APPLICATION OF FUZZY LOGIC IN QUALITATIVE PERFORMANCE MEASUREMENT OF SUPPLY CHAIN MANAGEMENT

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Application Of Fuzzy Logic In Qualitative Performance Measurement Of Supply Chain Management

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as the university supervisors.

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DEDICATION

To the Almighty God thanks for enabling me to complete this thesis. To my family: my husband and my son, my parents and Sisters. Special thanks to them for all support and encouragement they offered me.

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ABSTRACT

Supply chain involves all activities meeting the customers demand and transferring material through downstream into upstream of chain for fulfilling the demands. To achieve supply chain objectives, organizations should control the activities for increasing the efficiency and effectiveness. Performance measurement is a set of metrics that a manager applying for controlling the planned tasks and investing amounts of resources for obtaining predetermined goals. All the Supply Chain performance measures can be divided into two major groups qualitative and quantitative. In recent years many methodologies have been developed in terms of quantitative measures but most of them merely focus on the control mechanism based on reported measures whereas the qualitative aspect of the work is still unexplored. In this thesis, a fuzzy logic framework is developed and data on responsiveness and reliability was collected and fed into it and the final performance of supply chain management was obtained. Responsiveness was found to be 66% for supply chains in Kenya; this indicates that responsiveness was found to be good. Further input of reliability data also indicated that supply chain reliability in Kenya was found to be 74%, which was also found to be good. Fusion of the two outputs resulted into the final output measuring supply chain management performance which was found to be 67%, this indicated that the supply chain performance in Kenya was found to be good.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Over the past decade, there has been an increasing emphasis on Supply Chain Management as a vehicle through which firms can achieve competitive advantage on markets (Jugendra, 2012). It is not actually individual companies that compete with each other nowadays; rather the competition is between rival supply chains (Nomesh, 2012). Supply Chain Management consist of suppliers, manufacturers, distributors, retailers and customers which product flow from downstream to upstream and information flows in both directions (Shirouyehzad, 2011). To utilize the supply chain at its maximum performance level, organizations have to integrate its goals and activities (Manoj & Hudnurkar, 2011) and all its stakeholders.

Most of these companies are realized that, in order to evolve an efficient and effective supply chain needs to be assessed for its performance (Mehrdad & Abbas, 2008). A Performance Measurement System can be analyzed by asking questions such as What performance measures are used? What are they used for? How much do they cost? And what benefit do they provide? (Gopal & Jitesh, 2012). The performance measurement process has evolved since the mideighties. Performance measures provide the necessary feedback for management which assists in business decisions (Ezutah & Kuan, 2010). Models in the past have only explored limited dimensions of supply chain performance such as cost (Pyke & Cohen,1994), and flexibility (Sanchez & Perez,2005).

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 (Nomesh *et al.,* 2010). 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 (Ezutah & Kuan, 2010).

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 (Ezutah & Kuan, 2010). Fuzzy logic controller is useful when the problem is too complex to be solved with quantitative approaches (Shirouyehzad *et al.*, 2011). 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 (Gunasegaram & Kobu, 2007). 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 (Ezutah & Kuan, 2010).

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 has well-defined boundaries (Mehrad & Abbas, 2012).

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 (Zadeh, 1976) 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. 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 (Ezutah & Kuan, 2010).

1.1.1 Supply Chain Management

Supply Chain Management involves not only the integration of key business processes within the organization but also the integration of these processes throughout the entire supply chain (Nakhai *et al.*, 2008). Leading-edge companies have realized that the real competition is not company against company, but rather supply chain against supply chain‖ (Nakhai, *et al.*, 2008). According to the Global Supply Chain Forum, Supply Chain Management is the integration of key business processes from end user through original suppliers that provide products, services, and information that add value for the customers and other stakeholders‖ (Nakhai *et al.*, 2008).

Supply Chain Management has been defined to consist of different levels: supplier, manufacturer, distributer and consumer where materials flow downstream to upstream from supplier to customers, and information flows in both directions (Shirouyehzad *et al.*, 2011), A Supply Chain encompasses all activities in fulfilling customer demands and requests. These activities are associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as the associated information and funds flow. There are four stages in a supply chain: the supply network, the internal supply chain (which are manufacturing plants), distribution systems, and the end users. Moving up and down the stages are the four flows: material flow, service flow, information flow and funds flow (Piu, 1999).

The objective of Supply Chain Management is to achieve sustainable competitive advantage. Supply chain management is a cross-function approach including managing the movement of raw materials into an organization, certain aspects of the internal processing of materials into finished goods, and the movement of finished goods out of the organization and toward the end consumer

1.1.2 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, Work in progress, 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.

Performance of Supply Chain Management influences the efficiency and effectiveness for achieving the mentioned goals. The efficiency of supply chain depends on the response to the demand accurately and quickly and satisfying customer by creating the value for them leads to effectiveness (Mentzer, 2007). In the past, performance measures were mainly financial and result oriented, in order to support continuous improvement, the shift has been to measures which are more process oriented, utilize agents to explore the dynamics of a supply chain and incorporate only quantitative measures (Nomesh *et al.*, 2012).

Many attempts have been made on supply chain performance measurement using conventional approaches. Most of these approaches have, to a great extent contributed in performance measurement of a supply chain, but there are still rooms for improvement (Ezutah & Kuan 2010). 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 ((Nomesh, 2012). Moreover, quantitative appraisement of supply chain performance appears very difficult due to involvement of ill defined (vague) performance measures as well as metrics (Nomesh, 2012).

1.1.3 Fuzzy Logic

Fuzzy set theory (Shruti & Mudholkar, 2013**)** was developed to address contexts in which decision Makers need to accurately analyze and process information that is imprecise in nature. Fuzzy sets provide a conceptual framework, as well as an analytical tool to solve real World problems where there is a lack of specific facts and precision (Sirigiri, 2012**).** However, the application of fuzzy set theory and logic to management decisions has been generally lacking despite its potential value in many common situations (Mehrdad & Abbas, 2011). Nevertheless, human semantics are embedded in the meaning of fuzziness and comparison (Zadeh, 1983). On the other hand, the usage of multi granularity linguistic information can eliminate the difference from evaluators (Mehrdad & Abbas, 2011).

Fuzzy logic is a natural, continuous logic patterned after the approximate reasoning of human beings (Zadeh, 1965). As a theory mathematical discipline, fuzzy logic reacts to constantly changing variables(Zadeh,1965). It challenges traditional logic by not being restricted to the conventional binary computer values of zero and one. Instead, fuzzy logic allows for partial truths and multivalued truths(Zadeh,1965). Fuzzy logic is especially advantageous for problems that cannot be easily represented by mathematical modelling because data is either unavailable or incomplete or the process is too complex(Zadeh,1965). The real world language used in fuzzy control enables engineers to incorporate ambiguous, approximate human logic into computers, using linguistic modelling, as opposed to mathematical modelling, greatly simplifies the design and modification of a fuzzy logic system(Zadeh,1965).

A fuzzy system is a control system that utilizes the fundamental principles of fuzzy logic to deliver a definitive conclusion to a problem that is characterized by vague, ambiguous, imprecise, noisy, or even missing information (Zadeh, 1965). Systems of this nature are often referred to as fuzzy systems, fuzzy knowledge based systems and fuzzy inference system, all of which are relatively interchangeable and amount to the same thing (Zadeh, 1965). Fuzzy systems use fuzzy sets and fuzzy if-then rules as a part of computer systems. Decision making process in order to draw conclusions (Zadeh, 1965).

An objective of fuzzy logic has been to make computers think like people (Zadeh,1965). Fuzzy logic can deal with the vagueness intrinsic to human thinking and natural language and recognizes that its nature is different from randomness (Zadeh, 1965). Using fuzzy logic algorithms could enable machines to understand and respond to vague human concepts such as hot, cold, large, small, etc. It also could provide a relatively simple approach to reach definite conclusions from imprecise information (Zadeh, 1965)

1.2 Problem Statement

In dealing with many aspects of our daily life we recognize that many phenomena, situations and issues are imprecise. We use words such as high, low, moderate, adequate, extremely, large, tall, adult, mature, competent etc. to deal with problems ranging from law, financial management, engines, to psychology and education. Yet such expressions are incompatible with traditional quantitative modeling and information system design which generally require an either a yes or no response to a question. However, it is only making a small step to argue Degree of membership that if we can ‗reason ‘using such imprecise information, so should our machines (Cox, 1994).

All critical parameters in a Supply Chain Management are indicated subjectively by linguistic terms and are characterized by ill defined(vague) performance measures (Smolová & Pech, 2011). Hence the central issue faced during performance measurement is to deal with the inherent vagueness in such qualitative representation of knowledge.

Few models exist that measure qualitative supply chain performance but none incorporated reliability and responsiveness. Therefore, the study was inspired to address this gap by presenting an alternative approach of measuring reliability and responsiveness which are qualitative measures of Supply Chain Management using fuzzy logic concept.

1.3 Research Questions

i) What qualitative input variables or parameters can be used as linguistic variables to measure performance of Supply Chain Management?

ii) What fuzzy set of linguistic terms can be developed for the above linguistic variables and how will they be quantified using crisp input values and their degree of fuzziness obtained using a membership function?

iii) Which fuzzy rules will be generated by matching the above linguistic variables and linguistic terms and how will they be expressed in a fuzzy associative matrix in order to find individual linguistic variable output results affective performance?

iv) How will a defuzzication technique be used to compute a fuzzy aggregation of the above output results of each individual variable to obtain a single crisp output which measures an overall performance of supply Chain Management.

v) How will the framework that uses fuzzy logic to measure performance in Supply Chain Management be designed, developed, implemented and tested that uses

1.4 Research Objectives

1.4.1 Broad Objectives

1) To measure qualitative performance of Supply Chain Management using Fuzzy logic concept.

1.4.2 Specific Objectives

i) To determine qualitative input variables or parameters as linguistic variables to measure performance of Supply Chain Management.

ii) To develop a fuzzy set of linguistic terms for the above linguistic variables and quantify them using crisp input values and obtain their degree of membership or fuzziness using a suitable membership function.

iii) To determine fuzzy rules that can be generated by matching the linguistic variables and linguistic terms and express them in a fuzzy associative matrix in order to find individual linguistic variable output results affective performance.

iv) To compute a fuzzy aggregation of all the above output results of individual variables into a single crisp output which measures an overall quality performance of Supply Chain Management using a defuzzication technique.

v) To design, implement and test a framework that uses fuzzy logic to measure performance in Supply Chain Management.

1.5 Proposed Solution

All critical parameters of Supply Chain Management performance are indicated qualitatively and hence difficult to incorporate into traditional quantitative models to overcome this problem. This research proposes an alternative model of measuring qualitative factors using fuzzy logic concepts. According to Supply chain council (2010), the qualitative factors are reliability, responsiveness and flexibility. Previous researchers have developed a model that measures flexibility. The proposed framework will test Reliability and responsiveness attributes of performance to measure Supply chain management. This will involve analyzing data about qualitative factors using the data to inform the inputs to the proposed framework and generating the overall framework for the thesis.

1.6 Scope of study

This research will be conducted on the areas of qualitative performance measurement framework. The desirable parameters of qualitative performance measurement will be determined; data will then be collected on these parameters from various supply chains in Kenya. A design of a fuzzy logic framework will be generated for use in measuring performance of supply chain management.

1.7 Significance of study.

The research work intends to generate a simple to use model for establishing a more meaningful supply chain performance measurement approach using fuzzy logic, with this performance measurement method, supply chain managers can easily measure the performance of the whole chain with high accuracy, and then analyze the effectiveness of their strategies, identify their potential opportunities. All this feedback facilitates more objective decision making and performance improvement in supply chain management.

The study may also be useful to scholars and academicians. it focused on developing a framework for measuring supply chain reliability and responsivess using fuzzy logic concepts which have never been incorporated into previous frameworks. It may provide information to potential and current scholars on supply chain management new performance measurement The findings can be used as a basis for further research on supply chain management implementation both in the public and private sector.

CHAPTER TWO

LITERATURE REVIEW

2.1 Supply Chain Management

The origins of Supply Chain Management are not exactly known, but there is general reference to its introduction by consultants in the early 1980s. In the decades since, it has received considerable attention, initially starting within the business community. From the early 1990s, academic research started following supply chains and tried to establish some theoretical structure (Kamalabadi *et al.* 2008).

The term Supply Chain Management has not been used only with regard to the logistic activities and the planning and control of materials and information flows internally within a company or externally between companies. Some authors have used it to describe a strategic, interorganizational issues (Cox, 1994), others to discuss an alternative organizational form to vertical integration (Thorelli, 1986), others to identify and describe the relationship a company develop with its suppliers (Hines, 1994).

Supply Chain Management and other similar terms, such as network sourcing, supply pipeline management, value chain management, and value stream management have become subjects of increasing interest in recent years, to academics, consultants and business management (Nomesh *et al.,* 2012). It is recognized in some parts of the literature that the supply chain should be seen as the central unit of competitive analysis (Cox, 1994). Companies will not seek to achieve cost reductions or profit improvement at the expense of their supply chain partners, but rather seek to make the supply chain as a whole more competitive. In short, the contention in that it is supply chains, and not single firms, that compete is a central tenet in the field of Supply Chain Management. (Nomesh, Pranav & Jalaj, 2012).

Supply Chain Management has been defined to consist of different levels: supplier, manufacturer, distributer and consumer where materials flow downstream to upstream from supplier to customers, and information flows in both directions (Shirouyehzad *et al.,* 2011), The aim of supply Chain Management is to gain advantages in terms of customer service and cost over competitors. Supply Chain Management focuses on new terms such as marketing, new product development and customer service thus; one of the classified characteristics of the Supply Chain Management is establishing approaches for obtaining the customer satisfaction (Shirouyehzad *et al*., (2011).

Performance of Supply Chain Management influences the efficiency and effectiveness for achieving the mentioned goals. The efficiency of supply chain depends on the response to the demand accurately and quickly and satisfying customer by creating the value for them leads to effectiveness (Shirouyehzad *et al*., (2011).

Supply Chain Management is the task of integrating organizational units along a Supply Chain and coordinating materials, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving competitiveness of the Supply Chain as a whole (Stadtler, 2005).

Supply Chain Management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole. (Mentzer, 2001).

The main reason and objective of Supply Chain Management is to provide a strategic weapon to build up and enhance sustainable competitive advantage by cost reduction without compromising customer satisfaction (Mentzer, 2001). Moreover, the ability to understand the environment pressures that drive the Supply Chain Management and clearly note the barriers and implement solutions or bridges enables supply chain performance to maintain competitive advantage (Fawcett, 2008). The main goal and important aspect of Supply Chain is leveraging the expertise, experience, skills and capabilities of the Supply Chain Performance who comprise this competitive network (Shirouyehza *et al*., 2011).

Successful implementation of Supply Chain Management is seen as closely dependent upon the need for breaking down barriers not only between internal departments and business processes, but also across companies within the whole supply chain (Vollman, 1997). Its success is also associated with the challenging development of a new culture based on empowerment and ongoing and shared learning and continuous improvement.

Supply Chain Management is a network of facilities that produce raw materials, transform them into intermediate goods and then final products, and deliver the products to customers through a distribution system. It spans procurement, manufacturing and distribution (Hausman, 2006). The basic objective of Supply Chain Management is to optimize performance of the chain to add as much value as possible for the least cost possible‖. In other words, it aims to link all the supply chain agents to jointly cooperate within the firm as a way to maximize productivity in the supply chain and deliver the most benefits to all related parties (Finch 2006).

Kamalabadi *et al.,* (2008) definition of Supply Chain Management as Supply Chain Management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders‖

The implicit existence of supply chains highlights the need for firms to not only acknowledge upstream and downstream business entities but to also build sustainable and mutually beneficial relationships with their upstream and downstream partners (Kamalabadi *et al.,* 2001) found a positive relationship between a firm ‘s rate of performance improvement and the level of integration between the firm and the firm ‘s suppliers and customers.

This leads to another significantly addressed theory from Supply Chain Management literature; practitioners and academicians alike agree that Supply Chain Management is a means to create and sustain a competitive advantage and enhance organizational performance for the firm and for the entire supply chain (Kamalabadi *et al.*, 2008).

Several conditions must be present for successful Supply Chain Management adoption; the single most important prerequisite is a change in the corporate cultures of all members of the supply chain (Tan *et al.*, 1998). There are three identified reasons to form supply chains: to reduce inventory investment in the chain, 2) to increase customer service, and 3) to help build a competitive advantage for the channel"(Cooper & Ellram, 1993)

Firms that are going to be successful already know or must quickly realize that in today ‘s fast paced and interconnected business environment infused with mass globalization a firm will not survive in isolation but rather a single entity of an integrated supply chain (Tan *et al*, 1999).

Researchers have consistently acknowledged that today ‘s business environment is no longer reflective of firm versus firm but has progressed to that of supply chain versus supply chain (Kamalabadi *et al.*, 2008).

A wide variety of studies have developed and contributed to the evolving foundation of Supply Chain Management continually over the last 20 years (Kamalabadi *et al.*, 2008). The theoretical and practical importance of the management of the supply chain has been widely recognized through numerous studies (Cooper *et al.*, 1998).

A supply chain is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Mentzer, *et al*,2001). The numerous definitions and approaches to Supply Chain Management throughout history were investigated and stated that, it is important to realize that implicit with these definitions is the fact that supply chains exist whether they are managed or not (Mentzer *et al*.,2001).

2.2 Performance Measurement in Supply Chain Management

Traditionally, performance measurement is defined as the process of quantifying effectiveness and efficiency of action (Chan, 2003). In other words, measuring performance means transferring the complex reality of performance into a sequence of limited symbols that can be communicated and reported under similar circumstances (Chan, 2003).The performance measurement process has evolved since the mid-eighties of last century when its foundations were formalized and integrated into the management of organizations, have developed various models of performance measurement structures to reach metrics intra-organizational or interorganizational performance (Folan & Browne, 2005).

When you can measure something and express it in numbers, you have good background knowledge about it (Neely, 2008). What you measure is what you get (Norton, 1992). In other words, measuring performance means transferring the complex reality of performance into a sequence of limited symbols that can be communicated and reported under similar circumstances (Chan, 2003)

Performance measurement describes the feedback on operations which are geared towards customer satisfaction and strategic decisions and objectives (Bhagwat & Sharma, 2007)**.** Performance measures provide the necessary feedback for management which assist in business decisions (Ezutah & Kuan, 2010).

They further pointed out that performance measurement reflects the need for improvement in operational areas which are found wanton in performance measures.

Effective performance measurement has been identified as necessary in Supply Chain Management (Norton ,1992). Performance measurement has been identified as having the benefits of stabilizing the process and identifying areas for further improvement within the system (Bond, 2003). He further stated that measurement of performance will also reveal whether there is need for an organization 's continuation in its current method (maintaining the status quo) or adopting a re-engineering of its system to affect the areas which are found deficient. lack of adequate performance measurement has been identified as one of the major obstacles to efficient Supply Chain Management (Bond ,2003). It is an established fact that in order to improve supply chain effectiveness and realize a smooth flow of resources within it, there is a need to measure its performance (Bond, 2003).

Performance measurement is one of the important managerial keys which tries to integrate the tasks for controlling events. In this context, performance measurement is related to strategic intent, and the broad set of metrics used by managers to monitor and guide an organization within acceptable and desirable parameters. However, performance measurement implies an ability to monitor events and activities in a meaningful way (Morgan, 2004).

In modern business management, performance measurement assumes a far more significant role than quantification and accounting (Chan, 2003). Performance measurement can provide important feedback information to enable managers to monitor performance, reveal progress, enhance motivation and communications and diagnose problems(Chan,2003) Traditionally Performance Measurement Systems that are financially focused have already received wide critism on short term and profit orientation, encouraging local optimization, failing to support continuous improvement, and uni-dimensional measures(chan,2003).

2.3 Traditional approaches to Supply Chain Management Performance Measurement

Traditionally, companies have tracked performance based largely on financial accounting principles, many which date back to the ancient Egyptians and Phoenicians. Financial accounting measures are certainly important in assessing whether or not operational changes are improving the financial health of an enterprise, but insufficient to measure supply chain performance (Lapide, 2010).

2.3.1 Activity Based Costing:

Activity Based Costing enables the supply chain participants to obtain information about the structure of the production costs of other participants, assessing the effects of changes made by others, estimate the costs of new products, and identify areas of significant cost savings and better control of production costs of finished products (Sobańska, 2010). Supply chain describes the flow of goods, services, and information from the initial sources of materials and services to the delivery of products to consumers, regardless of whether those activities occur in the same organization or in other organizations (Lapide, 2007). Cost management is most effective when it integrates and coordinates activities across all companies in the supply chain as well as across each business function in an individual company's value chain. Attempts are made to restructure all cost areas to be more cost-effective (Sobanska, 2010).

The Activity-Based Costing (ABC) approach was developed to overcome some of the shortcomings of traditional accounting methods in tying financial measures to operational performance. The method involves breaking down activities into individual tasks or cost drivers, while estimating the resources (i.e., time and costs) needed for each one. Costs are then allocated based on these cost drivers. This approach allows one to better assess the true productivity and costs of a supply chain process. The domain of inter-organizational cost management is buyer supplier formalized interactions, the objective of which is to identify opportunities for joint cost reduction (Cooper & Slagmulder, 2004).

Activity-based costing has been developed by the industry in the US already in the 70's and 80's. It has gained broader awareness in businesses around 1988, when Cooper and Kaplan (1993) published a number of articles in the Harvard Business Review. In figure 2.1 the basic principle of traditional activity-based costing is demonstrated which is that all cost categories (e.g. personnel related cost, IT cost, building cost etc.) are assigned to activities. Additionally, drivers are specified which determine the cost level, like orders, order lines, number of products or square meters. Through the cost per activity and the volumes of the drivers, a tariff per activity can be calculated. Traditional activity-based costing is focusing on the assignment of all costs to activities.

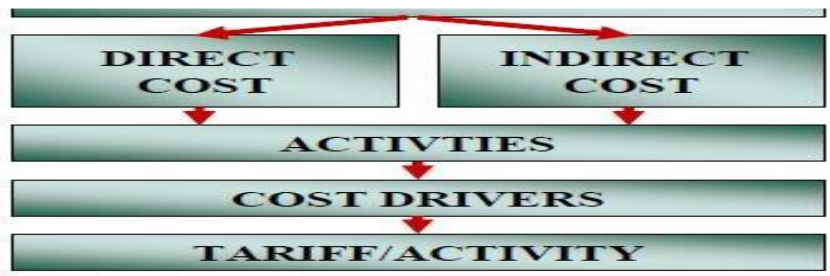

Figure 2. 1: Traditional Activity Based Costing (Source: http://lapide.ASCET.com)

2.3.2 Economic Value Analysis.

It estimates a company's return on capital or economic value-added these are based on the premise that shareholder value is increased when a company earns more than its cost of capital. One such measure, Economic Value Analysis, developed by Stern, Stewart & Co., attempts to quantify value created by an enterprise, basing it on operating profits in excess of capital employed (through debt and equity financing). Some companies are starting to use measures like Economic Value Analysis within their executive evaluations. Similarly, these types of metrics can be used to measure an enterprise ‘s value added contributions within a supply chain (Lapide, 2010). However, while useful for assessing higher level shareholder value, economic-value added metrics are less useful for measuring detailed supply chain performance.

2.3.4 Data Environmental Analysis.

It quantifies value created by an enterprise, basing it on operating profits in excess of capital employed (through debt and equity financing). These types of metrics can be used to measure an enterprise ‘s value added contributions within a supply chain. However, while useful for assessing higher level executive contributions and long term shareholder value, economic-value added metrics are less useful for measuring detailed supply chain performance.

Kuan (2010) provided a frame work with which to study supply chain performances by developing a Data Envelopment Analysis model for the internal supply chain performance efficiency using case study applications. Chaudhary *et al.,* (2012) developed Data Environment Analysis based approach suitable for measurement of supply chain efficiency when intermediate measures are built in into the evaluation scheme. Shruti and Mudholkar (2011), proposed Data Environment Analysis based supply chain efficiency functions aimed at identifying the inefficiency within the chain members by developing two efficiency functions for the manufacturer and the supplier.

2.4 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.

In their study, (Nomesh *et al.*, 2012), 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 their study, (Unahabhokha *et al*., 2007), 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 Supply Chain Operations Reference 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, (Chan, 2003) 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 covers 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. (Huang & Lau, 2003) Proposed a methodology for monitoring the Supply Chain 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. Supply Chain Operations Reference (SCOR) model presented the following five attributes of Supply Chain performance (Supply Chain Council, 2010):

1. *Supply Chain 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 (Aramean *et al*, 2007.

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 (Beamon, 1999). Flexibility was considered to be a qualitative factor (Hamidreza, 2010)

4. Supply Chain costs: The costs associated with operating the Supply Chain. Cost is one of the quantitative measures (Hamidreza., 2010) 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. The conceptual framework with the chosen variables is shown on Fig. 2.2

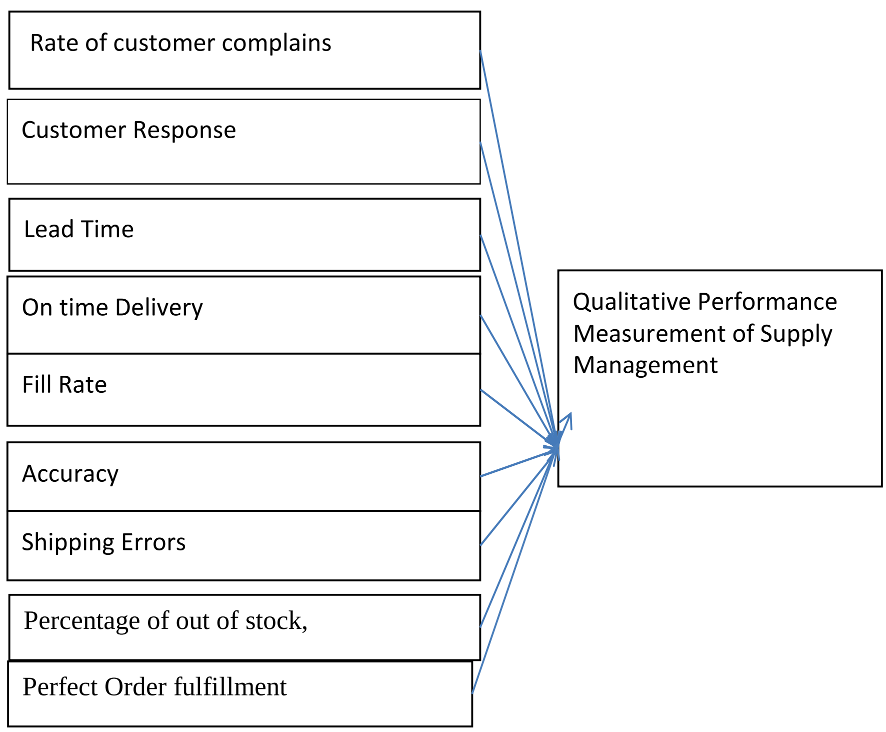

Figure 2. 2: Conceptual Framework for Qualitative performance management

(Adapted from supply chain council, SCOR model, 2010)

Models in the past have only explored limited dimensions of supply chain performance such as cost (Pyke & Cohen, 1994) and flexibility (Sanchez &

Perez, 2008). Hence this research aims to fill the gap by studying the other two aspects of qualitative supply chains. Which are reliability and responsiveness.

2.5 Fuzzy Logic Concepts

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 (Deepak *et al*., 2011).

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 (Shruti, & Mudholkar, 2013). 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. A Fuzzy Logic System consists of four main parts: fuzzier, rules, inference engine, and defuzzifier (Fuzzy Logic Fundamentals, 2011).

These components and the general architecture of a Fuzzy Logic System is shown in Figure 2.3.

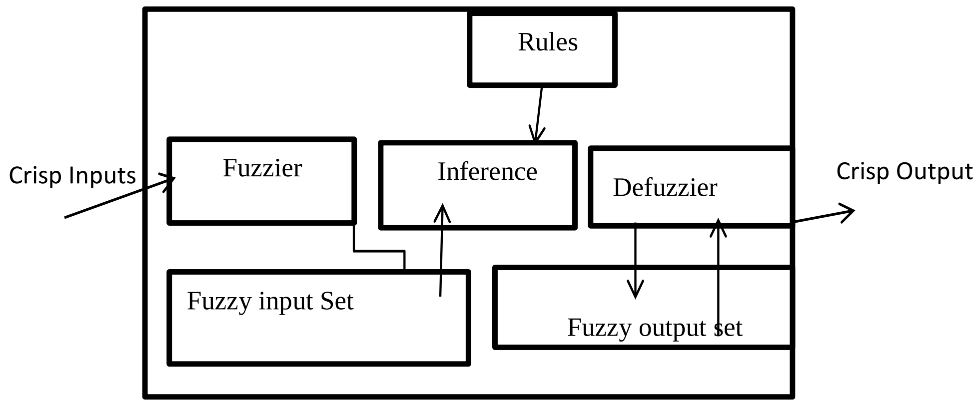

Figure 2. 3: Fuzzy Logic system

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 (“Fuzzy logic fundamentals”, 2011). 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 (“Fuzzy Logic Fundamentals”, 2011)

2.5.1 Fuzzification:

Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values

("Fuzzy Logic Fundamentals" ,2011). A linguistic variable is generally decomposed into a set of linguistic terms The first block inside the fuzzy controller is fuzzification. Fuzzification uses the concepts of fuzzy set theory and specifically fuzzy set operations.

The fuzzification block is used to transform the crisp values obtained from the input signal into grades of membership for linguistic terms of fuzzy sets (Zadeh, 1966). For example, the fuzzification of a man who is six feet in height may belong to two fuzzy sets „average‟ and „tall‟. The membership functions μA and μB are the terms used to characterize the two fuzzy sets „average‟ and „tall‟, respectively (Zadeh, 1966). The man ‘s height, 6 feet, belongs with a grade of 0.75 to the fuzzy set „average‟ and with a grade of 0.25 to the fuzzy set „tall‟ (Zadeh, 1966). The fuzzification step involves transforming the input value (6 feet) into the grades of membership (0.75 for „average‟ and 0.25 for „tall‟) (Zadeh, 1966).

