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A Literature Survey: Fuzzy Logic and Qualitative Performance Evaluation of Supply Chain Management

[1]Amina S. Omar, [2]Prof. Mwangi Waweru, PhD, and [3]Dr. Richard Rimiru, PhD
[1]*Jomo Kenyatta University of Agriculture and Technology, Mombasa Campus, Institute of Computer Science and Information Technology, P. O. Box 94090–80107, Mombasa, Kenya,*
[2,3]*Jomo Kenyatta University of Agriculture and Technology, Main Campus, Institute of Computer Science and Information Technology, P. O. Box Juja, Nairobi, Kenya,*

ABSTRACT
Fuzzy logic can be a powerful tool for managers to use instead of traditional mathematical models when evaluating the performance of supply chains. The flexibility of the model allows the decision maker to introduce vagueness, uncertainty, and subjectivity into the evaluation system. In this paper we survey an alternative method of the performance evaluation system as opposed to the traditional quantitative methods. Performance evaluations represent a critically important decision that often involves subjective information. Models and heuristic techniques that focus on the use of different types of information are available; however, with few exceptions, the models are not robust enough to be applied in a practical, managerially useful manner. Fuzzy logic models provide a reasonable solution to these common decision situations. After extensive exploration of the literature, we recommend an outcome of exploring Fuzzy logic approach in evaluating qualitative aspects of performance of supply chain management. In this paper we survey fuzzy logic as a robust and easy understanding method to evaluate qualitative aspects of performance of supply chains.

KEYWORDS *- Supply Chain, Performance Measurement, qualitative measures and fuzzy logic*

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I. INTRODUCTION

Many performance measures have been identified as appropriate for supply chain analysis, but have not yet been used in supply chain modeling research, although these measures may be important characteristics of a supply chain, their use in supply chain models is challenging, since the qualitative nature of such measures makes them difficult to incorporate into quantitative models [1]. Due to growing availability of qualitative information for performance measurement is more practical and easy to measure supply chain performance in linguistic terms, including vagueness concept [2]. Qualitative metrics do not possess quantitative values and cannot be measured by numerical numbers. In that case, linguistic terms are used to evaluate performance of qualitative metrics [2].

Fuzzy logic controller is useful when the problem is too complex to be solved with quantitative approaches [3]. Conventional measures (such as: profit, percentage of products delivered on time etc.) had the drawbacks of tending to measure financial metrics, and failed to include intangible and lagging indicators [4]. Fuzzy is an appropriate modeling method to deal with intangible and qualitative measures which uses fuzzy set theory and linguistic values and has been applied widely in various areas of Supply Chain Management [2].

Fuzzy logic is a problem solving methodology that provides a simple way of definite conclusions from vague and imprecise information. Fuzzy set theory was first introduced by Zadeh in 1965. He was motivated by observing that human reasoning can utilize concepts and knowledge that don't have well-defined boundaries [5]. Fuzzy set theory is a generalization of the ordinary set theory. A useful approach for examining many real-world problems is fuzzy approximate reasoning or fuzzy logic. This technique is based on the fuzzy set theory [6] that allows the elements of a set to have varying degrees of membership, from a non-membership grade of 0 to a full membership of 100 per cent or grade 1. This smooth gradation of values is what makes fuzzy logic match well with the vagueness and uncertainty typical of many real world problems. Given the preceding discussion, this literature review searched studies that relate to qualitative Supply chain performance Management evaluation to fuzzy logic. Therefore, we investigated how fuzzy logic has been applied in this field.

II. THEORETICAL LITERATURE REVIEW

2.1 Qualitative Performance Measurement of Supply Chain Management

Performance measurement is the process of using a tool or a procedure to evaluate a concrete efficiency parameter of the system the traditional performance measurement systems evaluate quantitative indicators directly related to production parameters: throughput, number of delayed orders, WIP, manufacturing lead time, etc. The problem is how to evaluate the performance of the systems in the presence of unexpected changes. Here, performance indicators may be of a qualitative nature, since they usually reflect subjective views of the expected behavior of the systems in those circumstances. In the field of performance measurement, inevitability of subjectivity has to an extent been accepted. They recognized that elimination of judgmental criteria and their associated subjectivity are unlikely. This suggests that many performance evaluation factors are subjective, and hence qualitative in nature.

