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Fuzzy Logic Framework for Qualitative Evaluation of Supply Chain Responsiveness

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ABSTRACT
Fuzzy logic can be a powerful tool for managers to use instead of traditional mathematical models when measuring the of supply chains responsivess. The flexibility of the model allows the decision maker to introduce vagueness, uncertainty, and subjectivity into the evaluation system. Responsiveness measurement represents a critically important decision that often involves subjective information. Fuzzy logic models provide a reasonable solution to these common decision situations. After extensive exploration of the literature, we recommend an outcome of developing a Fuzzy logic framework in measuring qualitative aspects of supply chain responsiveness. In this paper, responsiveness as one of the important factors of measuring qualitative performance is discussed and a fuzzy logic framework is developed to measure supply chain responsiveness.

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

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I. INTRODUCTION

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 [2]. 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 [3] **.**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 [14].

The performance measurement process has evolved since the mid-eighties. Performance measures provide the necessary feedback for management which assists in business decisions [14]. Models in the past have only explored limited dimensions of supply chain performance such as cost [4], and flexibility [14]. 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 [15]. 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 [5] **.**Fuzzy set theory is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings. 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 [15]. Moreover, quantitative appraisement of supply chain performance appears very difficult due to involvement of ill defined (vague) performance measures as well as metrics [15].

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 [6]. 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 [7].

Fuzzy logic is, however, not fuzzy. Basically, fuzzy logic is a precise logic of imprecision and approximate reasoning [6]. 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 [17].

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 [17]. 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 [17].

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. [18] 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.

I. 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 [15] 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, [15] 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 [15]. 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 [15] 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 [15].
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 [19]. Flexibility was considered to be a qualitative factor [15].
4. Supply Chain costs: The costs associated with operating the SC. Cost is one of the quantitative measures [15] 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.

III.FUZZY LOGIC FRAMEWORK DEVELOPMENT METHODOLOGY

Qualitative performance measurement evaluation of Supply Chain management for was done in five steps. Following the process of methodology will be described.

The first step was designing the questionnaire for gathering true required information from various supply chains in Kenya. The information was used to construct the proposed framework of performance measurement in Supply Chain Management. The answers contain the most interesting criteria which were used as input variable of the framework. Moreover, the questionnaire was designed in a way that it would help the researcher to define the correct membership function and fuzzy rules based on the range of answers. Therefore, role of the questionnaire in the research is to obtain the robust data of the Supply Chain Management which can be applied in the proposed Fuzzy Logic Framework.

Questionnaire was designed in two sections. The first section gathered general respondents information and information on what extent do they measure qualitative aspects of performance of supply chains based on the predetermined factors. The second section gathered information on responsiveness and reliability of supply chain performance. The correct range of data for each criterion was gathered through this questionnaire the responses entered in the FLC design module.

The next step in the methodology was to fuse two variables at a time depending on their importance, in order to reduce the rule base. Jamshidi [10] proposed to use sensory fusion to reduce a rule base size. This method consists in combining variables before providing them to input of the fuzzy controller [11]. In this study the variables were fused as shown. In the hierarchical fuzzy control structure from [12], the first-level rules are those related to the most important variables and are gathered to form the first-level hierarchy. The second most important variables, along with the outputs of the first-level, are chosen as inputs to the second level hierarchy, and so on. For Supply Chain Responsiveness, the first fusion will be between on time delivery and response time. On time delivery measures the percentage of all orders delivered by the requested delivery date, as indicated in the PO/contract during a defined period of time. Logistics managers can use this indicator to monitor supplier response time on shipments over a specified period of time [13].

The second fusion will be on lead time and probability out of stock. Lead time is the time of a supply chain network to respond to customer demands. Furthermore, in the worst case lead time corresponds to the response time when there are zero inventories. This was used as a measure of responsiveness in our previous work [14]

The third fusion was on Fill rate and shipment errors. This indicator measures the ability of the supplier to fill POs correctly. Shipments should always be checked against the shipping notice and the PO. What was shipped may not be what was ordered.

The fourth fusion will be between accuracy and number of complaints. Accuracy and customer complaints are more sensitive compare to fill rate and customer response time because when the company cannot provide ordered products accurately, it cause to the dissatisfaction and reduce output performance. Mentioned problem may not always cause to the complaints because customers prefer to change the company and provide the requirement from the competitors [15]. This is shown in figure.3.1 to figure 3.7