2.5.2 Linguistic variables and Linguistic Terms:

In 1970s, Zadeh introduced and developed the theory of approximate reasoning based on the notions of linguistic variable and fuzzy logic. Informally, by a linguistic variable we mean a variable whose values are words in a natural or artificial language. For example, Age is a linguistic variable whose values are linguistic terms such as young, old, very young, very old, quite young, more or less young, not very young and not very old, etc. (Zadeh, 1970). As is well-known, the values of a linguistic variable are generated from primary terms (e.g., young and old in the case of linguistic variable Age) by various linguistic hedges (e.g., very, more or less, etc.) and connectives (e.g., and, or, not) (Zadeh,1970).

In Zadeh ‘s view of fuzzy logic, the truth-values are linguistic, e.g., of the form true ‘very true ‘‘, more or less true ‘‘, false ‘‘, possible false ‘‘, etc., which are expressible as values of the linguistic variable Truth, and the rules of inference are approximate rather than exact. In this sense, approximate reasoning (also called fuzzy reasoning) is, for the most part, qualitative rather than quantitative in nature, and almost all of it falls outside of the domain of applicability of classical logic(Zadeh,1970). The primary aim of the theory of approximate reasoning is to mimic human linguistic reasoning particularly in describing the behavior of human-centered systems (Zadeh, 1970).

A linguistic variable is a variable whose values are expressed in linguistic terms (Mehrdad & Abbas, 2011). It is suitable to represent the degree of subjective judgment rather than crisp value in course evaluation process (Mehrdad & Abbas, 2011). There is a substantial body of work dealing with linguistic variables and their modeling with fuzzy sets. It is Zadeh‘s contention that Fuzzy logic computing with words (Zadeh, 1996). However, in applications, fuzzy sets and fuzzy logic are most often applied to variables which have an underlying numeric scale. Modeling non-numeric linguistic variables is acknowledged to be less well developed (Zadeh, 1996).

Most work relating fuzzy logic and fuzzy set theory to linguistic variables starts from the premise that Zadeh‘s contention is correct (Mehrdad &Abbas, 2011). It is also usual to define linguistic variables and linguistic terms using Zadeh‘s definition (Mehrdad & Abbas, 2011)

2.5.3 Linguistic Hedges

In human thinking and language, we often use uncertain or vague concepts. Our thinking and language is not binary, i.e., black and white, zero or one, yes or no. These are crisp sets that allow only full membership or no membership at all. Fuzzy sets represent commonsense linguistic labels like slow, fast, small, large, heavy, low, medium, high, tall, etc. (Kamalabadi, *et al.,* 2008). Fuzzy set theory is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings. In real life we add much more variation to our judgments and classifications. These vague or uncertain concepts are said to be fuzzy. We encounter fuzziness almost everywhere in our everyday lives.

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 (Zadeh, 1976). 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. 2.4

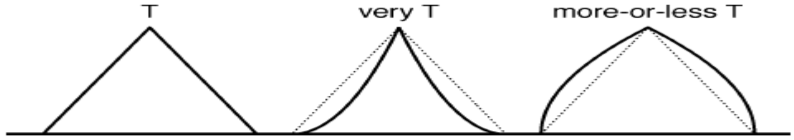

Figure 2. 4: Effects of the linguistic variables "Very" and "more-or- less"

2.5.4 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.

Fuzzy logic uses everyday spoken language to define rule base. Fuzzy logic usually uses IF/THEN rules, or constructs that are equivalent, such as fuzzy associative matrices. Rules are usually expressed in the form:

IF variable IS set THEN action

("Fuzzy Logic Fundamentals", 2011) The AND, OR, and NOT operators of Boolean logic exist in fuzzy logic, usually defined as the minimum, maximum, and complement; when they are defined this way, they are called the *Zadeh operators*, because they were first defined as such in Zadeh's original papers. ("Fuzzy Logic Fundamentals", 2011).

So for the fuzzy variables x and y: NOT x = (1 - truth(x)) x AND y = minimum(truth(x), truth(y)) x OR y = maximum (truth(x), truth(y))

(“Fuzzy Logic Fundamentals”, 2011). Figure 2.5 shows a typical rule base showing how the if/then rules can be used with input linguistic terms for a linguistic variable distance to give an output in linguistic terms for power.

Typical Rule Base				
Rule		Input Linguistic Terms for Distance		Output Linguistic Terms for Power
1	IF	Far	THEN	Positive_High
2	IF	Medium	THEN	Positive_Medium
3	IF	Close	THEN	Positive_Medium
4	IF	Zero	THEN	Zero

Figure 2. 5: Typical Fuzzy Logic Rule Base

2.6 Rule Base Reduction Methods

When a fuzzy controller is designed for a complex system, often several measurable output and actuating input variables are involved. In addition, each variable is represented by a finite number m of linguistic labels which would indicate that the total number of rules is equal to mn, where n is the number of system variables. As an example, consider n = 4 and m = 5 than the total number of fuzzy rules will be k = mn = 54 = 625. If there were five variables, then we would have k = 3125. From the above simple example, it is clear that the application of fuzzy control to any system of significant size would result in a dimensionality explosion.

One of the most important applications of fuzzy set theory has been in the area of fuzzy rule based system. Rule base reduction is an important issue in fuzzy system design, especially for real time Fuzzy Logic Controller (FLC) design. Rule base size can be easily controlled in most fuzzy modeling and identification techniques.

2.6.1 Automatic Estimation of Parameters of Complex Fuzzy Control Systems

The size of the rule base of complex fuzzy control systems grows exponentially with the number of input variables. Due to that fact, the reduction of the rule base is a very important issue for the design of this kind of controllers. Several rule base reduction methods have been developed to reduce the rule base size.

Fuzzy clustering is considered to be one of the important techniques for automatic generation of fuzzy rules from numerical examples. This algorithm maps data points into a given number of clusters (Klawonn, 2003). The number of cluster centers is the number of rules in the fuzzy system. The rule base size can be easily controlled through the control of the number of cluster centers. However, for control applications, often there is not enough data for a designer to extract a complete rule base for the controller (Klawonn, 2003).

A designer has to build a generic rule base. A generic rule base includes all possible combinations of fuzzy input values. The size of the rule base grows exponentially as the number of controller input variables grows. As the complexity of a system increases, it becomes more difficult and eventually impossible to make a precise statement about its behavior.

A simple and probably most effective way to reduce the rule base size is to use Sliding Mode Control. The motivation of combining Sliding Mode Control and Fuzzy Logic Control is to reduce the chattering in Sliding Mode Control and enhance robustness in Fuzzy Logic Control. The combination also results in rule base size reduction. However, this approach has its disadvantages as the parameters for the switch function have to be selected by an expert or designed through classical control theory (Hung, 1993).

Anwer (2005) proposed a technique for generation and minimization of the number of such rules in case of limited data sets. Initial rules for each data pairs are generated and conflicting rules are merged on the basis of their degree of soundness. The minimization technique for membership functions differs from other techniques in the sense that two or more membership functions are not merged but replaced by a new membership function whose minimum and maximum ranges are the minimum value of the first and maximum of the last membership function and bisection point of the two or more will be the peak of the new membership function. This technique can be used as an alternative to develop a model when available data may not be sufficient to train the model.

A neuro-fuzzy system (Ajith *et al.*, 1993; Halgamuge, 1994) is a fuzzy system that uses a learning algorithm derived from, or inspired by, neural network theory to determine its parameters (fuzzy sets and fuzzy rules) by processing data samples.

Modern neuro-fuzzy systems are usually represented as special multilayer feed forward neural networks (for example, models like ANFIS (Jang, 1993), FuNe (Halgamuge, 1994), Fuzzy RuleNet (Tschichold-German, 1994), GARIC (Berenji, 1992), HyFis (Kim, 1999) or NEFCON (Nauck, 1994) and NEFCLASS (Nauck, 1995)). A disadvantage of these approaches is that the determination of the number of processing nodes, the number of layers, and the interconnections among these nodes and layers are still an art and lack systematic procedures.

2.6.2 Sensory Fusion Method

Jamshidi (1997) 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 (Ledeneva, 2006). These variables are often fused linearly. For example, we want to fuse two input variables y1 and y2 (see Figure 1). The fused variable Y will be calculated as Y = ay1 + by2. Here, it is considered that the input variables of the fuzzy controller are represented by m = 5 linguistic labels. Therefore, in this case, the number of rules will be thus reduced from 25 to 5. As we can observe, more variables has the fuzzy controller, more reduction can be obtained. This is shown on Fig 2.6

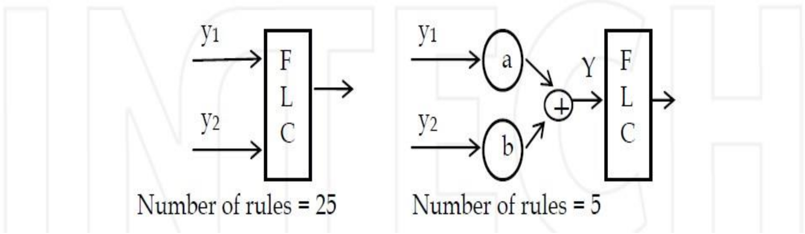

Figure 2. 6: Rule Base reduction of sensory fusion controller

The reduction of the dimension of the problem of control consists in decreasing the number of input variables n of the fuzzy controller. This reduction can be obtained by sensory fusion of the input variables. This method consists in combining mathematically variables before providing them to the input of the fuzzy controller. This variable is fused linearly.

2.6.3 Hierarchical Method

In the hierarchical fuzzy control structure from (Ledeneva, 2007), 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. Fig. 2.7 shows a schematic representation of a hierarchical fuzzy controller. Which fuses tow variables at a time.

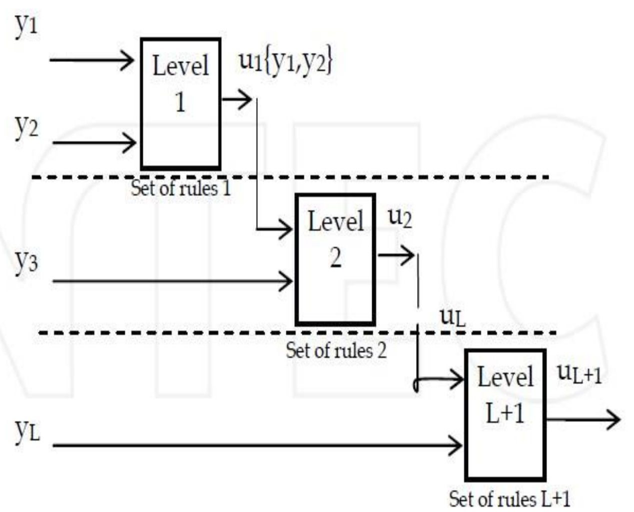

Figure 2. 7: Schematic representation of a hierarchical fuzzy controller (Source: http://cdn.intechopen.com/pdfs-wm/5755.pdf)

Raju (1993), propose to treat on a hierarchical basis the rule bases so that the number of rules increases linearly and no exponentially with the number of variables.

The set of rules is built in a hierarchical way; the input variables of the fuzzy controller are not anymore treated in parallel but are distributed according to various levels of reasoning. The control problem is thus solved sequentially. The rules are those related to the most important variables and are gathered to form the first level of hierarchy. The second most important variables, along with the output of the first level are chosen as inputs to the second level of hierarchy and so on. The goal of this hierarchical structure is minimize the number of fuzzy rules from exponential to linear function. Such rule base reduction implies that each system variable provides one parameter to the hierarchical scheme. Currently, the selection of such parameters is manually done.

2.6.4 Combination of Methods

The more number of input variables of the fuzzy controller we have, the more it is interesting to combine the methods presented above with a goal to reduce more number of rules. Figure 2.8 shows an example, the combination of the sensory fusion method and the hierarchical method for five variables. Initially, the variables are fused linearly, and then are organized hierarchically.

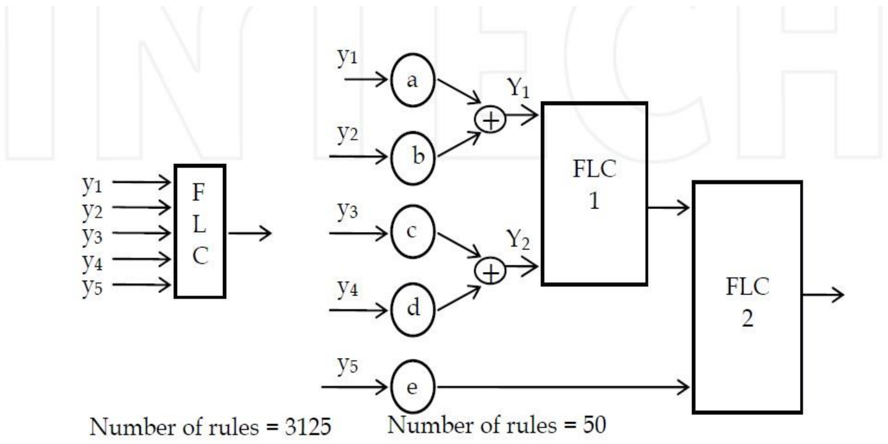

Figure 2. 8:Rule base reduction for the combination of sensory fusion from hierarchical methods (Source: http://cdn.intechopen.com/pdfs-wm/5755.pdf)

The more number of input variables of the fuzzy controller we have, the more it is interesting to combine the various techniques presented.

2.7 Fuzzy Associative Matrices

Fuzzy logic system is thus sometimes called an "expert" system because the rule base (also called the Fuzzy Associative Matrix. They describe the decisions a human operator would make in the control of a system. 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 Fuzzy Logic System, 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.

When there have two or more possible input combination, the output can be determined by using the Fuzzy Association Matrix which expressed the fuzzy logic in tabular form. Those possible inputs are commonly combined by using the AND or OR logic conjunctives. For an example, if a student able finished the exam paper in a short time and the student is completely know how to answer the questions, then the student can score in exam paper with grade A. Fig 2.1 shows a sample fuzzy associative matrix showing two variables Term and Level and their associated linguistic terms and the expected output.

Table 2. 1: Example of Fuzzy associative matrix2

Term/Level	Don‘t know	Somewhat know	Completely know
Long	D	C	B
Medium	D	C	A
Short	D	B	A

(Source : http://www.ukessays.com/essays/computer-science/example-of-fuzzy-associativematrix-fam-computer-science-essay.php)

2.8 Membership Functions

Membership functions are used in the fuzzication and defuzzication steps of a Fuzzy Logic System, to map the non-fuzzy input values to fuzzy linguistic terms and vice versa (Foundations of Fuzzy Logic, 2011). A membership function is used to quantify a linguistic term (Fuzzy Logic Fundamentals, 2011). It an important characteristic of fuzzy logic is that a numerical value does not have to be fuzzified using only one membership function. In other words, a value can belong to multiple sets at the same time (fuzzy Logic Fundamentals, 2011).

2.8.1 Types of membership functions

There are different shapes of membership functions, such as triangular, Gaussian, Trapezoidal etc. Membership functions can have a variety of different forms to describe the same function; however, the membership functions used in this study will be standardized throughout. The simplest membership functions are those who are formed using straight lines (Fuzzy logic fundamentals, 2011).

2.8.2 Triangular Membership Functions

One of the most basic piecewise linear function is the triangular membership function (Foundations of fuzzy logic, 2014). Figure 2.9 illustrates the membership function where a, b and c represent the x coordinates of the three vertices of μA(x) in the fuzzy set A. The coordinate a is defined as the lower boundary in set A whose degree of membership is zero. The coordinate c is defined as the upper boundary whose degree of membership is also zero. Finally, coordinate is the third apex of the triangle whose degree of membership is one (Because linguistic assessments merely approximate the subjective judgment of course evaluation) (Foundations of fuzzy logic,2014). The triangular membership functions can be considered to be adequate for capturing the vagueness of these linguistic assessments (Mehrdad and Abbas, 2011).

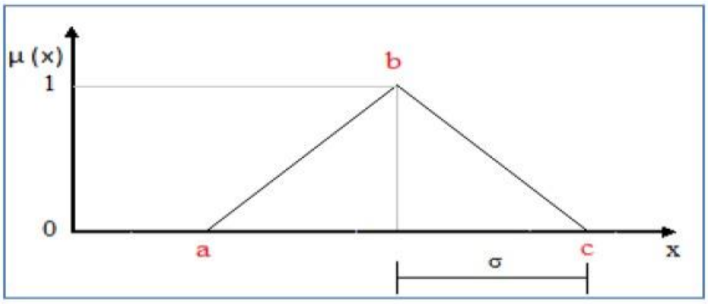

Figure 2. 9: Triangular Membership Function

Equation (1) represents the mathematical formula used to calculate the degree of membership for any element „x. in a fuzzy set A:

$$f(x,a,b,c) = \begin{cases} 0, & x \leq a \\ (x-a)/(b-a), & a \leq x \leq b \\ (c-x)/(c-b), & b \leq x \leq c \\ 0, & c \leq x \end{cases}$$

(1)

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

2.8.3 Gaussian Membership Function

Another fuzzy membership function that is used in fuzzy logic is the Gaussian membership function, which is represented according to Equation. (2) :

$$\mu(x) = [x - b/\sigma)^2] \quad (2)$$

(Retrieved from http://www.academia.edu/5542014/FuzzyLogic) Where x is the input variable, b is the Centre of the membership function and σ is the constant that represents the width of the membership function. Gaussian fuzzy membership functions are quite common with regards to fuzzy logic systems (Foundations of fuzzy logic,2014). Figure 2.10, illustrates a typical Gaussian membership function.

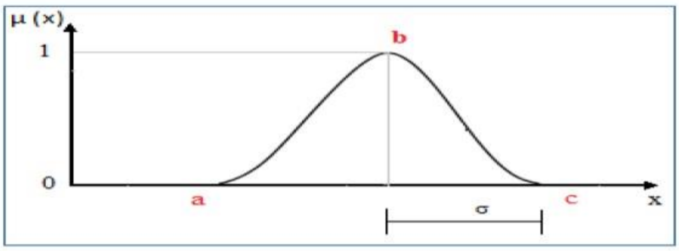

Figure 2. 10: Gaussian Membership Function

2.8.4 Trapezoidal Membership functions

A trapezoidal membership function is specified by four parameters {a, b, c, d} as shown in equation (3):

$$trapezoidal(x; a, b, c, d) = \begin{cases} 0, & x \leq a \\ x - a/b - a, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ d - x/d - c, & c \leq x \leq d \\ 0, & d \leq x \end{cases}$$

(3)

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

An alternative concise expression using min and max is shown in the equation 4:

$$trapezoidal(x; a, b, c, d) = \max(\min(x\text{-}a \quad /b - a, 1, d - x/d - c), 0)$$

(4)

(Fuzzy Logic Fundamentals‖, 2011)

The parameters {a, b, c, d} (with a < b <= c < d) determine the x coordinates of the four corners of the underlying trapezoidal Membership function. Figure 1(b) illustrates a trapezoidal Membership function defined by trapezoid (x; 10, 20, 60 95). Note that a trapezoidal Membership function with parameter {a, b, c, d} reduces to a triangular Membership Function when b is equal to c(Foundations of fuzzy logic,2014).

Due to their simple formulas and computational efficiency, both triangular Membership Functions and trapezoidal Membership Functions have been used extensively, especially in real-time implementations (Mehrdad & Abbas, 2011). However, since the Membership Functions are composed of straight line segments, they are not smooth at the corner points specified by the parameters (Mehrdad & Abbas, 2011). In the following we introduce other types of Membership Functions defined by smooth and nonlinear functions. Figure 2.11 illustrates a typical Trapezoidal membership function.

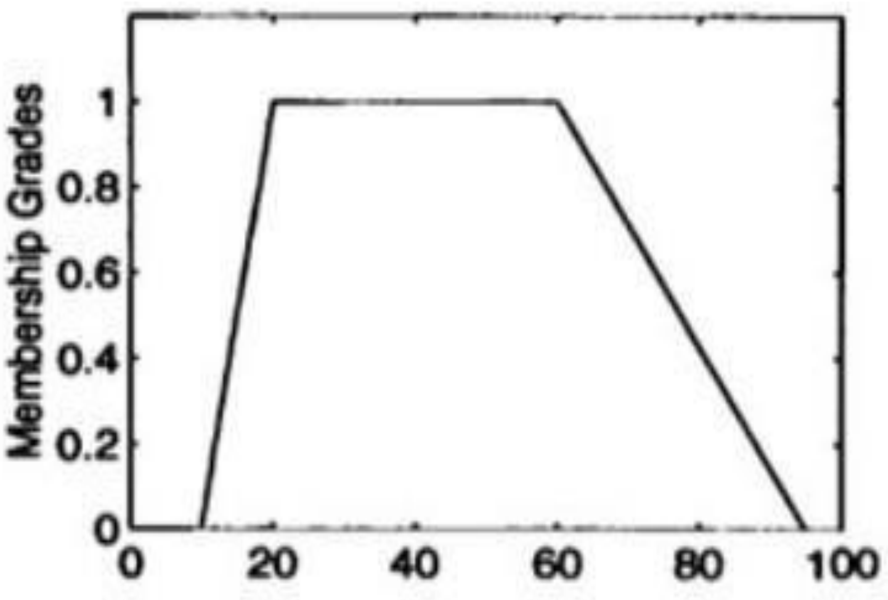

Figure 2. 11: Trapezoidal Membership function (Source: ―Fuzzy Logic Fundamentals‖, 2011)

2.9 Defuzzication

After the inference step, the overall result is a fuzzy value. This result should be defuzzied to obtain crisp output (Fuzzy Logic Fundamentals, 2011). This is the purpose of the defuzzier component of a Fuzzy Logic System. Defuzzication is performed according to the membership function of the output variable (Fuzzy Logic Fundamentals, 2011). For instance, assume that we have the result in

Figure 2.8 at the end of the inference. In this figure, the shaded areas all belong to the fuzzy result. The purpose is to obtain a crisp value, represented with a dot in the figure, from this fuzzy result (Fuzzy Logic Fundamentals, 2012).

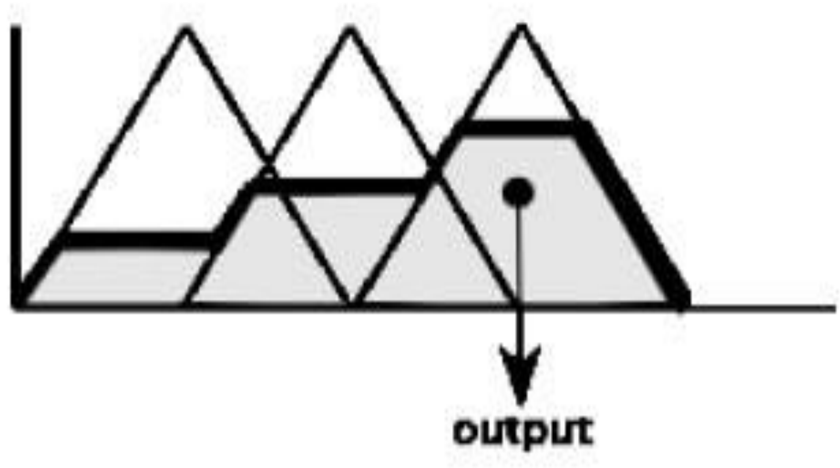

Figure 2. 12: Defuzzication step of a Fuzzy logic system (Source: Fuzzy Logic Fundamentals‖, 2011)

There are different algorithms for defuzzication too. The mostly-used algorithms are listed Without defuzzication, the final output from the inference stage would remain a fuzzy set. In most process applications; there is a requirement for a crisp control signal. In this step a fuzzy set is reduced to a single numbered output (Fuzzy Logic Fundamentals,2011). There are a number of defuzzication techniques available for this operation, some of which are described below:

2.9.1 Centre of Gravity (CoG) Method / Weighted Average Method

The Centre of Gravity method is a technique for finding a crisp value (*u*) from the mid-point of the output fuzzy set using a weighted average of the membership grades (Foundations of Fuzzy

Logic,2014). Suppose, there exists a fuzzy set within a discrete universe, and μ (xi) is its membership value in the membership function (Foundations of Fuzzy Logic, 2014). The following expression can be used to represent the weighted average of the elements in the support set:

$$Z *= \sum \mu c\ (\overline{Z}) \cdot \ \bar{Z} / \sum \mu c(\bar{Z})$$

(5)

(Fuzzy Logic Fundamentals, 2011)

2.9.2 Mean of Maximum (MoM) Method

The Mean of Maximum method is an approach used to find the average *z* where the membership of the fuzzy set is at a maximum (Fuzzy Logic Fundamentals,2011). It may occur that several maximum points exist and so, a common practice is to take the mean of all maximum values. This particular method disregards the shape of the fuzzy set entirely, but the computational complexity is simpler than other methods and yields relatively good results (Fuzzy Logic Fundamentals,2011). As mentioned previously, fuzzy systems use fuzzy rules and fuzzy reasoning to draw upon a conclusion for a given scenario. Fuzzy reasoning is based on a principle that allows a systems developer to map a function between two fuzzy sets; this is known as the extension principle (Fuzzy Logic Fundamentals,2011). For a given scenario there exists a fuzzy set A in a universe Z. The extension principle states that if there is a function, *f*, then the fuzzy set B is given by equation (6):

$$B = f(A) = \sum \mu A(xi) \ / \ f(xi) \ ..$$

(6)

2.11 Fuzzy Logic and Supply Chain Management Performance Measurement Systems

Many attempts have been made on supply chain performance measurement using conventional approaches. Most of these approaches have, to a great extent contributed in performance measurement of a supply chain, but there are still rooms for improvement (Ezutah & Kuan 2009). 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 (Nomesh *et al*., 2012). Moreover, quantitative appraisement of supply chain performance appears very difficult due to involvement of ill defined (vague) performance measures as well as metrics (Nomesh *et al*., 2012).

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 (Zadeh, 1999). 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 (Novak, 2000).

Fuzzy logic is, however, not fuzzy. Basically, fuzzy logic is a precise logic of imprecision and approximate reasoning (Zadeh ,1976). 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 (Zadeh, 1999).

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 (Zadeh, 1999). 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. (Novák, 2000). 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 (Zadeh ,1999).

2.11.1 Performance measurement variables as crisp inputs into Fuzzy Model

All machines can process crisp or classical data such as either '0' or '1'. In order to enable machines to handle vague language input such as 'Somehow Satisfied', the crisp input must be converted to linguistic terms with fuzzy components (Zadeh, 1999). Crisp sets are the sets that we have used most of our life. In a crisp set, an element is either a member of the set or not. This sharp edged boundary work nicely for binary operations and mathematics, but it does not work as nicely in describing the real world.

Using natural language and traditional crisp set values are obtained using linguistic terms such as fair, good and excellent which are introduced into the fuzzy decision making system (Zadeh, 1999). Universe of discourse i.e. the minimum & maximum value of every input variable is based on benchmarking information provided by experts in the Supply Chain Management based on their experience, intuition and expert’s judgment (Patidar & Sohani, 2013)

2.11.2 Fuzzification of crisp inputs into fuzzy sets

A fuzzy process is a process of crisp-fuzzy-crisp for a real system. The original input and the terminal output must be crisp variables, but the intermediate process is a fuzzy inference process. The reason why one needs to change a crisp to a fuzzy variable is that, from the point of view of fuzzy control or a human being 's intuition, no absolutely crisp variable is existed in our real world (Zadeh, 1999). A fuzzy set allows a member to belong to a set to some partial degree. Any physical variable may contain some other components.

Generally, fuzzification involves two processes: derive the membership functions for input and output variables and represent them with linguistic terms. The linguistic terms are identified using natural language, commonsense linguistic labels and traditional crisp set values. 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. Middle values for all the terms will be introduced and the concept of linguistic hedges will be used to identified for each fuzzy linguistic variable such as very low, very high and so on(Zadeh,1999).

The inputs are converted into then their quantification membership values of the fuzzy using a membership function. This process is equivalent to converting or mapping classical set to fuzzy set to varying degrees. The membership function defines the fuzzy set for the possible values underneath of it on the horizontal axis. The vertical axis, on a scale of 0 to 1, provides the membership value of the height in the fuzzy set. Membership functions for fuzzy sets can be defined in any number of ways as long as they follow the rules of the definition of a fuzzy set. The Shape of the membership function used defines the fuzzy set and so the decision on which type to use is dependent on the purpose.

The membership function choice is the subjective aspect of fuzzy logic; it allows the desired values to be interpreted appropriately.

A fuzzy system is a system that works based on imprecise knowledge which is stated by linguistic variables. A membership function is a part of Fuzzy Logic that provides information which maps the inputted numbers onto the linguistic variables (Shirouyehzad, *et al.,* 2011). A Membership Function is basically 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. For instance, high‖ or ‗medium‖ value is referring to Membership function of the fuzzy set that each point in the curve shows a number between 0 and 1(Hamidreza *et al.,* 2010).

2.11.3 Fuzzy Rules and the Inference Engine

Fuzzy control rule can be considered as the knowledge of an expert in any related field of application. The fuzzy rule is represented by a sequence of the form IFTHEN, leading to algorithms describing what action or output should be taken in terms of the currently observed information, which includes both input and feedback if a closed-loop control system is applied

(Ying, 2005). The law to design or build a set of fuzzy rules is based on a human being ‘s knowledge or experience, which is dependent on each different actual application (Ying, 2005). Fig 2.13 shows the input variables data must first be converted into crisp inputs. The inputs are then fuzified and an output fuzzy sets are defuzzified into a crisp output.

