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An Adaptive Neuro Fuzzy Inference System for Supply chain Agility Evaluation

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KEYWORDS

Agility;
Agile supply chain;
Adaptive Neuro Fuzzy Inference System (ANFIS);
Supply chain; Supply chain management

ABSTRACT

Nowadays, in turbulent and violate global markets, agility has been considered as a fundamental characteristic of a supply chain needed for survival. To achieve the competitive edge, companies must align with suppliers and customers to streamline operations, as well as agility beyond individual companies. Consequently Agile Supply Chain (ASC) is considered as a dominant competitive advantage. However, so far a little effort has been made for designing, operating and evaluating agile supply chain in recent years. Therefore, in this study a new approach has been developed based on Adaptive Neuro Fuzzy Inference System (ANFIS) for evaluating agility in supply chain considering agility capabilities such as Flexibility, Competency, Cost, Responsiveness and Quickness. This evaluation helps managers to perform gap analysis between existent agility level and the desired one and also provides more informative and reliable information for decision making. Finally the proposed model has been applied to a leading car manufacturing company in Iran to prove the applicability of the model.

1. Introduction

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 [23]. 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" [23]. Other related definitions of agility have been proposed since the construct is still in its initial stage of application to organizational phenomenon.

For instance, [21] has defined agility as" the ability to detect opportunities for innovation and seize those competitive market opportunities by assembling requisite assets, knowledge and relationships with speed and surprise". Researchers studying agility have emphasized that firm's ability to respond is a key measure of agility [7]. While agility is accepted as a wining strategy for growth, even a basis for survival in certain business environments, the idea of creating agile supply chain has become a logical step for

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companies [11]. Agility in supply chain, according to [11], 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. [24] has defined agility as the ability of a supply chain to rapidly respond to changes in market and customers' demands. 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 [14]. ASC has been advocated at the 21st century supply chain paradigm, and is seen as a winning strategy for companies wishing to become national and international leader [35]. However, the ability to build agile relationships has developed more slowly than anticipated [24] and also little effort has been made to build ASC assessment methodology in recent years. After embracing ASC an important question must be asked: How companies can evaluate agility in supply chains? This evaluation is essential for managers as it assists in achieving agility effectively by performing gap analysis between existent agility level and the desired one and 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.

Lack of 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 Artificial Neural Network 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.

This paper is organized as follows. Section 2 reviews the literature on Agile Supply Chain (ASC) and criticizes it (paper review); Section 3 represents the conceptual model using agile supply chain's capabilities such as Flexibility, Competency, Cost, Responsiveness and Quickness, and also contains an adaptive neuro fuzzy inference system (ANFIS) model which is proposed to evaluate agility in supply chains; Section four describes case study; In section 5 the applicability of the proposed model has been tested by using a leading car manufacturing company in Iran. Finally, in section 6 the main conclusion of this study is discussed.

2. Paper Preview

In the 1990s, the research interest was focused on finding systematic ways for manufacturer to approach agility in their supply chains. To help managers to attain a sustainable competitive advantage, numerous studies have attempted discuss agility in organizations. Table 1 provides various ways in which agility has been defined.

However, the definition of agility is still fuzzy, mainly because it largely deals with things already being addressed by industry and which are covered by existing research projects and programs. Since the introduction of agility paradigm, the potential benefits of implementing it in companies were soon widely recognized by researchers and industry (Sun et al. 2005). The paradigm, in its various forms now is recognized as a winning competitive advantage [5-4-7-8-13-16-23-27-33].

Parallel developments in areas of agility and Supply Chain Management (SCM) led to introduction of an agile supply chain [5]. 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 chains has become a logical step for companies [11].

According to Ismail 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. In 2000, Christopher has identified that Agile Supply Chain (ASC) requires various distinguishing capabilities to respond changing environments. These capabilities include four main elements [24]:

- Responsiveness, which is the ability to identify changes and respond to them quickly, reactively or proactively, and also to recover from them.
- Competency, which is the ability to efficiently and effectively realize enterprise objectives.
- Flexibility, which is the ability to implement different process and apply different facilities to achieve the same goal
- 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 researches can be categorized in three main categories:

- Conceptual model
- Empirical
- Expert judgment

Many researchers provide conceptual over views, different reference and mature models of agility. For instance [14] presented that to become a truly agile supply chain key enablers are classified into four categories:

Collaborative relationship as the supply chain strategy, Process integration as the foundation of supply chain, Information integration as the infra structure of supply chain and Customer /marketing sensitivity as the mechanism of supply chain. Table 2 provides some conceptual models that have been used in this study and their main points.