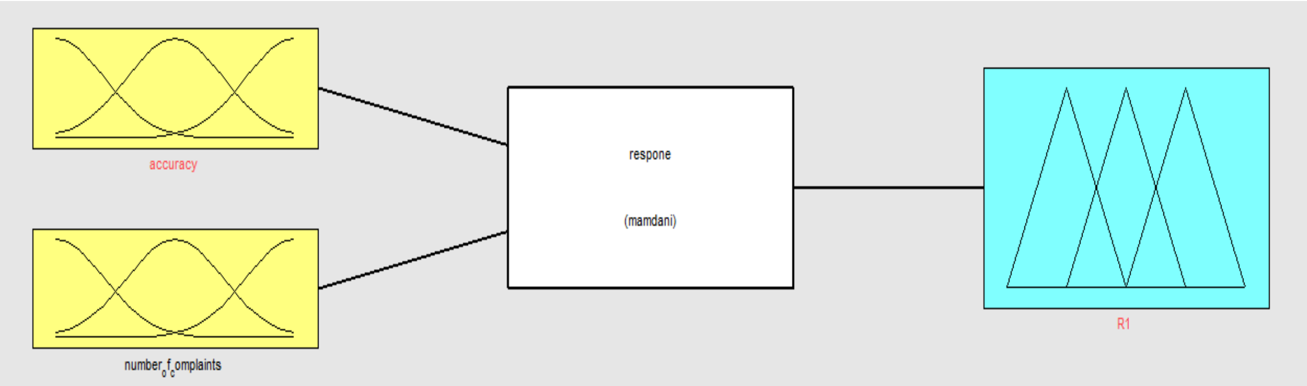

Figure 3.1: Basic FIS Editor in Matlab showing accuracy and number of complaints parameters fused linearly to produce Rep1 into a fuzzy model.

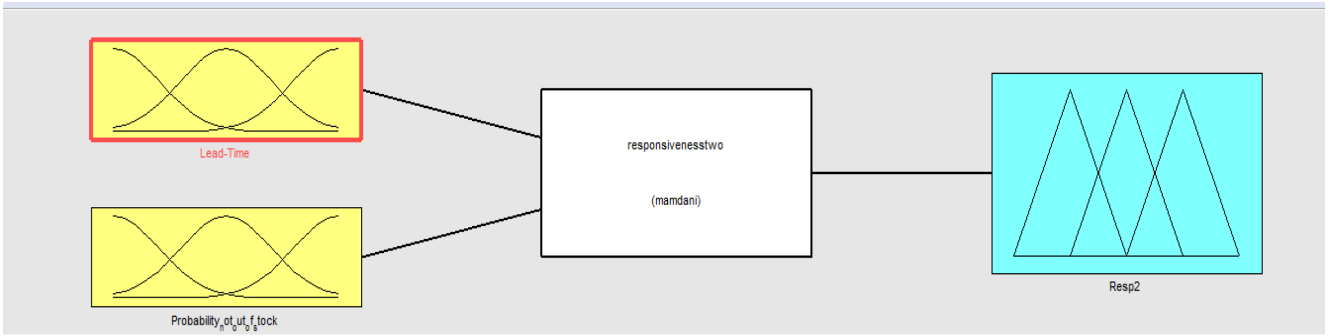

Figure 3.2: Basic FIS Editor in Matlab showing lead time and probability out of stock parameters fused linearly to produce Resp2 into a fuzzy model.

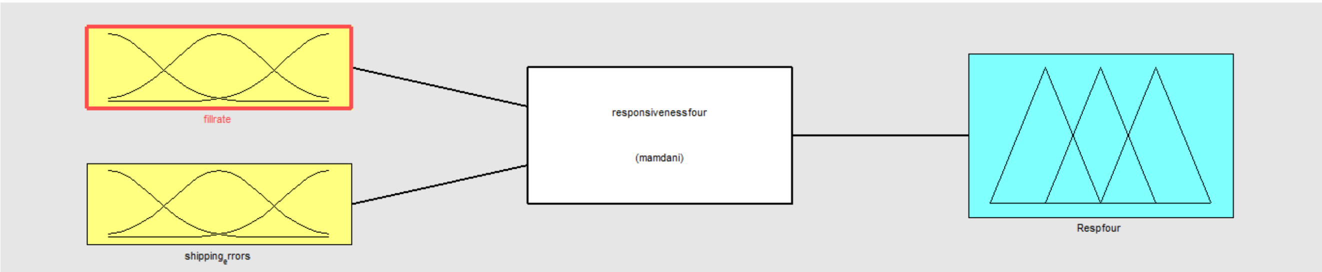

Figure 3.3: Basic FIS Editor in Matlab showing on time delivery and response time parameters fused linearly to produce Resp3 into a fuzzy model.

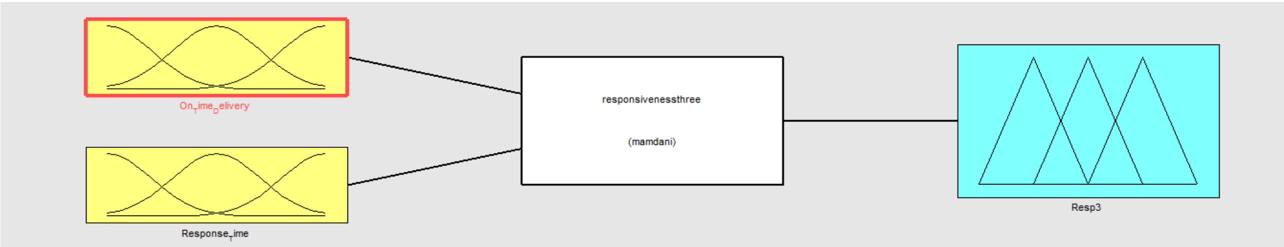

Figure 3.4: Basic FIS Editor in Matlab showing fill rate and shipping errors parameters fused linearly to produce Reps4 into a fuzzy model.

Figure 3.5: Basic FIS Editor in Matlab showing RESP1 and RESP2 outputs fused linearly to produce RESPFUSIONONE into a fuzzy model.