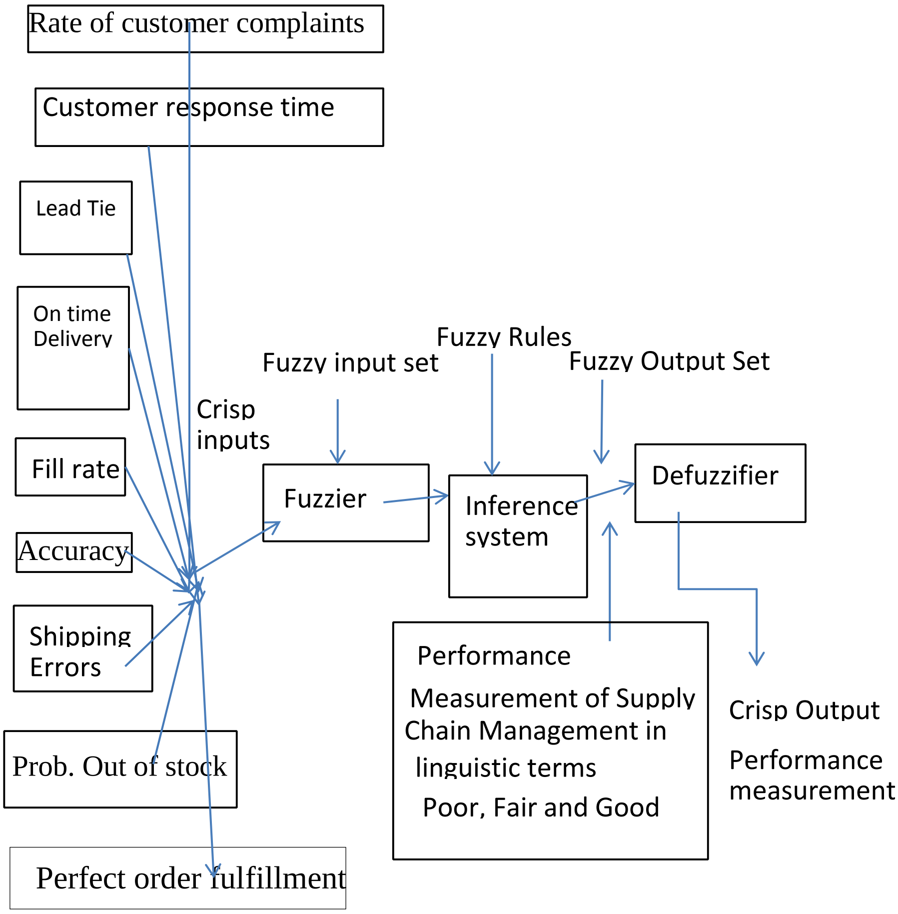

Figure 2. 13: Fuzzy Logic and Supply chain management and performance management variables source:(adapted from supply chain council,2010)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This section described the methods that were be used to gather the data for the proposed performance measurement framework of Supply Chain Management using fuzzy logic concepts. Data on qualitative performance measurement was collected from various industries. The supply chain managers, procurement officers and stores managers formed part of the team to supply information as they were the ones that deal with supply chains. The information provided was used as the primary data for this research. The data was analyzed and formed part of the factors used to design the performance measurement framework. This chapter covered Research design, Data Collection, Design Methodology and Data analysis

3.2 Population and Sample

The target population was Supply Chains in Kenya. purposive sampling was used where chosen specific people within the population were used in this research They will be purposively selected because all supply chain in Kenya meet a certain characteristic. All of them use the same supply chains such as the same distributors as all firms in Kenya have branches in all cities. Purposive sampling, also referred to as judgment, selective or subjective sampling is a non-probability sampling method that is characterized by a deliberate effort to gain representative samples by including groups or typical areas in a sample. The researcher relies on his/her own judgement to select sample group members. Purposive sampling is mainly popular in qualitative studies. Purposive sampling can be very useful for situations where you need to reach a targeted sample quickly and where sampling for proportionality is not the main concern.

3.3 Data Collection Instrumentation

This phase does describe the techniques that were employed to gather the requirements to evaluate the proposed system. The proposed method for data collection in this research was a questionnaire. The questionnaire is a well-known technique to collect demographic data and user's opinions (Preece, 2002). Mostly questionnaires are used to gather data from large numbers of people. Questionnaires are an inexpensive way to gather data from a potentially large number of respondents. Every step needs to be designed carefully because the final results are only as good as the weakest link in the questionnaire process. Although questionnaires may be cheap to administer compared to other data collection methods, they are every bit as expensive in terms of design time and interpretation

The proposed data collection instrument for this research was a design Likert scale that allowed me to assign numbers 1-5 to collect both qualitative and quantitative data about the supply chains from the sample population. Likert scale was chosen because of its straight forward nature, ease of analysis of data. An open ended questionnaire also accompanied the Likert scale to allow for collection of qualitative data on the general feelings of the sample population about the performance measurement factors of the supply chains in use today. Questionnaire was designed in two sections. The first section gathered general respondent's 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 crisp input values on responsiveness and reliability of supply chain performance from experts based on the selected linguistic terms. The correct range of data for each criterion was gathered through this questionnaire. Then, questionnaire was distributed to eighty companies that have Supply Chains. Therefore, role of the questionnaire in the research is to obtain the robust data of the industries which can be applied in the proposed Fuzzy Logic Model.

3.4 Data Collection

To assess the effectiveness of the proposed framework, a survey was conducted for Supply Chain Management of various companies in order to determine their performance measurement metrics. A survey has been defined as a ―means for gathering information about the characteristics, actions, or opinions of a large group of people‖ (Pinsonnault & Kraemer, 1993). Surveys are capable of obtaining information from large samples of the population. They are also well suited to gathering demographic data that describe the composition of the sample (McIntyre, 2003).

Primary data was collected from various supply chains in Mombasa which represented the entire nation. The questionnaires were administered to all firms by drop and pick method and the interview guides were administered personally by the researcher.

3.5 Design Methodology

After d the questionnaire was designed 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.

3.5.1 Fuzzication of the input and output variables by considering appropriate linguistic subsets.

Fuzzification comprises the process of transforming crisp value into grade of membership for linguistic terms of fuzzy sets. Qualitative Performance measurement parameters that were used will be reliability (perfect order fulfillment) and responsiveness. Flaws existed with supply chain models using only one supply chain performance measure (Beamon, 1999). Models using a single performance measure can indicate a lack of attention to other performance measures (Beamon, 1999). Responsiveness parameter were: customer response time, lead time, rate of customer complaints, on time delivery, fill rate, shipping errors. Lead time, customer complaints, shipping errors and customer response time were classified numerically and perfect order fulfillment, fill rate and on time delivery classified proportionally as shown in Table 3.1.

Table 3. 1: Qualitative performance measurement variables

.Factor	Definition
Customer Complaints	The number of customer complaints registered
Customer Response Time	The amount of time between an order and its corresponding delivery.
Lead Time	The time required once the product began its manufacture until the item is completely processed.
On Time Delivery	The percentage of orders delivered on or before the due date
Fill Rate	The proportion of orders that can be filled immediately
Shipping errors	The number of errors that occurred during shipment of products
Perfect order fulfillment	The percentage of orders delivered to the right place, with the right product, at the right time, in the right condition, in the right package, in the right quantity, with the right documentation, to the right customer, with the correct invoice

Adapted from "Qualitative performance measures in Supply Chain Management", by Chan, 2003& Aramean, 2007)

Linguistic labels of concentration **"**very**"** was added to the linguistic term set to show a degree of concentration for the performance measurement variables mentioned above. Five linguistic terms were considered "very low", low"," medium", "high", and "very high for the numerical group and other five linguistic terms will be considered "very poor"," poor"," Average", "good" and "very good" for the proportional group.

The linguistic terms were then be quantified on a numerical scale based on inputted numerical data collected from various Supply Chain Management system and membership functions were then be defined to determine their degree of membership. The triangular membership function shape was chosen because it is most popular in the performance measurement (Shirouyehzad *et al.,* 2011). The above linguistic variables and terms were then be matched and fuzzy rules generated, and expressed in a fuzzy associative matrix and output results obtained for each parameter which were then be aggregated into one crisp value using a defuzzication technique.

After determining the linguistic terms, membership function was used to map the value of the input variable to a degree of membership in each of the fuzzy sets. In this research a triangular membership function was used to obtain the degree of membership for each linguistic term that represents the performance measurement parameters.

The only condition for choosing membership function must satisfy is that it must be vary between 0 and 1 and one of the great strength of membership functions is that they can be made to overlap. The function must also be suitable in the point view of simplicity, speed and efficiency. Triangular Membership Function is commonly used because of its simplicity and easy computation. Triangular membership function shape was chosen because it is most popular in the performance measurement (Shirouyehzad *et al*., 2011) The result of their study indicated that triangular membership function give the best drive performance.

A triangular membership function is described by three parameters a, m and c and given by the Eq. (2), where a is a lower limit, b an upper limit and a value m, where a<m<b. Membership functions allow us to graphically represent a fuzzy set. The *x* axis represents the universe of discourse, whereas the *y* axis represents the degrees of membership in the [0, 1] interval as shown in fig 3.1. and the triangular membership equation is shown as equation (7).

$$f(x,a,b,c) = \begin{cases} 0, & x \leq a \\ (x-a)/(b-a), & a \leq x \leq b \\ (c-x)/(c-b), & b \leq x \leq c \\ 0, & c \leq x \end{cases} \qquad (7)$$

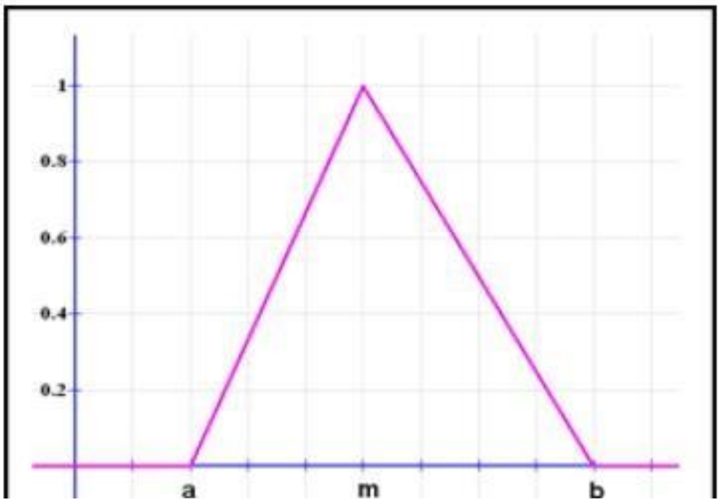

Figure 3. 1: Triangular Membership Function graphical representation

3.5.3 Construction of rules based on expert knowledge and/or the basis of available literature.

The rule base of the proposed Fuzzy Logic Framework were defined in three steps; firstly, total numbers of interactions between the input variables of the FLC will be defined. The numbers of rules were established based on the permutation with number of linguistic terms and number of criteria. The numbers of factors were eight for responsiveness and numbers of membership functions are five. For reliability the number of factors is four and the number of linguistic terms is five. Using Hierarchical Fusion method, two variables were fused at a time. The total amount of rules is 5^2 equal to 25 rules for every fusion resulting into 300 rules.

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 280 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 the membership functions and fuzzy rules were produced. Then the rules were matched the input data and help to show the result and analyze the output performance of supply chain management.

3.5.4 Defuzzication of the Output

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 defuzzication. Many methods have been developed for defuzzication. In this study, Weighted average method‖ (Center of gravity) technique will be applied, Weighted average defuzzication scheme is the most commonly used one in fuzzy logic applications because of its computational efficiency. In his study (Anjana, 2015) used the Weighted Average Formula method which showed maximum accuracy in measuring the performance of students in colleges. Formed by weighting each functions in the output by its respective maximum membership value. The weighted average equation is shown as equation (8)

$$Z *= \sum \mu c\ (\overline{Z}) \cdot \bar{Z} \ / \sum \mu c(\bar{Z}) \qquad (8)$$

Where z is the centroid μ(z) is the membership function of the input value

(Fuzzy Logic Fundamentals,2001)

3.6 Data Analysis

The data collected was analyzed using SPSS to get information about supply chain responsiveness and reliability factors. The data analyzed was presented in form of tables since they are visual and can be easily interpreted for use in this project. Statistical analysis was carried out in this project. This helped to get the mean for all supply chain responsiveness and reliability values. Using the statistical analysis, I was able to obtain the data required as crisp input into the developed Fuzzy Logic framework that measured the performance of Supply Chain Management. Membership functions of each values will have calculated using the triangular membership function equation (1) and the output mapped onto the linguistic terms on the triangular membership plots and then matched against fuzzy rules. The matched fuzzy rules that fire are then used in the defuzzication process. The Fuzzy set operator "AND" was then used to aggregate the output and a single crisp output is then obtained which measures the overall responsiveness, reliability and performance of supply chain management.

CHAPTER FOUR

DATA ANALYSIS, INTERPRETATION AND PRESENTATION

4.1 Introduction:

This chapter discusses the interpretation and presentation of the findings obtained from the field. The chapter presents the background information of the respondents, findings of the analysis based on the objectives of the study. Descriptive statistics was used in the findings of the study. The study targeted a sample size of 100 respondents from which 96 filled in and returned the questionnaires representing a response rate of 96.0%. The respondents were from various industries ranging from Information technology, health, shipping, airlines, importers of papers, rice and many other products, supermarkets etc. This response rate was considered satisfactory to make inferences for the study. The response rate was representative. According to Mugenda and Mugenda (2003), a response rate of 50% is adequate for analysis and reporting; a rate of 60% is good and a response rate of 70 percent and over is excellent. Based on the assertion, the response rate was considered to excellent. Part A of the questionnaire gathered information on the respondent's general characteristics. Table 4.1 shows the general characteristic of respondents based on the number of years they have been in operation and using various supply chains and Table 5.2 shows the number of years the respondents have worked for the organization.

4.2 General Respondents characteristics

Table 4.1 shows classification of respondents by the periods in business operation and their percentage frequency.

Table 4. 1Classification of respondents by the periods in business operations

No of Years	Frequency (%)
Below 1 year	6.67%
1-3 years	6.67%
3-5 years	13.33%
5 and Above	73.33%

The study sought to determine the duration which respondents had been operating their businesses, from the findings 73.3% of the respondents indicated 5 years and above, 13.33 % of the respondents indicated 3-5 years whereas 6.67 % of the respondents indicated 1-3 years and below 1 year. This implies that majority of the respondents had been in the same Supply chain for more than 5 years. The second part of the general characteristic is the working experience of the respondent and this is shown on Table 4.2.

Table 4. 2: Working Experience of the Respondents

No of Years	Frequency (%)
Below 1 year	12.50%
1-3 years	12.50%
3-5 years	25.00%
5 and Above	50.00%

The study requested the respondents to indicate the working experience of the respondents, from the finding 50% indicated they have been in their current position for over 5 years, 25% indicated 3-5 years, whereas 12.5 % indicated 1-3 years and 12.5% below I year, this is an indication that the study that majority of the respondents had been in the same Supply chain for more than 5 years.

Many supply chains exist but many lack performance measurement frameworks. Table 4.3 shows the availability of these frameworks**.**

Table 4. 3: Availability of any Supply Chain Performance Framework

Availability of any Supply Chain Performance Measurement Framework	**Frequency**
Yes	6.25%
No	93.75%

The study revealed that among the respondent firms 93.75% do not use any framework for measuring performance measurement while 6.25% do use a framework. This shows the need of establishing a framework for evaluating supply chain performance.

Supply chain performance measurement is necessary in order to evaluate whether it is performing well or not. Supply chain managers need to be trained on the same. Figure 4.4 shows whether any formal training has been undertaken by supply chain managers.

Table 4. 4: Formal Training of Supply Chain Performance Measurement

Any formal Training on Supply Chain Performance Measurement	**Frequency**
Yes	44.44%
no	55.56%

The study sought to determine whether the respondent had any formal training in evaluating supply chain performance from the findings the study established that 55.56% of the respondents indicated that they had formal training whereas

44.44% of the respondents indicated that did not have any formal training in evaluating supply chain performance, this implies that a considerable number of firms did not have any formal training but rely on their own experience to evaluate supply chain performance.

Many firms are familiar with supply chain performance variables and they do measure it in very informal ways. Table 4.5 shows the supply chain variables and the frequency at which they are used.

Table 4. 5: Familiarity with Supply Chain Management Performance measurement Variables

Parameters	**Frequency (%)**
Responsiveness	45.00%
Flexibility	20.00%
Reliability	10.00%
Cost	20.00%
Asset management	5.00%

The study sought to determine whether the firms use any of the stated performance measurement criteria. The findings indicated that majority of the respondents are familiar with responsiveness as a measure of supply chain performance measurement compared to the other parameters. Many supply chain managers are familiar with the qualitative performance measurement factors and use them on daily basis to measure how well their supply chain is doing but lack a formal framework for measuring them. This is shown in Table 4.6

Table 4. 6: Familiarity with Supply Chain Management Performance Measurement Variables

Response	Frequency (%)
yes	100%
no	0%

The study sought to determine whether the respondent firm was familiar with Qualitative performance measurement parameters. From the findings, it shows that 100% of the respondents are familiar with qualitative performance measurement.

4.3 The extent of using Qualitative performance measurement metrics.

This study sought to establish to what extent are the Qualitative performance measurement metrics used by firms. Data was collected by a 5 rating scale, 5 – very High Extent, 4-High Extent, 3-Moderate extent, 2-Low extent and 1- Very Low extent. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the item is used to a high Extent. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is used to a High Extent. A mean score of 2.5 or more but less than 3.5 would indicate the metric is used to a moderate extent. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics are used to a little extent and a mean score of less than 1.5 would indicate that the metric is used at a very low extent. The higher the mean score the greater the impact and vice versa. The data analysis is presented in table 4.7: Table 4.7 and 4.8 show to what extent reliability and responsivess were used to measure performance.

Table 4. 7: The extent to which performance measurement variables are used

Supply Chain Responsiveness	Mean	Std. deviation
Rate of customer complaints	2.8	1.140175
Customer response time	4.666667	2.701851
Lead time	3.266667	2.607681
On-time delivery	3.6	2
Fill rate	3.533333	1.095445
Probability out of stock	3.066667	2.073644
Accuracy	2.733333	1.224745
Shipping Errors	2.666667	2.061553

Table 4. 8 : The extent to which performance measurement variables are used

Perfect order fulfillment **(rate the following aspects):**	Mean
Correct product delivery	4.0
Correct condition and packaging	3.53
Correct time	3.8
Correct quantity	3.866667

As table 4.7 and 4.8 shows customer response time is used to a very high Extent with a mean score of 4.6. It is followed by Fill rate with a mean score of 3.6. The last one being shipping Errors with a mean score of 2.6. The standard deviations are greater than 1, indicating that there the respondents were of different opinions. As table 5.7 shows correct condition and packaging is used a Very High Extent with a mean score of 4.4. it is followed by Correct Product delivery with a mean score of 4.0. The last one is correct location with a mean score of 3.5.

4.4 Supply chain Responsiveness in Kenya

This study sought to establish the supply chain performance measurement which refers to the speed at which supply chains provides products to customers. Supply chain responsivess was measured using customer response time, shipping errors, Accuracy, fill rate, on time delivery, no of customer complaints, percentage out of stock.

Data for lead time was collected by a 5 rating scale, 1 – less than 1 day, 2-1 to 3 days, 3- 3 days, 4-3-5 days and 5- more than 5 days. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that lead time is more than 5 days. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 3 to 5 days. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 3 days. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 1 to 3 days and a mean score of less than 1.5 would indicate that the metric is measured as less than 1 day. The higher the mean score the greater the impact and vice versa.

Data for customer response time was collected by a 5 rating scale, 1 – less than 2 days, 2- 2 to 6 days, 3- 6 to 10 days, 4-10 to 12 days and 5- more than 12 days. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that lead time is more than 12 days. A mean score of

3.5 or more but less than 4.5 would indicate that the aspect is measured as 10 to 12 days. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 6 to 10 days. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 2 to 6 days and a mean score of less than 1.5 would indicate that the metric is measured as less than 2 days. The higher the mean score the greater the impact and vice versa.

Data for number of customer complaints was collected by a 5 rating scale, 1 – less than 5, 2- 5 to 30, 3- 30 to 45, 4-45 to 60 and 5- more than 60. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that customer complaints are more than 60. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 45 to 60. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 30 to 45. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 5 to 30 and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 5. The higher the mean score the greater the impact and vice versa.

Data for on time delivery was collected by a 5 rating scale, 1 – less than 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered on time is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for Fill Rate was collected by a 5 rating scale, 1 – less than 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods filled is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for shipping errors was collected by a 5 rating scale, 1 – less than 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of shipping errors is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods out of stock was collected by a 5 rating scale, 1 – less than 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods out of stock is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of accuracy of goods delivered was collected by a 5 rating scale, 1 – less than 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of accuracy is 80% to 100% .A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

As table 4.9 shows lead time has a mean of 2 which from the rating scale indicates that most supply chains respond in 1 to 3 days. Customer response time has a mean of 3.18 indicating that the number of days it takes for suppliers to deliver to their customers is on average of 6 to 10 days. Number of customer complaints has a mean of 1.2; this indicates that the number of complaints received within supply chains in Kenya are less than five. On time delivery has a mean score of 3.27 indicating that the percentage of goods delivered on time within the supply chains is 40% to 60%. Fill rate has a mean score of 3, indicating that the percentage of goods delivered immediately an order is placed is 40% to 60%. The number of shipping errors has a mean score of 2, indicating that the percentage of shipping errors is 20% to 40%. Accuracy in deliverer of goods has a mean score of 4, this indicates that percentage of accurate delivery of goods is 60% to 80%. Table 4.9 shows the results for supply chain responsiveness.

Table 4. 9:Results of Supply Chain Responsiveness

parameters	mean
Lead time(in days)	2.12
Customer response time: (in days)	3.18
Number of customer complaints: (in numbers)	1.2
on time delivery:	3.27
Fill rate (%):	3
Shipping errors (%):	2
Percentage out of stock (%):	2.3
Accuracy (%):	4

4.5: Supply Chain Reliability in Kenya

Reliability is a customer focused attribute. It is measured by how orders are fulfilled perfectly. Perfect order fulfillment is measured by the correct product delivery to the correct place, correct time, correct condition and packaging, correct quantity, correct documentation, and to the correct customer.

Data for percentage of goods delivered correctly was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4- 60% to 80% and 5- 80% to 100%.

Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered correctly is 80%

to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods delivered at correct locations was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered at correct locations is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods delivered at correct time was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered at correct time is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods delivered in correct quantity was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered in correct quantity is 80% to 100% .A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%.

A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods delivered in correct condition and package was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered in correct condition and packaging is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods delivered in correct customer was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered in correct customer is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa.

Data for percentage of goods delivered in correct documentation was collected by a 5 rating scale, 1 – 0 to 20 % were delivered on time, 2- 20% to 40%, 3- 40% to 60%, 4-60% to 80% and 5- 80% to 100%. Data was analyzed by mean scores, a mean score of 4.5 or more would be interpreted as indicating that the percentage of goods delivered in correct documentation is 80% to 100%. A mean score of 3.5 or more but less than 4.5 would indicate that the aspect is measured as 60% to 80%. A mean score of 2.5 or more but less than 3.5 would indicate the metric is measured as 40% to 60%. A mean score of less than 1.5 but less than 2.5 would indicate that the metrics is 20% to 40% and a mean score of less than 1.5 would indicate that the metric is measured as less than less than 20%. The higher the mean score the greater the impact and vice versa. Table 4.10 shows supply chain reliability in Kenya

Table 4. 10: ***Results of Supply Chain Reliability***

Performance measures	mean
Correct product delivery	4.2
Correct time	4
Correct quantity	4.12
Correct documentation	4.2

As table 5.10 shows correct product delivery has a mean of 4.2 which from the rating scale indicates that most supply chains deliver 60% to 80 % of products correctly. Correct location has a mean of 4.8 indicating that most supply chains deliver 60% to 80% of goods to the correct location. Correct time has a mean of 4 this indicates that 60% to 80% the most supply chains deliver goods at the correct time. Correct quantity has a mean score of 4.12 indicating that the percentage of goods delivered correctly within the supply chains is 60% to 80%. Correct packaging has a mean score of 4, indicating that the percentage of goods delivered in correct packaging is 60% to 80%. Correct condition has a mean score of 3.9, indicating that the percentage of goods delivered in their correct condition is 60% to 80%. Correct customer has a mean score of 3.9, this indicates that percentage of correctly delivered to the correct customer is 60% to 80%. Correct documentation has a mean score of 4.2; this indicates that the percentage of goods delivers are of correct documentation is 60% to 80%. The mean score for perfect order fulfillment is 4.0 which means that the percentage of orders fulfilled perfectly is between 60% to 80% within the supply chain in Kenya.

4.6 To develop a fuzzy set of linguistic terms for the determined linguistic variables and quantify them using crisp input values and obtain their degree of membership or fuzziness using a suitable membership function.

4.6.1: Quantification of Supply chain responsiveness parameters

This objective sought to quantify the linguistic terms developed and 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 using Equation (9). Data range of input and output parameters is shown in Tables 4.11 and 4.12.

$$f(x,a,b,c) = \begin{cases} 0, & x \le a \\ (x-a)/(b-a), & a \le x \le b \\ (c-x)/(c-b), & b \le x \le c \\ 0, & c \le x \end{cases} \qquad (9)$$

Table 4. 11 : Input Variables Data range

Input Name	Linguistic Variable	Range
Accuracy (%)	Very poor	0,12.5,25
On time Delivery	Poor	0,25,50
Fill rate	Average	25,50,75
Probability of orders not out of stock	Good	50,75,100
	Very Good	75,87.5,100
Shipping Errors		
Response Time(days)	Very Low	0-3
	Low	1.5-6
	Average	2.5-8.5
	High	6-12
	Very High	9-12 and above 12
Number of Complaints	Very Low	0-15
	Low	5-30
	Average	15-45
	High	20-60
	Very High	45-60
Lead Time	Very Low	0-1.5
	Low	0-2.5
	Average	1.25-3.75
	High	2.5-5
	Very High	3.75-5

Table 4. 12 : Output Variable Range for Responsiveness

Output Name	Linguistic Variable	Range
Supply Chain Responsivess	Poor	0-50
	Average	25-75
	Good	50-100

4.6.2 Degree of Membership for each supply chain performance parameters.

According to Janzen (6), fuzzy set theory suggests that there is no one practiced method for determining the shape and width of a fuzzy membership function. It is a subjective process that will vary with the designer of the control system. All the linguistic variables were mapped to their corresponding data range and their corresponding membership functions plots were obtained. Fig. 4.1 shows the membership plot for Accuracy measured propositionally from a scale of 0 to 100.

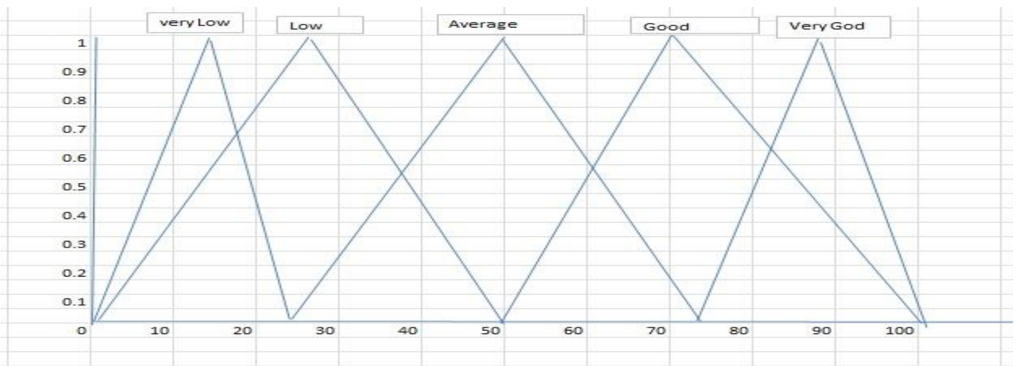

Figure 4 1: Membership Function Plot for % of orders delivered accurately

Percentage of orders delivered accurately from supply chains in Kenya was found to be 80%, which has an intersection between Good and Very good then membership degree can be calculated using Eq... (9) as

Accuracy = (100-80)/100-75 =0.8 Good and 0.2 Very Good

This indicates that percentage of supply chain accuracy was found to be good. on of the responsiveness variable was number of complains which was measured numerically on a scale of 0 to 60. Fig. 4.2 shows a membership function plot for number of complains

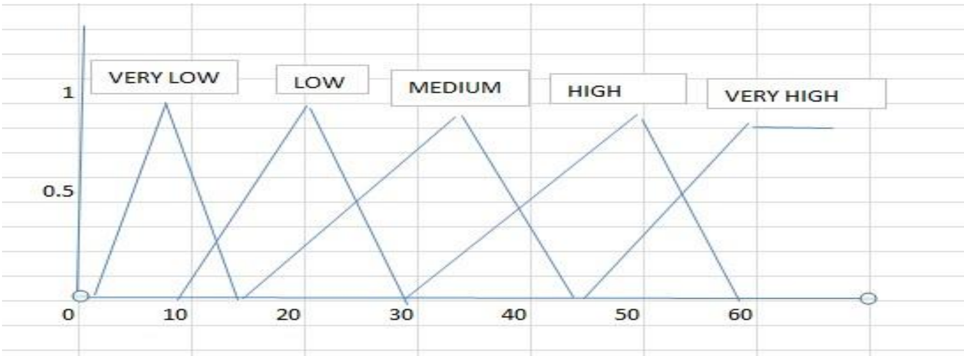

Figure 4 2: Membership Function Plot for number of complains

Number of complaints of supply chains in Kenya was found to be 14.4 which lies on the very low side and the low side, using the triangular membership function shown Eq. (9) the degree of membership is calculated 3-0/ 12.5-0=0.26 LOW and 0.74 VERYLOW.

Lead time is the time required once the product began its manufacture until the item is completely processed. It was measured numerically on a scale of 0 to 5. Fig 4.3 shows the membership function plot for Lead time. . This indicates that the number of complaints was found to be very low.

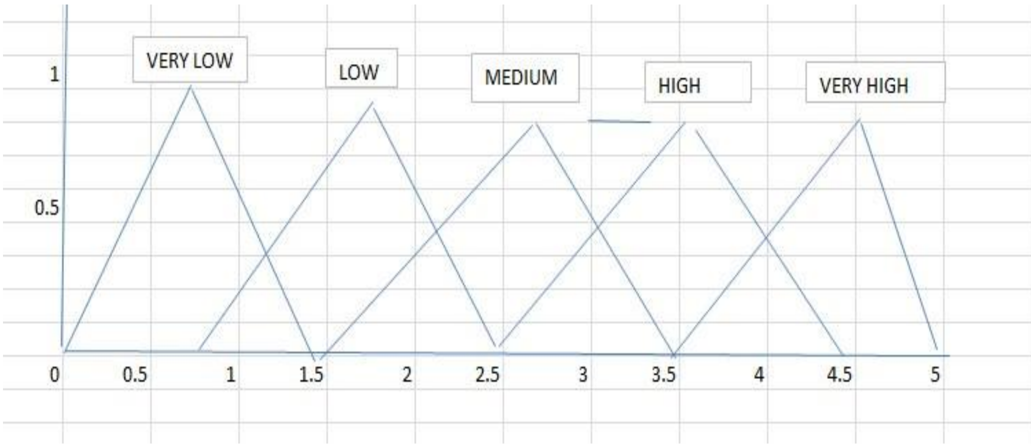

Figure 4 3: Membership Function Plot for Lead Time

Lead time of supply chains in Kenya was found to 2 days which lies between poor and average but it lies more on the average side, using the triangular membership function shown in Eq. (9) the degree of membership is calculated as 2.5-1.25/2.5-1.25=0.7 low and 0.3 Medium. This indicates that lead time was found to be Low.