According to [7] SC performance measures are categorized in three main types; Resource, Output and Flexibility and declared that output measures include customer responsiveness, quality and quantity of the final product produced. Some of the output measures can be measured numerically such as number of items produced but some of them such as customer satisfaction, responsiveness and product quality cannot be measured numerically.

In his new classification, [7] introduced performance measures of SCM. They divided all the metrics into quantitative and qualitative and then established sub factors for each category. Qualitative category is divided into quality, flexibility, visibility, trust and innovativeness [7]. They claimed that quality factor of the mentioned criteria have a full picture of the mentioned criteria which should be interpreted in the SCM qualitative performance. Quality is categorized into customer satisfaction, customer response time, lead time, on time delivery, fill rate, stock-out probability and accuracy.

Another performance measurement classification of agri-food was presented by [7] which include efficiency, flexibility, responsiveness, and food quality. Responsiveness classified in fill rate, product lateness, customer response time, lead time, customer complaints, shipping errors. Supply Chain Operations Reference (SCOR) model presented the following five attributes of Supply Chain performance [8].

*1. **SC reliability***. The performance of the SC in delivering the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer which is **Perfect Order Fulfillment**. Reliability is a customer-focused attribute.
2. Supply Chain responsiveness: The speed at which a Supply Chain provides products to the customer. Responsiveness classified in fill rate, product lateness, customer response time, lead time, customer complaints, shipping errors [7].
3. Supply Chain flexibility***:*** The ability to respond to marketplace changes to gain or maintain competitive advantage. Flexibility is presented into 4 categories: volume flexibility, delivery flexibility, mix flexibility and new product flexibility [22]. Flexibility was considered to be a qualitative factor [7].
4. Supply Chain costs: The costs associated with operating the SC. Cost is one of the quantitative measures [7] and it can be measured by distribution cost, manufacturing cost, inventory cost, warehouse cost, incentive cost and subsidy, intangible cost, overhead cost and sensitivity to long-term cost. All these are quantitative measures.
5. SC asset management: The ability to efficiently utilize assets. Metrics include: inventory days of supply and capacity utilization which is a quantitative measure.

Literature reveals that considerable amount of work has been carried out by pioneer researchers towards performance measurement metrics, which are categorized into qualitative and quantitative. This research will only look at qualitative aspects of performance.

2.2 FUZZY LOGIC

Fuzzy logic has become an important tool for number of different applications ranging from the control of engineering system to artificial intelligence. Practical applications of fuzzy logic pose a unique set of problems. The design of systems, which apply fuzzy logic to make use of human knowledge and experience, is a daunting task without facing engineering problems of real world systems. Fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership [9]. Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false [11]. When linguistic variables are used, these degrees may be managed by specific functions. Fuzzy logics provide the basis for logical systems dealing with vagueness, e.g. for formalizing common natural language predicates such as “tall” or “fast”. Design choices in this framework are made as to which real numbers to take as truth values, and which properties connectives should have. In fact logics based on real numbers occur in a number of areas in logic. Fuzzy logic is based on the theory of fuzzy sets, which a generalization of the classical is set theory. Saying that the theory of fuzzy sets is a generalization of the classical set theory means that the latter is a special case of fuzzy sets theory. To make a metaphor in set theory speaking, the classical set theory is a subset of the theory of fuzzy sets.

A fuzzy set is a set without a crisp, not clearly defined boundary. It can contain elements with a partial degree of membership with multi-valued logic. Fuzzification comprises the process of transforming discrete values into grades of membership (continuous) for linguistic terms of fuzzy sets. The membership function is used to associate a grade to each linguistic term. Defuzzify evaluate several membership sets established by the system designer for a fuzzy logic based control system, such as "speed too fast," "speed too slow" and "speed about right" at a specific input value.

Degree of membership is a specific value that defines how each point in the input space is mapped to the specific environment being studied lying between 0 and 1. Linguistic Variable means relating to language, (plain language words and statements). While variables in mathematics usually take numerical values, in fuzzy logic, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts [10].
A Fuzzy Logic System consists of four main parts: fuzzier, rules, inference engine, and defuzzifier [21]. These components and the general architecture of a Fuzzy Logic System is shown in Figure 2.1.