Figure 3.6: Basic FIS Editor in Matlab showing RESP3 and RESP4 outputs fused linearly to produce Respfusiontwo into a fuzzy model.

Figure 3.7: Basic FIS Editor in Matlab showing RESFUS1and REFUSION2 outputs fused linearly to produce RESPONSIVENESS into a fuzzy model.

The next step in the methodology was FLC design which includes membership function design and fuzzy rules design. In membership function design, factors divided into two groups; numerically and proportionally, according to the factors definitions. Using natural language, commonsense linguistic labels and traditional crisp set values, the numerical group will be measured as "high" or "low". While the proportional group will be measured as "poor" and "good". A fuzzy set is an extension of a crisp set which allows partial membership. The permissiveness of fuzziness in the human thought process suggests that much of the logic behind thought processing is not traditional two valued logic or even multivalued logic, but logic with fuzzy truths. Therefore a partial membership label "Medium" will be added in the linguistic term set for the numerical group and "Average " for the proportional group of the performance measurement variables.

Certain operators may be included to slightly change the meaning of the linguistic labels involved in a specific linguistic fuzzy rule. It a way to do so with a minor description loss is to use linguistic hedges **[6].** A linguistic hedge (also known as linguistic modifier) is a function that alters the membership function of the fuzzy set associated to the linguistic label, obtaining a definition with a higher or lower precision depending on the case. Two of the most well-known modifiers are the concentration linguistic hedge "very" and the dilation linguistic hedge "more-or-less." and their effects on a triangular membership function are shown in Fig. 3.11

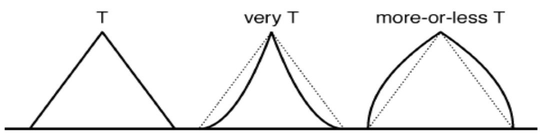

*Figure 3.11.*Effects of the linguistic Hedges "very" and "more-or-less"

The linguistic terms will then be quantified on a numerical scale based on inputted numerical data collected from various Supply Chain Management system and membership functions will then be defined to determine their degree of membership. The triangular membership function shape will be chosen because it is most popular in the performance measurement [3*]. The above linguistic variables and terms will then be matched and fuzzy rules generated, and expressed in a fuzzy associative matrix and output results obtained for each parameter which will then be aggregated into one crisp value using a defuzzication technique.

Range of the membership function depended on the alternatives that were designed for each criterion in the questionnaire. For instance alternatives which were designed for lead time has four alternatives; less than 1 day, 1 to 3 day, 3 days , 3 to 5 days and more than 5 days. First alternative in triangular membership function should be covered range of data which are less than 1 day. Therefore, four alternatives cover four types of membership function. Figure 3.12 shows the membership functions plots for the mentioned factors.

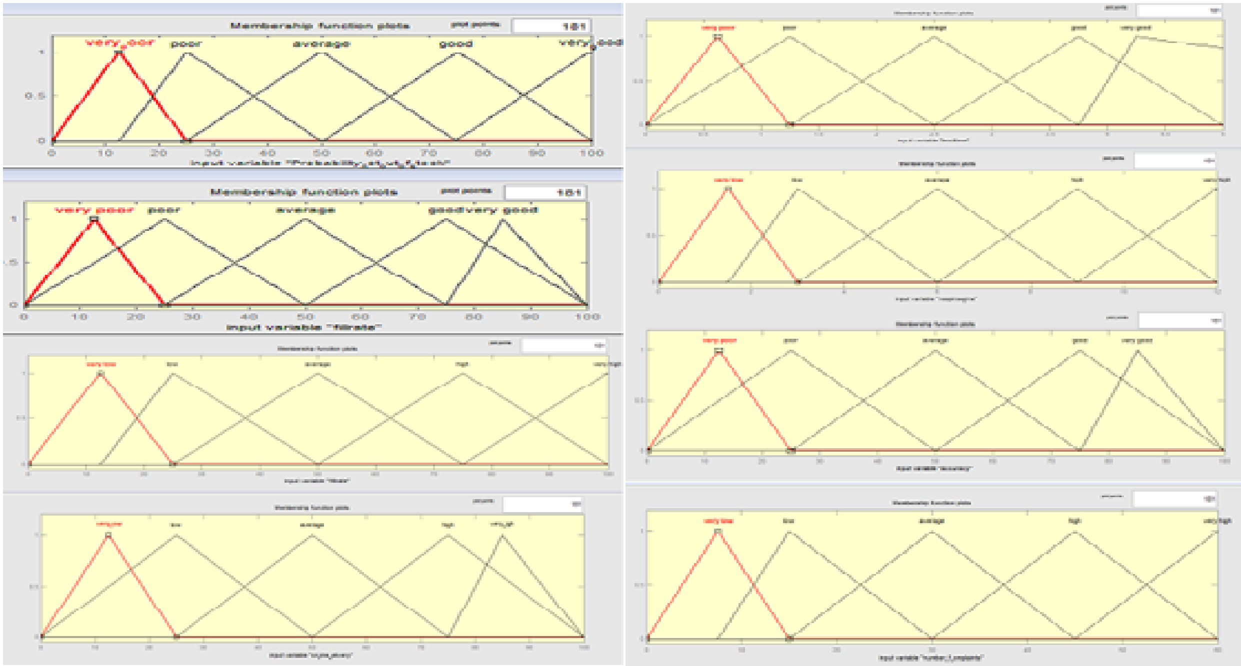

Figure 3.12: Responsiveness Membership Functions plots in Performance Measurement of SCM