Response time is the amount of time between an order and its corresponding delivery. It was measured on a scale of 0 to 12. Fig 4.4 shows the membership function plot for response time.

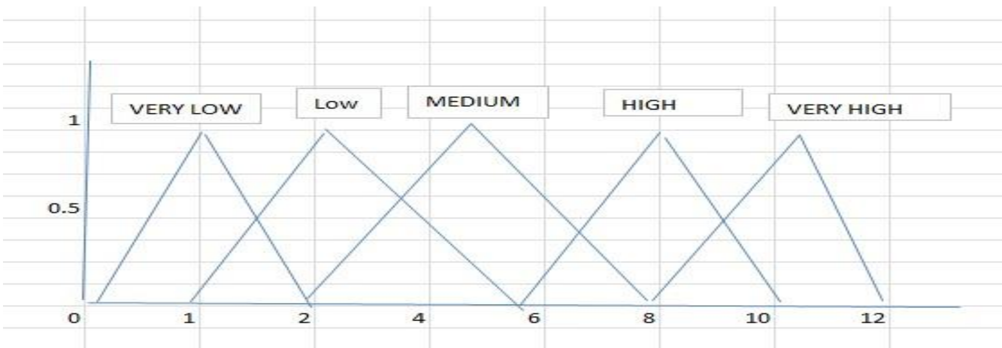

Figure 4 4: Membership Function Plot for Response time

Response times in days of supply chains in Kenya was found to be 8 days which lies on both medium and high but it lies more on the medium side, using the triangular membership function shown in Eq. (9) the degree of membership is calculated as 8-6/8-6=1 medium and 0 high. This indicates that the response rate was found to have a full membership on the medium side.

On time delivery refers to the percentage of orders delivered on or before the due date. It was measured proportionally on a scale of 0 to 100. Fig 4.5 shows the membership plot for on time delivery.

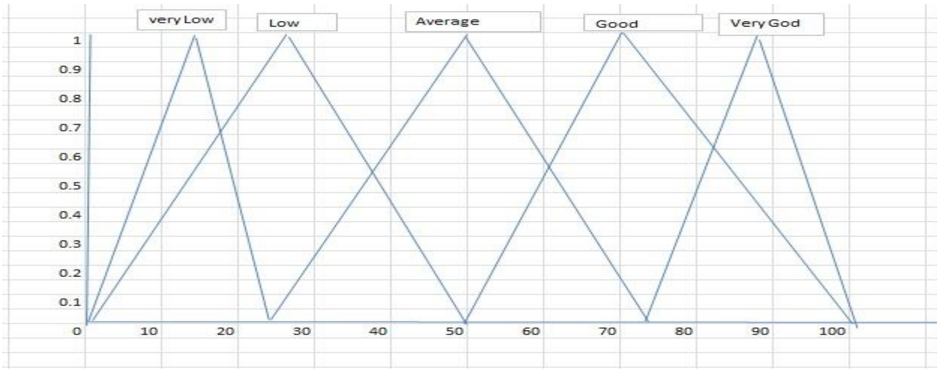

Figure 4 5: Membership Function Plot for On time Delivery

Percentage of on time delivery of supply chains in Kenya was found to be 65%, using the above triangular membership function Eq.(9(the degree of membership is calculated as

65.4-50/75-50=15.4/25 =0.6 AVERAGE and 0.4 Good. . This indicates that the percentage of orders delivered on time found to be Average

Fill rate refers to the proportion of orders that can be filled immediately. It was measured on a scale of 0 to 100. Fig. 4.6 shows the membership function plot for Fill rate.

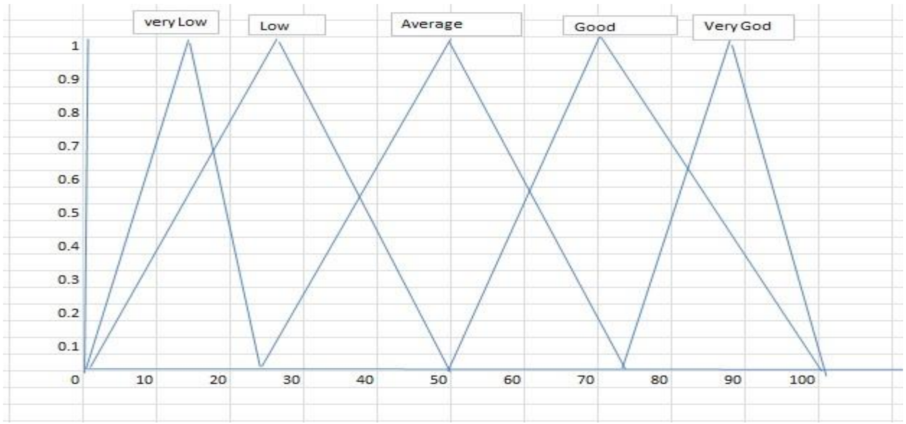

Figure 4 6: Membership Function Plot for Fill Rate

Percentage of Fill Rate of supply chains in Kenya was found to be 60%, using the triangular membership function shown in Eq. (9) , the degree of membership is calculated as 60-50/75-50=0.4 GOOD AND 0.6 AVERAGE. This indicates that the percentage of orders delivered on time found to be Average. Probability not out of stock refers to the percentage of items not out of stock. It was measured on a scale of 0 to 100. Fig 4.7 shows the membership function for probability not out of stock.

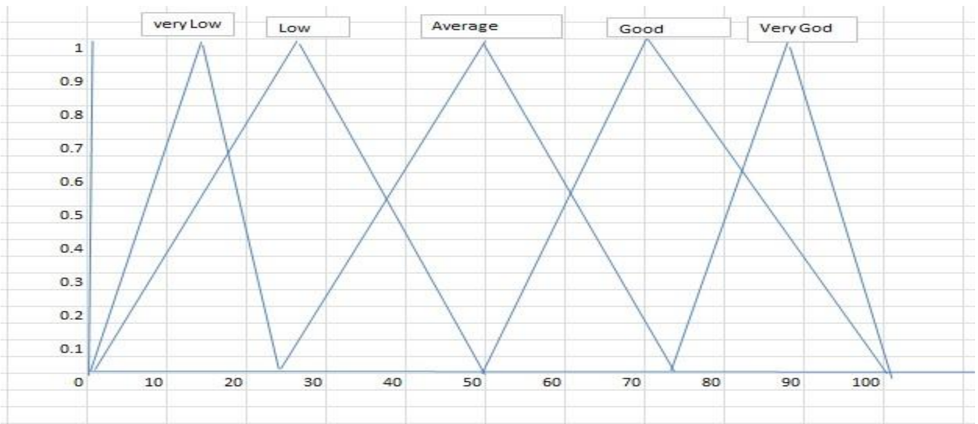

Figure 4 7: Membership Function Plot for Probability not out of stock

Percentage not out of stock for supply chains in Kenya was found to be 46%, which lies between both poor and average. It lies more on the low side and to the average side to a certain degree. To obtain the degree of fuzziness, the triangular membership function the degree of membership Eq. (9) is used to calculated as 100-54/100-50=0.92 Average and 0.08 GOOD. So we conclude that percentage out of stock is average.

Correct product delivery referred to the percentage of orders delivered with in the right quantity. It was measured proportionally on scale of 0 to 100. Fig 4.8 shows the membership function plot for correct product delivery.

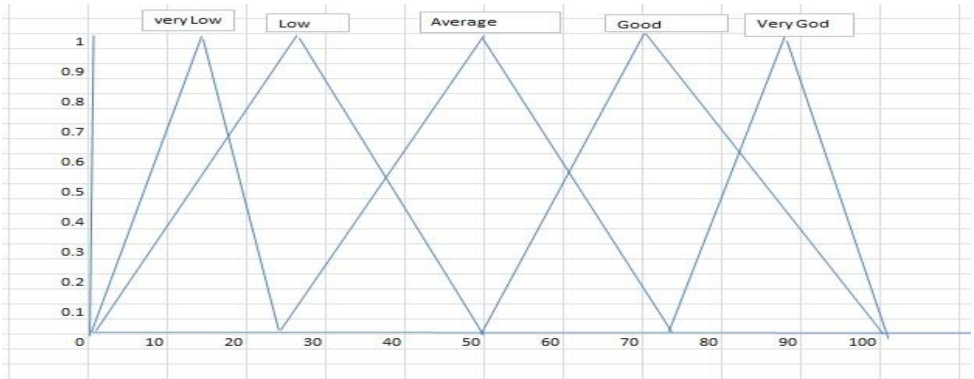

Figure 4 8: Membership Function Plot for Correct product delivery

Correct product delivery was found to be 84% which lies between very good and good but it lies more on the high side, using the triangular membership function the degree of membership in Eq. (9) is calculated 100-84/100-75=0.64 Good and 0.36 Very Good. This indicates that correct product delivery was found to be Good

Correct quantity referred to the percentage of orders delivered with in the right condition, in the right quantity. Fig 4.9 shows the membership function plot for correct quantity.

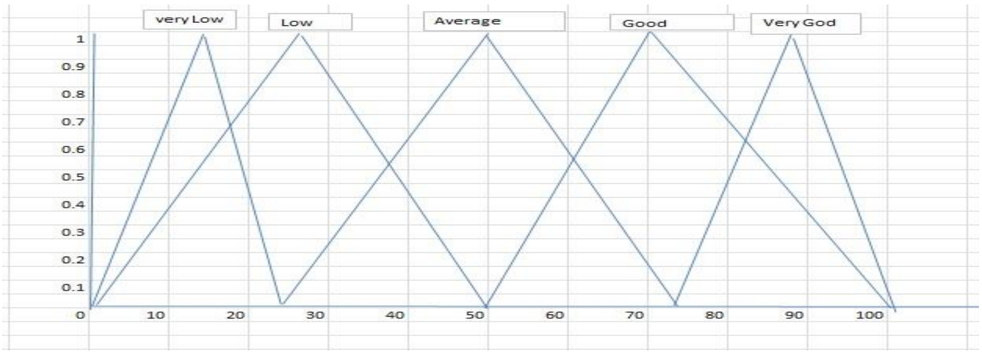

Figure 4 9: Membership Function Plot for Correct quantity

Correct quantity delivery was found to be 82% which lies between very good and good but it lies more on the high side, using the triangular membership function in Eq. (9) the degree of membership is calculated as 100-80/100-75=20/25=0.8 Good and 0.2 Very Good. This indicated that correct product delivery was found to be good.

Correct condition referred to the percentage of orders delivered in the right condition. Fig 4.10 shows the membership function plot for correct condition.

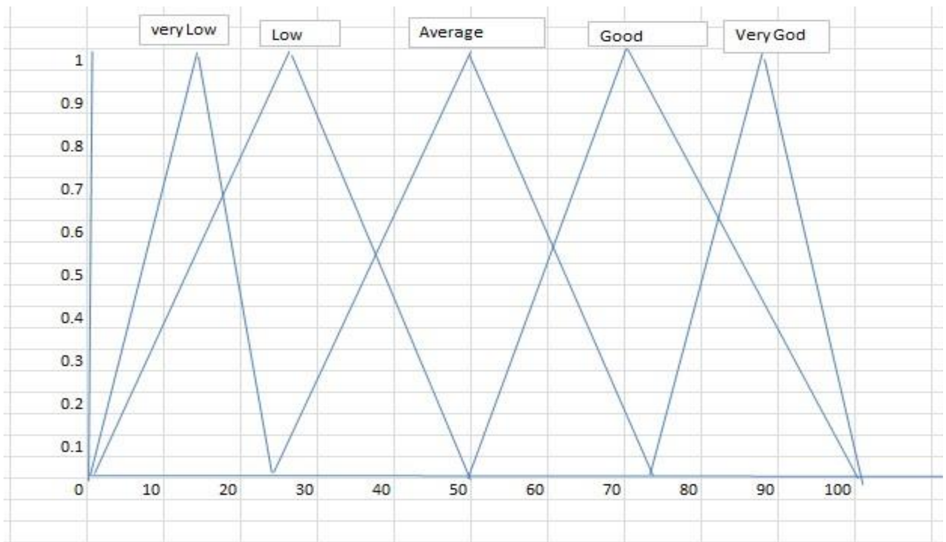

Figure 4 10: Membership Function Plot for Correct condition

Correct condition delivery was found to be 84% which lies between very high and high but it lies more on the high side, using the triangular membership function the degree of membership in Eq. (9) it is calculated as 100-84/100-75=0.64 Good and 0.36 Very Good. . This indicated that correct product condition delivery was found to be Good.

Correct time referred to the percentage of orders delivered at the right time. Fig 4.11shows the membership function plot for correct time.

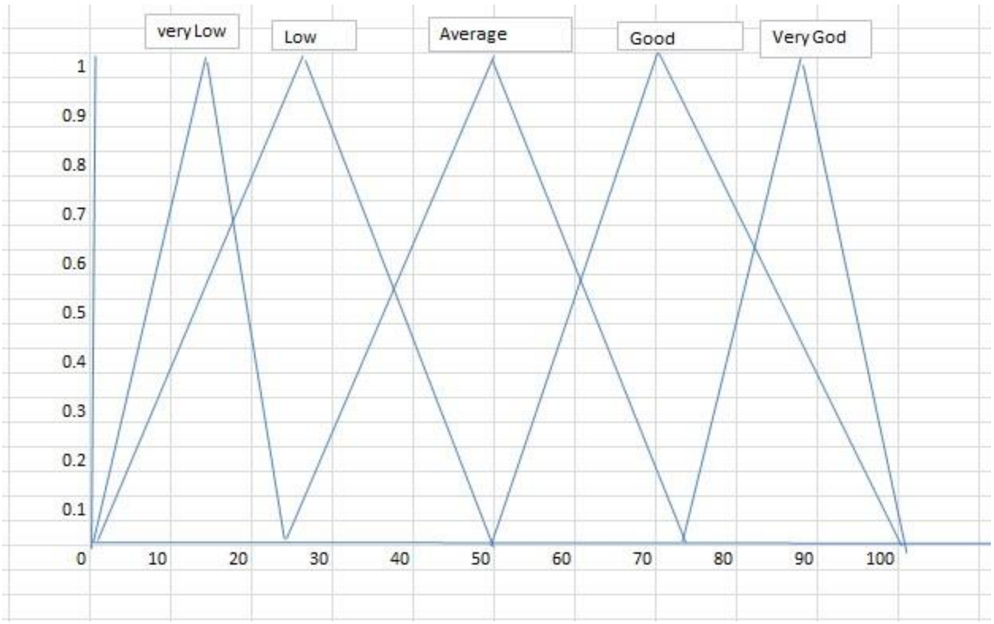

Figure 4 11: Membership Function Plot for Correct Time

Correct time was found to be 82% which lies between very good and good but it lies more on the good side, using the triangular membership function shown in Eq. (9) , the degree of membership is calculated as 100-82.4/100-75=0.70 Good and 0.3 Very Good. This indicated that correct product condition is good.

Shipping errors referred to the percentage of errors during shipment of goods. Fig 4.11shows the membership function plot for shipping errors.

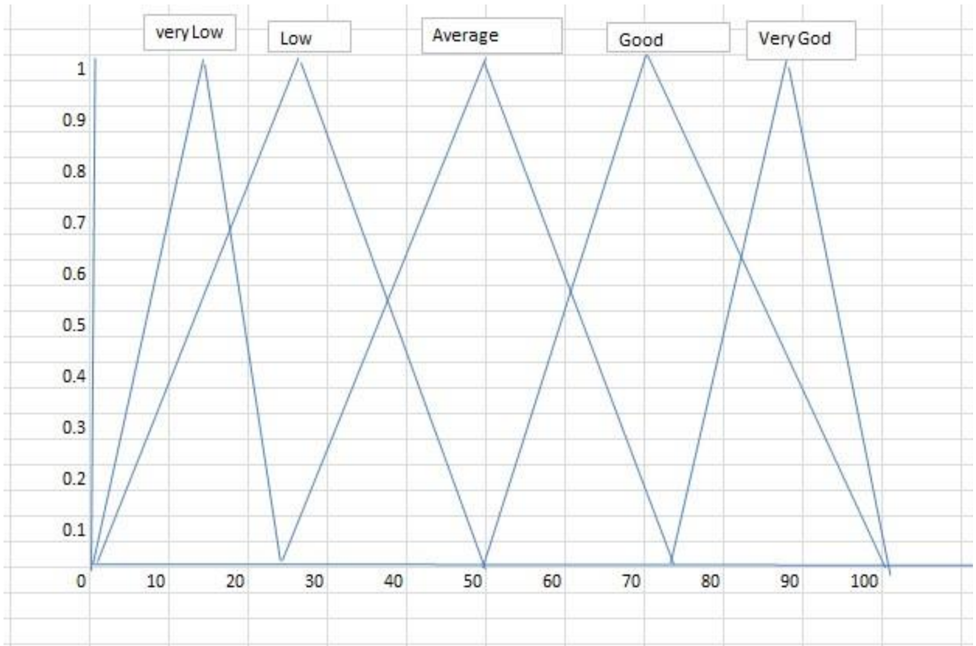

Figure 4 12: Triangular Membership Function Plot for Shipping Errors

Shipping errors was found to be 40%. Fill rate has a degree has a degree 0.6 average and 0.4 Good and shipping errors me had a degree 0.6 average and 0.4 good.

4.7: To determine fuzzy rules that can be generated by matching the linguistic variables and linguistic terms and express them in a fuzzy associative matrix in order to find individual linguistic variable output results affective performance.

This objective sought to generate fuzzy rules and express them in a Fuzzy associative matrix. The numbers of rules were established based on the permutation with number of membership function and numbers of criteria. The numbers of factors are four and numbers of linguistic terms are five for each factor. Jamshidi (Jamshidi, 1997) proposed to use a combination of hierarchical and fusion methods of variables. These variables are often fused linearly. The four variables were fused as two at time. Correct time and correct condition and correct quantity and correct product. The total amount of rules are 5^2 * 2 equal to 50 rules. This reduction 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 chain reliability.

4.7.1 Combined Sensory fusion method and Hierarchical methods of Fuzzy Rules Reduction

(Jamshidi, 1997) 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 (Ledeneva, 2006). In this study the variables were fused as shown. In the hierarchical fuzzy control structure from (Ledeneva, 2007), 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.

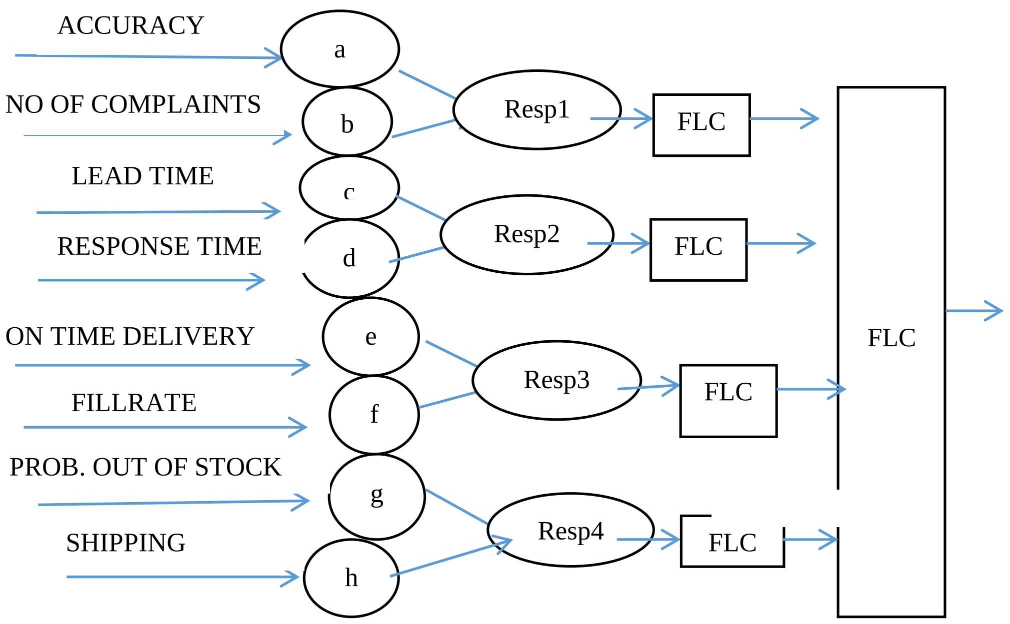

Figure 4 13: Sensory Fusion for Fuzzy Rules for Responsiveness Variables

For Supply Chain Responsiveness, the first fusion will be between on time delivery and response time to produce an output Resp1. 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(http://deliver.jsi.com/dlvr_content/resources/allpubs/guidelines/MeasSCPerf.pdf)

The second fusion will be on lead time and probability out of stock to produce an output Resp2. 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 (Grossmann, 2007). The third fusion was on Fill rate and shipment errors to produce an output Resp3. This indicator measures the ability of the supplier to fill Purchase Orders correctly. Shipments should always be checked against the shipping notice and the Purchase Orders. What was shipped may not be what was ordered.

The fourth fusion will be between accuracy and number of complaints to produce an output Resp4. 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 causes 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. (Hamidreza et al., 2010).

Further fusion will be between Resp1 and Resp2 to produce an output Resfusion1. Resp3 and Resp4 will be fused together to produce an output Resfusion2. The Final fusion will be on Resfusion1 and Resfusion2 to produce the overall output Responsiveness.

For supply chain reliability which is perfect order fulfillment.an order is perfect if only all the metrics are perfect. (supply chain council,2008). The Perfect Order is an order delivered to a customer that is ―complete, accurate, on time and in perfect condition‖ (Hoffman 2002). The first fusion was between correct time and correct quantity to produce an output Rel1. The second fusion will be on correct condition and correct product delivery to produce an output Rel2.The final fusion will be between Rel1 and Rel2 to produce an overall output of Reliability.

The input and output parameters are created in editor as shown in the figure 5.6. We have considered eight input parameters and one 4 outputs which are then fused together to get the final output. Accuracy and Number of complaints were fused together to produce an output Resp1 as shown in Fig 5.7. On time delivery and response time were fused together to produce an output Resp2 as shown in Fig 5.9. Lead Time and probability out of stock was fused together to produce an output Resp3 as shown in fig 5.8. Shipping errors and filtrate were fused together to produce an output Resp4 as shown in Fig 5.10. The outputs Resp1 and Resp2 were further fused together to produce an output of Respfusion1 as shown in Fig 5.11. Resp3 and Resp4 are fused together to produce an output Respfusion2 as shown in Fig 5.12. The outputs Respfusion1 and Respfusion2 are then combined further to produce the final output Responsiveness of supply chains. For supply chain reliability which is perfect order fulfillment.an order is perfect if only all the

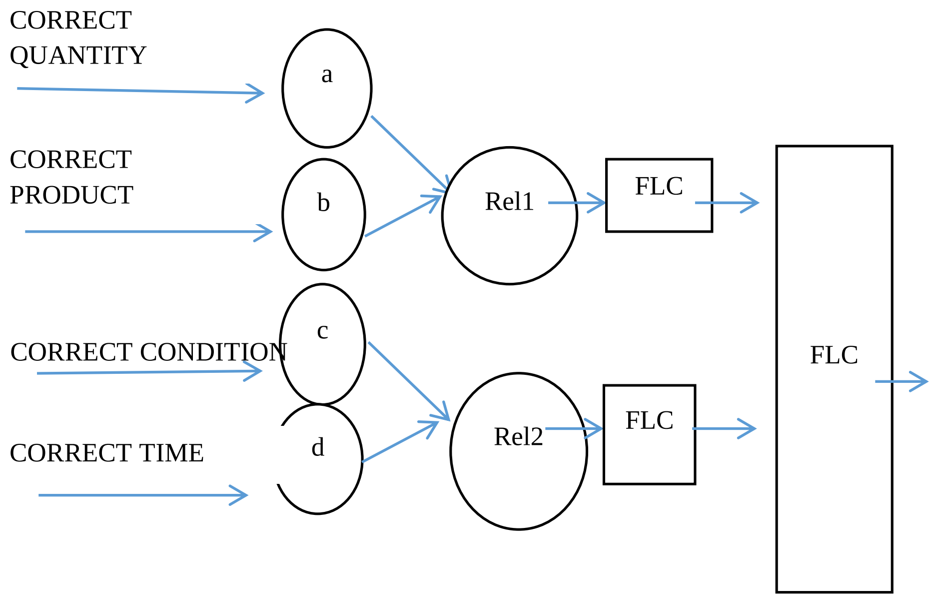

Figure 4 14: Sensory Fusion for Fuzzy Rules for Reliability variables

4.7.2 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. Resp1 output was s fusion between Accuracy and number of complains. Table 4.13 shows Resp1 output for the different combinations of various linguistic terms input for the two variables.

Table 4. 13: 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

Resp2 output was s fusion between Lead Time and Percentage not out of stock. Table 4.14 shows Resp2 output for the different combinations of various linguistic terms input for the two variables.

Table 4. 14 :Resp2 Output

Lead Time/Percentage not out of stock	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very low	NA	NA	Average	Good	Very Good
Low	NA	NA	average	Good	Very Good
Average	Poor	Poor	average	Average	POOR
High	Poor	Poor	Poor	NA	NA
Very High	Very poor	Poor	Poor	NA	NA

Resp3 output was s fusion between on Time delivery and Response Time. Table 4.15 shows Resp3 output for the different combinations of various linguistic terms input for the two variables.

Table 4. 15 :Resp3 Output

On time Delivery/Response Time	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

Resp4 output was s fusion between Fill Rate and percentage of shipping errors. Table 4.16 shows Resp4 output for the different combinations of various linguistic terms input for the two variables.

Table 4. 16: Resp4 Output

Respfusion1 output was s fusion between Resp1 and Resp2 outputs. Table 4.16 shows Respfusion1 output for the different combinations of various linguistic terms input for the two variables.

Fill rate/ Percentage of shipping errors	**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

Table 4. 17: Resfusion1 Output

Resp1/Resp2	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	Poor	Poor	Poor	Poor
Poor	Poor	Poor	Poor	Poor	Poor
Average	Poor	Poor	Average	Average	Average
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Respfusion1 output was s fusion between Resp3 and Resp4 outputs. Table 4.18 shows Respfusion2 output for the different combinations of various linguistic terms input for the two variables.

Table 4. 18 : Resfusion2 Output

Resp3/Resp4	Very poor	Poor	Average	Good	Very Good
Very poor	Very Poor	Poor	Poor	Poor	Poor
Poor	Poor	Poor	Poor	Poor	Poor
Average	Poor	Poor	Average	Average	Average
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Responsiveness if the final output which was s fusion between Respfusion1 and Respfusion2 outputs. Table 4.19 shows Responsiveness output for the different combinations of various linguistic terms input for the two variables.

Table 4. 19: Associative Matrix for Responsiveness

Respfus1/Respfus2	Very poor	Poor	Average	Good	Very Good
Very poor	Very poor	Poor	poor	Poor	Poor
Poor	Poor	Poor	poor	Poor	Poor
Average	Poor	Poor	Average	Average	Average
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	average	Good	Very Good

Reliability was measured in terms of percentage of orders delivered with the right product, at the right time, in the right condition, in the right quantity. Rel1 output was s fusion between correct quantity and correct time. Table 4.20 shows Rel1 output for the different combinations of various linguistic terms input for the two variables.