Tab. 1. Definition of Agility

No	Authors	Definition of agility
1	Kidd (1994)	Agility is synthesized use of developed and well-known technologies and methods of manufacturing. That is, it is mutuality compatible with lean manufacturing, Computer Integrated Manufacturing, Total Quality Management, Material Requirement Planning, Business Process Reengineering, employee empowerment.
2	Goldman, Negal, (1995)	Agility means delivering value to customers, being ready for change, valuing human knowledge and skills and forming virtual partnership.
3	Gunasekaran (1998)	Agility is the capability of reaching unpredictable market changes in a cost-effective way, simultaneously prospering from the uncertainty.
4	Bullinger (1999)	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.
5	Yusuf et al.(1999)	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.
6	Naylor et al.(1999)	Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a violate marketplace
7	Christopher (2000)	Agility is defined as the ability of an organization to respond rapidly to changes in demand both in terms of volume and variety.
8	Van Hoek (2001)	Agility is all about customer responsiveness and market turbulence and requires specific capabilities that can be achieved using "lean thinking"
9	Stratton& Warburton (2003)	Innovative products and unstable demand typify agile supply drivers.
10	Harrison & Van Hoak (2005)	Agility is a supply chain wide capability that aligns organizational structures, information systems, logistics processes and, in particular, mindsets.

Tab. 2. Conceptual model based studies

Conceptual Model		
Authors	**Year**	**Main points**
Gunasekaran	1999	4 key dimensions: strategies, Tec, people and system
Martin Christopher	2000	ASC's enablers
Van Hoak	2001	Agility audit in supply chains
Denis Towill	2001	Integrated model for enabling ASC: principles, programs, actions
Y.Yusuf	2003	Agile supply chain capabilities
Ching Torang Lin	2005	A conceptual model for assessing agility in supply chain
Ashis Agarval	2006	Identifying agility index in supply chain
Sowford	2006	A process approach to ASC
Daniel Vazquez	2007	Conceptual model for assessing ASC, Agility drivers, enablers and outcomes
Gunasekaran	2008	Modeling and control of supply chain

Table 3 illustrates the comparison between empirical and expert judgment considering some main attributes such as Simplicity, Generalization, Model sensitivity to sampling, the type of data (fuzzy-crisp),the type of variables , calculation speed .

Tab. 3. Comparison of Empirical and Expert judgment based studies

	Author	Description	Simplicity	Generalization	Model sensitivity to sampling	Data	Variable	Calculation speed
Empirical studies	Damien J.Power 2001	Critical success factors in agile supply chain using regression analysis	Low	–	High	Crisp	continuum	Low
	Margaret Weber 2002	Agility assessment in virtual organization	Low	–	High	Crisp	contnuum	low
	Y.Yusuf 2003	Study the relation between Capabilities and objectives in ASC	medium	–	High	Crisp	continuum	medium
	Luica Avella 2007	Using structural equation to test conceptual model	medium	–	High	Crisp	contnuum	Medium
	Hessami. 2008	Identifying effective factors on Agile supply chain	medium	–	High	Crisp	continuum	Medium
Expert Judgment based studies	Peidue Ihu 2002	Evaluation model of ASC's performance	medium	medium	Low	Fuzzy	Linguistic Term	Medium
	Ching Torng 2005	Assessing agility using experts judgments	medium	medium	Low	Fuzzy	Linguistic Term	Medium
	Ashish Agrawal 2005	Modeling the metrics of lean, agile and leagile supply chain based on ANP model	Low	High	Low	Crisp	continuum	Low
	Vipul Jain 2007	Evaluating agility in supply chain based on rule mining	Low	–	High	fuzzy	Linguistic Term	High

The aggregation of above approaches can be criticized as they haven't considered the impact of enablers in assessing agility in supply chains and also the scale used to aggregate the agility capabilities has two limitations:

(l) Such techniques do not consider the ambiguity and multi possibility associated with mapping of individual judgment to a number and (2) 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 assessment, most measures are described subjectively using linguistic terms, and cannot be handled effectively using conventional assessment approaches.

However, 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 decisions [14].

