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EVALUATING CUSTOMER SATISFACTION IN SUPPLY CHAIN

A Thesis in

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by

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ABSTRACT

In the literature many aspects of supply chain are analyzed and studied for improvement. The element that has been examined the least is customer satisfaction as it relates to supply chain. Customer satisfaction is necessary for the success of any company. Thus understanding the factors of a supply chain which affect customer satisfaction is most important. The purpose of this research is to identify the common factors in a supply chain which directly and indirectly relate to customer satisfaction, identify the degree to which each affects customer satisfaction and develop a methodology to determine the customer satisfaction level of a supply chain. With the use of fuzzy set theory, a methodology to measure the customer satisfaction level is developed. This methodology is demonstrated with an actual case study. By identifying the factors that influence customer satisfaction, a company can focus on improving specific areas. The methodology will allow them to evaluate the performance of the company by improving their customer satisfaction level.

Keywords: Supply Chain, Customer Satisfaction, Fuzzy Set Theory

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Chapter 1

Introduction

In today's world, efficiency is most important. This is especially true when dealing with a supply chain. In order to achieve that efficiency, many aspects of a supply chain are considered such as inventory, production and transportation. When looking into improving a supply chain, companies focus on the three levels of activities of Supply Chain Management processes, strategic, tactical and operational planning. At the *strategic* level, decisions concerning the whole organization are considered. They involve the size and location of the company's sites, the supplier selection, the products to be manufactured and the markets to be targeted. At the *tactical* level, decisions on measures that will produce cost benefits are focused on. Transportation routes and methods, as well as warehouse strategies are some of those decisions. The *operational* decisions are mostly related to the day to day activities of the company such as processing customer orders and scheduling production (Ravindran & Warsing, 2013).

In general, the supply chain activities that companies strive to improve involve the flow of products, information and funds among customers, retailers, wholesalers/distributors, manufacturers and suppliers. A lot of work in the literature can be found involving wholesalers/distributors, manufacturers and suppliers. Academics have looked into supplier selection methods, production scheduling activities of the manufacturers and inventory control and transportation of goods for wholesalers and manufacturers. Outside of customer service practices, not much can be found in the literature regarding the activities related to retailers and customers. This might be due to the fact that customers and their demands vary greatly depending on the supply chain. Thus similarities in customer needs have not been extensively considered.

Supply chain responsiveness is a topic that has been discussed in the literature. According to Ravindran and Warsing (2013), supply chain responsiveness refers to the extent to which customer needs and expectations are met, and the extent to which the supply chain can flexibly accommodate changes in these needs and expectations. Another definition of supply chain responsiveness is the ability of a supply chain to respond to large order quantities, handle a large variety of products, meet short lead times, build highly innovative products, meet a high service level and handle supply chain uncertainty (Chopra & Meindl, 2009). Both definitions provide the understanding that the supply chain caters primarily to the needs of the customer. Consequently, responsiveness is a factor that customers are interested in when evaluating a supply chain. The one drawback is the necessary trade-off that exists between responsiveness and efficiency. According to Chopra and Meindl (2009), supply chain efficiency is the inverse of the cost of making and delivering a product to the customer. Thus, the higher the efficiency, the lower the cost. Unfortunately, a supply chain can only increase its cost and become less efficient to improve its responsiveness. Customer satisfaction, which is the main focus of this thesis, includes supply chain responsiveness as a factor. Customers are also interested in supply chain efficiency, which implies a lower cost for products. Thus customer satisfaction encompasses both supply chain efficiency and responsiveness.

1.1 Motivation of the Thesis

A customer starts the chain of events within a supply chain when the customer decides to purchase a product offered for sale by a company. According to Chopra and Meindl (2009), "a supply chain consists of all parties involved in, directly or indirectly, in fulfilling a customer request". Therefore, the customer is the most important element of a supply chain. In order for a company to be successful, it needs to maintain a high level of customer satisfaction. To do so, the

company must be aware of its customers' needs. The company should be capable of providing products and services, while being able to accurately predict customer wants and needs. By having the foresight of customers' actions, the company is able to plan more efficiently. Additionally business decisions that are favorable to the company can be made. Scott Gross, the author of "*When Customers Talk*" mentioned that "Service happens on the inside, and everyone is a player" (Gross & BIGresearch, 2005). By this comment, he meant that customers significantly influence the quality of services they receive. He also meant that every little detail should be considered when trying to satisfy customers. Thus, actions taken to improve various elements of a supply chain do have an effect on customers and ultimately on how they perceive the company.

Customer satisfaction is vital for a company to succeed. Therefore a company must be aware of the direct and indirect factors influencing customer satisfaction. Each company has specific factors which will be unique to its own products and services. Universal factors influencing customer satisfaction also exist across all supply chains. In order to monitor their progress in the domain, companies also need to be able to measure customer satisfaction. Service level and fill rate are terms that have been used in the literature for trying to maintain a certain level of customer service when planning inventory levels and production schedules among others.

Factors within a supply chain that affect customer satisfaction need to be identified. Associated metrics which will help measure customer satisfaction also need to be established. Since a certain amount of uncertainty and vagueness is to be expected when it comes to customer satisfaction, fuzzy set theory, a tool capable of handling uncertainty and vagueness in terms, is proposed as a suitable method to deal with the vagueness of some of the factors influencing customer satisfaction.