Table 4. 20: Associative Matrix for Rel1 Output

Correct quantity/correct time	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
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

Rel2 output was s fusion between correct product and correct condition. Table 4.21 shows Rel2 output for the different combinations of various linguistic terms input for the two variables

Table 4. 21 : Associative Matrix for Rel2 Output

Correct product/correct condition	Very poor	Poor	Average	Good	Very Good
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

Reliability output was s fusion between Rel1 and Rel2 outputs. Table 4.22 shows final reliability output for the different combinations of various linguistic terms input for the two variables

Table 4. 22: Associative Matrix for Reliability Output

Rel1/Rel2	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
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

From the Associative matrices fuzzy rules were generated. Table 4.23 shows fuzzy rules generated for accuracy and number of complains to produce Resp1 output

Table 4. 23: Fuzzy rules for accuracy and number of complains

If accuracy is very poor and number of complains is very low then resp1 is N/A
If accuracy is very poor and number of complains is low then resp1 is N/A
If accuracy is very poor and number of complains is medium then resp1 is N/A
If accuracy is very poor and number of complains is High then resp1 is Poor
If accuracy is very poor and number of complains is very high then resp1 is very poor
If accuracy is poor and number of complains is very low then resp1 is N/A
If accuracy is poor and number of complains is low then resp1 is N/A
If accuracy is poor and number of complains is medium then resp1 is N/A
If accuracy is poor and number of complains is High then resp1 is Poor
If accuracy is poor and number of complains is very high then resp1 is very poor
If accuracy is average and number of complains is low then resp1 is average
If accuracy is average and number of complains is medium then resp1 is average
If accuracy is average and number of complains is High then resp1 is average
If accuracy is average and number of complains is very high then resp1 is poor
If accuracy is average and number of complains is very high then resp1 is poor
If accuracy is good and number of complains is very low then resp1 is good
If accuracy is good and number of complains is low then resp1 is good
If accuracy is good and number of complains is medium then resp1 is average
If accuracy is good and number of complains is High then resp1 is N/A
If accuracy is good and number of complains is very high then resp1 is n/a
If accuracy is very good and number of complains is very low then resp1 is very good
If accuracy is very good and number of complains is low then resp1 is very good
If accuracy is very good and number of complains is medium then resp1 is average
If accuracy is very good and number of complains is high then resp1 is very N.A

From the Associative matrices fuzzy rules were generated. Table 4.24 shows fuzzy rules generated for lead time and percentage not out of stock to produce Resp2 output

Table 4. 24: Fuzzy rules for lead time and percentage out of stock

If lead time is very low and percentage not out of stock is very poor then Resp2 is N/A
If lead time is very low and percentage not out of stock is very poor then Resp2 is N/A
If lead time is very low and percentage not out of stock is average then Resp2 is average
If lead time is very low and percentage not out of stock is good then Resp2 is good
If lead time is very low and percentage not out of stock is very good then Resp2 is very good
If lead time is low and percentage not out of stock is very poor then Resp2 is N/A
If lead time is low and percentage not out of stock is very poor then Resp2 is poor
If lead time is low and percentage not out of stock is average then Resp2 is average
If lead time is low and percentage not out of stock is good then Resp2 is good
If lead time is low and percentage not out of stock is very good then Resp2 is very good
If lead time is medium and percentage not out of stock is very poor then Resp2 is poor
If lead time is medium and percentage not out of stock is very poor then Resp2 is poor
If lead time is medium and percentage not out of stock is average then Resp2 is average
If lead time is medium and percentage not out of stock is good then Resp2 is average
If lead time is medium and percentage not out of stock is very good then Resp2 is poor
If lead time is high and percentage not out of stock is very poor then Resp2 is poor
If lead time is high and percentage not out of stock is very poor then Resp2 is poor
If lead time is high and percentage not out of stock is average then Resp2 is poor
If lead time is high and percentage not out of stock is good then Resp2 is n/a
If lead time is high and percentage not out of stock is very good then Resp2 is n/a
If lead time is very high and percentage not out of stock is very poor then Resp2 is very poor
If lead time is very high and percentage not out of stock is poor then Resp2 is poor
If lead time is very high and percentage not out of stock is average then Resp2 is poor
If lead time is very high and percentage not out of stock is good then Resp2 is N/A
If lead time is very high and percentage not out of stock is very good then Resp2 is N/A

From the Associative matrices fuzzy rules were generated. Table 4.25 shows fuzzy rules generated for on time delivery and response time to produce Resp3 output

Table 4. 25 : Fuzzy Rules for on time delivery and Response time

If on time delivery is very poor and response time is very low then Resp3 is n/a
If on time delivery is very poor and response time is very low then Resp3 is n/a
If on time delivery is very poor and response time is very low then Resp3 is n/a
If on time delivery is very poor and response time is very low then Resp3 is poor
If on time delivery is very poor and response time is very low then Resp3 is very poor
If on time delivery is poor and response time is very low then Resp3 is n/a
If on time delivery is poor and response time is very low then Resp3 is n/a
If on time delivery is poor and response time is very low then Resp3 is n/a
If on time delivery is v poor and response time is very low then Resp3 is poor
If on time delivery is poor and response time is very low then Resp3 is very poor
If on time delivery is average and response time is very low then Resp3 is average
If on time delivery is average and response time is very low then Resp3 is average
If on time delivery is average and response time is very low then Resp3 is average
If on time delivery is average and response time is very low then Resp3 is poor
If on time delivery is average and response time is very low then Resp3 is poor
If on time delivery is good and response time is very low then Resp3 is good
If on time delivery is good and response time is very low then Resp3 is good
If on time delivery is good and response time is very low then Resp3 is average
If on time delivery is good and response time is very low then Resp3 is poor
If on time delivery is good and response time is very low then Resp3 is n/a
If on time delivery is very good and response time is very low then Resp3 is very good
If on time delivery is very good and response time is very low then Resp3 is good
If on time delivery is very good and response time is very low then Resp3 is average
If on time delivery is very good and response time is very low then Resp3 is n/a
If on time delivery is very good and response time is very low then Resp3 is n/a

From the Associative matrices fuzzy rules were generated. Table 4.26 shows fuzzy rules generated for fill arte and shipping errors to produce Resp4 output

Table 4. 26 : Fuzzy rules for Fill rate and Shipping Errors

If fill rate is very poor and shipping errors is very low the Resp4 is n/a
If fill rate is very poor and shipping errors is low the Resp4 is n/a
If fill rate is very poor and shipping errors is medium the Resp4 is n/a
If fill rate is very poor and shipping errors is high the Resp4 is poor
If fill rate is very poor and shipping errors is very high the Resp4 is very poor
If fill rate is poor and shipping errors is very low the Resp4 is n/a
If fill rate is poor and shipping errors is low the Resp4 is n/a
If fill rate is poor and shipping errors is medium the Resp4 is n/a
If fill rate is poor and shipping errors is high the Resp4 is poor
If fill rate is poor and shipping errors is very high the Resp4 is very poor
If fill rate is average and shipping errors is very low the Resp4 is average
If fill rate is average and shipping errors is low the Resp4 is average
If fill rate is average and shipping errors is medium the Resp4 is average
If fill rate is average and shipping errors is high the Resp4 is poor
If fill rate is average and shipping errors is very high the Resp4 is poor
If fill rate is good and shipping errors is very low the Resp4 is good
If fill rate is good and shipping errors is low the Resp4 is good
If fill rate is good and shipping errors is medium the Resp4 is average
If fill rate is good and shipping errors is high the Resp4 is n/a
If fill rate is good and shipping errors is very high the Resp4 is n/a
If fill rate is very good and shipping errors is very low the Resp4 is very good
If fill rate is very good and shipping errors is low the Resp4 is good
If fill rate is very good and shipping errors is medium the Resp4 is average
If fill rate is very good and shipping errors is high the Resp4 is n/a
If fill rate is very good and shipping errors is very high the Resp4 is n/a

From the Associative matrices fuzzy rules were generated. Table 4.27 shows fuzzy rules generated for resp1 and resp2 to produce Respfusion1 output

Table 4. 27: Fully rules generated for Resp1 and Resp2

If resp1 is very poor and resp2 is very poor then Respfusion1 is very poor
If resp1 is very poor and resp2 is poor then Respfusion1 is very poor
If resp1 is very poor and resp2 is average then Respfusion1 is poor
If resp1 is very poor and resp2 is good then Respfusion1 is poor
If resp1 is very poor and resp2 is very good then Respfusion1 is poor
If resp1 is poor and resp2 is very poor then Respfusion1 is poor
If resp1 is poor and resp2 is poor then Respfusion1 is poor
If resp1 is poor and resp2 is average then Respfusion1 is poor
If resp1 is poor and resp2 is good then Respfusion1 is poor
If resp1 is poor and resp2 is very good then Respfusion1 i poor
If resp1 is average and resp2 is very poor then Respfusion1 is poor
If resp1 is average and resp2 is poor then Respfusion1 is poor
If resp1 is average and resp2 is average then Respfusion1 is average
If resp1 is average and resp2 is good then Respfusion1 is average
If resp1 is average and resp2 is very good then Respfusion1 is average
If resp1 is good and resp2 is very poor then Respfusion1 is very poor
If resp1 is good and resp2 is poor then Respfusion1 is very poor
If resp1 is good and resp2 is average then Respfusion1 is very average
If resp1 is good and resp2 is good then Respfusion1 is very good
If resp1 is good and resp2 is very good then Respfusion1 is good
If resp1 is very good and resp2 is very poor then Respfusion1 is poor
If resp1 is very good and resp2 is poor then Respfusion1 is poor
If resp1 is very good and resp2 is average then Respfusion1 is average
If resp1 is very good and resp2 is good then Respfusion1 is good
If resp1 is very good and resp2 is very good then Respfusion1 is very good

From the Associative matrices fuzzy rules were generated. Table 4.28 shows fuzzy rules generated for resp3 and resp4 to produce Respfusion2 output

Table 4. 28 : Fuzzy rules for Resp3 and Resp4 output

If resp3 is very poor and resp4 is very poor then Respfusion2 is very poor
If resp3 is very poor and resp4 is poor then Respfusion2 is very poor
If resp3 is very poor and resp4 is average then Respfusion2 is poor
If resp3 is very poor and resp4 is good then Respfusion2 is poor
If resp3 is very poor and resp4 is very good then Respfusion2 is poor
If resp3 is poor and resp4 is very poor then Respfusion2 is poor
If resp3 is poor and resp4 is poor then Respfusion2 is poor
If resp3 is poor and resp4 is average then Respfusion2 is poor
If resp3 is poor and resp4 is good then Respfusion2 is poor
If resp3 is poor and resp4 is very good then Respfusion2 i poor
If resp3 is average and resp4 is very poor then Respfusion2 is poor
If resp3 is average and resp4 is poor then Respfusion2 is poor
If resp3 is average and resp4 is average then Respfusion2 is average
If resp3 is average and resp4 is good then Respfusion2 is average
If resp3 is average and resp4 is very good then Respfusion2 is average
If resp3 is good and resp4 is very poor then Respfusion2 is very poor
If resp3 is good and resp4 is poor then Respfusion2 is very poor
If resp3 is good and resp4 is average then Respfusion2 is very average
If resp3 is good and resp4 is good then Respfusion2 is very good
If resp3 is good and resp4 is very good then Respfusion2 is good
If resp3 is very good and resp4 is very poor then Respfusion2 is poor
If resp3 is very good and resp4 is poor then Respfusion2 is poor
If resp3 is very good and resp4 is average then Respfusion2 is average
If resp3 is very good and resp4 is good then Respfusion2 is good
If resp3 is very good and resp4 is very good then Respfusion2 is very good

From the Associative matrices fuzzy rules were generated. Table 4.29 shows fuzzy rules generated for respfusion1 and respfusion2 to produce the final Responsiveness output

Table 4. 29 : Fuzzy Rules for Respfusion1 and Respfusion2

If respfusion1 is very poor and respfusion2 is very poor then Responsiveness is very poor
If respfusion1 is very poor and respfusion2 is poor then Responsiveness is very poor
If respfusion1 is very poor and respfusion2is average then Responsiveness is poor
If respfusion1 is very poor and respfusion2 is good then Responsiveness is poor
If respfusion1 is very poor and respfusion2is very good then Responsiveness is poor
If respfusion1 is poor and respfusion2is very poor then Responsiveness is poor
If respfusion1 is poor and respfusion2is poor then Responsiveness is poor
If respfusion1 is poor and respfusion2 is average then Responsiveness is poor
If respfusion1 is poor and respfusion2is good then Responsiveness is poor
If respfusion1 is poor and respfusion2is very good then Responsiveness is poor
If respfusion1 is average and respfusion2is very poor then Responsiveness is poor
If respfusion1 is average and respfusion2 is poor then Responsiveness is poor
If respfusion1 is average and respfusion2 is average then Responsiveness is average
If respfusion1 is average and respfusion2is good then Responsiveness is average
If respfusion1 is average and respfusion2is very good then Responsiveness is average
If respfusion1 is good and respfusion2is very poor then Responsiveness is very poor
If respfusion1 is good and respfusion2is poor then Responsiveness is very poor
If respfusion1 is good and respfusion2is average then Responsiveness is very average
If respfusion1 is good and respfusion2is good then Responsiveness is very good
If respfusion1 is good and respfusion2 is very good then Responsiveness is good
If respfusion1 is very good and respfusion2 is very poor then Responsiveness is poor
If respfusion1 is very good and respfusion2is poor then Responsiveness is poor
If respfusion1is very good and respfusion2 is average then Responsiveness is average
If respfusion1 is very good and respfusion2is good then Responsiveness is good
If respfusion1 is very good and respfusion2is very good then Responsiveness is very good

From the Associative matrices fuzzy rules were generated. Table 4.30 shows fuzzy rules generated for correct quantity and correct time to produce Rel1 output

Table 4. 30 : Fuzzy Rules for Correct Quantity and Correct Time

if correct quantity very poor and correct time is very poor then Rel1 is very poor
if correct quantity very poor and correct time is poor then Rel1 is very poor
if correct quantity very poor and correct time is average then Rel1 is poor
if correct quantity very poor and correct time is good then Rel1 is poor
if correct quantity very poor and correct time is very good then Rel1 is poor
if correct quantity poor and correct time is very poor then Rel1 is very poor
if correct quantity poor and correct time is poor then Rel1 is very poor
if correct quantity poor and correct time is average then Rel1 is poor
if correct quantity poor and correct time is good then Rel1 is poor
if correct quantity poor and correct time is very good then Rel1 is poor
if correct quantity average and correct time is very poor then Rel1 is poor
if correct quantity average and correct time is poor then Rel1 is poor
if correct quantity average and correct time is average then Rel1 is average
if correct quantity average and correct time is good then Rel1 is average
if correct quantity average and correct time is very good then Rel1 is good
if correct quantity good and correct time is very poor then Rel1 is poor
if correct quantity good and correct time is poor then Rel1 is poor
if correct quantity good and correct time is average then Rel1 is average
if correct quantity good and correct time is good then Rel1 is good
if correct quantity good and correct time is very good then Rel1 is good
if correct quantity very good and correct time is very poor then Rel1 is poor
if correct quantity very good and correct time is poor then Rel1 is poor
if correct quantity very good and correct time is average then Rel1 is average
if correct quantity very good and correct time is good then Rel1 is good
if correct quantity very good and correct time is very good then Rel1 is very good

From the Associative matrices fuzzy rules were generated. Table 4.31 shows fuzzy rules generated for correct product and correct condition to produce Rel2 output.

Table 4. 31 : Fuzzy Rules for Correct Quantity and Correct Time

if correct product very poor and correct condition is very poor then Rel2 is very poor
if correct product very poor and correct condition is poor then Rel2 is very poor
if correct product very poor and correct condition is average then Rel2 is poor
if correct product very poor and correct condition is good then Rel2 is poor
if correct product very poor and correct condition is very good then Rel2 is poor
if correct product poor and correct condition is very poor then Rel2 is very poor
if correct product poor and correct condition is poor then Rel2 is very poor
if correct product poor and correct condition is average then Rel2 is poor
if correct product poor and correct condition is good then Rel2 is poor
if correct product poor and correct condition is very good then Rel2 is poor
if correct product average and correct condition is very poor then Rel2 is poor
if correct product average and correct condition is poor then Rel2 is poor
if correct product average and correct condition is average then Rel2 is average
if correct product average and correct condition is good then Rel2 is average
if correct product average and correct condition is very good then Rel2 is good
if correct product good and correct condition is very poor then Rel2 is poor
if correct product good and correct condition is poor then Rel2 is poor
if correct product good and correct condition is average then Rel2 is average
if correct product good and correct condition is good then Rel2 is good
if correct product good and correct condition is very good then Rel2 is good
if correct product very good and correct condition is very poor then Rel2 is poor
if correct product very good and correct condition is poor then Rel2 is poor
if correct product very good and correct condition is average then Rel2 is average
if correct product very good and correct condition is good then Rel2 is good
if correct product very good and correct condition is very good then Rel2 is very good

From the Associative matrices fuzzy rules were generated. Table 4.32 shows fuzzy rules generated for Rel1 and Rel2 to produce final Reliability output.

Table 4. 32: Fuzzy rules for Rel1 and Rel2 output

If Rel1 is very poor and Rel2 is very poor then Reliability is very poor
If Rel1 is very poor and Rel2 is poor then Reliability is very poor
If Rel1 is very poor and Rel2 is average then Reliability is poor
If Rel1 is very poor and Rel2 is good then Reliability is poor
If Rel1 is very poor and Rel2 is very good then Reliability is poor
If Rel1 is poor and Rel2 is very poor then Reliability is very poor
If Rel1 is poor and Rel2 is poor then Reliability is very poor
If Rel1 is poor and Rel2 is average then Reliability is poor
If Rel1 is poor and Rel2 is good then Reliability is poor
If Rel1 is poor and Rel2 is very good then Reliability is poor
If Rel1 is average and Rel2 is very poor then Reliability is poor
If Rel1 is average and Rel2 is poor then Reliability is poor
If Rel1 is average and Rel2 is average then Reliability is average
If Rel1 is average and Rel2 is good then Reliability is average
If Rel1 is average and Rel2 is very good then Reliability is good
If Rel1 is good and Rel2 is very poor then Reliability is poor
If Rel1 is good and Rel2 is poor then Reliability is poor
If Rel1 is good and Rel2 is average then Reliability is average
If Rel1 is good and Rel2 is good then Reliability is good
If Rel1 is good and Rel2 is very good then Reliability is good
If Rel1 is very good and Rel2 is very poor then Reliability is poor
If Rel1 is very good and Rel2 is poor then Reliability is poor
If Rel1 is very good and Rel2 is average then Reliability is average
If Rel1 is very good and Rel2 is good then Reliability is good
If Rel1 is very good and Rel2 is very good then Reliability is very good

4.8: To compute a fuzzy aggregation of all the output results of individual variables into a single crisp output which measures an overall quality performance of Supply Chain Management using a defuzzication technique.

This objective sought to establish to aggregate the output the input of all the parameters established from this research, into a single crisp output which will be the performance measurement of supply chain management. The crisp output will then be matched with the output membership function in order to obtain a linguistic term for it. The input values were based on the mean scores of each performance measurement variables.

Of the nine defuzzication methods, the best method to use remains as an unanswered question. The choice of which defuzzication technique to use is context or problem-dependent.

An important aspect of a defuzzication method is the continuity of the output signal. In this respect, the defuzzication methods. The weighted average method satisfies this criterion because, it assumes overlapping output membership functions. The weighted average method provides continuity which means that a small change in the input should not produce a large change. The weighted average method is computationally efficient and it is the most commonly used in fuzzy logic applications than the other methods (Hellendoorn & Thomas 1993, Ross 2005).

Weighted average defuzzication scheme is the most commonly used one in fuzzy logic applications because of its computational efficiency. In his study (Anjana, 2015) used the Weighted Average Formula method which showed maximum accuracy in measuring the performance of students in colleges. The students' performance level is primarily judged by the marks obtained by the students and hence the defuzzified value has to be somewhat near to the marks obtained by the student. Similarly, the supply chain performance level is primarily judged by the responsiveness and reliability of supply chains and hence the defuzzified value has to be somewhat near to the value of responsivess and reliability. Hence this defuzzification method is suitable for getting accurate output of performance measurement systems. The Weighted average formula is shown in Eq. (10)

$$Z *= \sum \mu c\ (\overline{Z}) \cdot \bar{Z}\ /\ \sum \mu c(\bar{Z}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (10)$$

4.8.1: Supply Chain Reliability Output

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For rel1 which was a fusion between correct quantity and correct time. Correct quantity was found to be 80% and correct time was found to be 82.4%. both values lie between good and very good sides of the triangular membership function. Correct quantity has a degree of 0.8 good and 0.2 very good while correct time has a degree of 0.7 good and 0.3 very good. The rules that fired based on the input data as a result of fusion between correct quantity and correct time is shown on table 4.33

Table 4. 33 : Fired Rules for correct quantity=80% and Correct time=82.4%

Correct quantity/correct time	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	Very poor	Poor	Poor	Poor
Poor	Very poor	Very poor	Poor	Poor	Poor
Average	Poor	Poor	Average	Aver ıge	Good
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Fired fuzzy rules are: -

1. If Correct Quantity Is Good and Correct Time Is Good, Then Rel1 Is Good
2. If Correct Quantity Is Good and Correct Time Is Very Good, Then Rel1 Is Good
3. If Correct Quantity Is Very Good and Correct Time Is Good, Then Rel1 Is Good
4. If Correct Quantity Is Very Good and Correct Time Is Very Good, Then Rel1 Is Very good

The output of correct quantity and correct time output lie between linguistic variables good and very good. According to the output triangular membership function above the output for correct quantity and correct time lie between 50% and 100%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of Fuzzy rules

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an and‖ operator is used, as shown in Table 4.34

Table 4. 34: The aggregation output of the fired rules for Rel1 output using " AND" operator

AND	**Good=0.7**	**Very good=0.3**
Good=0.8	0.7	0.3
Very good=0.2	0.2	0.2

Using the weighted average formula shown in Eq. (10) Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Rel1= (0.7*75+0.3*75+0.2*75+0.2*87.5)/ (0.7+0.3+0.2+0.2) =78%

Rel2 output

Aggregation of all outputs based on the rules that fired. For rel2 which was a fusion between correct product and correct condition. Correct quantity was found to be 84% and correct time was found to be 84%. both values lie between good and very good sides of the triangular membership function. Correct quantity has a degree of 0.64 good and 0.36 very good while correct time has a degree of 0.64 good and 0.36 very good. Table 4.35 shoes the fired rules based on the input provided.

Table 4. 35 : Fired rules for Correct product=84% and Correct condition=84% inputs

Correct Product/Correct Condition	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	Very poor	Poor	Poor	Poor
Poor	Very poor	Very poor	Poor	Poor	Poor
Average	Poor	Poor	Average	Averıge	Good
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Fuzzy rules that fired for rel2 output

Since 84% AND 84 % both lie on the GOOD and VERY GOOD on the triangular Membership function. The matched rules are:

1. If correct product is good and correct condition is good, then rel2 is good
2. If correct product is good and correct condition is very good, then rel2 is good
3. If correct product is very good and correct condition is good, then rel2 is good
4. If correct product is very good and Correct Condition is very good, Then Rel2 is very good

The output of correct quantity and correct time output lie between linguistic variables good and very good. According to the output triangular membership function above the output for correct quantity and correct time lie between

50% and 100%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of Fuzzy rules

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an AND operator is used, as shown in Table 4.36

Table 4. 36: The aggregation output of the fired rules for Rel2 output

AND	Good=0.64	Very good=0.36
Good=0.64	0.64	0.36
Very good=0.36	0.36	0.36

Using the weighted average formula shown in Eq. (10) Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Rel2=(0.64*75+0.36*75+0.36*75+0.36*87.5)/(0.64+0.36+0.36+0.36)=78%

Final reliability output

Aggregation of all outputs based on the rules that fired. For reliability which was a fusion between Rel1 and Rel2. Rel1 was found to be 78% and Rel2 was found to be 78% both values lie between good and very good sides of the triangular membership function. Correct quantity has a degree of 0.94 good and 0.06 very good while correct time has a degree of 0.94 good and 0.06 very good. Table .4.37 shows the Associative matrix between rel1 and rel2 outputs

Table 4. 37:Associative matrix of fusion between Rel1=78% and Rel2 =84% inputs

REL1/REL2	Very poor	Poor	Average	Good	Very Good
Very poor	Very Poor	Very poor	Poor	Poor	Very Poor
Poor	Very Poor	Very Poor	Poor	Poor	Very Poor
Average	Poor	Poor	Average	Average	Average
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Fuzzy rules that fired for rel2 output

1. If rel1 is good and rel2 is good, then reliability is good
2. If rel1 is good and rel2 is good, then reliability is good
3. If rel1 is v good and rel2 is very good, then reliability is good
4. If rel1 is v good and rel2 is very good, then reliability is v good

The output of the fusion lies between linguistic variables good and very good. According to the output triangular membership function above the output for correct quantity and correct time lie between 50% and 100%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of Fuzzy rules

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an AND operator is used, as shown in Table 4.38

Table 4. 38 :The aggregation output of the fired rules for Rel1 and Rel2 outputs

AND	**Good=0.88**	**Very good=0.12**
Good=0.88	0.88	0.12
Very good=0.12	0.12	0.12

Using the weighted average formula shown in Eq. (10) Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Final Reliability= (0.88*75+0.12*75+0.12*75+0.12*87.5)/
(0.94+0.06+0.06+0.06) =74.4%

Supply chain Responsiveness

The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Resp1 which was a fusion between Accuracy and number of complains. Accuracy was found to be 80% and number of complains was found to be 3.0. Accuracy has a degree 0.8 Good and 0.2 very good and 0.28 low and 0.74 very low. Table 4.39 shows the associative matrix between accuracy and number of complains and their corresponding outputs in linguistic terms

Table 4. 39:Associative Matrix: Accuracy=80% and number of complains=3 to get 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	Very good	Average	NA	NA

Fuzzy Rules that fired for Resp1 output

1. If accuracy is good and number of complains is very low then r1 is good

2. If accuracy good is number of complains is low then r1 is good

3. If accuracy is very good and number of complains is very low then r1 is very good

4. If accuracy is very good and number of complains is low then r1 is very good

The output of the fusion lies between linguistic variables good and very good. According to the output triangular membership function above the output for Accuracy and number of complains lie between 50% and 100%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an and‖ operator is used, as shown in Table 4.40

Table 4. 40:The aggregation output of the fired rules for Resp1 output

AND	Very Low=0.74	Low=0.28
Good=0.8	0.74	0.28
Very good=0.2	0.2	0.2

Using the weighted average formula shown on Eq. (10) Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp1 = (0.74*75+0.28*75+0.2*87.5+0.2*87.5)/ (0.74+0.2+0.2+0.28) =79%

Resp2: Fusion between Lead time and probability out of stock

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Resp2 which was a fusion between Lead time and Probability not out of stock. Lead time was found to be 2.12 and probability not out of stock was found to be 54%. Lead time has a degree 0.7 Low and 0.3 Medium and Probability not out of stock 0.92 average and 0.08 Good. Table 4.41 shows the associative matrix that shows Resp2 output in linguistic terms

Table 4. 41:Association matrix for lead-time=2 and probability not out of stock=54% to get Resp2 output

Lead Time/Percentage not out of stock	Very poor	poor	Average	Good	Very Good
Very low	NA	NA	Average	Good	Very Good
Low	NA	Poor	Average	Good	Very Good
Medium	poor	poor	Average	Average	Poor
High	poor	poor	Poor	NA	NA
Very High	Very poor	poor	Poor	NA	NA

<u>Fuzzy rules that fired for rel2 output</u>

The matched rules are

1. If lead time is low and % out of stock is average, then resp2 is average
2. If lead time is low and % out of stock is good, then resp2 is good
3. If lead time is medium and % out of stock is average, then resp2 is average
4. If lead time is medium and % out of stock is good, then resp2 is average

The output of the fusion lies between linguistic variables average and good. According to the output triangular membership function above the output for Lead time and Probability not out stock lie between 50% and 75%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of fuzzy rules

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an ―and‖ operator is used, as shown in Table 4.42

Table 4. 42 :The aggregation of the fired rules for Resp2 output

AND	**Average=0.92**	**Good=0.08**
Low=0.7	0.7	0.08
Medium=0.3	0.3	0.08

Using the weighted average formula shown in Eq. (10) to get Resp2 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp2 = (0.7*50+0.08*75+0.3*50+0.08*50)/ (0.7+0.3+0.08+0.08) =52%

Resp3: Fusion between on time delivery and response time

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Resp3 which was a fusion between on time delivery and Response time. on time delivery was found to be 65.6% and response time was found to be 8 days on time delivery has a degree 0.6 average and 0.4 Good and Response time had a degree 0.88 low and 012 very low. Table 4.43 shows Resp3 output

Table 4.43: Associative Matrix: on time delivery=65.6% and Response time=8 days to get Resp3

On Time Delivery/Response Time	Very Low	Low	Medium	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	Poor	NA
Very Good	Very Good	Good	Average	Na	Na

<u>Fuzzy rules that fired for resp3 output</u>

1. If on time delivery is average and response time is very low then resp3 is average
2. If on time delivery is average and response time is lowt hen resp3 is average
3. If on time delivery is good and response time is very low then resp3 is good
4. If on time delivery is good and response time is low then resp3 is good

The output of the fusion lies between linguistic variables average and good. According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75%. The output membership function. the chosen midpoints are 50% for good and 75% for very good:

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an ―and‖ operator is used, as shown in Table 4.44

Table 4.44 :The aggregation output of the fired rules for resp3 output using "And" operator

AND	Very Low=0.12	Low=0.88
Average=0.92	0.12	0.88
Good=0.08	0.08	0.08

Using the weighted average formula shown in Eq. (10) Resp3 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp3 = (0.12*50+0.88*50+0.08*75+0.08*75)/ (0.7+0.3+0.08+0.08) =57%

Resp4: Fusion between Fill rate and shipping errors

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Resp4 which was a fusion between Filtrate was found to be 60% and number of percentage of shipping errors was found to be 40%. Fill rate has a degree has a degree 0.6 average and 0.4 Good and shipping errors me had a degree 0.6 average and 0.4 good. Table 4.45 shows the output Resp4.

Table 4.45: Associative Matrix: Fill rate=60% and shipping errors=40% to get Resp4

Fill rate/Percentage of shipping errors	**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

<u>Fuzzy rules that fired for resp4 output</u>

1. If fill rate is average and % of shipping errors is poor, then resp4 is average
2. If fill rate is average and % of shipping errors is average, then resp4 is average
3. If fill rate is good and % of shipping errors is poor, then resp4 is good
4. If fill rate is good and % of shipping errors is average, then resp4 is average

The output of the fusion lies between linguistic variables poor and average According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of fuzzy rules

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an ―and‖ operator is used, as shown in Table 4.44

Table 4.44: The aggregation output of the fired rules for resp4 output using "And" operator

AND	Poor =0.4	Average-0.6
Average=0.6	0.4	0.6
Good=0.4	0.4	0.4

Using the weighted average formula shown in Eq. (10). to get Resp4 output. Each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp4 = (0.4*50+0.6*50+0.4*75+0.4*50)/ (0.4+0.6+0.4+0.4) =56%

Respfusion1: Fusion Between Resp1 and Resp2 Outputs

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Respfusion1 which was a fusion between Resp1 and Resp2. Resp1 was found to be 79% and Resp2 was found to be 52%.. Resp1 had a membership degree of 0.84 good and 0.16 very good. While Resp2 had a degree of 0.92 average and 0.08 poor. Table 4.47 shows the output Respfusion1 based on the fired rules.