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

3. Methodology

To evaluate supply chain agility two main steps should be carried out: Firstly, a conceptual model has been developed based on literature review to identify measurement criteria, in this step capabilities of supply chain have been used to define supply chain agility in three basic segments: Sourcing, Manufacturing and Delivery.

Secondly, an 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.

A. Model Construction

As mentioned earlier, agile supply chain concerns change, uncertainty and unpredictability within business environment and makes appropriate responses to change. Therefore, an agile supply chain has various distinguishing capabilities. In order to carry out the supply chain agility assessment model, a committee of decision-maker has been formed.

The member of the committee are supply chain managers, strategic managers and finance managers academic experts. It is assumed that the group members will carry out necessary brainstorming sessions and reach to consensus. 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 and literature is shown in figure1 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 (Table 4) and twenty four sub-attributes (Table 5) are the basis of the conceptual model.

Tab. 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 & Quickness	Sharifi and Zhang 1999, Goldman et al. 1994, kidd 1999, Lin et al 2006 Vickery, Calantone 1999, Handfield & Pannesi 1992, Vickery & Drog 1999, Tersine & 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 & Enllarm 1993, Goldman et al. 1994, Crocitto & Yusuf 2003

Tab. 5. Sub- attributes of the conceptual model

Code	Sub-attributes	Reference
SF_1	numerous available suppliers	Sharifi and Zhang 1999, Goldman et al. 1994
SF_2	flexibility in volume	Sharifi and Zhang 1999, Goldman et al. 1994
SF_3	flexibility in variety	Swafford 2006
MF_1	flexible manufacturing system	Powar & Sohal 2001
MF_2	CAM based manufacturing	Ismail & Sharifi 2005, Towill 2001
MF_3	variety and volume of productions	Sharifi and Zhang 1999
DF_1	variety of supply schedules for meeting costumers' needs	Swafford 2006

Code	Sub-attributes	Reference
DF_2	flexibility in volume of product	Swafford 2006
SR_1	Adaptability of deliver time by suppliers	Van Hoak 2001
SR_2	suppliers' delivery time	Van Hoak 2001
SR_3	supplier relation management	Copanico 1996, Coyle et al.1996
MR_1	Time of establishment and changing parts	Sharifi and Zhang 1999
MR_2	Responsiveness level to the market changes	Swafford 2006, Goldman et al. 1994
C_1	cooperation and internal-external balance	Agrawal & Shankar 2002, Lee et al.1999
MC_1	new product introduce	Ismail & Sharifi 2005
MC_2	quality of products or services	Swafford 2006, Sharifi & Zhang 1999
MC_3	integration	Cristopher & Towill 2001
MC_4	time of new product development	Goldman 19994
C_2	capabilities of human resources	Willis 1995, Sharifi & Zhang
SO	Sourcing cost	Cooper 1993, Goldman et al.1994
MO_1	production cost	Swafford 2006, Goldman et al.1994
MO_2	establishment cost	Swafford 2006, Goldman et al.1994
MO_3	The cost of changing parts	Swafford 2006, Goldman et al.1994
DO	delivery cost	Van Hoak 2001, Sharifi & Zhang 1999

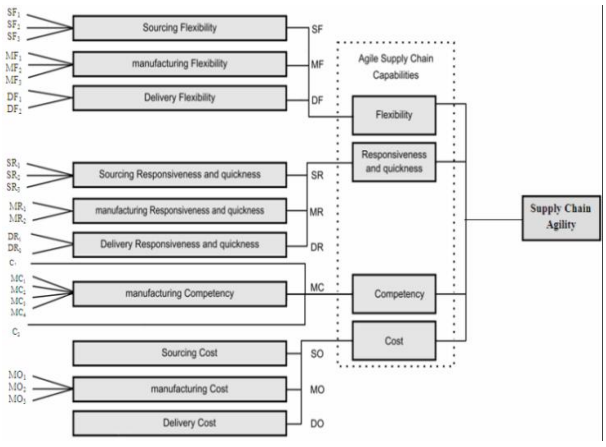

Fig. 1. The conceptual model

B. Designing ANFIS Architecture

Fuzzy set theory is a perfect mean for modeling uncertainty (or imprecision) arising from mental phenomena, which 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 premise (antecedent), THEN conclusion (consequent)