1.2 Objectives

The purpose of this research is to analyze and evaluate customer satisfaction as it relates to the elements of supply chain. The first goal is to identify the factors which directly or indirectly relate to customer satisfaction. The second goal is to identify the extent or degree to which each factor affects customer satisfaction. The final goal of this research is to create a methodology which will help measure customer satisfaction based on the factors identified.

1.3 Organization of the Thesis

The second chapter of this thesis constitutes a literature review of topics, such as supply chain management, customer satisfaction and fuzzy logic. Additionally, previous work on the evaluation of customer satisfaction will also be discussed. Chapter 3 of the thesis describes the methodology that will be used to ultimately measure the customer satisfaction level. An illustrative example of the methodology is also provided in chapter 3. This example will demonstrate the application of the methodology when all the data is available. Chapter 4 of the thesis evaluates the customer satisfaction level of a real company's supply chain. Company data will be used to demonstrate the application of the methodology to a real supply chain by sharing some of their performance measure data for the year 2012. The final chapter concludes the thesis by recapitulating the motivation, goals and application of the work. Future research on this matter will be discussed as well.

Chapter 2

Literature Review

As mentioned earlier, customer satisfaction is necessary for a company's success and is directly tied to profitability. Happy customers tend to be loyal. If they are loyal, they buy more products and even refer other customers. In order to ensure the happiness of its customers, a company has to determine the customer's needs and do everything in its power to provide for these needs. The first step in the process of establishing a means to provide satisfaction to customers is to thoroughly understand the customer's needs.

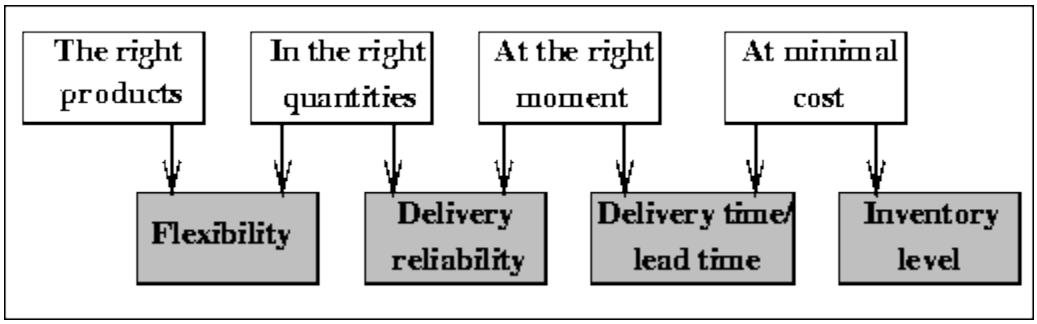
This chapter will first provide an overview of supply chain management followed by customer satisfaction. A discussion of methods utilized to identify customers' needs will be presented followed by a discussion of various factors affecting customer satisfaction. Unfortunately, an investigation involving actual supply chain customers for the discovery of those factors was not undertaken in this study. All factors presented will be taken from the literature and will be based on previous academic research. The fuzzy logic concept along with some of its applications will be explained and discussed. Finally, previous literature on the calculation of customer satisfaction in supply chain will be presented.

2.1 Supply Chain Management

In order to understand the link between customer satisfaction and supply chain management, one needs to understand the goal of supply chain management. Based on definitions collected from the literature (Teigen & EIL, University of Torronto, 1997; Simchi-Levi, et al., 2002; Abdolvand & Bahrami, 2011; Partridge, 2013; Ravindran & Warsing, 2013), supply chain

management is a set of approaches used to efficiently intergrate the diverse stages of a supply chain with a minimum cost while maintaining customer satisfaction.

Simchi-Levi *et al.* and Partridge's definitions both point out that a system wide approach is to be taken when dealing with satisfying a given customer satisfaction level. Partridge refers to it as a "cradle-to-grave" approach to customer service, which means from the beginning to the end of the supply chain. His reasonning is that "Because supply chains are interconnected at every level, bad service at one link will ricochet throughout the chain, ultimately impacting the end user" (Partridge, 2013). From Simchi-Levi *et al.*'s definition, the two key elements of supply chain management are cost and service level (Simchi-Levi, et al., 2002). Abdolvand and Bahrami focused on inventory, transaction speed and customer needs (Abdolvand & Bahrami, 2011). Ravindran and Warsing (2013) focused on supply chain engineering which encompasses key activities for the effective management of a supply chain. They stressed that the important distinction "between supply chain engineering (SCE) and suppply chain management is the emphasis in SCE on the design of the supply chain network and the use of mathematical models and methods to determine the optimal strategies for managing the supply chain (Ravindran & Warsing, 2013). From Teigen's definition of supply chain management, four main areas of concern were identified (Figure 2-1). "*Delivery reliability* and *delivery times* are both aspects of customer service, which is highly dependent on *flexibility* and *inventory*" (Teigen & EIL, University of Torronto, 1997). Thus, customer satisfaction, inventory and flexibility are key terms within supply chain.



(Teigen & EIL, University of Torronto, 1997)

Figure 2-1: Hierarchy of Objectives

2.2 Customer Satisfaction

Customer satisfaction depends on the customers themselves and on what they defined as quality, whether it is product or service quality. Berry *et al.* (1994) defined quality as "conformance to the customer's specification". Understanding what is meant by customer satisfaction might give valuable insight on what customer expectations actually are. There are many definitions for customer satisfaction. All definitions point to the fact that customer satisfaction is subjective.

