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A Fuzzy Logic-Based Methodology for Bullwhip Effect Quantifying

M.Shoar[1],J.Jassbi[1], A.Makui[2]
1Department of Industrial Management, Islamic Azad University, Science and Research, Tehran, Iran
2Department of Industrial Engineering, Iran Science and Technology University, Tehran, Iran
Maryam_shoar@yahoo.com

***Abstract*—The Bullwhip Effect (BE) has been considered as one of the most important issues in supply chain management. Although it is well established that demand signal processing, order batching, gaming and pricing are the main sources that lead to the BE, but sometimes we are facing problems in qualifying it. One reason for that could be the incomplete, inconsistent, uncertain or unclear data. In that situation, the BE quantification is the most significant activities which can be performed by us. Therefore, the aim of this paper is to create a methodology which use a fuzzy inference system (FIS) based on the experience of experts to quantify the BE to reducing its negative impacts.**

Keywords- Bullwhip effect; Fuzzy inference system (FIS); Qualification; Supply chain

I. INTRODUCTION

Since the introduction of the term supply chain management (SCM) in 1982, it has received ever-growing interest both in the literature and industrial practice. The main reason for this interest is that it has so many facets. The tasks of accomplishing the aims of the SCM are so demanding that is more an ongoing endeavor than a single short term project. This broad scope of the SCM faces the difficulty of finding a suitable definition and description of the term [1].One of the most important problems which have been addressed in supply chains is bullwhip effect (BE). The bullwhip effect refers to the phenomenon of demand variability amplification along a supply chain while moving upstream.

The main challenge in managing the BE is to reduce inefficiencies and attenuate its propagation throughout the supply chain, so that optimization of resources used in different levels becomes possible. To attain that, managers must single out what are the causes of the BE in a supply chain and learn how to measure its intensity [2].

The quantification of the BE has been an important research topic in the field of supply chain management. The BE researches can be divided in four main categories:

- Conceptual framework
- Analytical framework
- Simulation framework
- Heuristic framework

Table 1 provides some conceptual frameworks that have been proposed.

Table 2 illustrates the comparison of attributes between analytical, simulation and heuristic frameworks.

According to above literature review, sometimes, we are facing problems in its qualification. One reason for that is the incomplete, inconsistent, uncertain or unclear data. In this situation, the BE quantification is the most significant activities which could be done by us. In the present paper, the BE quantification using fuzzy inference system (FIS) is present. The novelty of this research is in considering four factors to create a methodology to be more flexible in measuring the BE. Therefore, we have constructed a fuzzy rule based system based on the experience of experts to estimate the BE in supply chains. One actual manufacturing supply chains was used as case study to indicate that the model can be useful for managers to quantify and reduce the BE.

TABLE I. SOME CONCEPTUAL FRAMEWORKS

Year	Author	Description
1997	Lee et al	The bullwhip effect
2006	Miragliotta	Layers and mechanisms: A new taxonomy for the bullehip effect
2006	Desney et al	On bullwhip in supply chains – historical review, present practice and expected future impact
2007	Alony and Munoz	The bullwhip effect in complex supply chain

TABLE II. THE COMPARISON BETWEEN ANALYTICAL, SIMULATION AND HEURISTIC FRAMEWORKS.

Year	Author	Description	Approach	The cause of BE
2000	Lee et al	The value of information sharing in two-level supply chain	Analytical	Demand signal processing
2000	Chen, Drezner and Levi	Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead time and information	Analytical	Demand signal processing, Information
2001	Riddalls and Bennet	Optimal control of batched production and its effect on amplification	Analytical	Order batching
2004	Holland, Sodhi	Quantifying the effect of batch size and order error on the Bullwhip Effect using simulation	Simulation	Order batching

Year	Author	Description	Approach	The cause of BE
2000	Lee et al	The value of information sharing in two-level supply chain	Analytical	Demand signal processing
2008	Tozan and Vayvay	Fuzzy and Neuro-Fuzzy forecasting approaches to whiplash effect in supply chains	heuristic	Demand signal processing
2008	Fazel Zarandi et al	A fuzzy agent-based model for reduction of bullwhip effect in supply chain	heuristic	Demand signal processing
2008	Wangphanich, Kara	A simulation model of Bullwhip Effect on a multi – stage Supply Chain	Simulation	Inventory control
2009	Makui et al	The bullwhip effect and Lyapunov exponent	Analytical	Pricing