Table 4.47: Associative Matrix : Resp1=79% AND Resp2= to get Respfusion1 output

Resp1/Resp2	**Very poor**	**poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	poor	poor	Poor	poor
Poor	Poor	poor	poor	Poor	poor
Average	Poor	poor	Average	aver ge	average
Good	Poor	poor	Average	Good	good
Very Good	Poor	poor	average	Good	Very Good

Fuzzy rules that fired for reliability output

1. If resp1 is good and resp2 is average, then respfusion1 is average
2. If resp1 is good and resp2 is good, then respfusion1 is good
3. If resp1 is very good and resp2 is average, then respfusion1 is average
4. If resp1 is very good and resp2 is good, then respfusion1 is good

The output of the fusion lies between linguistic variables average and good According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an ―and‖ operator is used, as shown in Table 4.48

Table 4. 48: The aggregation output of the fired rules for Respfusion1 output

AND	Poor=0.08	Average=0.92
Good=0.84	0.08	0.84
Very good=0.16	0.08	0.16

Using the weighted average formula shown in Eq. (10), Respfusion1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Respfusion1 = (0.08*50+0.84*75+0.08*50+0.16*75)/ (0.08+0.08+0.84+0.16) =72%

Respfusion2: fusion between resp3 and resp4 outputs

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Respfusion1 which was a fusion between Resp3 and Resp4. Resp3 was found to be 63% and Resp2 was found to be 55%. Resp3 had a membership degree of 0.72 average and 0.26 good While Resp4 had a degree of 0.76 average and 0.24 good. Table 4.49 shows an associative matrix that shows respfusion2 output based on the fired rules

Table 4. 49: Associative matrix for Resp3=57% and Resp4=56% to get Respfusion2

Resp3/Resp4	**Very poor**	**poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	poor	poor	Poor	poor
Poor	Poor	poor	poor	Poor	poor
Average	Poor	poor	Average	Aver ge	average
Good	Poor	poor	Average	Good	good
Very Good	Poor	poor	Averag e	Good	Very Good

Fuzzy rules that fired for respfusion2 output

1. If resp3 is average and resp4 is average, then respfusion1 is average
2. If resp3 is average and resp4 is good, then respfusion1 is good
3. If resp3 is good and resp4 is average, then respfusion1 is average
4. If resp3 is good and resp4 is good, then respfusion1 is good

The output of the fusion lies between linguistic variables average and good According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an ―and‖ operator is used, as shown in Table 4.50

Table 4. 50: The aggregation output for fired rules for Respfusion2 output.

AND	**Average=0.76**	**Good=0.24**
Average=0.72	0.72	0.24
Good=0.2	0.2	0.2

Using the weighted average formula shown in Eq. (10) Respfusion2 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Respfusion2 = (0.72*50+0.2*75+0.24*50+0.2*75)/ (0.72+0.2+0.24+0.2) =57%

Responsiveness fusion between respfusion1 and respfusion2 output

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Performance which was a fusion between Responsiveness and Reliability. Responsiveness was found to be 68% and Reliability was found to be 74.4%. both lie between average and good side of the output triangular membership function. Responsiveness has a membership degree of 0.64 good and 0.36 average While Reliability had a degree of 0.52 good and 0.44 average. Table 4.51 shows the final responsiveness output based on the fired rules in an Associative matrix

Table 4. 51: Associative matrix for Respfusion1=685 and Respfusion2=74.4%

Responsiveness/Reliability	Very poor	poor	Average	Good	Very Good
Very poor	Very poor	poor	Poor	Poor	poor
Poor	Poor	poor	Poor	Poor	poor
Average	Poor	poor	Average	Average	average
Good	Poor	poor	Average	Good	good
Very Good	Poor	poor	Average	Good	Very Good

Fuzzy rules that fired for performance output

1. If responsiveness is average and reliability is average, then performance is average
2. If responsiveness is average and reliability is good, then performance is average
3. If responsiveness is good and reliability is average, then performance is average
4. If responsiveness is good and reliability is good, then performance is good

The output of the fusion lies between linguistic variables average and good According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an ―and‖ operator is used, as shown in Table 4.52

Table 4.52: The aggregation output of the fired rules for responsiveness output using "And" operator

AND	Average=0.36	Good=0.64
Average=0.48	**0.36**	**0..36**
Good=0.52	**0.48**	**0.52**

Using the weighted average formula shown in Eq. (10), Responsiveness output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Responsiveness = (0.52*50+0.48*50+0.36*50+0.52*75)/
(0.36+0.48+0.36+0.52) =68%

Supply chain performance measurement

Supply chain performance was obtained by fusing responsiveness and reliability outputs. Aggregation of all outputs based on the rules that fired. Performance which was a fusion between Responsiveness and Reliability. Responsiveness was found to be 68% and Reliability was found to be 74.4% both values lies between Average and Good sides of the triangular membership function. Using Equation (8) Responsiveness has a degree of 0.28 average and 0.72 good and Reliability has a degree of 0.04 average and 0.96 good. Table 4.52 shoes the fired rules based on the input provided.

Table 4. 52: Fired Rules for Responsiveness=68% and Reliability=74.4%

Responsiveness /Reliability	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	Very poor	Poor	Poor	Poor
Poor	Very poor	Very poor	Poor	Poor	Poor
Average	Poor	Poor	Average	AverageE	Good
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Fuzzy rules that fired for rel2 output

Since 84% and 84 % both lie on the good and very good on the triangular

Membership function. The matched rules are

1. If responsiveness is average and reliability is average, then performance is average
2. If responsiveness is average and reliability is good, then performance is average
3. If responsiveness is good and reliability is average, then performance is average
4. If responsiveness is good and reliability is good, then performance is good

The output of responsiveness and reliability output lie between linguistic variables average and good According to the output triangular membership function the output for responsiveness and reliability lie between 25% and 75%. The output membership function. the chosen midpoints are 50 for average and 75 for good:

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an and operator is used, as shown in Table 4.54

Table 4. 54: The aggregation of fired rules for performance output

AND	Average=0.04	Good=0.96
Average=0.28	0.04	0.28
Good=0.72	0.04	0.72

Using the weighted average formula shown in Eq. (10), to get Performance output. Each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Performance= (0.04*50+0.28*50+0.04*50+0.72*75)/ (0.04+0.28+0.04+0.72) =67%

Therefore, the overall supply chain management performance was found to be 67%. Which is good.

4.9: To design, develop, implement and test a framework that uses fuzzy logic to measure performance in Supply Chain Management.

4.9.1 Framework Tool System Design

Here we designed the system through the use of use case, activity diagrams, sequence diagram, class diagram, package diagram and robust analysis diagram. A set of functional and nonfunctional requirements are also identified in this stage.

The design framework helps to represent the general functionality of the system for it to be implemented. They are as follows

4.9.2 Framework Tool Requirement Analysis and Design

4.9.2.1 Nonfunctional requirements

I. Latency of the software system
II. Safety property of protecting the framework from unauthorized access
III. Good and easy to use software interface
IV. Scalability of the system to support additional uses
V. Scalability to support additional quality factors
VI. Localizability—ability to make adaptations due to regional differences
VII. Modifiability or extensibility to include other sub attributes of software system
VIII. Evolve ability—support for new capabilities or ability to exploit new technologies
   a System should show some processing at the background
   b Should respond within 1 minute to user's request
   c System should be portable to any platform with minimal modifications on it
   d Documentation should contain the user manual and interface design

4.9.2.2 Functional Requirements

The following are the major identified functional requirements expected from the assessment framework to be developed in this project

I. System would represent sub responsiveness and reliability attributes with regard to qualitative factors.
II. System awarded scores to individual qualitative attribute depending on object selection by users
III. System evaluated individual qualitative attribute score based on sub attributes selected by the users

IV. System evaluated both qualitative aspects scores and total score for both of them
V. System communicated to users using interface on qualitative attribute score
VI. System protected users of the system from unauthorized access

4.9.3 UML DIAGRAMS

4.9.3.1 Use Case Diagram Analysis

A use case analysis is the most common technique used to identify the requirements of a system (normally associated with software/process design) and the information used to both define processes used and classes (which are a collection of actors and processes) which was used both in the use case diagram and the overall use case in the development or redesign of a software system or program. The use case analysis is the foundation upon which the system was built. Based on this the following use case was developed for the proposed assessment framework as shown in figure 4.1.5

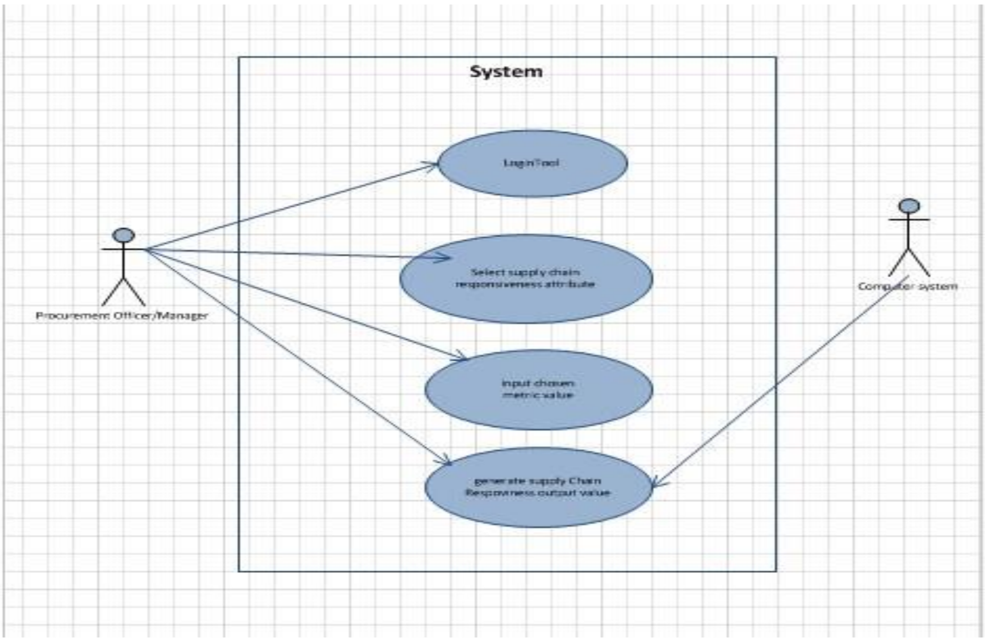

Figure 4. 15: Use Case Diagram

4.9.3.2 Classes:

From the requirements and general observation and objectives of the assessment framework, an overall class of quality was identified as the parent class with sub characteristics forming the child classes as shown in the diagram below. The attributes of the class were name, score, sub characteristics and methods like get name, get score, get attribute score, evaluate attribute score and evaluate total score. They are as shown below. Similarly, a class Quality assessor was identified since he is the one to assess the class quality with a one to many relationships to the class quality. They are represented as shown in figure 4.16

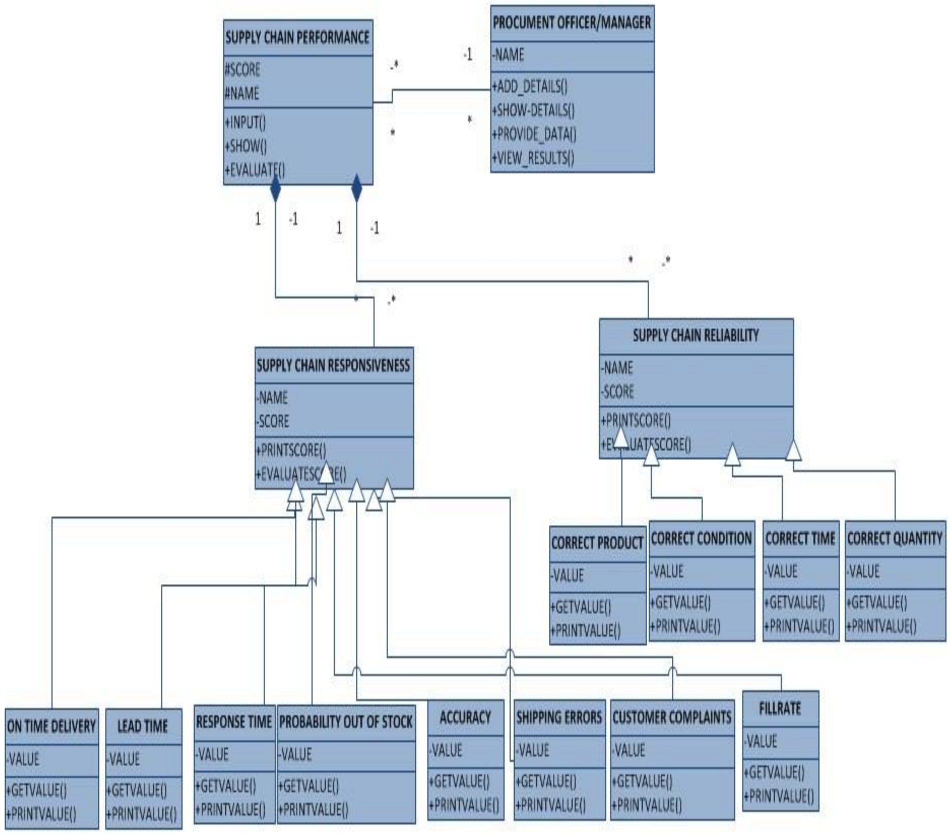

Figure 4 16: Class Diagrams

4.9.3.3 Sequence Diagram

This Sequence diagrams describe interactions among classes in terms of an exchange of messages over time. This was necessary to know how messages flowed within the software framework to be developed. The sequence diagram generated is as shown in figure 4.17

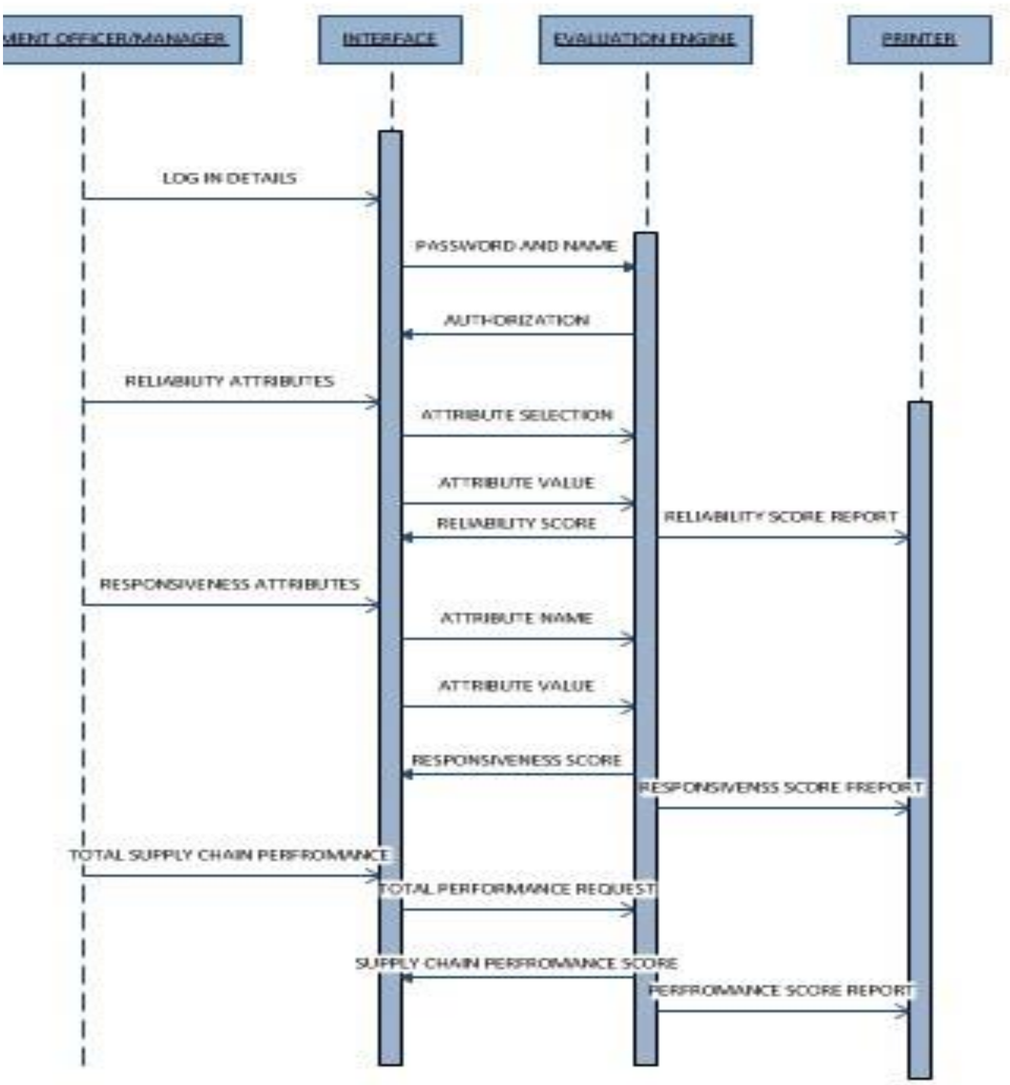

Figure 4 15: Sequence Diagrams

4.9.3.4 Activity Diagram

The activity diagram helped me to analyze and understand the general workflows that surround the usage of the framework in assessing software quality in the industry. Activity diagram is basically a flow chart to represent the flow form one activity to another activity. The activity can be described as an operation of the system. The activity diagram generated is shown in Figure 4.18, Figure 4.19 and Figure 4.20

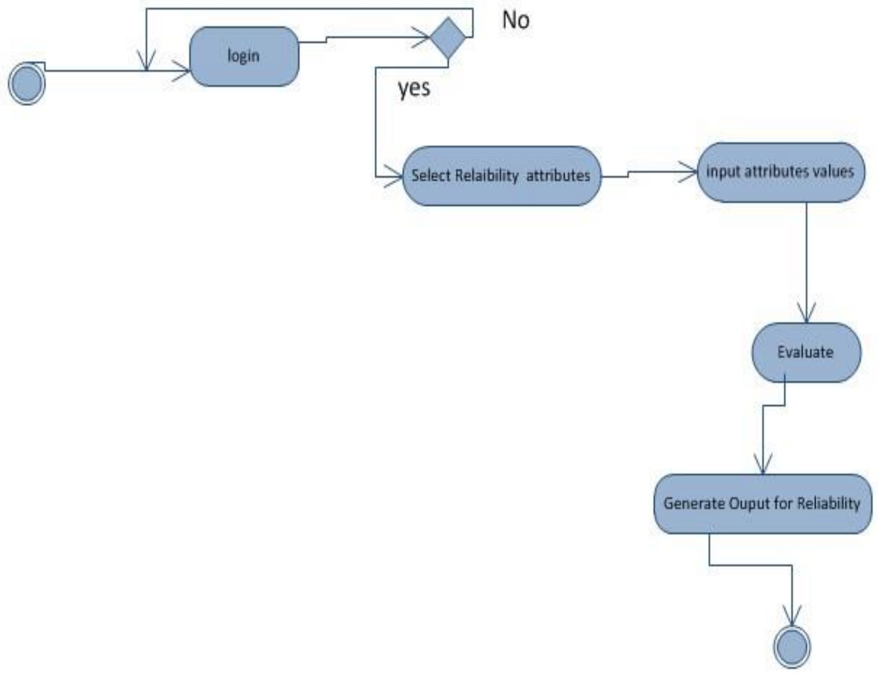

Figure 4 16: Activity Diagram 1

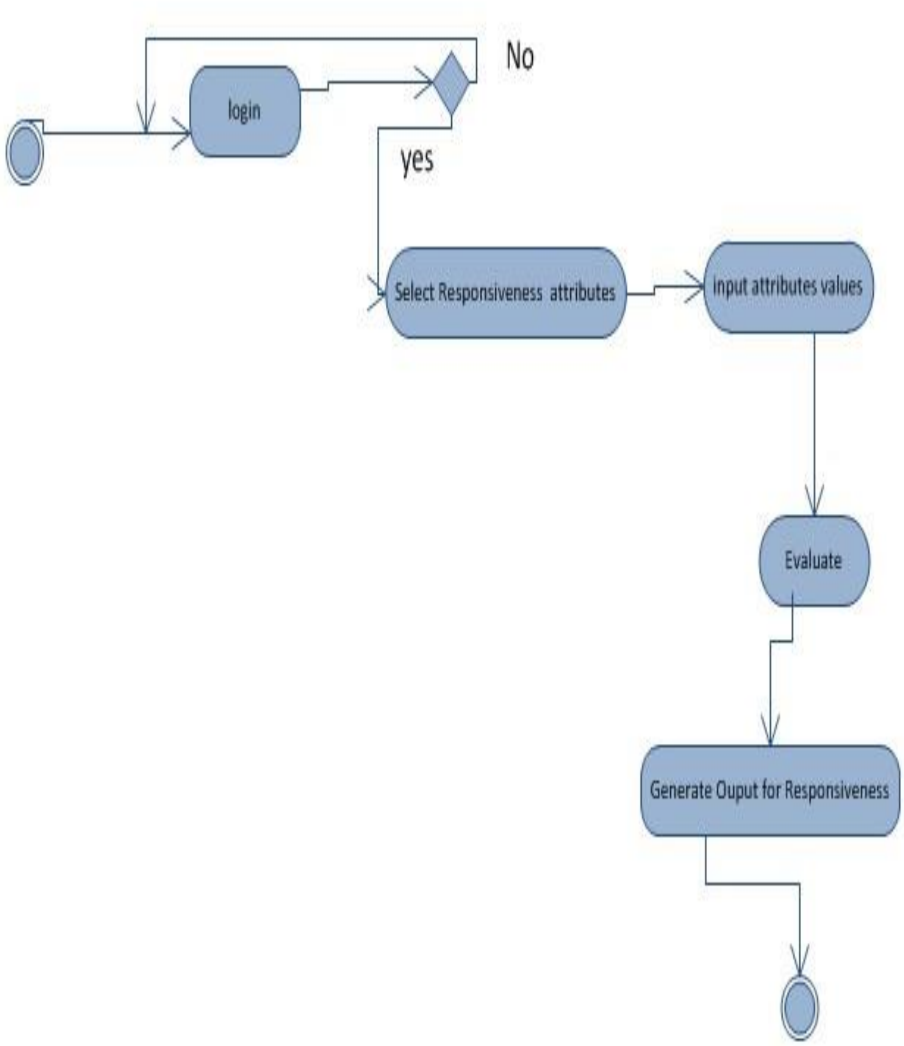

Figure 4 17: Activity Diagram 2

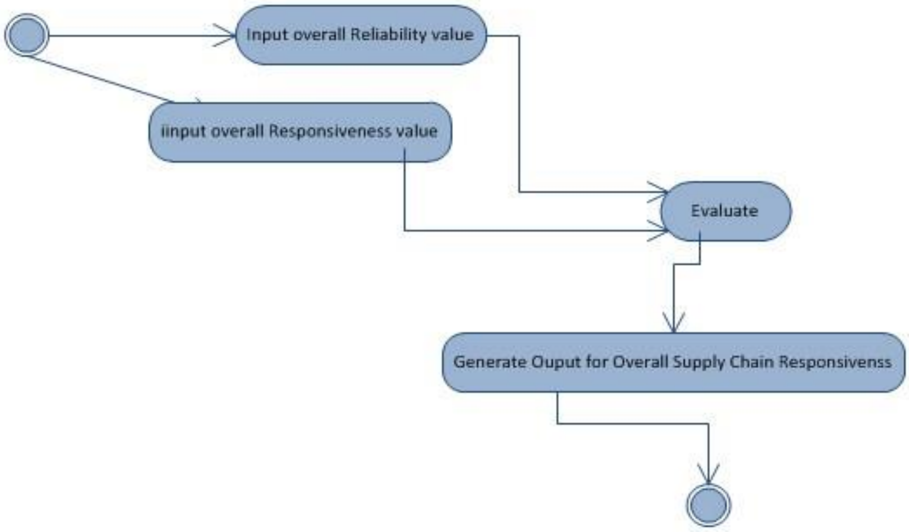

Figure 4 18: Activity Diagram 3

4.9.3.5 Package Diagram

This diagram depicts the various packages are as shown below. They include quality statistical engine to be used to analyze the quality score and generate trends for various software identified in system assessed using the framework, The attribute assessor were used to assess the individual quality attributes for the software system. The report generator will be used to produce individual quality reports for each software quality attribute assessed and the overall quality score for the entire software system developed. The package diagram is shown in fug 4.21

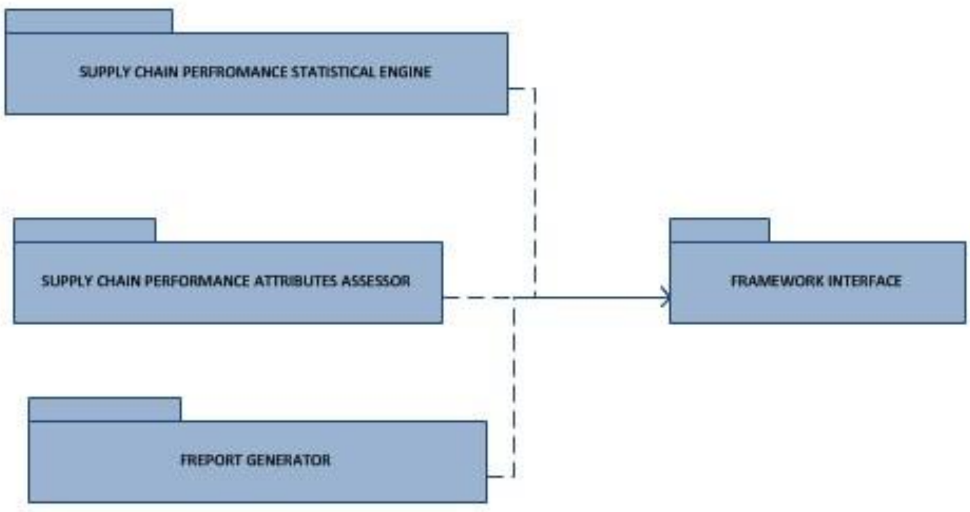

Figure 4 19: Package Diagram

4.9.4: Interface Designs

The first screen that appears is the Frame work interface Front face of framework which displays two options. if the user wants to measure responsivess then he can click on the first option or if he wants to measure reliability then he clicks on the second option as shown on Figure 4.22

Figure 4 20: Framework Main Form

If the user clicks on reliability option, the screen shown on Fig 4.23 appears and the user will be required to enter the required data.

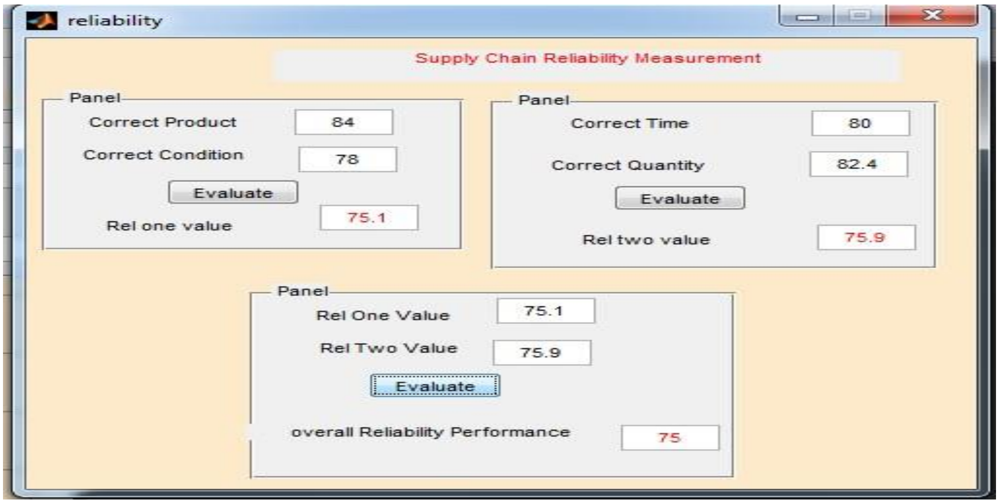

Figure 4 21: Interface for Reliability Measurement

If the user selects the responsiveness option, then the screen shown on fig 4.24 appears. The user will be required to input all the required data.

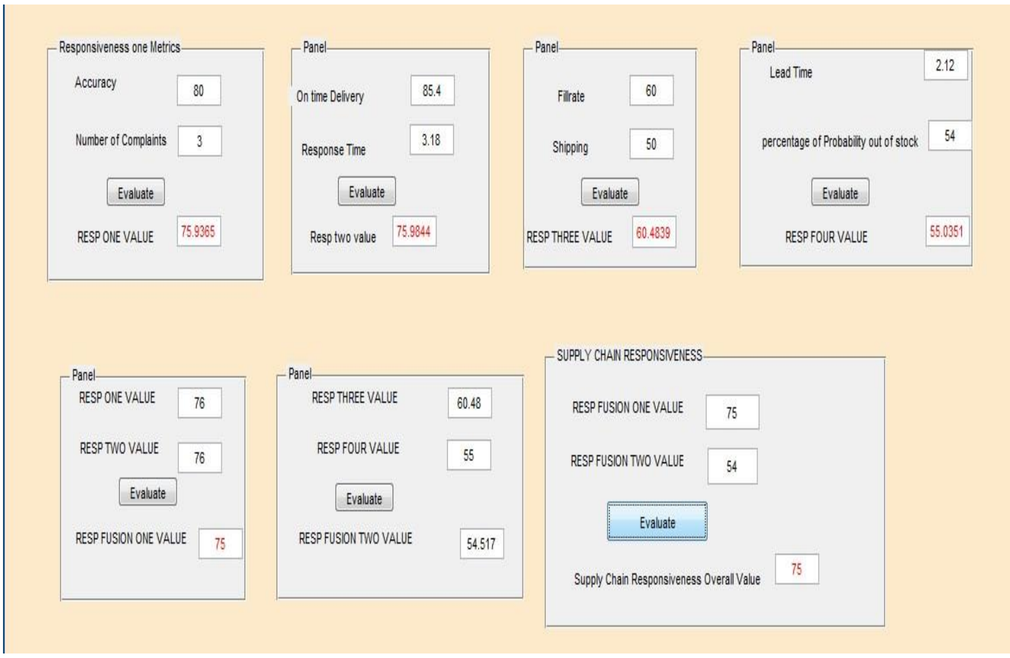

Figure 4 22: Interface for Responsiveness Measurement

Once the output values of the responsivess and reliability are obtained they are then fed into the next screen on fig 4.25

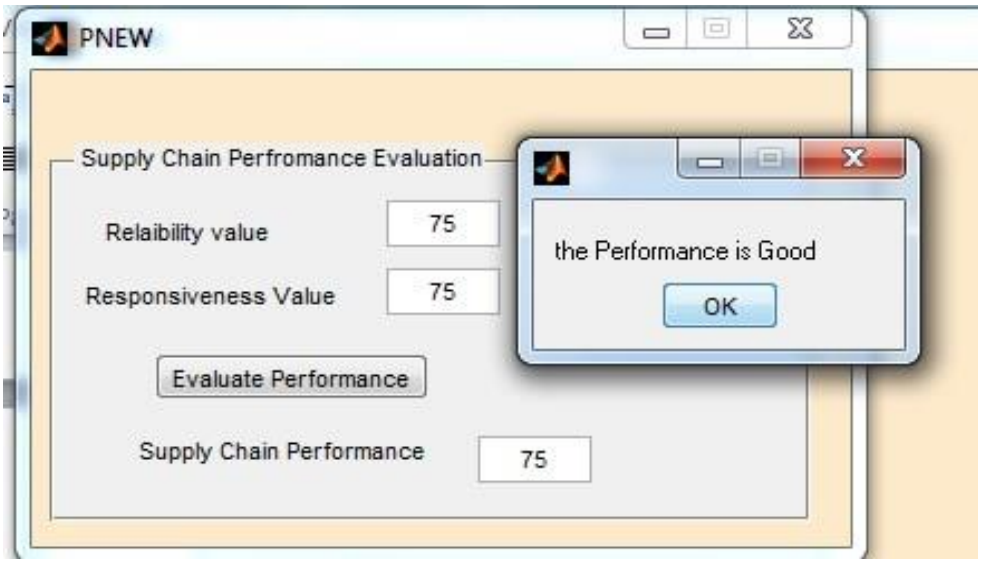

Figure 4 23: Interface for Supply Chain Performance Measurement

CHAPTER FIVE

FRAMEWORK TESTING AND VALIDATION

5.1 Introduction

In this chapter the framework developed was tested to ascertain its relevance in performance evaluation of supply chains in Kenya. A total of 3 supply chain managers were engaged in review process of the software framework. This was necessary to ensure that an improvement of supply chains performance evaluation framework was achieved and that the tool developed as the product of the research meets its intended objectives of research of producing an evaluation model.