The rule base of the proposed Fuzzy Logic Framework was defined in three steps; firstly, total numbers of interactions between the input variables of the FLC were defined. The numbers of rules were established based on the permutation with number of membership function and numbers of criteria. The numbers of factors are eight for responsiveness and numbers of membership functions are eight. Using Hierarchical Fusion method, two variables were fused at a time. The total amount of rules are 5^2 equal to 25 rules for every fusion. In second step, some illogical relationships between the rules found and were omitted from the rule base. These rules showed states that had illogical interaction between two or more criteria. For example if the "accuracy" variable be "high" or "very high" then the "response time" would not be "very low" or "low". It's because when the speed of production is not short enough, the company cannot response to the order of customer before due date. Finally, in last fuzzy rule design step, remaining
rules were contracted in 104 general rules and the output for each rule was determined by the researcher.

The contraction was done for better decision making for each output state and easy understanding for find out the relationships between the factors. In the last step of the methodology, the fuzzy logic toolbox of MATLAB was applied to entering the membership functions and fuzzy rules. Furthermore, the software helped to show the result and analyze the output performance of supply chains. The following section shows the result of the research and discuss about the output analysis in the qualitative performance measurement in Supply Chain Management. Fig. 3.13, 3.14, 3.15, 3.16, 3.17 and 3.18 respectively shows fuzzy rules and Fig. 3.19 shows an output membership function for responsiveness and reliability.

Rule Editor: responsivenessone

File Edit View Options

1. If (Accuracy is very poor) and (Number_of_complaints is average) then (Resp1 is poor) (1)
2. If (Accuracy is very poor) and (Number_of_complaints is high) then (Resp1 is poor) (1)
3. If (Accuracy is very poor) and (Number_of_complaints is very_high) then (Resp1 is very poor) (1)
4. If (Accuracy is poor) and (Number_of_complaints is very_low) then (Resp1 is poor) (1)
5. If (Accuracy is poor) and (Number_of_complaints is low) then (Resp1 is poor) (1)
6. If (Accuracy is poor) and (Number_of_complaints is average) then (Resp1 is poor) (1)
7. If (Accuracy is poor) and (Number_of_complaints is high) then (Resp1 is poor) (1)
8. If (Accuracy is poor) and (Number_of_complaints is very_high) then (Resp1 is poor) (1)
9. If (Accuracy is average) and (Number_of_complaints is very_low) then (Resp1 is poor) (1)
10. If (Accuracy is average) and (Number_of_complaints is low) then (Resp1 is poor) (1)
11. If (Accuracy is average) and (Number_of_complaints is average) then (Resp1 is average) (1)
12. If (Accuracy is average) and (Number_of_complaints is high) then (Resp1 is average) (1)
13. If (Accuracy is average) and (Number_of_complaints is very_high) then (Resp1 is average) (1)
14. If (Accuracy is good) and (Number_of_complaints is very_low) then (Resp1 is poor) (1)
15. If (Accuracy is good) and (Number_of_complaints is low) then (Resp1 is average) (1)
16. If (Accuracy is good) and (Number_of_complaints is average) then (Resp1 is average) (1)
17. If (Accuracy is good) and (Number_of_complaints is high) then (Resp1 is good) (1)
18. If (Accuracy is good) and (Number_of_complaints is very_high) then (Resp1 is good) (1)
19. If (Accuracy is very good) and (Number_of_complaints is very_low) then (Resp1 is poor) (1)
20. If (Accuracy is very good) and (Number_of_complaints is low) then (Resp1 is poor) (1)
21. If (Accuracy is very good) and (Number_of_complaints is average) then (Resp1 is average) (1)
22. If (Accuracy is very good) and (Number_of_complaints is high) then (Resp1 is good) (1)
23. If (Accuracy is very good) and (Number_of_complaints is very_high) then (Resp1 is very good) (1)
24. If (Accuracy is poor) and (Number_of_complaints is high) then (Resp1 is poor) (1)
25. If (Accuracy is poor) and (Number_of_complaints is high) then (Resp1 is poor) (1)

Fig 3.13: Fuzzy logic rules for responsiveness one which is a fusion between accuracy and no of complaints