II. METHODOLOGY

A. CONCEPTUAL MODEL

The four main cases of the BE have been identified by Lee et al. which has become the standard for this phenomenon. They include [3]:

- Demand Signal Processing – where amplification is introduced as a result of companies responding to feedback loops and time delays.
- Order Batching – where it is more economic for demand to be aggregated to obtain economies in either the production or transportation system.
- Gaming – this arises at times when there is a shortage in supply or deliveries are missed, and were first studied by Houlihan. In order to ensure that they can satisfy the incoming demand, an echelon will over-order if it is perceived that supply will be restricted.
- Pricing – where a company varies the price on a product in order to stimulate demand.

In the previous section, we referred to some articles that are based on one or more of these causes of the BE. Four main causes were used as the basis of conceptual model which can be seen in fig.1.

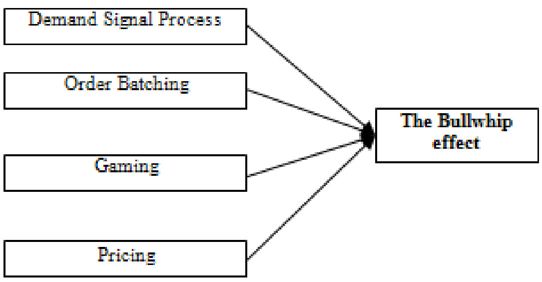

Figure 1. The conceptual model

B. FUZZY MODEL

In this paper a fuzzy model based on fuzzy inference system is introduced for measuring the BE by considering all the above mentioned four factors. The fuzzy inference system can initialize and learn linguistic and semi-linguistic (Sugeno) rules; hence it can be considered as direct transfer knowledge, which is the main advantage of fuzzy inference system over classical learning systems and Neural Networks. Often the rules of the fuzzy system are designated a priori and the parameters of the membership functions are adapted in the learning process form input-output data sets [4].

Basically, a fuzzy inference system is composed of five functional blocks: a rule base, a database, a decision-making unite, a fuzzification inference, a defuzzification inference. These function blocks are shown in Fig.2.

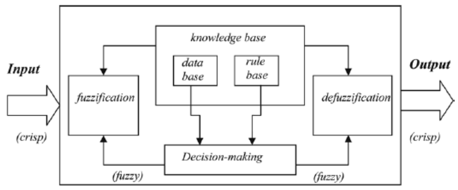

Figure 2. Block diagram for a fuzzy inference system

The first step to construct a fuzzy model is to select a membership function for each variable. A membership function is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1[4]. In this paper, membership functions are used to calculate the degree of fuzzy BE in different values expressed by linguistic term such as low, low to medium, medium, medium to high and high. Also we have used triangular membership function.

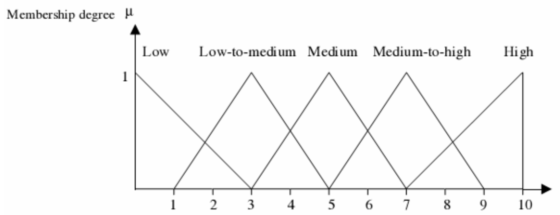

Figure 3. Fuzzy scale for qualification

Next step is to create a rule base. All uncertainties, nonlinear relationships, or model complications are included in the descriptive fuzzy inference procedure in the form of IF-THEN statements. In general, a fuzzy IF-THEN rule has two constitutes; first the IF part and the second the THEN part; which are called premise and consequent, respectively. The general form of a fuzzy IF-THEN rule is IF Z is A THEN f is B[5].To do this step, the verbal options of experts regarding the effects of different factor such as demand signal processing, order batching, gaming, pricing may be gathered and processed for generating a rule base and using them as inputs of our fuzzy inference system that has been shown in figure2. For instance, the following some of rules have been used in rule blow:

TABLE III. SOME OF THE RULES THAT USE IN RULE BASE

1	If demand signal processing is low and order batching is low and gaming is low to medium and pricing low is then bullwhip effect is low
2	If demand signal processing is medium and order batching low is and gaming is and low to medium pricing is low then bullwhip effect is low to medium
3	If demand signal processing is medium and order batching is medium to high and gaming is medium and pricing is low then bullwhip effect is medium to high
4	If demand signal processing is medium to high and order batching is medium and gaming is low and pricing is medium to high then bullwhip effect is medium to high

In the last step, due to great number of rules, we need an algorithm to aggregate the rules. The process of driving overall conclusion form the individual consequents contributed to each rule in the rule base is known as aggregation of the rules[6]. We use Mamdani approach for aggregation rules. Finally, we got a rule base with 32 rules.

III. CASE STUDY

The proposed methodology has been applied to an Iranian manufacturing company to evaluate the BE. This company produces four types of productions. It represents a four- product and three- stage supply chain with end customers, three retailers and one manufacturer. A committee of experts were formed and then asked them to determine the shape of the membership function based on subject judgment. This job was performed through brainstorming. MATLAB software is used to drive final aggregated result by Mamdani (Max/ Min) inference method, and also to find a crisp value for the aggregated output, we have chosen the center of gravity, the most prevalent and physically appealing of all the defuzzification methods. Then we have mentioned in proposed methodology, the BE level of supply chain in this company is evaluate 4.21. It can be labeled low to medium BE.

IV. VALIDATION

In this stage, we have studied the validity of our constructed fuzzy system. For this propose, we provided two series of information. The first series is the output of our system (BE1) and the second series is the bullwhip effect being qualified by using the previous prevailing method.

We chose Kruskal-Wallis test. This test can be applied in the one factor ANOVA case. It is a non-parametric test for the situation where the samples are not from normal distribution/population or the variances are heterogeneous [7].

The hypothesis test is as follow:

$H_0 : \mu_1 = \mu_2$

$H_1 : \mu_1 \neq \mu_2$

Test statistic: $$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_I}{n_i} - 3(n+1) \quad (1)$$

Significance level: typically set 0.05

For testing this hypothesis, Pvalue is calculated 0.317. H_0 cannot be rejected because the test statistic is not in the critical region and there is no significant difference between two mentioned data in table.3. It means that we cannot find a significant difference between system behavior and the previous prevailing method.

TABLE IV. SYSTEM OUTPUT (1) AND THE PREVIOUS PREVAILING METHOD (2)

BE1	**BE2**
5.1	4.2
9.1	8.3
6	7.2
4.7	3.1
1.2	2.6
3.9	5

V. CONCLUSION

The bullwhip effect is an important phenomenon in supply chains. Four possible sources for bullwhip effect are recognized in the literature by Lee et al: demand signal processing, order batching, gaming, pricing. Quantitative solutions to attenuate this effect has been proposed in various research studies but however in those researches just one factor in the system would significantly impact on other factors and influence the supply chain performance. Therefore, there is required a methodology which helps manager quantifying and view all the above mentioned four main causes. The methodology of using fuzzy logic in quantifying the bullwhip effect in a supply chain has been described in this paper. The unique feature of this system is concerned with the adoption of fuzzy inference system to deal with bullwhip effect, and in particular predicting bullwhip effect when vague and inaccurate data is exist. The fuzzy rule based system is most useful in modeling some complex system that can be observed by humans because linguistic variables as fuzzy rule base.

We have implemented proposed methodology in a Iranian company and the bullwhip effect labeled low to medium. This evaluation facilitates rapid decision making and predictable feature actions for managers.also the system behavior is analyzed as we provided two series of information. The first series is the output of our system and the second series is the bullwhip effect being qualified by using the previous prevailing method. We chose Kruskal-Wallis test. And no significant difference was fund between two series of data.

VI. FURTHER RESEARCH

Further research is necessary to define the conceptual model as network. It means that pay attention to the effect of each cause on the rest of causes.

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