Barve's definition (Barve, 2011) is the following: "Customer satisfaction is the customer's reaction to the value received from the purchase or utilization of the offering. Customer satisfaction represents the customer's reaction to his or her perception of the value received as a result of using a particular product or service. That reaction will be influenced by the desired value (ideal standard) as well as by the perceived value of competitive offerings (industry norms, expectations based on use of competitor products)". Abdolvand and Bahrami (2011) in turn define customer satisfaction as: "The constant comparisons made between the actual performance and expected performance of the customer". According to Ravindran (2013), a customer is satisfied when "perception exceeds expectations". Additionally, improving

customer's perception of performance or decreasing customer's expectations can lead to an increase in customer satisfaction.

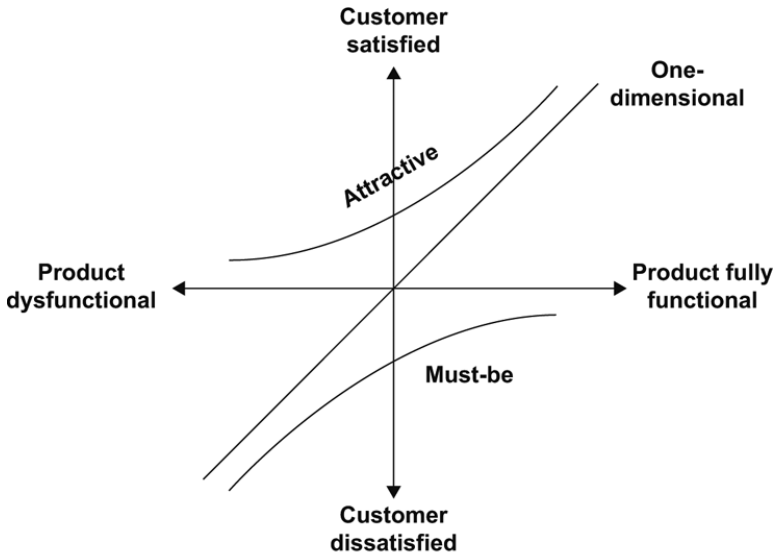
All of these definitions suggest that a customer's satisfaction is based on what he or she received in relation to what was expected. The expectations of the customers are influenced by many factors including company and competitor advertisements.

Customer satisfaction should not be confused with customer value. "Customer value is the measure of a company's contribution to its customer, based on the entire range of products, services, and intangibles that constitute the company's offerings" (Simchi-Levi, et al., 2002). Customer value will not be assessed in this study but it will be used to assess customer satisfaction. Lalpanmawia (2012) defined customer value as "the way the customer perceives the entire company's offerings". Since customer perception must be known to accurately measure customer satisfaction, customer value will be used to accurately calculate customer satisfaction. Customer perception encompasses several dimensions which are: *Conformance to Requirements*, *Product Selection*, *Price and Brand*, *Value-added Services* and *Relationships and Experiences* (Lalpanmawia, 2012).

2.2.1 Kano Model

In the business world, The Kano Model has been considered an important customer satisfaction reference for many. The Kano Model was first developed by Dr. Noriaki Kano, a Japanese professor and international consultant. According to Sauerwein *et al*. (1996), Kano distinguishes between three types of product requirements which influence customer satisfaction (Figure 2-2). The first requirement type is *Must-be requirements*. These requirements must be fulfilled or the customer will be extremely dissatisfied. Their fulfillment on the other hand will not increase customer satisfaction. Because must-be requirements are considered basic product

criteria, they are expected to be fulfilled without explicitly being asked to be fulfilled by the customer. The second requirement type is *One-dimensional requirements*. As fulfillment level increases, customer satisfaction will also increase. Customer satisfaction is "proportional to the level of fulfillment" (Sauerwein, et al., 1996). One-dimensional requirements are usually explicitly demanded by the customer. The third requirement type is *Attractive requirements.* These requirements are the product criteria which have the greatest influence on customer satisfaction. As can be seen in Figure 2-2, fulfilling attractive requirements leads to a more than proportional satisfaction. Customers will not explicitly ask for the fulfillment of attractive requirements.



Source: Kano *et al.* (1984)

Figure 2-2: The Kano Model

In the article "*Kano Model: Recent development*", Zultner and Mazur (2006) describe the Kano Model requirements in more detail. They identified three additional requirement in addition to the 'must-be' (expected), 'one-dimensional' (desired) and 'attractive' (exciting) requirements. The term '*indifferent*' is used to identify requirements that customers do not care about. The term '*reverse*' is used for a requirement that customers would prefer not to have. It is also possible to

have a '*skeptical*' category which refers to a requirement for which the customer's responses are unknown. Figure A-1 in Appendix A shows all six types of requirement.

According to Sauerwein *et al.* (1996), the advantages of classifying customer requirements with the Kano method are:

- Priorities for product development
- Better understanding of product requirements
- Optimal combination with quality function deployment
- Help with trade-off situations in the product development stage
- A wide range of possibilities for differentiation when discovering and fulfilling attractive requirements

Although the Kano model refers to requirement types for products, the model will be used in this work to classify the measures for the different factors influencing customer satisfaction. Additionally, understanding product requirements and being able to differentiate oneself among others are benefits that will help a company increase its customer satisfaction. Conklin *et al.* (2004) also made reference to the Kano model when identifying key drivers on the data of a service sold at a retail store. They referred to must-be attributes as key dissatisfiers and pointed out the necessity of identifying them. This necessity is due to the fact that "failure on any key attribute results in failure overall" (Conklin, et al., 2004). When using the Kano method, the best strategy that will lead to a high level of customer satisfaction is to "fulfill all must-be requirements, be competitive with regard to one-dimensional requirements and stand out from the rest with regards to attractive requirements" (Sauerwein, et al., 1996).