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, derive, another fact called a conclusion. This form of knowledge representation, Characterized as shallow knowledge, is quite in the context of linguistics because it expresses human empirical and heuristic knowledge in our own language of communication. Fuzzy inference systems are one of the most applied and popular systems developed for fuzzy reasoning which use fuzzy logic for modeling uncertainty (or imprecision) arising from mental phenomena, which are neither random nor stochastic. 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 fuzzy inference system 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. In the literature, there are several inference techniques developed for fuzzy rule-based systems, such as Mamdani and Sugeno [15-28]. 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:

$$If \quad x_1 is \tilde{A}_1 and\ x_2 is \tilde{A}_2 ..and\ x_n \ is \tilde{A}_n then\ y = f\left(x_1, x_2, ..., x_n\right) \tag{1}$$

Where $\tilde{A}_i$ are fuzzy sets (fuzzy partitions of each input) and y is a crisp function. To calculate the final output value of a Sugeno FIS, $\bar{y}$, from j=1 to m output subsets, y_j, weighted by input fuzzy set membership values, $\mu_{Ai,}$ for i=1 to n antecedents as :

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

In a sugeno model each rule has a crisp output, given by a function; because of this the overall output is obtained via a weighted average defuzzification (Eq. 2), as shown in figure 2
This process avoids the time-consuming methods of defuzzification necessary in the Mamdani model.

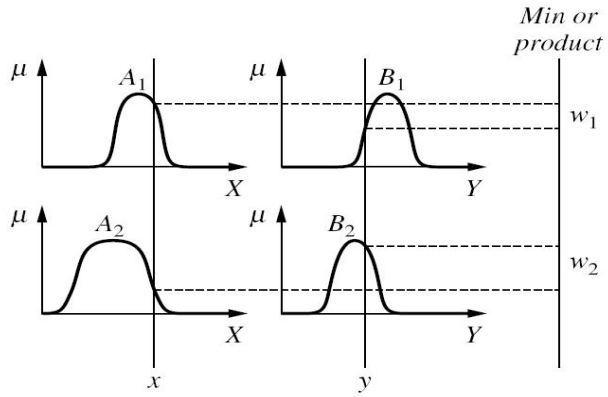

Fig.2. The Sugeno fuzzy model

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 – given for example by a human expert and perform reasoning by means of rules. However, fuzzy systems do not provide a mechanism to automatically acquire and/or tune those rules. On the other hand neural-networks are adaptive systems that can be trained and tuned from a set of samples. Once they are trained, neural-networks 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 neural-networks 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 artificial neural networks (ANNs) theory in order to determine their properties (fuzzy sets and fuzzy rules) by processing data samples. Neuro-fuzzy systems harness the power of the two paradigms: fuzzy logic and ANNs, by utilizing the mathematical properties of ANNs in tuning rule-based fuzzy systems that approximate the way human's process information. Adaptive neuro fuzzy inference system (ANFIS) was proposed by Jang (1993) is one of the most popular techniques has been applied frequently in recent years. The most common inference system used in ANFIS is a first order Sugeno FIS which is in the form (1). During the training procedure, rule parameters including antecedent parameters and consequent parameters will be tuned to present more accurate outputs with the minimum error. Jang [12] presented some training algorithms for tuning the ANFIS. Least square estimator is used to tune the consequent parameters as back propagation for antecedent parameters. Table 6 summarizes the learning procedure in ANFIS

Tab. 6. Learning Procedure in ANFIS

	Forward pass	**Backward pass**
Premise parameters	Fixed	Gradient descent
Consequent parameters	Least square estimate	Fixed
Signals	Node outputs	Error rates

Now we briefly describe the architecture of ANFIS and its layers.

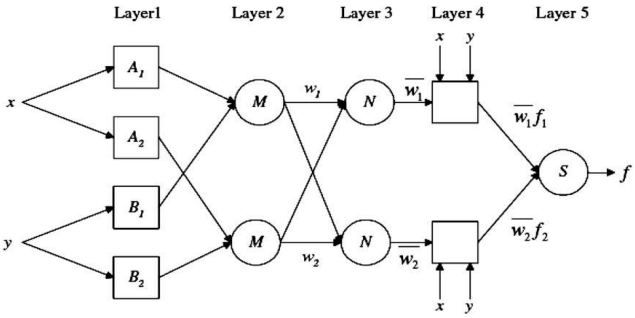

Fig. 3. Structure of ANFIS layers

Layer 1: in this layer we fuzzify all inputs by introducing fuzzy partitions. A wide range of fuzzy membership functions such as triangular and bell shaped membership functions. For example, by applying a bell shaped membership function we have:

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

Layer 2: in the second layer, differentiable T-Norms like product operator are used to derive the firing level of rules as below:

$$O_i^2 = w_2 = \mu_{A_i}(X)\,\mu_{B_i}(Y) \tag{4}$$

Layer 3: firing levels of rules are normalized as below:

$$O_i^3 = \overline{w}_i = \frac{w_i}{\sum w_i} \tag{5}$$

Layer 4: In this layer, 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 model). Thus, the outputs of this layer are given by:

$$O_i^4 = \overline{w}_i\, f \tag{6}$$

Layer 5: in the last layer the final output of system is calculated as the weighted average of previous nodes:

$$O^5 = \sum \overline{w}_i \, f_i \tag{7}$$

4. Case Study Distribution

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 distributer 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 has 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.

5. Model Implementation

Step 1: Rule Generation

There are some ways for rule generation in ANFIS. The common way is grid partitioning which partitions the 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 was developed by Yager and Filev [34] is an efficient clustering approach which approximates the center of clusters by using a density function called mountain function.

This approach uses the grid points as alternatives of cluster centers. Chiu [3] used data points as clusters center alternatives instead of grid points in mountain clustering and called the method subtractive clustering. In this paper, subtractive clustering has been used to generate the FIS the range of influence, the squash factor, the acceptance ratio, and the rejection ratio were set at o.5, 1.25, 0.5, and 0.15 respectively during the process of subtractive clustering. Also, for deriving flexibility (FI), Competency (Cm), Cost (Co), Quickness and Responsiveness (Qu) we have used four sub ANFIS (Figure 4.) according to their sub criteria shown in conceptual model and the modified rules of trained ANFIS have been shown in the appendix.

Step2: Data Generation and Training the ANFIS

In order to collect the knowledge from experts a questionnaire was used which was made by randomly generating the combinations of flexibility, competency, cost, responsiveness and quickness in the range of 0-10. 150 data set were collected of which 120 used for training the ANFIS and the rest for checking and validation of the model. Figure 4 shows the architecture of the main ANFIS for deriving supply chain agility. The output space (agility level) was partitioned by five membership functions as shown in figure 5. By inserting ANFIS output to the system we can derive the agility level. Also, the trend of training error and checking error has been shown in figure 6. 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 is acceptable. Then we derived the value of supply chain agility by a trained ANFIS. The ANFIS output in Iran Khodro (a leading car manufacturing company) is calculated 4.58. By matching the selected membership function for agility variable with crisp output (4.58) the supply chain of this company can be labeled "Medium agile" that, according to experts' opinions, it should be "High agile".

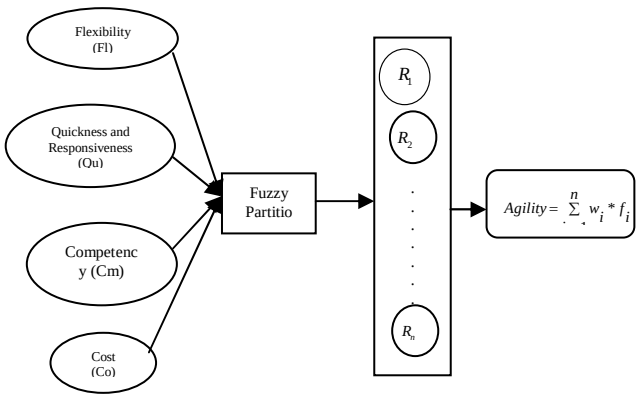

Fig.4. Architecture of ANFIS for deriving supply chain agility

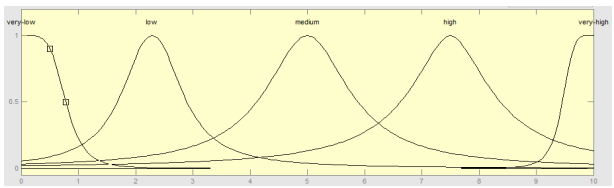

Fig. 5. Membership functions for output (Agility level)

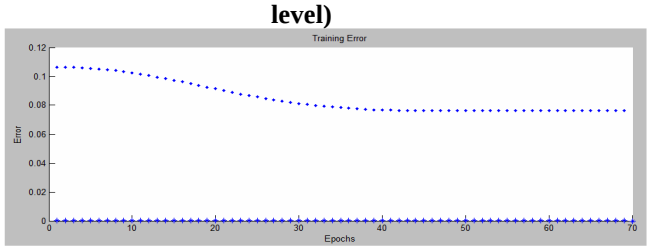

Fig. 6. Trend of errors

Step 3: Validation of the Model

As we mentioned in step 2, after receiving the data from experts about their opinions of agility level of supply chain to the set of inputs values, we divided them into two categories. We used one data set for training ANFIS and the other 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 7. In this plot training data appears at circles with the checking data, appearing as plus, so 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 was 0.07 and Mean magnitude of relative error (MMRE) of 0.012 was observed that are acceptable amounts. We have also chosen sign test for significant testing. It is a standard test to test difference between population means for two paired samples which are equal.