Rule Editor: responsivenesstwo

File Edit View Options

1. If (Lead-Time is verylow) and (Probability_not_out_of_stock is average) then (Resp2 is average) (1)
2. If (Lead-Time is verylow) and (Probability_not_out_of_stock is good) then (Resp2 is good) (1)
3. If (Lead-Time is verylow) and (Probability_not_out_of_stock is very_good) then (Resp2 is very good) (1)
4. If (Lead-Time is low) and (Probability_not_out_of_stock is average) then (Resp2 is average) (1)
5. If (Lead-Time is low) and (Probability_not_out_of_stock is good) then (Resp2 is good) (1)
6. If (Lead-Time is low) and (Probability_not_out_of_stock is very_good) then (Resp2 is very good) (1)
7. If (Lead-Time is average) and (Probability_not_out_of_stock is very_poor) then (Resp2 is very poor) (1)
8. If (Lead-Time is average) and (Probability_not_out_of_stock is poor) then (Resp2 is poor) (1)
9. If (Lead-Time is average) and (Probability_not_out_of_stock is average) then (Resp2 is average) (1)
10. If (Lead-Time is average) and (Probability_not_out_of_stock is good) then (Resp2 is average) (1)
11. If (Lead-Time is high) and (Probability_not_out_of_stock is very_poor) then (Resp2 is poor) (1)
12. If (Lead-Time is high) and (Probability_not_out_of_stock is poor) then (Resp2 is average) (1)
13. If (Lead-Time is high) and (Probability_not_out_of_stock is average) then (Resp2 is average) (1)
14. If (Lead-Time is very_high) and (Probability_not_out_of_stock is very_poor) then (Resp2 is very poor) (1)
15. If (Lead-Time is very_high) and (Probability_not_out_of_stock is poor) then (Resp2 is poor) (1)
16. If (Lead-Time is very_high) and (Probability_not_out_of_stock is average) then (Resp2 is poor) (1)
17. If (Lead-Time is very_high) and (Probability_not_out_of_stock is good) then (Resp2 is very poor) (1)

Fig 3.14: Fuzzy logic rules for responsiveness two which is a fusion between lead time and probability out of stock

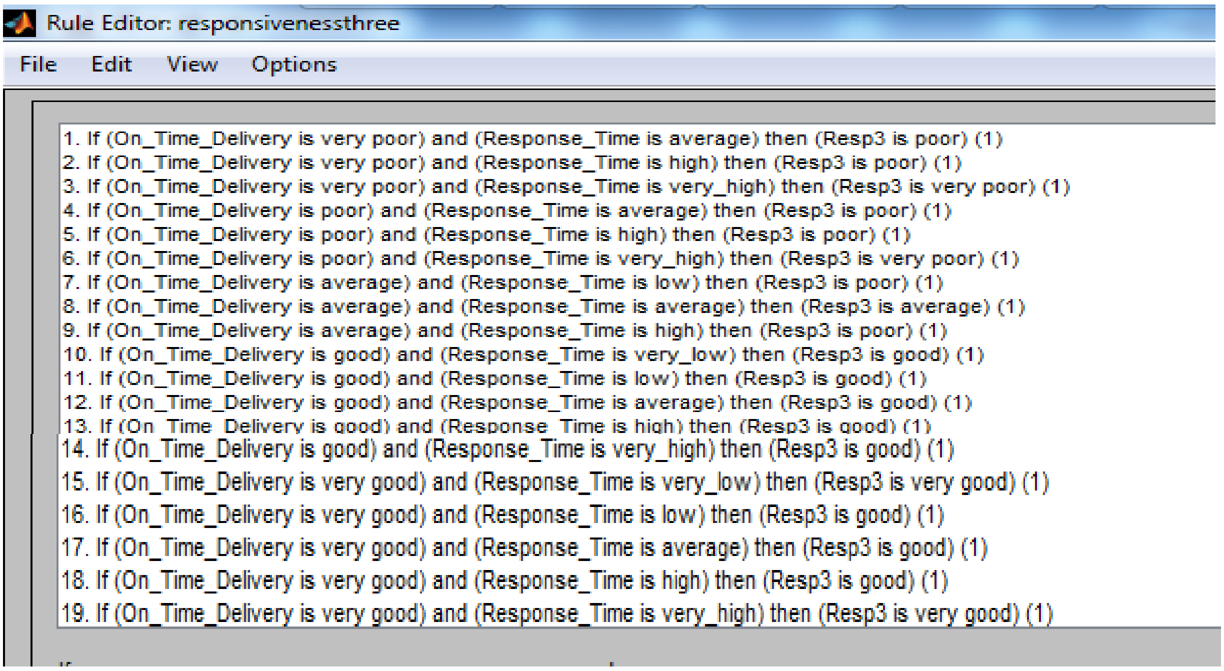

Fig 3.15: Fuzzy logic rules for responsiveness three which is a fusion between on time delivery and response time