2.2.2 Identifying Requirements

Different methods can be used to identify the requirements or drivers of customer satisfaction. The first step in identifying the requirements or drivers of customer satisfaction is collecting all attributes affecting satisfaction. This first step is always the same regardless of the particular application. It involves interviews or surveys of the customers in order to gain a list of attributes the customer feels affects their feelings towards a product or service. Zutner and Mazur (2006), Johnston (1995) and Conklin *et al.* (2004) all used different methods of interviews to collect the attributes. Zutner and Mazur (2006) interviewed their customers. Johnston (1995) used a version of the critical incident technique (CIT) to collect views of customers on different services provided. He states "It must also be recognized that CIT collects only extreme views and may not gather service quality "incidents" close to, or within, the zone of tolerance". The zone of tolerance is a range of performance that customers consider satisfactory. Any increase in this range results in a negligible change in perception. Conklin *et al.* (2004) use data on a real service that is sold in a retail outlet. Gunasekaran *et al.* (2004) agree on the importance of survey rating on the level of customer perceived value of product. In this research, this step will be done by collecting various drivers or performance measures relating to customer satisfaction in the literature. Additional drivers unique to the company might be collected from the company.

The second step of identifying the type of the requirement or driver was carried out differently in all three papers mentioned. The Kano questionnaire, used by Zutner and Mazur (2006) uses the Kano evaluation table to classify a requirement. For each requirement, a pair of questions is asked to which the customer can answer in one of five ways: *like, must-be, neutral, live with, dislike*. The first question concerns the reaction of the customer to the product having (functional) a feature or requirement. The second question concerns the customer's reaction to the product not having (dysfunctional) a requirement. The table in Zutner and Mazur's paper (2006)

is an abbreviated version of the actual Kano evaluation table (Table 2-1) presented by Sauerwein *et al.* (1996).

Table 2-1: Kano Evaluation Table

Customer Requirements → / ↓		Dysfunctional 1. like	2. must-be	3. neutral	4. live with	5. dislike
Functional	1. like	Q	A	A	A	O
	2. must-be	R	I	I	I	M
	3. neutral	R	I	I	I	M
	4. live with	R	I	I	I	M
	5. dislike	R	R	R	R	Q

Customer Requirement is:

A: Attractive
M: Must-be
R: Reverse
O: One-dimensional
Q: Questionable result
I: Indifferent

(Sauerwein, et al., 1996)

Johnston (1995), who investigated determinants of service quality, used the frequency of mention of each determinant, both satisfying and dissatisfying, to detect the dominant determinants. The paper by Conklin *et al.* (2004) illustrates the use of the Shapley value, from cooperative game theory, to identify first the key dissatisfiers, enhancers and to determine their share on the overall customer dissatisfaction or satisfaction measure. The key drivers are identified using their Shapley value. The higher the Shapley value, the larger the overlap between failures on this attribute and dissatisfied values overall. Enhancers are requirements that can lead to the delight of a customer. Conklin *et al.* point out the difficulty of using standard linear modeling techniques to identify must-be attributes due to the non-linear relationship between these attributes and overall customer satisfaction. Additionally, it is also "more difficult to

identify good enhancers than dissatisfiers because customer satisfaction research tends to focus on processes that are key components of the service" (Conklin, et al., 2004).

2.3 Drivers of Customer Satisfaction in Supply Chain

In order to evaluate the performance in improving the customer satisfaction level, supply chain metrics must be linked to customer satisfaction. Very little work can be found linking customer satisfaction with supply chain metrics. The research usually focuses on supply chain performance measures or on supply chain service quality.

2.3.1 Supply Chain Factors

Very few researchers have specifically looked at the factors influencing customer satisfaction in the supply chain. Guo and Han (2010) suggested that customer satisfaction was affected by the following factors: *quality, service, commitment* and *price*. Liang and Tang (2007) actually developed a method to evaluate customer satisfaction in the Supply Chain. They used *response speed, commitment, price* and *quality* as factors. Abdolvand and Bahrami (2011) looked at the factors affecting customer satisfaction in the supply chain from the perspective of industrial buyers. They recorded the following: *Integrated supply chain, Buyer satisfaction, Trust, Commitment, Communication, Cooperation* and *Long-term Orientation*. The communication factor they mentioned was also referred to by Simchi-Levi *et al.* (2002) who stated that "Many supply chain partners engage in information sharing so that manufacturers are able to use retailer's up-to-date sales data to better predict demand and reduce lead times. This information sharing also allows manufacturers to control the variability in supply chains (known as the bullwhip effect), and by doing that reduce inventory and smooth out production". Since

information sharing leads to an effective supply chain, it in turn generates an increase in customer satisfaction. The big question is how much information can you share with a customer and not be transparent to competitors?

Based on the factors mentioned above, it can be seen that the most common factors of the customer satisfaction in supply chain are *Commitment*, *Price* and *Quality*. Quality must be broken down into both product and service quality. It would be wise to have it encompass process quality as well, because it is a necessity in a well-developed supply chain. In addition to these three factors, others should be considered. The *Response Speed* which was also used by Liang and Tang (2007) and the *Brand*'s reputation which is a dimension of customer perception should also be considered as customer satisfaction factors in supply chain.