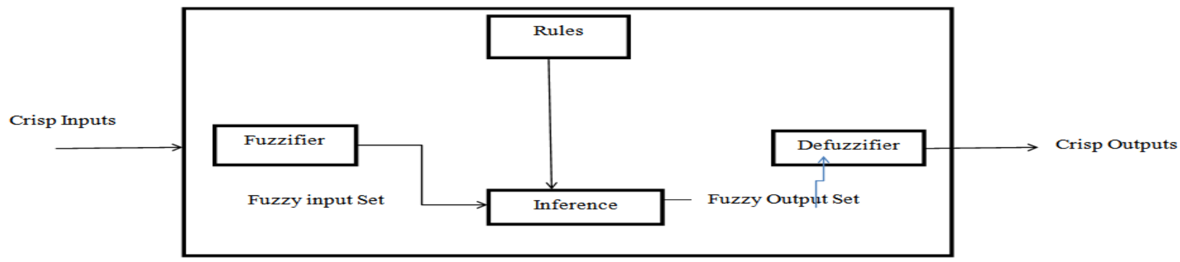

Figure 2.1 Fuzzy Logic System

The process of fuzzy logic involves obtaining a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions [21]. This step is known as fuzzication. Afterwards, an inference is made based on a set of rules and lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzication step [21].

2.3 Role of Fuzzy Logic in Qualitative Performance Evaluation of Supply Chain Management.

Conventional evaluation systems are representatives of structured systems that employ quantifiable and non-quantifiable measures of evaluation. It is often difficult to quantify performance dimensions. For example, “responsiveness” may be an important part of evaluating performance of supply chains. However, how exactly does one measure “responsiveness”. Fuzzy approach can be effectively utilized to handle imprecision and uncertainty [15]. This approach to performance evaluation allows the organization to exercise professional judgment in evaluating its supply chains. In real problems, performance evaluation techniques engage in handling cases like subjectivity, fuzziness and imprecise information. It is often difficult to quantify performance dimensions because all critical parameters in a Supply Chain Management are indicated subjectively by linguistic terms and are characterized by ambiguity [14] **.**Fuzzy set theory is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings. Application of the fuzzy set theory in evaluation systems can improve evaluation results [2]. The performance measurement process has evolved since the mid-eighties. Performance measures provide the necessary feedback for management which assists in business decisions [2]. Models in the past have only explored limited dimensions of supply chain performance such as cost [16], and flexibility [15]. Many performance measures have been identified as appropriate for supply chain analysis, but have not yet been used in supply chain modeling research, although these measures may be important characteristics of a supply chain, their use in supply chain models is challenging, since the qualitative nature of such measures makes them difficult to incorporate into quantitative models [1].

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Supply chain performance extent can be attributed as a function of multiple criteria/attributes. Most of the criterions/attributes being intangible in nature; supply chain performance appraisement relies on the subjective judgment of the decision-makers [1]. Moreover, quantitative appraisement of supply chain performance appears very difficult due to involvement of ill defined (vague) performance measures as well as metrics [1].

A feature typical of the natural language, to be in no way circumvented, is the vagueness of its semantics. That is why a description delivered in the natural language cannot be translated directly into mathematical formulas [17]. To be able to apply the classical mathematics, we have to have the task described in precise figures. This method, however, can return unsatisfactory results, as precise figures often do not properly reflect the reality. Fuzzy logic offers a solution to the problem, since it allows us to model the meanings of words used in the natural language [18].

Fuzzy logic is, however, not fuzzy. Basically, fuzzy logic is a precise logic of imprecision and approximate reasoning [17]. More specifically, fuzzy logic may be viewed as an attempt at formalization/mechanization of two remarkable human capabilities. First, the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility; in short, in an environment of imperfect information. And second, the capability to perform a wide variety of physical and mental tasks without any measurements and any computations [6].

Reality has almost always an aspect of randomness and an aspect of vagueness. The mathematical apparatus of the theory of fuzzy sets provides a natural basis for the theory of possibility, playing a role which is similar to that of measure theory in relation to the theory of probability [6]. Vagueness can be modeled using the theory of fuzzy sets, while the randomness is modeled with reliance on the probability theory and possibly other theories like the theory of possibility, different rates of veracity, etc. [18]. Viewed in this perspective, a fuzzy restriction may be interpreted as a possibility distribution, with its membership function playing the role of a possibility distribution function, and a fuzzy variable is associated with a possibility distribution in much the same manner as a random variable is associated with a probability distribution [6].

Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. In a sense, fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. Marsili-Libelli (2004) set up the following steps which are necessary for successful application of modeling through a general fuzzy system: Fuzzification of the input and output variable by considering appropriate linguistic subsets, Construction of rules based on expert knowledge and/or the basis of available literature, The result appears as a fuzzy subset and therefore, it is necessary to defuzzify the output and obtain a crisp output.

2.3.1 Fuzzification of Supply Chain management performance input variables

Fuzzy algorithms execute in three major stages: fuzzification, inference, and defuzzification. In the fuzzification stage, real world sensory inputs in a given universe of discourse are characterized on the closed interval [0, 1] according to their levels of membership in fuzzy sets. These sets are given names which express qualities of the input variable using easily understood linguistic terms. Linguistic Variable means relating to language, (plain language words and statements). While variables in mathematics usually take numerical values, in fuzzy logic, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts. [10]. Numeric values for qualitative performance measures do not exist. Therefore the opinion of decision makers (acting as measuring instruments) has to be transformed into numeric values.

Since human judgments and preference are often vague and can't estimate his preference with an exact numerical value. It is more realistic to use lingual expressions to describe the desired value, e.g. “very low”, “low”, “fair”, “high”, “very high”, “strongly”, “somewhat”, and “undecided”, "satisfied", "dissatisfied", etc. [2]. Due to this type of existing fuzziness in the survey process, fuzzy set theory is an appropriate method for dealing with uncertainty. For a fuzzy logic based supply chain performance parameters such as number of complaints, percentage of orders delivered on time, percentage of shipping errors etc. could be measured as high, very high, low, very low and medium for the numerical group and very good, good, average, poor and very poor for the proportional group.

2.3.2 Membership functions

Using fuzzy concepts, evaluators can use linguistic terms to assess the indicators in a natural language expression and each linguistic term can be associated with a membership function. A membership function maps the value of the input variable to a degree of membership in each of the fuzzy sets. The fuzzified value then, represents the level of truth of each of these linguistic terms for a given input. Typical shapes include triangular, square, singleton, Gaussian or asymmetric types.

In this paper a triangular membership function will be used to obtain the degree of membership for each linguistic term that represents the performance measurement parameters. Conventionally designed questionnaire frequently use a *Likert* scales to gauge the feeling of respondents. The parameters associated with the membership function are provided by expert judgments. The questionnaire sought the satisfaction level of the experts concerning e.g. number of complaints of supply chains using a 5-point *Likert* scales. E.g. number of complaints will be measured on a scale of 1 for 0-15, 2 for 15-30, 3 for 15-45, 4 for 45 to 60 and 5 for more than 60 to represent very low, low, medium, high and very high respectively. While for the proportional group a scale 1 for 0-25, 2 for 12.5 to 50, 3 for 25 to 75, 4 for 50 to 100 and 5 for 75 to 100 to represent very poor, poor, average, good and very good respectively.