The framework was created to introduce new approach for measuring qualitative performance in Supply Chain Management. The Fuzzy Logic Controller was used as an inference system because it is a robust and easy understanding approach for using linguistic terms into logical rules. For showing the performance of the quality factor in supply chains, three companies were selected and separate interview with them conducted. Interviewer asked from the expert managers to respond to the actual data.

5.2 Testing Method

To test the fuzzy logic framework. the software developed was given to supply chain managers/procurement officers and shown to them how to use the model developed in MATLAB. They were therefore using it by clicking on an option that best describes the attribute and elements of factor that has been indicated on the interface. The same score was to be recorded in paper sheet as shown below to ensure that the values entered and overall output match. To conduct the research, the following companies that had supply chains were engaged

Company Name

1 BValley Printers
2 Maersk Line
3 Mewa Hospital

Mewa hospital was chosen since they do a lot of procurement of hospital supplies and therefore a supply chain performance evaluation model would be of a greater interest in the supply chain performance evaluation model. Similarly, I wanted to ensure that I pick a wider range of products supply chain for evaluation to provide wider option of test results and ascertainment of the framework tool.

BValley printers are the distributors of cartridges and photo copy papers in Mombasa. their supply chain performance data would provide wider test for reliability and responsiveness of the supply chain. This was necessary to cover a wider range of the testability of the model.

Maersk line is a transport company. This company was necessary to ensure that I test wider range of Business Domain. The model was used in evaluating of their Procurement and performance of their supply chains. In this framework assessment of reliability and responsiveness was of utmost necessity. Therefore, it provides the best option of the assessment of the factors

Once they testing firms were developed, they actually conducted the test, collected results. The results also helped them to identify areas of improvement in the development of their performance evaluation framework. They also gave their comments on observations they have made as regards the fuzzy logic framework. The comments are stated in the section of results.

5.3 Testing Results for Responsiveness of Supply chains using the developed Fuzzy logic framework

5.3.1. Mewa Hospital

The supply chain performance was analyzed with the framework and the following results were observed as shown in Table 5.1

Table 5. 1 : Mewa Hospital data for Supply Chain Reliability

Sno.	**Supply chain reliability**	**% of correctness in delivery**
1	**Correct product**	60-80%
2	Correct time	60-80%
3	Correct quantity	60-80%
4	Correct documentation	60-80%

Results of Assessment

Table 5.1 shows the achieved data from the mentioned companies. The data inserted in the Software and the output show the result of the performance. From the table it was noted that the supply chain delivered 60-80% of all products correctly, at the correct time, correct condition and correct documentation. When the inputs were entered into the fuzzy logic framework in Mat lab, The framework would measure their reliability performance as 50% from 100. The results obtained are shown in Fig 5.1

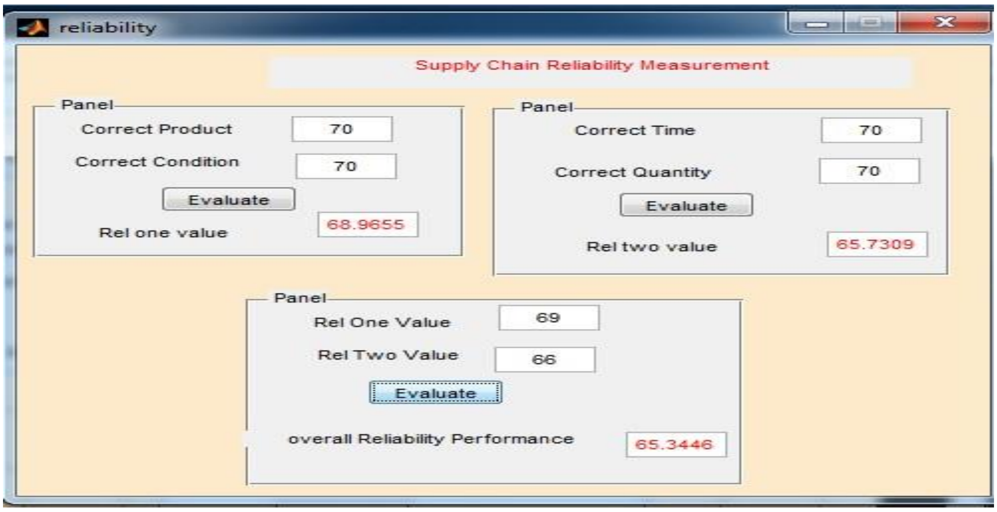

Figure 5 1: Reliability Performance Output for Mewa Hospital Supply Chain

The supply chain performance was analyzed with the framework and the following results were observed as shown in Table 5.2

Table 5. 2 : Mewa Hospital testing data for supply chain responsiveness

Sno.	Supply chain responsiveness metric	No of days
1	Lead time(in days)	1 to 3 day
2	Customer response time	Less than 2 days
3	Number of complaints	Less than 5
4	On time delivery (%)	60%-80%
5	Filtrate(%)	60%-80%
6	Shipping errors (%)	Less than 20%
7	Percentage not of stock (%)	60% to 80%
8	**Accuracy (%)**	**60% to 80%**

Table 5.2 shows the data collected it can be noted that the lead time was 1 to 3 days, customer response time was less than 2 days, number of complaints registered in a month are less than 5, 60% to 80% of all products delivered on time, the fill rate was 60% to 80%. the shipping errors were less than 20%, the percentage of goods not out of stock was 60% to 80% and percentage of accuracy of goods was 60% to 80%.

The data was inserted in the software and the output shows the result of the reliability performance. When the inputs were entered into the fuzzy logic framework in Matlab, The framework would measure their responsiveness performance as 50% from 100. The results obtained are shown in Fig 5.2.

Figure 5 2: Supply Chain Responsiveness Performance Output For Mewa Hospital

The reliability and responsiveness output are input into the interface provided in Fig. 3 and the final performance output is obtained.

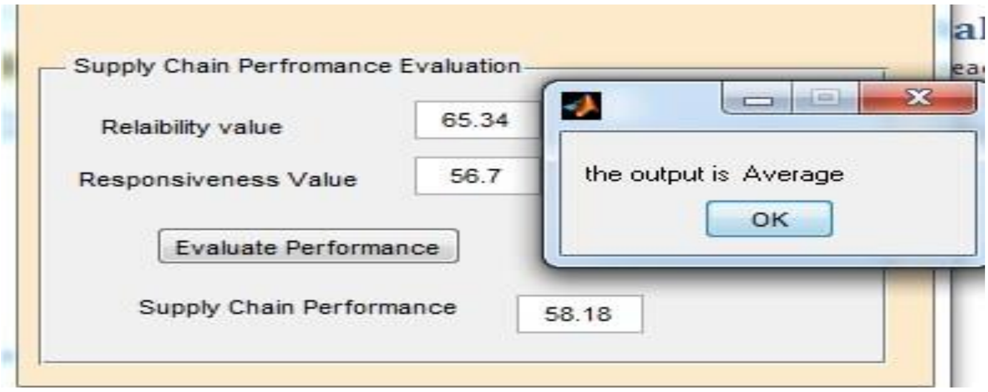

Figure 5 3: Supply Chain Performance Output for Mewa Hospital

Form the data collected it can be noted that supply chain responsiveness was 58% On the basis of this result it can be noted that responsiveness

5. 3.2. Maersk Line

Their supply chain was evaluated using the framework and the following results were obtained as shown in Table 5.3

Table 5. 3: Supply chain reliability testing data for Maersk Line

SNO	**Supply chain reliability data**	**Range**
1	Correct product delivery	60-80%
2	Correct time	40-60%
3	Correct quantity	80-100%
4	Correct documentation	80-100%

Table 5.3 shows the data collected it can be noted that most products were 80-100% delivered correctly, with the right quantity and correct documentation. But it was noted that most products were slightly delayed in delivery. The data was inserted in the software and the output shows the result of the reliability

performance. When the inputs were entered into the fuzzy logic framework in Matlab, The framework would measure their reliability performance as 50% from 100. The results obtained are shown in Fig 5.4.

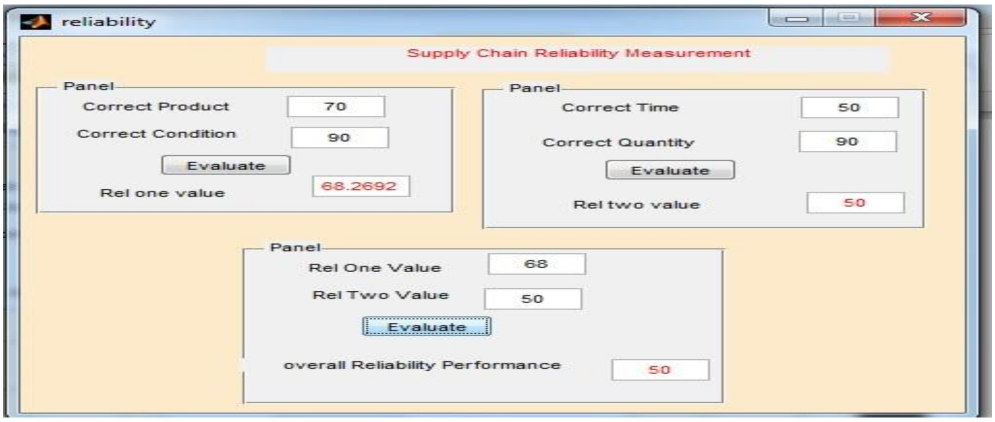

Figure 5 4: Reliability Output for Maersk Line Supply Chains

The supply chain performance was analyzed with the framework based on the date provided in Table 5.4

Table 5. 4 : Supply chain responsiveness data for Maersk Line

Sno.	Supply chain responsiveness variables	No of days
1	Lead time(in days)	3
2	Customer response time	2 to 6 days
3	Number of complaints	Less than 5
4	On time delivery (%)	60%-80%
5	Filtrate(%)	60%-80%
6	Shipping errors (%)	Less than 20%
7	Percentage out of stock (%)	20% to 40%
8	Accuracy (%)	60% to 80%

Table 5.4 shows the data collected it can be noted that the lead time was 3 days, customer response time was 2 to 6 days, number of complaints registered in a month are less than 5, 60% to 80% of all products delivered on time, the fill rate was 60% to 80%. the shipping errors were less than 20%, the percentage of goods not out of stock was 20% to 40% and percentage of accuracy of goods was 60% to 80%.

The data was inserted in the software and the output shows the result of the reliability performance. When the inputs were entered into the fuzzy logic framework in Mat lab, the framework would measure their responsiveness performance as 50% from 100. The results obtained are shown in Fig 5.5

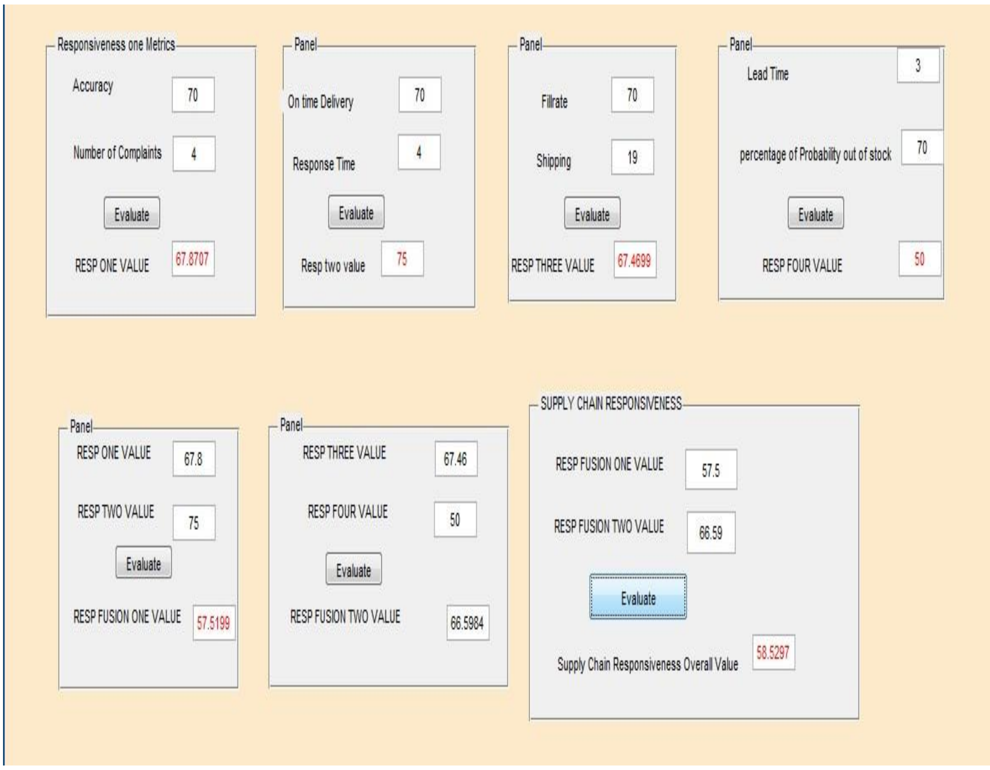

Figure 5 5: Supply Chain Responsiveness output for Maersk Line

Fig. 5.6 shows the screen used for the overall supply chain performance. The user need to input the reliability and responsivess values obtained.

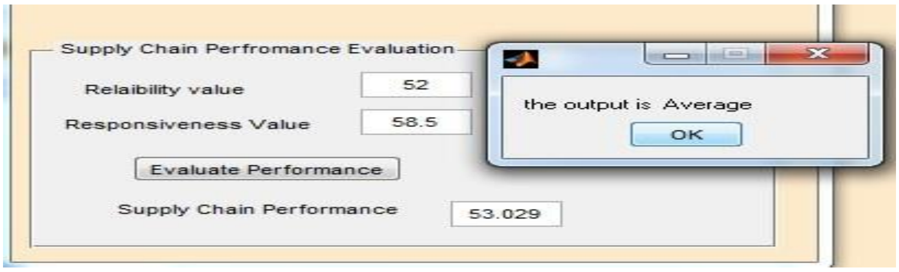

Figure 5 6: supply chain performance output for Bvalley Supply Chains

Form the data collected it can be noted that supply chain responsiveness was 53% On the basis of this result it can be noted that responsiveness which was average. Table 5.5 shows data collected for reliability of supply chains for Bvalley printers.

Table 5. 5 : Bvalley Printers Supply Chain reliability testing data

SNO	**Supply chain reliability variables**	**Range**
1	Correct product	80-100%
2	Correct quantity	60-80%
3	Correct time	60-80%
4	Correct documentation	60-80%

Table 5.6 shows the data collected it can be noted that most products were 80-100% delivered correctly, with the right quantity and correct documentation. The data was inserted in the software and the output shows the result of the reliability performance. When the inputs were entered into the fuzzy logic framework in Mat lab, The framework would measure their reliability performance as 50% from 100. The results obtained are shown in Fig 5.7

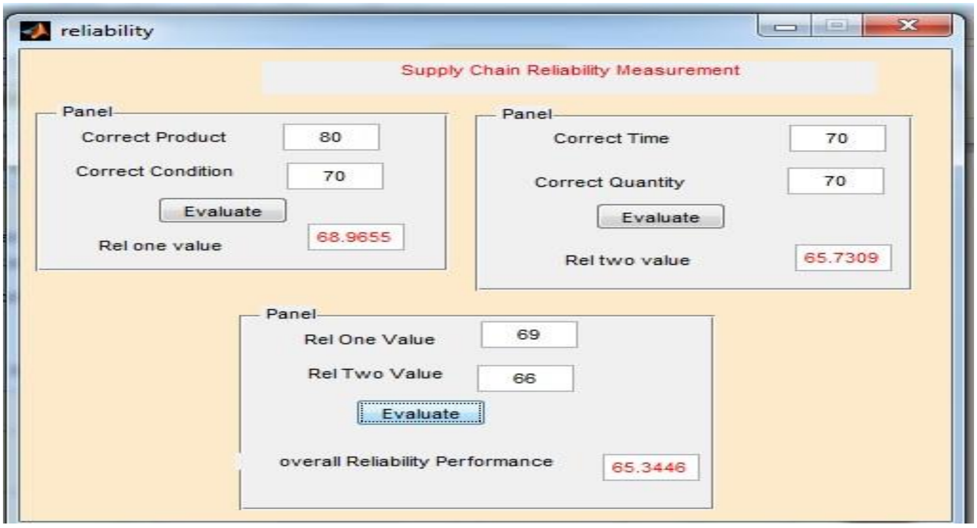

Figure 5 7; Supply Chain Reliability output for Bvalley Printers

Form the data collected it can be noted that supply chain reliability was **65.3%** On the basis of this result it can be noted that reliability was good. Table 5.6 shows responsiveness data for Bvalley printers.

Table 5. 6 :Bvalley Printers supply chain Responsiveness testing data

Sno.	**Supply chain responsiveness metric**	**No of days**
1	Lead time(in days)	3
2	Customer response time	2 to 6 days
3	Number of complaints	Less than 5
4	On time delivery (%)	60%-80%
5	Filtrate(%)	60%-80%
6	Shipping errors (%)	Less than 20%
7	Percentage not of stock (%)	20% to 40%
8	Accuracy (%)	60% to 80%

Table 5.7 shows the data collected it can be noted that the lead time was 3 days, customer response time was 2 to 6 days, number of complaints registered in a month are less than 5, 60% to 80% of all products delivered on time, the fill rate was 60% to 80%. the shipping errors were less than 20%, the percentage of goods not out of stock was 20% to 40% and percentage of accuracy of goods was 60% to 80%.

The data was inserted in the software and the output shows the result of the reliability performance. When the inputs were entered into the developed software, the framework would measure their responsiveness performance as 50% from 100. The results obtained are shown in Fig 5.8.

Figure 5 8: Supply Chain Responsiveness Output for Bvalley Printers

Form the data collected it can be noted that supply chain responsiveness was 54.5% On the basis of this result it can be noted that responsiveness was found to be average. Fig 5.9 shows the final Supply Chain Performance management.

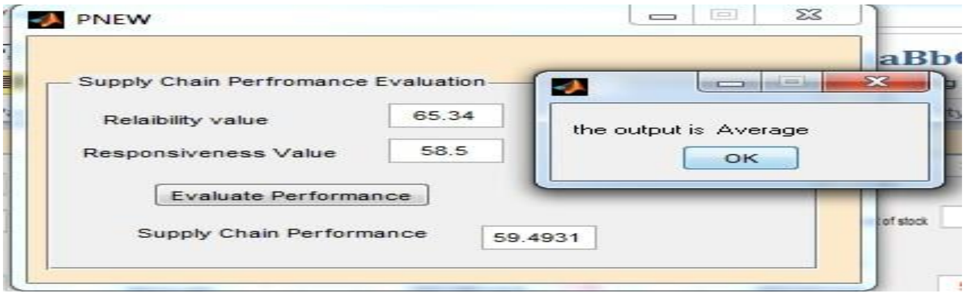

Figure 5 9: Supply Chain Performance of Bvalley Printers

5.4 Observation from the Testing process

It can be observed that the framework tool enables procumbent managers/officers to identify their supply chain performance. Similarly, the framework enables them to assess whether the supply chain performance is good or not. Similarly, the framework provides qualitative basis of assessment that other methods do not provide.

It was also observed by validations that the framework should maintain the output representing the performance as poor, average and Good. This was necessary since they found it difficult to weigh the presence of some attributes in numbers. To make this possible a message box was used in the tool to ensure that the clients can click on the evaluate performance button which best suites and represent their needs and desires in the framework tool developed in this research project.

5.5. Validating the Fuzzy Logic Framework

The methodology we applied to develop the framework can efficiently deal with the uncertainties and vagueness that have surrounded Supply chain performance measurement This can be mainly done via the fuzzy logic concepts. Additionally, we were able to include the experts' knowledge and expertise in the body of the supply chain management this was done through selecting critical parameters using the Supply chain operations reference model adopted by supply chain council (2010).. In this way, we could avoid the complexity and difficulty of designing traditional models, which are non-user-friendly for those who are not expert.
Another useful approach in justifying the validity of the Fuzzy logic framework lies on the selection of important performance parameters. According to the evidence currently available in the literature, all of the qualitative parameters included in the framework have considerable effects on supply chain performance management

According to the results from the present study, the framework can be considered as a more useful, comprehensive tool to measure the performance of supply chain management compared to the current methods of performance assessment, which rely mainly on the evaluators' observations or quantitative measurement.

To validate the fuzzy logic framework, the data set shown in table 5.1 was used which was used for performance evaluation of quality of supply chain management in rubber glove manufacturers in Malaysian companies. Most of the parameters were used in the fuzzy logic framework of this research. The output showed the result of the performance is shown in Table 5.7

Table 5. 7: Test data for quality of supply chains in Malaysian companies

Case number	Accuracy	Customer complains	Lead Time	Fill rate	Customer response time	On time delivery	Output performance
Mean of all supply chains	90%	10	2 days	50%	10 days	90%	76.9

Using data from case shown in Table 5.8 in our as input in our framework, the output was a fusion between accuracy and number of complaints.

5.5.1 Supply chain Responsiveness Framework validation

The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Resp1 which was a fusion between Accuracy and number of complains. Accuracy was found to be 90% and number of complains was found to be 10. Using Equation (8) Accuracy has a degree 0.2 Good and 0.8 very good and 00.5 low and 0.5 very low. Table 5.8 shows the associative matrix between accuracy and number of complains and their corresponding outputs in linguistic terms

Table 5. 8 : Associative Matrix: accuracy and number of complains for Resp1

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	Very Good	Average	NA	NA

Fuzzy rules that fired for matched rules

1. If accuracy is good and number of complains is very low, then r1 is good
2. If accuracy good is number of complains is low, then r1 is good
3. If accuracy is very good and number of complains is very low, then r1 is very good
4. If accuracy is very good and number of complains is low, then r1 is very good

The output of the fusion lies between linguistic variables good and very good. According to the output triangular membership function above the output for Accuracy and number of complains lie between 50% and 100%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an "and" operator is used, as shown in Table 5.9

Table 5. 9 : The aggregation of fired rules for Resp1 output

AND	**Very Low=0.5**	**Low=0.5**
Good=0.2	0.2	0.2
Very good=0.8	0.5	0.5

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp1 = (0.2*75+0.2*75+0.5*87.5+0.2*87.5)/ (0.2+0.2+0.5+0.3) =65%

Resp2: fusion between lead time and probability not out of stock

Using data for case A as our inputs for the fuzzy logic framework, the output was a fusion between lead time probability out of stock, the second variable was not part of the framework but since lead-time was the same as the one found in this research it was assumed to be the same as the data for our research. The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Resp2 which was a fusion between Lead time and Probability not out of stock. Lead time was found to be 2. and probability not out of stock was found to be 54%. Lead time has a degree 0.7 Low and 0.3 Medium and Probability not out of stock 0.92 average and 0.08 Good. Table 5.10 shows the associative matrix that shows Resp2 output in linguistic terms

Table 5. 10:Associative Matrix for lead-time and Probability not out of stock

Lead Time/Percentage not out of stock	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very low	NA	NA	Average	Good	Very Good
Low	NA	Poor	Average	Good	Very Good
Medium	poor	Poor	Average	Average	Poor
High	poor	Poor	Poor	NA	NA
Very High	Very poor	Poor	Poor	NA	NA

Fuzzy rules that fired for resp2 output

The matched rules are

1. If lead time is low and % out of stock is average, then resp2 is average
2. if lead time is low and % out of stock is good then resp2 is good
3. if lead time is medium and % out of stock is average then resp2 is average
4. if lead time is medium and % out of stock is good then resp2 is average

The output of the fusion lies between linguistic variables average and good. According to the output triangular membership function above the output for Lead time and Probability not out stock lie between 50% and 75%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good:

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an "and" operator is used, as shown in Table 5.11

Table 5. 11 : The aggregation of fired rules for Resp2 output

AND	**Average=0.92**	**Good=0.08**
Low=0.7	0.7	0.08
Medium=0.3	0.3	0.08

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp2 = (0.7*50+0.08*75+0.3*50+0.08*50)/ (0.7+0.3+0.08+0.08) =52%

Resp3: fusion between on time delivery and response time

The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Resp3 which was a fusion between on time delivery and Response time. on time delivery was found to be 90% and response time was found to be 10 days on time delivery has a degree 0.2 good and 0.8 very good and Response time had a degree 0.5 high and 0.5 very high. Table 5.12 shows Resp3 output

Table 5. 12:Associative matrix of On time delivery and Response time

On time Delivery/Response Time	Very low	Low	Medium	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	Poor	Very poor
Very Good	Very good	Good	Average	Poor	Very poor

Fuzzy rules that fired for resp3 output

1. If on time delivery is good and response time is high, then resp3 is poor
2. If on time delivery is good and response time is very high, then resp3 is poor
3. If on time delivery is very good and response time is high, then resp3 is poor
4. If on time delivery is very good and response time is very high, then resp3 is poor

The output of the fusion lies between linguistic variables poor and very poor. According to the output triangular membership function above the output for on time delivery and response time lie between 0% and 25% The output membership function. the chosen midpoints of 25

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an "and" operator is used, as shown in Table 5.13

Table 5. 13: The aggregation of the fired rules to get Resp3 output

AND	**Very Low=0.5**	**Low=0.5**
Good=0.2	0.2	0.2
Very Good=0,8	0.5	0.5

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp3 = (0.2*25+0.2*25+0.5*25+0.5*25)/ (0.2+0.2+0.5+0.5) =25%

Resp4: fusion between fill rate and shipping errors

Using data for case A as inputs in our framework, output was a fusion between fill rate and shipping errors, the second variable was not part of the framework but since fill rate was 50% similar to the one found in this research, it was assumed that shipping errors will also be 40% of the data found in this research.

The input values were based on the mean scores of each responsivess variables. Aggregation of all outputs based on the rules that fired. For Resp4 which was a fusion between Filtrate was found to be 60% and number of percentage of shipping errors was found to be 40%. Fill rate has a degree has a degree 0.6 average and 0.4 Good and shipping errors me had a degree 0.6 average and 0.4 good. Table 5.14 shows the output Resp4.

Table 5. 14: Associative matrix for fill rate and shipping errors

Fill rate/Percentage of shipping errors	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

Fuzzy rules that fired for resp4 output

1. If fill rate is average and % of shipping errors is poor, then resp4 is average
2. If fill rate is average and % of shipping errors is average, then resp4 is average
3. If fill rate is good and % of shipping errors is poor, then resp4 is good
4. If fill rate is good and % of shipping errors is average, then resp4 is average

The output of the fusion lies between linguistic variables poor and average According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an "and" operator is used, as shown in Table 5.15

Table 5. 15 :The aggregation output for Resp4

AND	**Poor =0.4**	**Average-0.6**
Average=0.6	0.4	0.6
Good=0.4	0.4	0.4

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Resp3 = (0.4*50+0.6*50+0.4*75+0.4*50)/ (0.4+0.6+0.4+0.4) =56%

Respfusion1: fusion between resp1 and resp2 outputs

The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Respfusion1 which was a fusion between Resp1 and Resp2. Resp1 was found to be 65% and Resp2 was found to be 52%. Resp1 had a membership degree of 0.6 good and 0.4 very good. While Resp2 had a degree of 0.92 average and 0.08 poor. Table 5.16 shows the output Respfusion1 based on the fired rules.

Table 5. 16 :Associative matrix for Resp1 and Resp2

Resp1/Resp2	**Very poor**	**poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	poor	Poor	Poor	Poor
Poor	Poor	poor	Poor	Poor	Poor
Average	Poor	poor	Average	Average	Average
Good	Poor	poor	Average	Good	Good
Very Good	Poor	poor	Average	Good	Very Good

Fuzzy rules that fired for respfusion1 output

1. If resp1 is good and resp2 is average, then respfusion1 is average
2. If resp1 is good and resp2 is good, then respfusion1 is good
3. If resp1 is very good and resp2 is average, then respfusion1 is average
4. If resp1 is very good and resp2 is good, then respfusion1 is good

The output of the fusion lies between linguistic variables average and good According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an "and" operator is used, as shown in Table 5.16

Table 5.16: The aggregation output of the fired rules using "And" operator

AND	Poor=0.08	Average=0.92
Good=0.6	0.08	0.6
Very good=0.4	0.08	0.08

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Respfusion2 = (0.08*50+0.6*75+0.08*50+0.08*75)/ (0.08+0.6+0.0.8+0.08) =70%

Respfusion1: fusion between resp3 and resp4 outputs

The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Respfusion1 which was a fusion between Resp3 and Resp4. Resp3 was found to be 25% and Resp2 was found to be 56%. Resp3 had a membership degree of 0.72 average and 0.26 good While Resp4 had a degree of 0.5 poor and 0.5 very poor. Table 5.17 shows an associative matrix that shows respfusion2 output based on the fired rules

Table 5. 17:Associative matrix for Resp3 and Resp4

Resp3/Resp4	Very poor	poor	Average	Good	Very Good
Very poor	Very poor	poor	Poor	POOR	Poor
Poor	Poor	Poor	Poor	POOR	Poor
Average	Poor	Poor	AVERAGE	average	Average
Good	Poor	Poor	AVERAGE	Good	Good
Very Good	Poor	Poor	average	Good	Very Good

Fuzzy rules that fired for respfusion2 output

1. If resp3 is average and resp4 is very poor, then respfusion2 is poor
2. If resp3 is average and resp4 is poor, then respfusion2 is poor
3. If resp3 is good and resp4 is poor, then respfusion1 is poor
4. If resp3 is good and resp4 is very poor, then respfusion3 is poor

The output of the fusion lies between linguistic variables average and good According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for average

Aggregation of the fuzzy rules:

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an "and" operator is used, as shown in Table 5.18

Table 5. 18 :Aggregation of Resp3 and Resp4 output based on fired rules

AND	**Poor =0.5**	**Very poor=0.5**
Average=0.72	0.5	0.5
Good=0.2	0.2	0.2

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Respfusion2 = (0.5*23+0.5*25+0.2*25+0.2*25)/ (0.5+0.5+0.3+0.3) =57%

Responsiveness fusion between respfusion1 and respfusion2 outputs

The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For Performance which was a fusion between Resfusion1 and Respfusion2. Respfusion1 was found to be 70% and Respfsuin2 was found to be 57%. both lie between average and good side of the output triangular membership function. Respfusion1 has a membership degree of 0.28 average and 0.72 good While resfusion2 had a degree of 0.3 average and 0.8 good. Table 5.19 shows the final responsiveness output based on the fired rules in an Associative matrix.