Most of the previous research focuses on service, the obvious part of the supply chain affecting customer satisfaction. Berry *et al.* (1994) said that service was a key component to a company's success. They stated that "Excellent service is a profit strategy because it results in more new customers, more business with existing customers, fewer lost customers, more insulation from price competition, and fewer mistakes requiring the performance of services". Service quality measures can be qualitative or quantitative. In the literature, five broad service dimensions that customers use as criteria to judge service quality were found. The rate of importance of each dimension was also provided as judged by the customers of five large, well known US companies. The five dimensions are:

- *Reliability* (32%) : the ability to perform the promised service dependably and accurately
- *Responsiveness* (22%): the willingness to help customers and provide prompt service
- *Assurance* (19%): the knowledge and courtesy of employees and their ability to convey trust and confidence
- *Empathy* (16%): the caring, individualized attention provided to customers

- *Tangibles* (11%): the appearance of physical facilities, equipment, personnel, and communication materials

SERQUAL is a technique developed by Berry *et al.* (1994) to measure a company's service quality performance against customer's service quality needs in service and retail industry. It uses a survey in two parts, with 22 questions in each part. Part I measures service expectations and part II measures service perceptions. SERQUAL will not be used as a measurement technique in this research.

Johnson (1995) looked at the determinants of service quality. The 18 determinants listed in Table 2-2 were found from his research and study. Many of the determinants of service quality were previously mentioned in one form or another.

Table 2-2: Johnson's Service Quality Determinants

Access	Aesthetics	Attentiveness/Helpfulness
Availability	Care	Cleanliness/Tidiness
Comfort	Commitment	Communication
Competence	Courtesy	Flexibility
Friendliness	Functionality	Integrity
Reliability	Responsiveness	Security

(Johnston, 1995)

Value-added services were mentioned previously as one dimension of customer perception. They differentiate companies from their competitors and provide a competitive edge. Other reasons for a company to add these services include "the commoditization of products", "the need to get closer to the customer" and "the increase in information technology capabilities"

(Lalpanmawia, 2012). These services include but are not limited to support, maintenance, and information access.

2.3.2 Supply Chain Measures

Gunasekaran *et al.* (2004) studied supply chain performance measures. Metrics for order planning, supply chain link, production level, delivery link, customer service and satisfaction, supply chain logistics, and costs were recognized. In addition to the customer service and satisfaction measures, many of the other metrics can be applied as customer satisfaction measures since they have a significant impact on customer satisfaction. The metrics of order planning could be applied as customer satisfaction measures, including *order lead-time* and *customer order path* (aka transportation path). The metrics of delivery link, including *on-time delivery*, *number of faultless notes invoiced*, *flexibility of delivery systems to meet customer needs and total distribution cost* could also be applied. The metrics of logistics cost, including *cost associated with assets and return on investment* and *information processing cost* could be applied. Finally, the metrics for customer service and satisfaction which include *flexibility*, *customer query time* and *post transaction measures of customer service* could also be applied as customer measures.

In the inventory aggregation problem under risk pooling, Gaur and Ravindran (2006) considered responsiveness a factor when looking to maintain good response times to customers. Other typical measures of customer service are the *fill rate*, which is the ability of a company to fill orders from inventory within a due date, and *on-time deliveries*, which is the ability to deliver products to customers within the time quoted. *Service level* is also related to customer service. It is the fraction of time of positive inventory, meaning the probability of not stocking out. It can be used to measure the safety stock level, which is the amount of stock held in excess of the expected demand to prevent stockouts.

Not all of the measures mentioned are currently being measured in supply chains. As a result, it will be difficult to find current supply chain data representing all of the factors needed for this study. The most common measures will be used. Additionally, some data cannot be released by the company for this study. These measures will be dealt with fuzzy logic.

2.4 Fuzzy Logic

In order to take into account the impact of the diverse factors or requirements, fuzzy logic will be used in this thesis. Kllir *et al.* (1997) noted that one of the principal motivations for introducing fuzzy sets is to represent imprecise concepts. Fuzzy Logic is a concept that is most useful when dealing with problems with a vague rule of thumb and common sense. In other words, when the membership of a variable to a certain set is not absolute, meaning that the variable is not a definite part of a set, the use of fuzzy logic helps determine to what extent the variable is a member of that set. This is done through the use of membership functions.

2.4.1 Fuzzy Logic Terms

Each fuzzy set is defined in terms of a relevant universal set by a membership function. The membership function gives a value in the closed interval [0, 1] representing the degree of membership of an element in a set. It helps deal with the uncertainty of the element's belonging to that set, sometimes due to the imprecision of the linguistic term used. Membership functions can take several forms. They can be triangular functions, trapezoidal functions or quadratic functions among others, or simply an assignment of a value in the closed unit interval to each element of the set. The membership functions are also used to denote numerical or linguistic values of elements. Setting of the membership function can be done from ratings collected from

customer surveys. Assume we have a triangular membership function $M(x)$ where $0 \leq M(x) \leq 1$. For example, let the function be defined as follow:

$$M(x) = \begin{cases} 0 & for\ x \leq 3 \\ \frac{x-3}{5-3} & for\ 3 \leq x \leq 5 \\ 1 & for\ 5 \leq x \leq 6 \\ \frac{8-x}{8-6} & for\ 6 \leq x \leq 8 \\ 0 & for\ x \geq 8 \end{cases} \quad (1)$$

For x = 3. 5, the fuzzy value is,

$$M(3.5) = \frac{3.5-3}{5-3} = 0.25 \quad (2)$$

Once the fuzzy set is defined, sets of rules which are usually referred to as production rules are used to evaluate/combine the fuzzy values. These production rules will combine each level of each requirement type to each other and inference a satisfaction level in the case of their occurrence. A production rule is in the form of a logic statement, such as IF A = *x* then B = *y*.