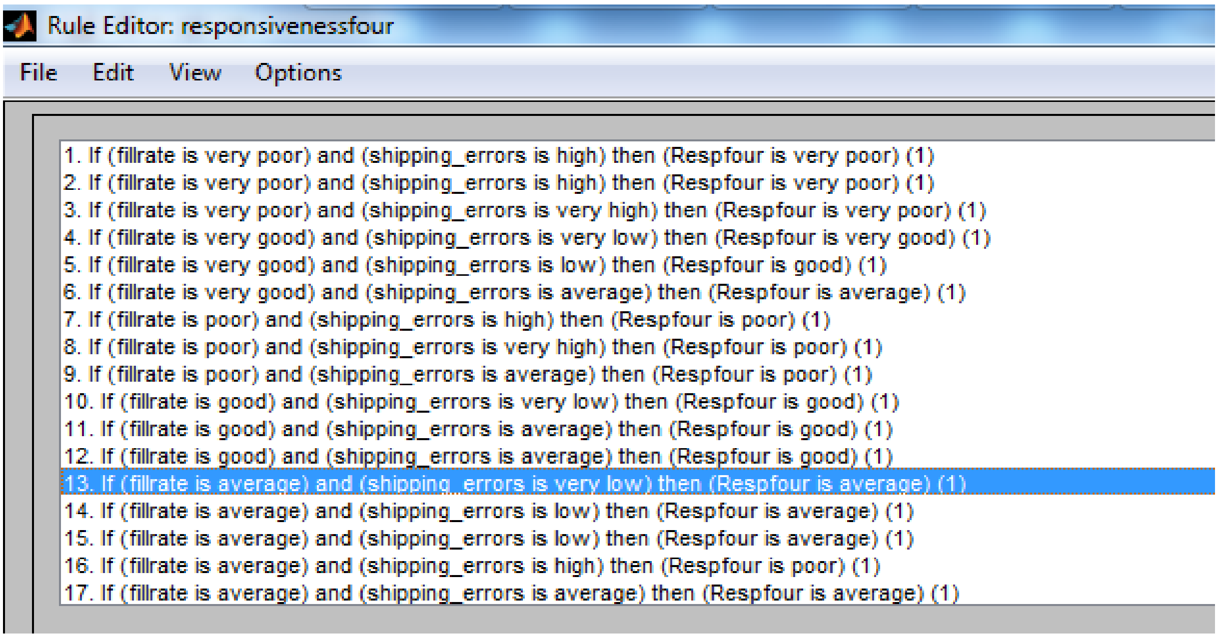

Fig 3.16: Fuzzy logic rules for responsiveness four which is a fusion between fill rate and shipping errors

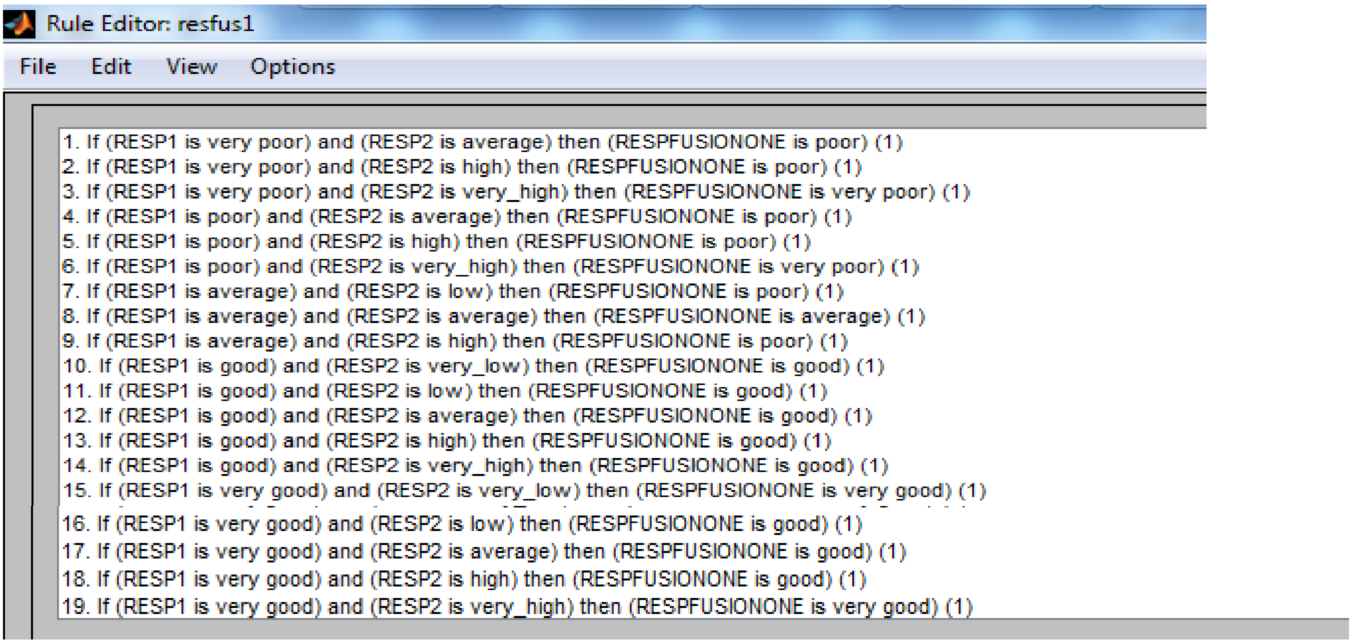

Fig 3.17: Fuzzy logic rules for resfusion1 which is a fusion between Resp1 and Resp2