Table 5. 19 : Associative matrix for reliability and responsiveness

Responsiveness /Reliability	**Very poor**	**poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	poor	Poor	Poor	poor
Poor	Poor	poor	Poor	Poor	poor
Average	Poor	poor	Average	Average	average
Good	Poor	poor	Average	Good	good
Very Good	Poor	poor	Average	Good	Very Good

Fuzzy rules that fired for performance output

1.if responsiveness is average and reliability is average then performance is average

2. If responsiveness is average and reliability is good then performance is average

3. If responsiveness is good and reliability is average then performance is average

4. If responsiveness is good and reliability is good then performance is good

The output of the fusion lies between linguistic variables average and good According to the output triangular membership function above the output for on time delivery and response time lie between 50% and 75% The output membership function. the chosen midpoints are 50% for poor and 75% for

Aggregation of Fuzzy rules responsiveness output

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an AND operator is used, as shown in Table 5.20

Table 5. 20 :The aggregation of the fired rules for Respfusion1 and Respfusion2

AND	**Average=0.2**	**Good=0.8**
Average=0.28	0.28	0..72
Good=0.72	0.2	0.72

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Responsiveness = (0.28*50+0.72*50+0.2*50+0.72*75)/ (0.28+0.72+0.72+0.2) =60%

Responsiveness was found to be 60%. Although the framework did not include percentage shipping errors and probability out of stock which were all assumed. so it cannot serve to measure responsiveness of supply chain management because the two missing variables are very important for measuring of supply chain management. hence the validity of the fuzzy logic frame work developed in this research.

5.5.2: Supply Chain Reliability Framework validation

In his study Yousef Amer, proposed a model to evaluate perfect order fulfillment of a global retail firm. He used delivery time, correct quantity of orders and quality value is measured based on the defect rate of the delivered order quality. According to supply chain council (2010). Perfect order fulfillment is determined by correct time, quantity, product and condition. Yet this study did not include the last two hence invalid to measure reliability of supply chains. The input values were based on the mean scores of each responsivess variables.

Aggregation of all outputs based on the rules that fired. For rel1 which was a fusion between correct quantity and correct time. Correct quantity was found to be 54% and correct time was found to be 34%. Correct quantity has a degree of 0.84 average and 0.16 good while correct time has a degree of 0.64 poor and 0.36 very poor. The rules that fired based on the input data as a result of fusion between correct quantity and correct time is shown on table 5.21

Table 5. 21:Associative matrix for correct quantity and correct time

Correct quantity/correct time	**Very poor**	**Poor**	**Average**	**Good**	**Very Good**
Very poor	Very poor	Very poor	Poor	Poor	Poor
Poor	Very poor	Very poor	Poor	Poor	Poor
Average	Poor	Poor	Average	Average	Good
Good	Poor	Poor	Average	Good	Good
Very Good	Poor	Poor	Average	Good	Very Good

Fired fuzzy rules are: -

1. If correct quantity is average and correct time is very poor, then Rel1 is poor
2. If correct quantity is average and correct time is poor, then Rel1 is poor
3. If correct quantity is good and correct time is very poor, then Rel1 is poor
4. If correct quantity is good and correct time is poor, then Rel1 is poor

The output of correct quantity and correct time output lie between linguistic variables good and very good. According to the output triangular membership function above the output for correct quantity and correct time lie between 50% and 100%. The output membership function. the chosen midpoints are 75 for good and 87.5 for very good Fig. 5.10 shows Rel1 output membership function and the chosen mid-points.

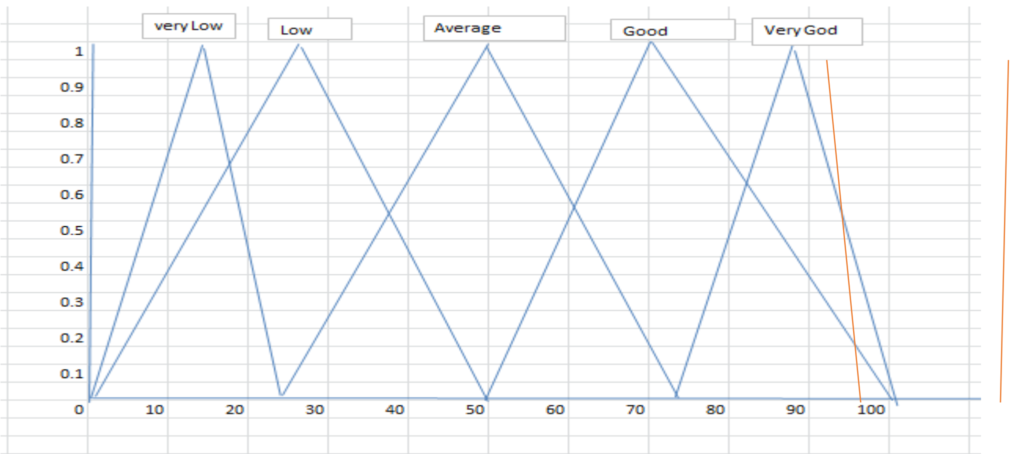

Figure 5 10: Rel1 output Membership Function

Aggregation of Fuzzy rules for Rel1 output

And, from the membership functions, we can calculate the truth value of each fuzzy proposition and of the fuzzy conjunction the minimum degree of membership is taken as the output when an “and” operator is used, as shown in Table 5.22

Table 5. 22 :The aggregation of the fired rules for reliability output

AND	**Poor=0.64**	**Very poor=0.36**
Average=0.84	0.64	0.36
Good=0.16	0.16	0.16

Using the weighted average formula Resp1 output each output membership degree will be multiplied by the midpoints of the linguistic output value area.

Reliability=
(0.64*25+0.36*25+0.16*25+0.16*25)/(0.64+0.36+0.16+0.16)=25%

Based on only Correct time and quantity reliability was found to be 25%.

5.6 Critique of the exiting frameworks

Supply chain management can be measured using reliability and responsiveness. The first framework attempted to measure quality of supply chain management. it used only six of the eight variables and hence cannot be used fully to measure responsiveness of supply chains. While the second framework only used two out of the four variables used in the framework of this research and hence cannot be used to measure reliability of supply chains. since the two are not valid for measuring reliability, and hence both the two did not qualify to measure the performance of supply chain management.

CHAPTER SIX

CONCLUSIONS AND FUTURE WORK

6.1 Introduction

In this study, a fuzzy system was implemented using fuzzy logic theory to obtain, supply chain performance output.

6.2 Implications of study

The findings of this study allow for the research to conclude, with certainty, the assertion that The design of the fuzzy logic model was more complex due to the high number of unique membership functions required to achieve the desired output.

6.3 Limitations of study

At this point, it may seem that fuzzy logic it is the answer to all performance management issues with the supply chains. This is not the case. Fuzzy logic can best be described as a convenient way to map an input space to an output space‖. Other than trying to understand the concepts of fuzzy theory, there is no one right way to develop a fuzzy system. However, for this particular study the drawback and limitations of the design can be described as follows:

Defining fuzzy sets and membership functions can be an extremely tedious task. It is normally performed by a collaborative effort of operators, process engineers and those who possess expert knowledge in the relevant process field. Even then, there is a reasonable chance of debate among each party when attempting to formulate the fuzzy sets and membership functions.

There is no one correct design procedure for developing a fuzzy system. Selecting a system type, Sugeno or Mamdani, comes down to the designer. Interpretation of and preference for a particular form of fuzzy theory.

6.4 Knowledge contribution

This research has generated a Fuzzy Logic Framework that allows managers to measure the performance of supply chain management, which allows them to introduce vagueness, uncertainty, and subjectivity into the performance measurement system. Since many models that exist measure the quantitative factors and very few measure qualitative factors covering only flexibility and delivery metric (one aspect of responsiveness). No framework has been developed to measure responsiveness and reliability. Using Fuzzy Logic concepts. Since the two metrics are most widely used for measuring supply chain performance there was an urgent need to a have an easy to use framework for measuring the two which in turn will also be measuring the management of Supply Chains.

6.5 Conclusions

The research work generated a simple to use framework that will allow managers to use Fuzzy Logic concepts instead of traditional mathematical model when measuring performance of supply chain management. It will allow the decision maker to introduce vagueness, uncertainty, and subjectivity into the performance measurement system. Most performance measurement variables are subjective and qualitative in nature and hence difficult to incorporate into quantitative models. This research provides a framework for incorporating such qualitative performance measures. It focused on responsiveness and reliability, which are very important measures of supply chain management performance.

6.6 Further Work

Integration of both quantitative and qualitative performance measurement Parameters into the framework as this will measure complete Supply Chain Management performance in all aspects including the financial ones. Automatic generation of fuzzy rules, fuzzy sets and their quantification thereby reducing the dependency on expert knowledge This would also offer a more accurate means of developing the membership functions associated with the process, as the data obtained would be analyzed by this system.

REFERENCES

Anwer, M.J. (2005). A Simple Technique for Generation and Minimization of Fuzzy Rules. *IEEE International Conference on Fuzzy Systems*, CD-ROM Memories, Nevada.

Aramyan, L.H., Oude Lansink, A.G., Vander Vorst, J.G., & Van Kooten, O. A.(2007). Performance measurement in Agri-food supply chains: a case study. Supply Chain Management: *An International Journal of Supply Chain Management*, *12*(4), 304-315.

Beamon, B. M. & Balcik, B.(2008) . Performance measurement in humanitarian relief chains. *International Journal of Public Sector Management*, *21*, 4-25.

Beamon, B.M. (1999). Measuring Supply Chain Performance, *International Journal of Operations and Production Management*, *19*(*3*), 275-292.

Bhagwat, R. & Sharma, M.K. (2007). Performance measurement of supply chain management: a balanced scorecard approach. *Journal of Computers and Industrial Engineering*, *53*(1), 43–62.

Bhagwat, R., & Sharma, M.K. (2007). Performance measurement of supply chain management using the analytical hierarchy process. *Journal of Production Planning and Control*, *18*(8), 666– 680.

Chan, F.T.S. (2003). Performance measuring in a supply chain. *International Journal of Manufacturing Technology*, *2*(1), 534-548.

Chaudhari1, O.K., Khot, P.G & Deshmukh, K.C. (2012). Soft Computing Model for Academic Performance of Teachers Using Fuzzy Logic. *British Journal of Applied Science & Technology*,*2*(2), 213-226.

Cooper, M. C., & Ellram, L. M. (1993). Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy. *The International Journal of Logistics Management*, *4*(2), 13-24.

Cox, E. (1994). The Fuzzy Systems Handbook: A Practitioner 's Guide to Building, Using and Maintaining Fuzzy Systems. London: Academic Press.

Deepak, K., Ramakrishna, H., & Jagadeesh, R. (2011). Assessment of Supply Chain Agility Using Fuzzy Logic For A Manufacturing Organization, *International Journal Of Software Engineering And Computing‖*, *3*(*1*), 25-29.

Ezutah, U.O., & Kuan, Y.W. (2010). Supply Chain Performance Evaluation and Challenges. *American Journal of Engineering and Applied Sciences*: 2 (*1*), 202-211.

Fawcett, S., E. (2008). Benefits, barriers, and bridges to effective supply chain management. Supply Chain Management: An International Journal, *13*(1), 35-48.

Finch, P. (2006). Supply chain risk management, Supply Chain Management. *An International Journal*, *9*(2), 183 – 196.

Foundations of Fuzzy Logic, (2014). Retrieved from http://www.mathworks.com/help/fuzzy/foundations-of-fuzzy-logic.html

Frohlich, M., & Westbrook, R. (2001). Arcs of integration: an international study of supply chain strategies. *Journal of Operations Management*, *19* (*2*), 185–200.

Fundamentals of Logic Concepts (2011). Retrieved from http://ptgmedia.pearsoncmg.com/images/0135705991/samplechapter/0135705991.pdf

Gopal, P.R.C., & Jitesh, S. (2013). Designing and Managing supply chains. *International Journal of Productivity and Performance Management, 6*(3), 293-316, 1741-0401.

Grossmann, I. E. (2005). ―Enterprise-wide Optimization: A New Frontier in Process Systems Engineering‖, *AICHE Journal*, *51*, 1846-1857

Gunasekaran, A., Patel, C., and Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations and Production Management*, *21*(2), 71-87.

Hamidreza, P., Rosnah, Y., Tang, S. H., & Seyed, M. H. (2010) Qualitative performance measurement of supply chain management using fuzzy logic controller. Paper presented at 11th Asia Pacific Industrial Engineering and Management System. Malaysia.

Hausman, W.H. (2005). Supply chain performance metrics. The practice of supply chain management: where theory and application coverage (p. 356). New York: Springer.

Hines, P. (1994). Lean logistics. *International Journal of Physical Distribution & Logistics Management, 27*(*3-4*), 153-71.

Hoffman, D. (2002). ―Supply Chain Excellence: All Roads Lead to The Perfect Order,‖ AMR Research Report Retrieved from http://cdcsoftware.com/download/whitepaper/b6.pdf

Huang, G.Q., Lau, J.S.K., & Mak, K.L. (2003). The impact of sharing production information on supply chain dynamics: A review of literature. *International Journal of Production*. *41*(*7*), 1483-1517.

Hung, P., & Browne, J. (2005). A review of performance measurement: Towards performance management. *Computers in Industry, 56*(2), 663–680.

Jamshidi, M. (1997). *Fuzzy Control Systems*. Springer-Verlag, chapter of Soft Computing, pp.42–56.

Jugendra, D., Prajapati, G.L., & Tokekar, S.,V.(2012). Designing and Managing the Supply Chain using Fuzzy Logic Approach. *IJCA Special Issue on Issues and Challenges in Networking, Intelligence and Computing Technologies* ICNICT (5), 4-7, New York: Foundation of Computer Science.

Kaplan, R.S., & Norton, D.P. (1992). The balanced scorecard – measures that drive performance. *Harvard Business Review*, *70* (1), 71-79.

Klawonn, F., Höppner, F. (2003). What is Fuzzy About Fuzzy Clustering? – Understanding and Improving the Concept of the Fuzzifier. In: M.R. Berthold, (Eds.),Advances in Intelligent Data Analysis(pp254-264). Berlin: Springer.

Ledeneva, Y., & Reyes, G, C. A. (2006b). Automatic Estimation of Fusion Method Parameters to Reduce Rule Base of Fuzzy Control Complex Systems. In: *Gelbukh A., (Eds.): MICAI*, LNAI 4293, (pp. 146-155). Ledeneva, Y., Berlin Heidelberg: Springer.

Manoj, H.(2012). Issues and Challenges in Networking, Intelligence and Computing Technologies. *International Journal of Computer Applications 4(*2*).*

McIntyre, L.J. (2003). The practical skeptic: Core concepts in sociology. Mountain View, CA: Mayfield Publishing.

Mehrdad, M., & Abbas N. A. (2011). Supplier Performance Evaluation Based On Fuzzy Logic. *International Journal of Applied Science and Technology*, *1(*5*), 257* -265.

Mentzer, J.T. (2007). Fundamentals of supply chain management: twelve drivers of competitive advantage. California: Sage Publication Inc.

Mentzer, J.T., DeWitt, W., Keebler J.S., Min, S., Nix, N.W., Smith, C.D., & Zachariah, Z.G. (2001). Defining supply chain management. *Journal of Business Logistics*, *22*(2), 1-25.

Mentzer, J.T., Meyers, M.B. & Stank, T.P. (2007). Handbook of Global Supply Chain Management. California: Sage Publications Inc.

Morgan, C. (2004). Structure, speed and salience: performance measurement in the supply chain. *Business Process Management Journal, 10*(5), 522-536.

Mugenda, O. and Mugenda, A. (Ed.). (2003). Research Methods: quantitative and qualitative approaches. Nairobi: ACTS press.

Nakhai, K., Bayat, A., Ahmadi, P., Ebrahimi, A. & Safari, K.M. (2008). Presentation a New Algorithm for Performance Measurement. Of Supply Chain by Using FMADM Approach. *World Applied Sciences Journal 5* (5), 582-589.

Neely, A. (2008). The evolution of performance measurement research. *International Journal of Operations and Production Management*, *1*(2), 1264-1277.

Neely, A., Gregory, M. & Platts, K. (2008). Performance measurement system design: A literature review and research agenda. *International Journal of Operational and Production. Management*, *25*(2), 1228-1263.

Nomesh, B., Pranav, S., & Jalaj, B. (2012). Quantification of agility of a Supply Chain using Fuzzy Logic. *American Journal of Engineering and Applied Sciences*: *2* (2), 100-106.

Novak, V., Perfilieva, I., and Mockor, J. (2000), *Mathematical principles of fuzzy logic*, Dordrecht: Kluwer.

Patidev, D. & Sohani, N. (2013). Green Supply Chain Management: A Hierarchical Framework for Barriers. International Journal of Engineering Trends and Technology *4*(5),21-72.

Pinsonneault, A. & Kraemer, K. L. (1993). Survey research methodology in management information systems: An assessment. *Journal of Management Information Systems, 10*(2),75105.

Preece, J., Rogers, Y., & Sharp, H. (2002) Interaction design: Beyond human-computer Interaction. New York: John Wiley & Sons, Inc.

Pyke, D.F. & Cohen, M.A. (1994). Multi-product integrated production-distribution systems. *European Journal of Operational Research, 74,* 18-49

Pyke, D.F. & Cohen, M.A. (1994). Multi-product integrated production-distribution systems

Raju, G.V.S., & Zhou, J. (1993). Hierchical Fuzzy control. Man and cybernetics. *IEEE Transactions on systems 23*(4), 973-980

Salant, P. & Dillman, D.A. (1994). How to Conduct Your Own Survey. New York, NY: John Wiley & Sons, Inc.

Sánchez, A. & Pérez, M. (2005). Supply Chain Flexibility and Firm Performance: A Conceptual Model and Empirical Study in the Automotive Industry. *International Journal of Operations & Production Management*, 25, 7-8.

Sánchez, A., & M. Pérez, (2005). Supply Chain Flexibility and Firm Performance: A Conceptual Model and Empirical Study in the Automotive Industry. *International Journal of Operations & Production Management*, 25, 7-8.

Schulz, S. F. & Heigh, I. (2009). Logistics performance management in action within a humanitarian Organization. *Management Research News*, *32*, 1038-1049.

Semerci, C. (2004).. The Influence of Fuzzy Logic Theory On Students ‘Achievement. *The Turkish Online Journal of Educational Technology*, *3* (2), 9-11.

Shirouyehzad, H., Panjehfouladgaran, R., & Badakhshian, M. (2011). Vendor performance management using Fuzzy logic controller. The Journal of Mathematics and Computer Science,.*2*(12), 311-318.

Sirigiri, P., Gangadhar, P.V. & Kajal. K.G. (2012). Evaluation of teacher ‘s performance using Fuzzy Logic Techniques. *International Journal of Computer Trends and Technology, 3(*2*),* 200-210.

Sirigiri, S. J. & Mudholkar, R.R. (2013). International Journal of Soft Computing and Engineering, *3*(2), 306-320.

Smolová, J. & Pech, M. (2011). Dynamic supply chain modeling using a new fuzzy hybrid negotiation mechanism," International Journal of Production Economics, *59*(1-3) ,443-453

Sobańska, I. R. (2010). Podejście Operacyjne i Strategiczne. Warszawa: C.H. Beck.

Stadtler, H. (2005). Supply chain management and advanced planning- basics, overview and challenges. *European Journal of Operations Research, 163*(3), 575-588.

Stadtler, H., Kilger, C., (2005). Supply chain Management and advance planning‖. (3rd ed.). Berlin, Germany: Springer.

Supply Chain Council, Inc. (2010). Supply Chain Operations Reference (SCOR) mode. Overview - Version 10.0.

Tan, K.C., Kannan, V.R., & Handfield, R.B. (1998). Supply chain management: Supplier performance and firm performance. *International Journal of Purchasing and Materials Management, 34* (3), 2-9.

Thorelli, H.B. (1986). Networks: Between markets and hierarchies. *Journal of performance in transport logistics, 38*(3), 439-456.

Unahabhokha, C., Platts, K. &HuaTan, K. (2007). Predictive performance measurement system: A fuzzy expert system approach. Benchmarking: *An International Journal, 14*(1), 77-79.

Vollman, T. E., Berry, W. L. & Whybark, D. C. (1997), Manufacturing Planning and Control Systems. Canada: Irwin Publishers.

Waters-Fuller, N. (1995). JIT purchasing and supply: a review of the literature. *International Journal of Operations & Production Management, 15*(9), 220-36.

Yates, D. S., David. S. M., & Daren, S. S. (2008). The Practice of Statistics, (3rd ed.).N.Y: Freeman.

Ying, B., Hanqi, Z., & Zvi, S. R. (2005), Fuzzy Logic Control to Suppress Noises and Coupling Effects in a Laser Tracking System‖, *IEEE Trans on Control Systems Technology*, *13*(1),113-121.

Zadeh, L.A. (1976). Fuzzy set as a basis for theory of possibility. *Fuzzy Sets Systems*, *1*(2), 3-28.

Zadeh, L. A., (1983). A computational approach to fuzzy quantifiers in natural language. *Computers and Mathematics with Applications*; *9*(1), 149–84.

Zadeh, L.A. (1998). Maximizing sets and fuzzy mark of algorithms. *IEEE Transactions on Systems Man and Cybernetics, 28* (1), 9-15.

Zadeh, L. A. (1999). Some reflections on the anniversary of Fuzzy sets and systems. Journal of Fuzzy sets and systems, *100*(2), 1-3.

Zhang, L.A. & Xu, C. (2009). Supply chain coordination of loss-averse newsvendor with contract. Journal of *Tsinghua Science and Technology*, *10*(2), 133-140

APPENDICES

Appendix 1: Introduction Letter

Jomo Kenyatta University of Agriculture and Technology

Institute Of Computer Science and Information Technology

P.O BOX 62000 NAIROBI 00200

Amina Saleh Omar,

P.O Box 87160,

Mombasa.

Dear Mr./Mrs./Miss,

Re: Request To Participate in MSc. Research Questionnaire

I am an M.Sc. Computer Systems student in department of computing at the institute of computer science and information technology. I am currently doing a project entitled Qualitative performance measurement of supply chain management using fuzzy Logic.

Today's marketplace is shifting from individual company performance to supply chain performance: the entire chain's ability to meet end-customer needs. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions All the Supply Chain performance measures can be divided into two major groups qualitative and quantitative. In recent years many methodologies have been developed in terms of quantitative measures but most of them merely focus on the control mechanism based on reported measures whereas the qualitative aspect of the work is still unexplored. Measuring qualitative factors is not easy because they are not representing numerically and the subjective nature of such measures, makes it difficult to incorporate into quantitative models. Fuzzy logic enables a person to model the uncertainty within the subjective formulation of knowledge or opinions.

It is therefore important to develop a framework that can be used in measuring the qualitative factors in supply chain management using fuzzy logic.

I will be glad if you would assist me to research on this by filling in the questionnaire, which hopefully should take you less than 10 minutes. I wish to particularly obtain your response with regard to experience and some methodologies you have applied in Supply chain performance management I will be glad if you will complete and return the questionnaire by 20th October 2014.

Kind feel free to forward any comments that relates to this study. The information obtained will be used purely for academic purpose and treated with utmost confidentiality.

Thank you for your time and cooperation

Amina Saleh Omar-**CS382-C005-1971/2011**

amina_bameda@yahoo.com

Appendix 2: Questionnaires

Qualitative Performance measurement of supply Chain Management Questionnaire

1. **Preface;** This questionnaire will help in collecting data for use in writing the Thesis on qualitative performance measurement for supply chains in Kenya and to develop a framework to be used for evaluating supply chains using fuzzy logic
2. **Introduction**

This questionnaire is intended to collect data on qualitative aspects of performance measurement of supply chain management. This data will be used to write a thesis paper that aims at researching qualitative performance measurement of Supply chain management in Kenya Today. The information collected in this questionnaire will be treated as confidential as possible and would not be used for any other purposes other than intended work in the thesis. I will greatly appreciate if you take 5-6 minutes to fill in the Questionnaire.

This questionnaire is divided into **TWO Sections** each to be filled appropriately.

1. ***General Section***: This section intends to collect general information on respondents and the companies' frameworks for measuring supply chains performance by ticking on appropriate options provided.

2. ***Qualitative performance measurement Section***: This section intends to collect data specifically on qualitative performance measurement with regard to enlisted qualitative factors. Answer all the questions according to your knowledge, skills and position within your organization. The questionnaire aims to check up the performance measurement of your Supply chain within your organization pointing out different viewpoints.

2. Remark.

As a student undertaking an Msc Program in JKUAT, This questionnaire is NOT to assess people and their work or knowledge. The questionnaire aims only to collect data and assess performance of Supply Chains within organizations in Kenya. And using the data write a Thesis for award of Msc computer systems, Feel free to respond to it. In case of clarification or any correspondences you can contact us through email using the following emails address: amina_bameda@yahoo.com

Thank you for your patience

SECTION ONE

GENERAL SECTION (Tick Appropriately)

Respondent : Procurement Officers/Managers /Stores Managers

1. Type of industry your organization operates in :

Name of industry	(please tick here)
Automotive	
Computer	
Household	
Electronics	
furniture	
Medical	
Metal and Mining	
Sports and Leisure	
Textile	
Pharmaceuticals	

Other(specify)	

2. How many years has your company been operating in this business:
   a) Below 1 year
   b) 1-3 years
   c) 3-5 years
   d) 5 and Above

3. How many Years have you been in your position:

   a)Below 1 year
   b)1-3 years
   c)3-5 years
   d)5 and Above

4. Have you developed any framework for performance measurement of your supply chain:

   a)None
   b)1-5
   c)5-10
   d)Above 10

4. Do you have any formal training in performance measurement of supply chain management?

Yes No N/A

5. Are your familiar with any performance measurement framework of supply chain management

   Yes No N/A

Activity Based costing Economic value analysis

Data environmental analysis SCOR model OTHER

If Other Specify…………………….

6. Are you familiar with any performance measurement factors of supply chains

Yes No N/A

If Yes select the most appropriate options for your firm

Responsiveness Flexibility Reliability cost

Asset Management

7. Do you measure any of the qualitative factors presented above

Yes No N/A

8. To what extent do the following qualitative performance measurement metrics affect your supply chain performance?

Use the following scale:

1-Very Low Extent

2-Low Extent

3- Moderate Extent

4-High Extent

5-Very High Extent

Supply Chain Responsiveness	1	2	3	4	

Rate of customer complaints Customer response time Lead time On-time delivery Fill rate Shipping Errors					
Perfect order fulfillment (rate the following aspects):	1	2	3	4	5
Correct product delivery Correct location Correct time Correct quantity Correct condition and packaging Correct customer Correct documentation					

Any other(please specify)

____

____

SECTION TWO

This section investigates the actual performance measurement qualitative factors which are responsiveness and reliability. Tick the most appropriate option Applicable to you.

RESPONDENT: Procurement Manager/Procurement Officer/Stores Manager

SUPPLY CHAIN RESPONSIVENES: This refers to the speed at which a Supply Chain provides products to the customer. The metrics are Lead time, Response time, no of customer complaints, on-time delivery, percentage out of stock and accuracy.

	Less than 1 day	**1 to 3 days**	**3 days**	**3 to 5 days**	**more than 5 days**
Lead time(in days)					

	Less than 2 days	**2 to 6 days**	**6 to 10 days**	**10 to 12 days**	**more than 12 days**

Customer response time: (in days)					

	Less than 5	**5 to 30**	**30 to 45**	**45 to 60**	**more than 60**
Number of customer complaints: (in numbers)					
Other(specify)					
	Less than 20%	**20% to 40%**	**40% to 60%**	**60% to 80%**	**80% to 100%**
on time delivery:					
Fill rate(%):					

Shipping errors(%):					
Percentage out of stock(%):					
Accuracy(%):					
Others(specify)					

SUPPLY CHAIN RELIABILTY

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. Perfect order fulfillment refers to Percentage of purchase order items where the following corresponds exactly to the request made.it is measured in percentage.

Perfect order fulfillment metrics		**0 to 20%**	**20% to 40%**	**40% to 60%**	**60% to 80%**	**80% to 100%**
Correct product delivery						
Correct location						
Correct time						
Correct quantity						
Correct condition and packaging						

Correct customer						
Correct documentation						
Other(specify)						

THANK YOU VERY MUCH FOR YOUR TIME.

Parameters explanation:

.Factor	Definition
Customer Complaints	The number of customer complaints registered
Customer Response Time	The amount of time between an order and its corresponding delivery.
Lead Time	The time required once the product began its manufacture until the item is completely processed.
On Time Delivery	The percentage of orders delivered on or before the due date

Fill Rate	The proportion of orders that can be filled immediately
Shipping errors	The number of errors that occurred during shipment of products
Perfect order fulfillment	The percentage of orders delivered to the right place, with the right product, at the right time, in the right condition, in the right package, in the right quantity, with the right documentation, to the right customer, with the correct invoice