The defuzzification which follows is the step of converting a fuzzy value into a numerical or common linguistic term. To defuzzify a fuzzy value is to determine a crisp output value from the fuzzy values. This can be done by calculating the center of gravity of the area under the curve of the fuzzy values. The formula of the center of gravity, *C*, is as follows:

$$C = \frac{\sum M_A(x)x}{\sum M_A(x)} \quad (3)$$

where:

$$M_A(x) = fuzzy\ membership\ function\ of\ set\ A$$

$$x = numerical\ value\ that\ is\ fuzzified$$

This formula is for a discrete function. Continuous functions would require integrating the area under the curve.

2.4.2 Fuzzy Logic Applications

Kosko (1997) provides multiple illustrations of how fuzzy systems are used to help everyday products with their functions. Japan and Korea, for example, manufacture fuzzy washing machines. Fuzzy washing machines are considered more efficient than dumb washing machines with fixed commands. This is due to the fact that fuzzy washing machines tailor their wash to the relative cleanliness of the clothes they wash. More specifically, the wash strategy changes based on a set of fuzzy rules which take clarity of the wash water and the saturation time to wash as inputs while returning the wash time as an output. Another example would be fuzzy cameras, which tune the autofocus with fuzzy rules. Basically, the camera lens is adjusted by fuzzy rules based on the relative contrast between regions of the image (Kosko, 1997).

Fuzzy logic is not only useful in the operation of products, it is also used when measuring vague concepts such as risk. De Ru and Eloff (1996) demonstrated the use of fuzzy logic in performing a risk analysis in a computing facility. Correctly modeling risk in a computing facility is essential since management decisions on counter measures and resource allocation is based on output from this analysis. After pinpointing all the risks associated with the computing facility, it was discovered that many of the inputs to the risk analysis were difficult to quantify. Fuzzy sets were used to calculate the degree of membership of the risk of the hard drive age, the dial-up access and the employee satisfaction. The use of fuzzy sets made it easier to compare the risk level of those influences on the system's vulnerability. Another fuzzy set was then used to calculate the risk factor of the system itself based on the individual risk levels. Using fuzzy logic, the risk analysis of this computing facility was made comprehensible and easy to assess.

2.5 Customer Satisfaction Evaluation

Since satisfaction is a psychological state, it is considered a subjective concept. Measuring a subjective concept can be difficult. Thus, there have been very few researchers, who have actually studied the customer satisfaction measurement problem. Only one paper was found in the literature which attempted to study this problem. Liang and Tang (2007) used a satisfaction coefficient to calculate customer satisfaction.

In their paper, the authors used four general criteria to measure customer satisfaction. The expected trend is that if the supply chain increases the quality of these four criteria or factors named in this research, the customer satisfaction level will also be increased. Response speed, commitment, price and quality are the four criteria that will be divided into a total of ten sub-criteria. Response speed in this case means "the reaction ability of the supply chain when the environment is changing" (Liang & Tang, 2007). Response speed has three sub-criteria which are not explicitly listed. The second criterion, commitment, also has three sub-criteria which are the percentage of out of stock, the rate of punctuality and the rate of complaint. Two ways of expressing price were used to influence customer satisfaction. The first compared the average price of each product to the target supply chain and the rival supply chain. The second takes into account the average discount rate of each product. As price decreases, the customer satisfaction level increases. Finally, product quality and service quality both comprise the quality criterion. Product quality is measured by the ratio of the amount of returns and repairs to the total amount of purchases in a period of time. Service quality is measured by the time taken to solve a customer complaint.

Customer satisfaction was calculated with the weighted sum of the criteria measures. A non-linear optimization model was used to determine the weights for each criterion by minimizing the errors between the decision maker's preference to the criteria and the objects

weights. The values of the decision maker's preference were identified using the Analytical Hierarchy Process model. The criterion measure (p_i) of each criterion i is determined by the computational formula in the following table (Table 2-3). The actual criterion value in the supply chain is denoted by v_i and the expectation satisfaction value (u_i) can be determined by a questionnaire.

Table 2-3: Computational Formula for Measure Criteria

	$u_i \leq v_i$	$u_i \geq v_i$
The higher u_i, the higher customer satisfaction is	$p_i = u_i / v_i$	$p_i = 1$
The lower u_i, the higher customer satisfaction is	$p_i = 1$	$p_i = 1 – (u_i - v_i)/ v_i$

(Liang & Tang, 2007)

Chapter 3

Methodology

As mentioned in chapter one, this research had three distinct goals. The first was to identify the factors which directly or indirectly relate to customer satisfaction. The second was to identify the degree to which each factor affects customer satisfaction. Finally, the third was to create a methodology to help measure customer satisfaction in supply chain based on the factors identified. In order to reach these goals, a review of the work done regarding customer satisfaction in supply chain was conducted.

One article regarding the measurement of customer satisfaction in supply chain was discovered (Liang & Tang, 2007). Unlike this research, the article did not take into account the different types of factors. This means that all the factors considered in that study were treated as one-dimensional factors. If the level of one factor increased, the level of customer satisfaction consequently increased. In this research, different types of factors will be taken into account, as well as the expectations of the customers.