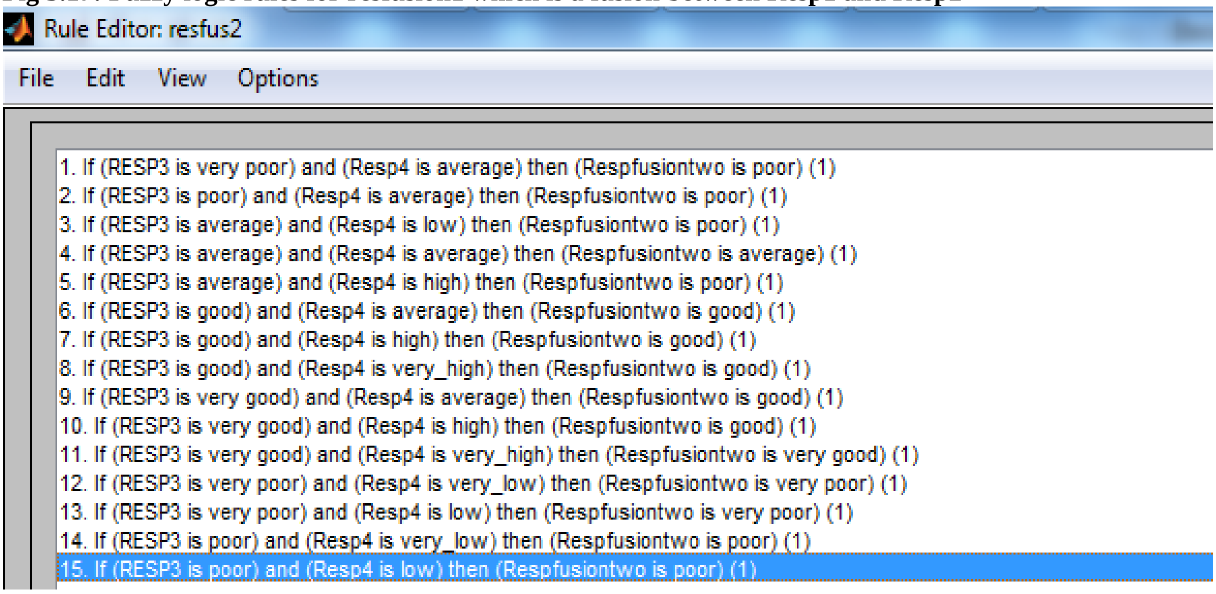

Fig 3.18: Fuzzy logic rules for Respfusiontwo which is a fusion between Resp3 and Resp4

The triangular membership function shown in Equation (1) is then used in MATLAB to obtain the degree of fuzziness for each input variable.

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

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

For instance if number of complaints are 40 in a specified time period, 40 has an intersection between average and high then membership degree can be calculated using Eq.(2) as

$$f(x)=\frac{c-x}{c-b} \qquad (2)$$

$$F=\frac{60-40}{60-30}=0.67$$

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 Eq.(2) as

$$F=\frac{60-34}{60-30}=0.866$$

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 using .Eq. (2) as

$$F=\frac{100-67}{100-50}=0.74$$

0.74 good and 0.26 average, so this will be considered as good. After obtaining the degree of membership for each input variable. The fuzzy rules that match the inputs degree of membership are fired and the output is mapped into the output membership functions.

The final step in developing the fuzzy logic framework is to input data collected for all the defined supply chain responsiveness parameters in the rule viewer in Matlab and the output which is a fusion between two variables at a time will be generated as shown in fig 3.20, 3.21 and 3.22 respectively

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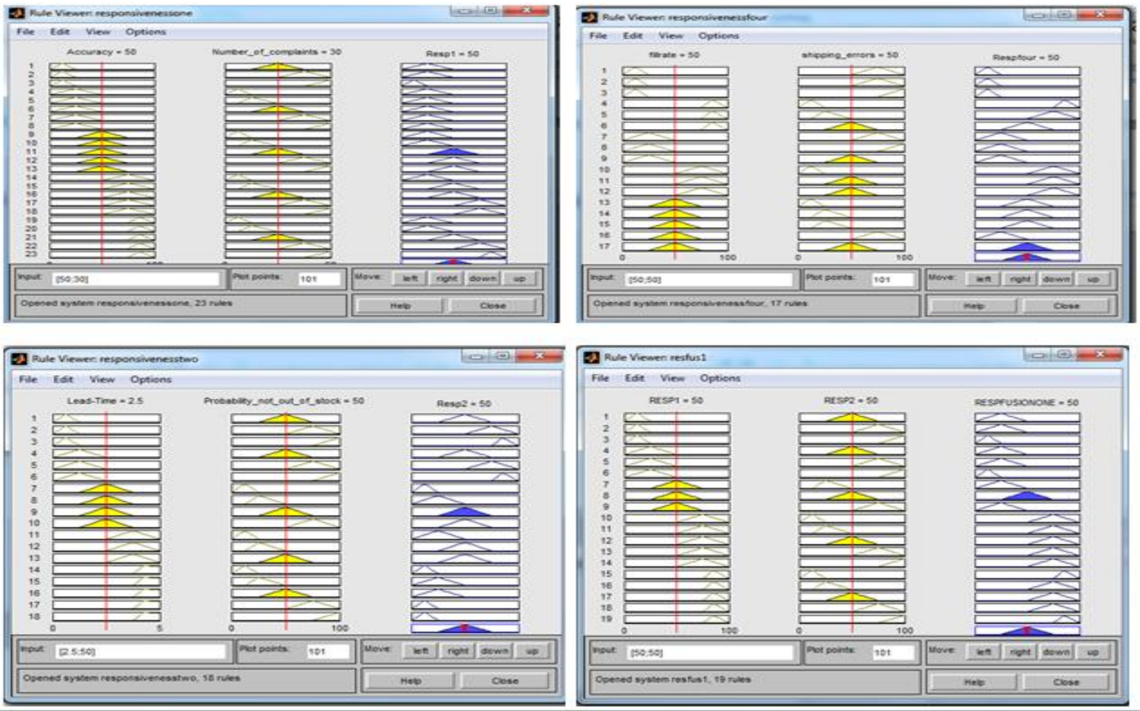