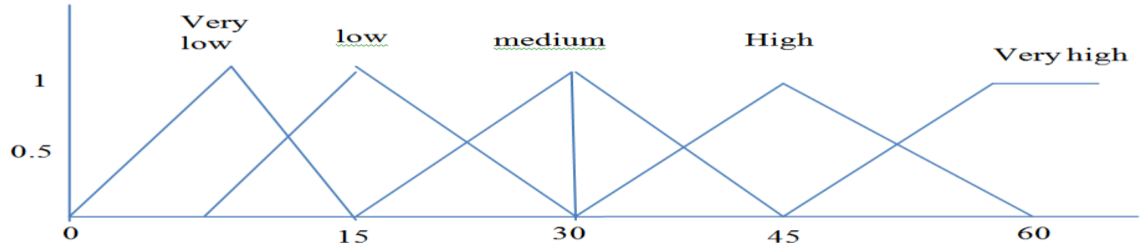

Fig 2.2 : Membership function for number of complains

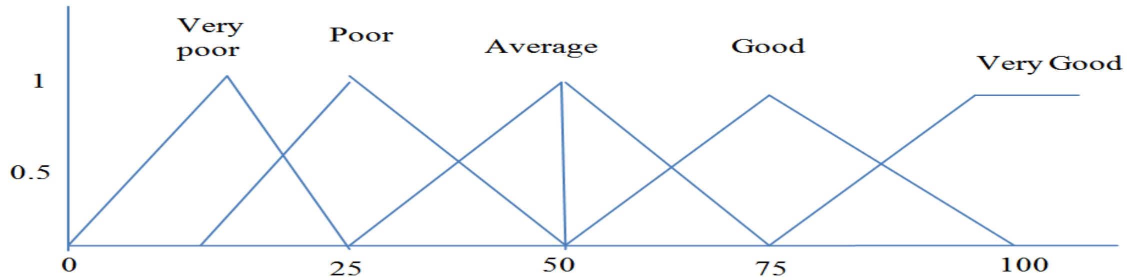

Fig 2.3: Membership function for percentage of orders delivered on time.

The triangular membership function shown in Equation (2) is then used to obtain the degree of fuzziness for each input variable.

$$f(x;a,b,c) = \begin{Bmatrix} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{Bmatrix} \quad (1)$$

(Retrieved from http://www.academia.edu/5542014/Fuzzy _Logic)

For instance if number of complaints are 30 in a specified time period, then it can be concluded that number of complaints is certainly average and the membership degree can be calculated as 30-0/30-0=1. Similarly if the value is greater than 30 and less than 45, then this value lies between both high and average thus the degree of membership shows to what extent the input presents a value represented by a the specified fuzzy set. E.g. 34 lie more on the average side. Then the degree of membership can be calculated using equation 1 as 60-34/60-30=26/30=0.866. This implies it has a degree of 0.87 average and 0.13 high. So this will be considered as average. For percentage of orders delivered on time, e.g. if 67% of them are delivered on time. This lies between average and good but more on the good side, then the degree of membership will be calculated as (100/67)/100-50=0.74 good and 0.26 average, so this will be considered as high.

2.3.3 Fuzzy Associative Matrices

A fuzzy associative matrix expresses fuzzy logic rules in tabular form. These rules usually take two variables as input, mapping cleanly to a two-dimensional matrix. In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. Row captions in the matrix contain the values that linguistic variables can take, column captions contain the values for linguistic variables, and each cell is the resulting output when the input variables take the values in that row and column. Table shows Accuracy and number of complaints fused together to give resp1 output which will again be fused with other responsiveness variables.

Table 5.15
Resp1 output

Accuracy/Number of complaints	Very low	low	Average	High	Very High
Very poor	NA	NA	NA	POOR	VERY POOR
Poor	NA	NA	NA	POOR	VERY POOR
Average	AVERAGE	AVERAGE	AVERAGE	POOR	POOR
Good	GOOD	GOOD	AVERAGE	NA	NA
Very Good	Very good	good	average	NA	NA

2.3.4 Fuzzy rules

Human beings make decisions based on rules. Although, we may not be aware of it, all the decisions we make are all based on computer like if-then statements. If the weather is fine, then we may decide to go out. If the forecast says the weather will be bad today, but fine tomorrow, then we make a decision not to go today, and postpone it till tomorrow. Rules associate ideas and relate one event to another. Fuzzy machines, which always tend to mimic the behavior of man, work the same way. However, the decision and the means of choosing that decision are replaced by fuzzy sets and the rules are replaced by fuzzy rules. Fuzzy rules also operate using a series of if-then statements. For instance, if X then A, if Y then B, where A and B are all sets of X and Y. the number of rules are determined by number of linguistic variables ^ number of variables. E.g. if accuracy is very poor and number of complaints is high then responsivess will definitely be poor. If accuracy is good and number of complaints is very low then responsiveness must be good.

2.3.5 Defuzzification

For obtaining a crisp value that would be required by the administrators or engineers to determine performance value. After completing the fuzzy decision process, Fuzzy output values are converted into a single crisp value or final decision that would be required by the administrator’s or managers of Supply Chain Management systems. This process is entitled defuzzification. Many methods have been developed for defuzzification. In this study, a “Centroid” (Center of Area) technique will be applied, which is one of the most common methods. After defuzzification process, obtained fuzzy number is geometrical figure. The crisp value is calculated as below (Figure 2.4, Equation (2). (Semerci, 2004).