Additionally, the methodology presented in this research is geared towards manufacturing companies. In order to be efficient, quantitative measures reflecting the performance of each factor should be sought. These quantitative measures can mostly be found in the supply chain of manufacturing companies. Even though quantitative performance measures are preferred because of their accuracy, qualitative measures will still be accepted. In some cases, qualitative measures are the only alternative because of the lack of quantitative measures representing a factor. This methodology also requires the input of the customers. Therefore, a section of the work will require some interaction with the customers.

3.1 Factors of Customer Satisfaction in Supply Chain

The first goal of identifying the factors affecting customer satisfaction in supply chain is done by reviewing the literature. Out of several studies, some factors are selected as pertinent to this research due to their relation to customer satisfaction in supply chain. *Price, brand, quality, commitment* and *response speed* were the factors that are picked. *Price* is directly related to customer satisfaction. As the price of a product increases, the satisfaction of the customer decreases. *Brand* is one of the dimensions of customer perception. Customers tend to be attracted to companies whose brand name is most popular or recognized for a specific aspect of their product because "a brand name is a guarantee of quality in the buyer's mind" (Lalpanmawia, 2012). *Quality* can be divided into three different types, *product quality*, *service quality* and *process quality*. *Product Quality* and *Service Quality* are the two types that are directly related to customer satisfaction. *Process Quality* is being considered because it indirectly affects customer satisfaction. A supply chain with a highly efficient process will attract more customers. It will also be able to handle the customers in a manner that is more than satisfactory. *Commitment* can be interpreted in two different ways. The first definition refers to the employee's apparent commitment to their work, their diligence and thoroughness (Johnston, 1995). The second definition refers to the commitment of the supply chain which will make customers purchase without worry (Liang & Tang, 2007). Both definitions are considered in this research when mentioning commitment. Finally, *Response Speed* indicates the ability of the supply chain to react when the environment is changing.

To reflect the performance of each factor, performance measures have been identified. These performance measures are also handpicked from the literature. Table 3-1 lists the measures selected for each factor. All measures do not have to be present for the calculation of customer

satisfaction level. Even though two or three measures would be preferred for each factor, one performance measure could suffice for some factors.

Table 3-1: Performance Measures for Factors of Customer Satisfaction

Factors	**Performance Measures**
Price	Average price in market
Brand	Rank of company within the market
Commitment	Rate of complaints
	Rate of on-time delivery (punctuality)
	Fill rate
Response Speed	Lead-time delivery
	Average delivery times
Process Quality	Traceability measure
	Forecasting accuracy
	Inventory turns / Days of inventory
Product Quality	Ratio of fixed and returned product amount to the total amount of purchased product in a period of time
	Percentage of product undergoing test quality
	Percentage of quality failure
Service Quality	Rate of shipping errors
	Rate of outage
	Time taken to solve a customer complaint
	Value-Added service measures

The subsequent steps of the methodology will be different for each supply chain because each supply chain will have their own measurements for the factors of customer satisfaction mentioned above. Those steps will also be different due to the fact that they require some inputs from the customer. These steps will thus be the interactive part of the methodology.

3.2 Influence of Factors on Customer Satisfaction

The second goal of identifying the degree to which each factor affects customer satisfaction in supply chain can be done in different steps. First and foremost, the customer needs to identify what type of requirement the factors represent. This is done using Table 2-1: Kano Evaluation Table. By completing this evaluation, the customer thus classifies the factors among the six types of customer requirements: must-be, one-dimensional, attractive, reverse, indifferent and skeptical (questionable result). Skeptical and indifferent factors will not be included in this research. Since all the factors that are taken into account are selected from studies based on customer surveys, the factors are expected to be neither questionable nor indifferent to the customer. This step depicts the manner in which each factor affects customer satisfaction in supply chain.

The extent to which the factors influence customer satisfaction is determined by calculating the weights of each factor within each type of requirement. Since the one-dimensional requirements and reverse requirements behave similarly, they can be combined into one type. The difference will be that the weights of the factors of the one-dimensional requirement type will be positive and the weights of the factors of the reverse requirement type will be negative. Additionally, if a factor is represented by multiple performance measures, weights for the

measures of the factor also need to be determined. The rating method can be used to calculate the weights of the factors and the weights of the performance measures. This method was chosen due to its simplicity and the fact that the number of factors to rate is minimal.

If the evaluation of the factors is done by one customer, the customer must first rate the factors on a scale of 1 to 10. The weight of each factor j (w_j) is then calculated using the following formula:

$$w_j = \frac{v_j}{\sum v_j} \tag{4}$$

where v_j is the rating assigned to factor j.

If multiple customers are involved in the process, the weights calculated by each customer can be averaged. Another method is to average the ratings of the customers for each factor first and then calculate the weights. In case of outliers, the highest and lowest ratings can be dropped. Having multiple customers participate in the process of calculating the customer satisfaction level is preferred. Masud and Ravindran (2008) discuss different methods that are available for calculating the factor weights.

3.3 Evaluation of Customer Satisfaction in Supply Chain

The ultimate goal of this research is to measure the level of customer satisfaction in supply chain. This is done in multiple steps. These steps will provide the level of customer satisfaction for a supply chain. They will consist of calculating a satisfaction value for each performance measure, calculating the level of satisfaction within each type of requirement and then combining the level of satisfactions of the requirement to obtain the final customer satisfaction level.