Fig 3.20: Rule Viewers for fusion of supply chain responsivess parameters and their intermediate outputs

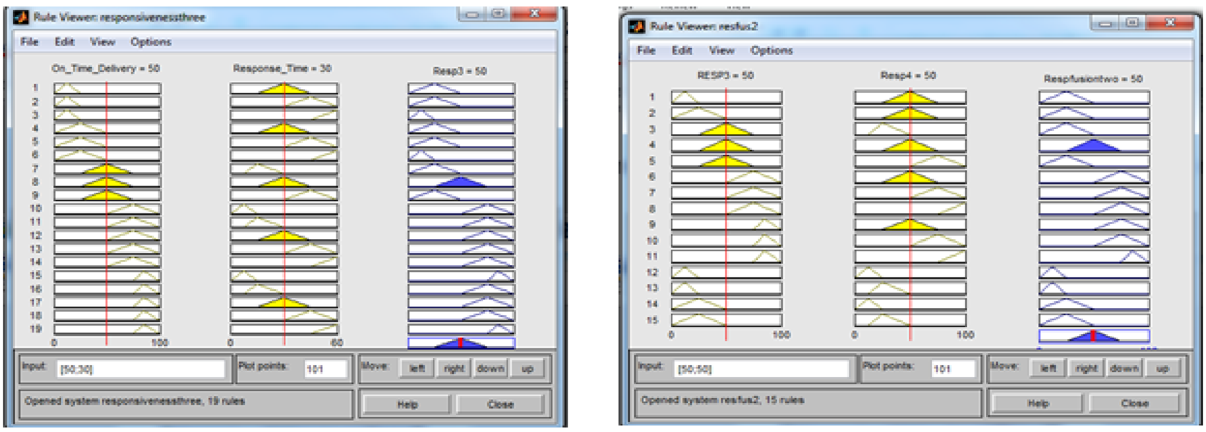

Fig 3.21: Rule Viewers for fusion of supply chain responsivess parameters and their intermediate outputs

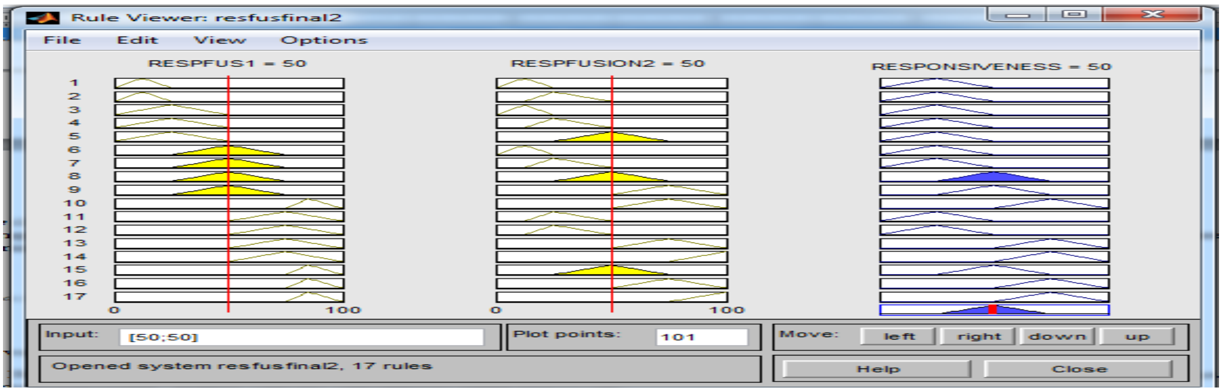

Fig 3.22: Rule Viewers for final supply chain responsivess performance measurement

To obtain the degree of membership the triangular membership function in Eq.(1) will be used to map the overall responsiveness into the output membership function as shown in fig. 3.19

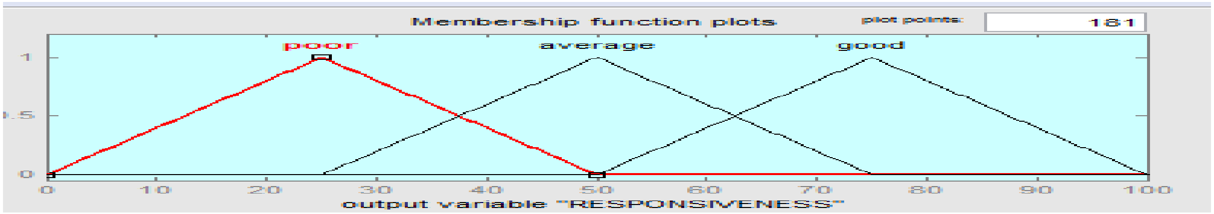

Figure 3.19: Output Membership functions for Responsiveness.

IV. CONCLUSION

This study has addressed the questions of how to measure supply chain. Supply responsiveness has become an important avenue in recent times. Many organizations around the world have been attempting to implement performance concepts in their supply chain. The evaluation of supply chain responsiveness gains vital importance in modern scenario. Responsivess 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. Responsivess 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 should periodically evaluate their supply chain responsivess. Well performing supply chain result in improving the response and service to the customer, therefore increasing the supply chain profitability.

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