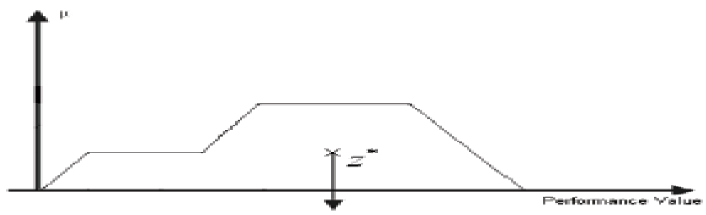

Figure 2.4 Defuzzification with Centroid method

$$z^* = \frac{\int \mu_C(z) \times z \times dz}{\int \mu_C(z) \times dz} \qquad (2)$$

III. RELATED WORK

While fuzzy logic techniques have earned their place in a variety of field ranging from engineering to financial sector, to medicine, few efforts have been made to test the potential usefulness of these methods in the modeling supply performance evaluation. This section discusses the literature survey about the past and current research application of fuzzy logic. In his study, [1] , proposed a Fuzzy logic framework for quality as one of the important factors of qualitative performance is discussed to be measured by means of fuzzy logic controller in Malaysian rubber glove manufacturers. A suitable fuzzy inference mechanism and associated rule has been discussed. It introduces the principles behind fuzzy logic and illustrates how these principles could be applied by Supply chain managers to evaluate supply chain performance. This study only focused on one aspect of qualitative performance measurement of supply chain management.

In his study, [19] developed a fuzzy expert system approach to forward looking performance measurement system of delivery metric in two Thai textile companies. The developed system enables managers to develop systematic ways to predict future performance and identify potential problems in a company. Using the SCOR model delivery metric is only one of the factors of responsiveness and hence cannot be used to evaluate the complete supply chain performance management.

In his study, [1] Presented innovative fuzzy logic process based method for performance measurement in SCM. Their Qualitative category was divided into quality, flexibility, visibility, trust and innovativeness. This framework didn't cover all the responsiveness and reliability factors which according to the SCOR model are two of the parameters that can be used to measure supply chain performance. Fuzzy rules applied to define qualitative terms. [20] proposed a methodology for monitoring the SC network with applying fuzzy logic for some reasons such as accuracy, reliability, compactness and lack of the concept of justification in rule-base system. This study focused on monitoring the supply chain network and not evaluating the performance of supply chain management.

IV. RECOMMENDATIONS

The review reveals that considerable amount of work has been carried out to identify performance measurement metrics of supply chains both qualitative and quantitative. Further exploration of both the theoretical and empirical literature review seems clear that there most of the performance measurement are qualitative in nature are complex, subjective and ambiguous, therefore conventional evaluations are inappropriate and incompetent. However fuzzy logic is a very powerful tool to compensate this limitation and deal with vague and complex situations. This clearly reveals that there is an urgent need for an alternative approach for evaluating qualitative aspects of performance of supply chain management. The previous research focused on quality aspects of supply chains performance, delivery metrics, flexibility, so it seems clear that there an urgent need for implementation of qualitative performance measurement framework which looks into the other qualitative factors which are responsiveness and reliability. Hence, this survey recommends further research works on alternative framework for evaluating the other aspects of qualitative performance using Fuzzy Logic.

V. CONCLUSIONS

This study has addressed the questions of how to supply chain responsivess. One of the success keys for managers is selecting the most appropriate supply chain based on their performances. The evaluation of supply chain responsivess gains vital importance in modern scenario. Performance in nature is associated with complexity and ambiguity; therefore conventional evaluations are inappropriate and incompetent. However fuzzy logic is a very powerful tool to compensate this limitation and deal with vague and complex situations. Performance of any supply chain can be effectively evaluated using fuzzy inference system. Exploration of fuzzy logic helps in dealing with decision-makers' linguistic evaluation information efficiently, thereby eliminating ambiguity, imprecision and vagueness arising from subjective human judgment. Also for any industries to be survive in today competitive market they had to be truly performing and should periodically evaluate their supply chain performance. Performance of supply chain result in improving the response and service to the customer, therefore increasing the supply chain profitability.

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