The hypothesis test is as follows:

Ho: $\mu 1=\mu 2$

H1:$\mu 1\neq\mu 2$

Test statistic=Min (w-, w+)

Alpha: Typically set to 0.05

Conclusion: the null hypothesis will be rejected if the test statistic is in critical region.

After the hypothesis testing (sign test) PVALUE is calculated .081, considering α=0. and pVALUE >α. Since H0 cannot be rejected, there is no significant difference between two paired samples. It means our system behavior doesn't have significant difference with experts' knowledge. And it should be mentioned that the current validation of ANFIS model is also based on experts' knowledge as the data about agility level of supply chain is currently not available.

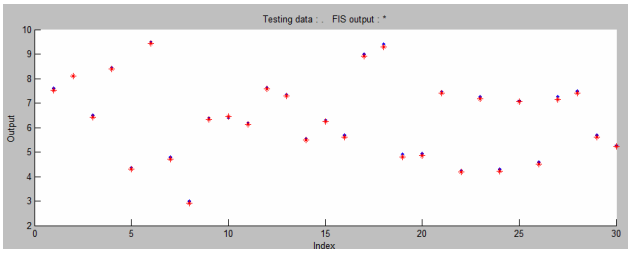

Fig. 7. Comparison of ANFIS outputs and testing data

6. Conclusion

Since Agile Supply Chain (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 (conventional) evaluation are unsuitable and ineffective, so we have developed an Adaptive Neuro Fuzzy Inference System (ANFIS) using ASC capabilities for deriving agility level in supply chain. Fuzzy inference system 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 has the following features: It 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 mean magnitude of relative error (MMRE) as criteria 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, the proposed methodology is applicable to other countries' manufacturing companies, too. 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 assessment.

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Appendix

This Appendix shows the fuzzy rule base. There are 26 fuzzy rules:

1. If (Fl is MF1) and (Qu is MF1) and (Cm is MF1) and (Co is MF1) then
$Ca = 0.3938\,Fl + 0.2314\,Qu + 0.07149\,Cm + 0.276\,Co + 1.013$

2. If (Fl is MF2) and (Qu is MF2) and (Cm is MF2) and (Co is MF2) then
$Ca = 0.3551\,Fl + 0.3041\,Qu + 0.2337\,Cm + 0.2771\,Co + 0.6154$

3. If (Fl is MF3) and (Qu is MF3) and (Cm is MF3) and (Co is MF3) then
$Ca = 0.4117\,Fl + 0.2206\,Qu + 0.1157\,Cm + 0.2256\,Co + 1.444$

4. If (Fl is MF4) and (Qu is MF4) and (Cm is MF4) and (Co is MF4) then
$Ca = 0.4425\,Fl + 0.1921\,Qu + 0.1494\,Cm + 0.2209\,Co + 1.057$

5. If (Fl is MF5) and (Qu is MF5) and (Cm is MF5) and (Co is MF5) then
$Ca = 0.49\,Fl + 0.3555\,Qu + 0.05525\,Cm + 0.2887\,Co + 0.05678$

6. If (Fl is MF6) and (Qu is MF6) and (Cm is MF6) and (Co is MF6) then
$Ca = 0.49\,Fl + 0.3555\,Qu + 0.05525\,Cm + 0.2887\,Co + 0.05678$

7. If (Fl is MF7) and (Qu is MF7) and (Cm is MF7) and (Co is MF7) then
$Ca = 0.4882\,Fl + 0.2391\,Qu + 0.1863\,Cm + 0.2554\,Cu + 0.2741$

8. If (Fl is MF8) and (Qu is MF8) and (Cm is MF8) and (Co is MF8) then
$Ca = 0.4257\,Fl + 0.3333\,Qu + 0.1036\,Cm + 0.2566\,Co + 0.1446$

