.146 Cm + 0.2699 Co + 0.8343$$

10. If (FI is MF10) and (Qu is MF10) and (Cm is MF10) and (Co is MF10) then

$$Ca = 0.3987 FI + 0.2169 Qu + 0.06065 Cm + 0.312 Co + 1.001$$

11. If (FI is MF11) and (Qu is MF11) and (Cm is MF11)

and (Co is MF11) then

$$Ca = 0.3685 FI + 0.3059 Qu + 0.03984 Cm + 0.3588 Co + 0.2567$$

12. If (FI is MF12) and (Qu is MF12) and (Cm is MF12) and (Co is MF12) then

$$Ca = 0.3698 FI + 0.2428 Qu + 0.2317 Cm + 0.3591 Co + 0.2719$$

13. If (FI is MF13) and (Qu is MF13) and (Cm is MF13) and (Co is MF13) then

$$Ca = 0.3972 FI + 0.2679 Qu + 0.1021 Cm + 0.2685 Co + 1.092$$

14. If (FI is MF14) and (Qu is MF14) and (Cm is MF14) and (Co is MF14) then

$$Ca = 0.3823 FI + 0.338 Qu + 0.003243 Cm + 0.3301 Co + 0.0238$$

15. If (FI is MF15) and (Qu is MF15) and (Cm is MF15) and (Co is MF15) then

$$Ca = 0.599 FI + 0.2217 Qu + 0.1159 Cm + 0.2618 Cu - 0.008236$$

16. If (FI is MF16) and (Qu is MF16) and (Cm is MF16) and (Co is MF16) then

$$Ca = 0.3976 FI + 0.3072 Qu + 0.1425 Cm + 0.3246 Co - 0.007304$$

17. If (FI is MF17) and (Qu is MF17) and (Cm is MF17) and (Co is MF17) then

$$Ca = 0.357 FI + 0.2801 Qu + 0.2215 Cm + 0.2369 Co + 1.257$$

18. If (FI is MF18) and (Qu is MF18) and (Cm is MF18) and (Co is MF18) then

$$Ca = 0.4863 FI + 0.2649 Qu + 0.2265 Cm + 0.2732 Co + 0.0283$$

19. If (FI is MF19) and (Qu is MF19) and (Cm is MF19) and (Co is MF19) then

$$Ca = 0.3132 FI + 0.3717 Qu + 0.07705 Cm + 0.2847 Co + 0.1999$$

20. If (FI is MF20) and (Qu is MF20) and (Cm is MF20) and (Co is MF20) then

$$Ca = 0.46 FI + 0.2736 Qu + 0.1578 Cm + 0.39 Co + 0.05168$$

21. If (FI is MF21) and (Qu is MF21) and (Cm is MF21) and (Co is MF21) then

$$Ca = 0.4067 FI + 0.2867 Qu + 0.179 Cm + 0.2821 Co + 0.2154$$

22. If (FI is MF22) and (Qu is MF22) and (Cm is MF22) and (Co is MF22) then

$$Ca = 0.5739 FI + 0.2274 Qu + 0.1369 Cm + 0.2147 Co - 0.01302$$

23. If (FI is MF23) and (Qu is MF23) and (Cm is MF23) and (Co is MF23) then

$$Ca = 0.4566 FI + 0.2765 Qu + 0.07887 Cm + 0.3353 Co + 0.004836$$

24. If (FI is MF24) and (Qu is MF24) and (Cm is MF24) and (Co is MF24) then

$$Ca = 0.6866 FI + 0.4411 Qu + 0.2265 Cm + 0.5183 Co + 0.1429$$

25. If (FI is MF25) and (Qu is MF25) and (Cm is MF25) and (Co is MF25) then

$$Ca = 0.3114 FI + 0.5596 Qu + 0.004569 Cm + 0.348 Co - 0.02812$$

26. If (FI is MF26) and (Qu is MF26) and (Cm is MF26) and (Co is MF26) then

$$Ca = 0.1642 FI + 0.0246 Qu + 0.5982 Cm + 0.3887 Co + 0.3308$$

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