9. If (Fl is MF9) and (Qu is MF9) and (Cm is MF9) and (Co is MF9) then
$Ca = 0.3628\,Fl + 0.2521\,Qu + 0.146\,Cm + 0.2699\,Co + 0.8343$

10. If (Fl is MF10) and (Qu is MF10) and (Cm is MF10) and (Co is MF10) then
$Ca = 0.3987\,Fl + 0.2169\,Qu + 0.06065\,Cm + 0.312\,Co + 1.001$

11. If (Fl is MF11) and (Qu is MF11) and (Cm is MF11) and (Co is MF11) then
$Ca = 0.3685\,Fl + 0.3059\,Qu + 0.03984\,Cm + 0.3588\,Co + 0.2567$

12. If (Fl is MF12) and (Qu is MF12) and (Cm is MF12) and (Co is MF12) then
$Ca = 0.3698\,Fl + 0.2428\,Qu + 0.2317\,Cm + 0.3591\,Co + 0.2719$

13. If (Fl is MF13) and (Qu is MF13) and (Cm is MF13) and (Co is MF13) then
$Ca = 0.3972\,Fl + 0.2679\,Qu + 0.1021\,Cm + 0.2685\,Co + 1.092$

14. If (Fl is MF14) and (Qu is MF14) and (Cm is MF14) and (Co is MF14) then
$Ca = 0.3823\,Fl + 0.338\,Qu + 0.003243\,Cm + 0.3301\,Co + 0.0238$

15. If (Fl is MF15) and (Qu is MF15) and (Cm is MF15) and (Co is MF15) then
$Ca = 0.599\,Fl + 0.2217\,Qu + 0.1159\,Cm + 0.2618\,Cu - 0.008236$

16. If (Fl is MF16) and (Qu is MF16) and (Cm is MF16) and (Co is MF16) then
$Ca = 0.3976\,Fl + 0.3072\,Qu + 0.1425\,Cm + 0.3246\,Co - 0.007304$

17. If (Fl is MF17) and (Qu is MF17) and (Cm is MF17) and (Co is MF17) then
$Ca = 0.357\,Fl + 0.2801\,Qu + 0.2215\,Cm + 0.2369\,Co + 1.257$

18. If (Fl is MF18) and (Qu is MF18) and (Cm is MF18) and (Co is MF18) then
$Ca = 0.4863\,Fl + 0.2649\,Qu + 0.2265\,Cm + 0.2732\,Co + 0.0283$

19. If (Fl is MF19) and (Qu is MF19) and (Cm is MF19) and (Co is MF19) then
$Ca = 0.3132\,Fl + 0.3717\,Qu + 0.07705\,Cm + 0.2847\,Co + 0.1999$

20. If (Fl is MF20) and (Qu is MF20) and (Cm is MF20) and (Co is MF20) then
$Ca = 0.46\,Fl + 0.2736\,Qu + 0.1578\,Cm + 0.39\,Co + 0.05168$

21. If (Fl is MF21) and (Qu is MF21) and (Cm is MF21) and (Co is MF21) then
$Ca = 0.4067\,Fl + 0.2867\,Qu + 0.179\,Cm + 0.2821\,Co + 0.2154$

22. If (Fl is MF22) and (Qu is MF22) and (Cm is MF22) and (Co is MF22) then
$Ca = 0.5739\,Fl + 0.2274\,Qu + 0.1369\,Cm + 0.2147\,Co - 0.01302$

23. If (Fl is MF23) and (Qu is MF23) and (Cm is MF23) and (Co is MF23) then
$Ca = 0.4566\,Fl + 0.2765\,Qu + 0.07887\,Cm + 0.3353\,Co + 0.004836$

24. If (Fl is MF24) and (Qu is MF24) and (Cm is MF24) and (Co is MF24) then
$Ca = 0.6866\,Fl + 0.4411\,Qu + 0.2265\,Cm + 0.5183\,Co + 0.1429$

25. If (Fl is MF25) and (Qu is MF25) and (Cm is MF25) and (Co is MF25) then
$Ca = 0.3114\,Fl + 0.5596\,Qu + 0.004569\,Cm + 0.348\,Co - 0.02812$

26. If (Fl is MF26) and (Qu is MF26) and (Cm is MF26) and (Co is MF26) then
$Ca = 0.1642\,Fl + 0.0246\,Qu + 0.5982\,Cm + 0.3887\,Co + 0.3308$