3.3.1 Satisfaction Value of Performance Measures

Customer satisfaction is based on the perception of what is received and what should be received. Thus, customers have an expectation for the values of each performance measure that is considered. To evaluate customer satisfaction, both the expected value and the actual performance of a measure are needed. Therefore, the customer must provide the expected value or goal for each performance measure that is being analyzed. The satisfaction values of the measures will be calculated using the expected values provided by the customer and the actual values of the performance measures of the supply chain being reviewed. The satisfaction values of the measures will in turn be used to calculate the level of satisfaction for each type of requirement. When the goal is to maximize the value of the performance measure and the actual value of the performance measure exceeds the expected value for that performance measure, the satisfaction value is set to 1. When the goal is to minimize the value of the performance measure and the actual value of the performance measure is lower than the expected value for that performance measure, the satisfaction value is also set to 1. Otherwise, the satisfaction value is calculated using an equation. Let the satisfaction value be denoted by X, the expected value by *E* and the actual performance measure value by *A*. To obtain the satisfaction value, an acceptable range for the values of the performance measures is also needed. Let *Max* and *Min* be the maximum and minimum values of the range of the performance measure. They are the extreme values possible for the actual value of the performance measure and thus also apply for the expected value. The following equations will be used to calculate the satisfaction value of each performance measure:

If higher performance measures increase customer satisfaction (*max A*),

$$X = 1 - \left| \frac{E - A}{Max - Min} \right| \qquad \text{for E > A} \quad (5)$$

$$X = 1 \qquad \text{for E} \leq \text{A} \quad (6)$$

If lower performance measures increase customer satisfaction (*min A*),

$$X = 1 - \left| \frac{E - A}{Max - Min} \right| \quad \text{for E < A} \quad (7)$$

$$X = 1 \quad \text{for E} \geq \text{A} \quad (8)$$

For example, customer satisfaction increases when fill rate increases. Thus if the actual value of the fill rate is lower than the expected fill rate value, equation (5) is used to calculate the satisfaction value. If the actual value of the fill rate is higher than the expected fill rate value, the satisfaction value is set to 1. Let the actual value of the fill rate be A = 93 % and the expected value be E = 97 %. The range of the fill rate performance measure is 0 to 100 %. The satisfaction value would be calculated as:

$$X = 1 - \left| \frac{E - A}{Max - Min} \right| = 1 - \left| \frac{97 - 93}{100 - 0} \right| = 0.96 \quad (9)$$

On the other hand, customer satisfaction increases when price decreases. Thus if actual price of an item is higher than its expected price, equation (7) is used to determine the satisfaction value. Otherwise, the actual price for the item is lower than the expected price. In this case, the satisfaction value is set to 1. Let the actual price of the item be $50 and the expected price be $65. Let the range of the price for that item be $35 to $110. The satisfaction value would be:

$$X = 1 \quad (10)$$

Ideally, all factors should be represented by at least one performance measure recorded in the supply chain in order to calculate the level of customer satisfaction efficiently. If there exists no measure that can represent the performance of a factor for that supply chain, the calculation of the customer satisfaction level should proceed without the use of that factor. If a supply chain intends on calculating its customer satisfaction level, performance measures that are currently lacking should start being noted for future use.

3.3.2 Satisfaction Level by Type of Requirement

When analyzing the influence of each factor on customer satisfaction in supply chain, the customer classifies each factor to one type of requirement. Only four out of the six types of requirements are used in the thesis: one-dimensional requirements, reverse requirements, must-be requirements and attractive requirements. In addition, the factors of the one-dimensional type and the reverse type should be handled together due to the similarity between the two requirement types. Thus, only three types of requirements remain. The satisfaction level for each of type of requirement present is then calculated. To perform this calculation, the satisfaction values for all performance measures are aggregated within their requirement type. This is accomplished using the weighted sum method. The weights of the factors and of the performance measures are used in this section.

The satisfaction level of each requirement type is calculated by using the following formula:

$$SL_{Req\ Type} = \sum_{i=1}^{M} \sum_{j=1}^{N} w_{ij} w_j X_j \tag{11}$$

where:

$$M = total\ number\ of\ factors\ representing\ the\ requirement\ type$$

$$i = factor \qquad i = 1, 2, \dots, M$$

$$N = total\ number\ of\ performance\ measures\ in\ the\ requirement\ type$$

$$j = performance\ measure \qquad j = 1, 2, \dots, N$$

$$X_j = satisfaction\ value\ of\ performance\ measure\ j \qquad j = 1, 2, \dots, N$$

$$w_j = weight\ of\ performance\ measure\ j \qquad j = 1, 2, \dots, N$$

$$w_{ij} = weight\ of\ factor\ i\ relating\ to\ performance\ measure\ j$$

Note: $w_{ij} = 0$ $if\ performance\ measure\ j\ is\ not\ a\ measure\ of\ factor\ i$

The satisfaction level equation contains two sets of weights for the satisfaction value. The first represents the weight of the factor. The second represents the weight of the performance measure. Since the performance measures were weighted within their respective factors, the total weight of the satisfaction value is the product of the two set of weights.

For example, let price and commitment be the factors of the one-dimension requirement. Let the weights for the factors be 0.75 for price and 0.25 for commitment. The price factor has the average price in the market as a performance measure. The weight for the average price is thus 1. The commitment factor has more than one performance measure: rate of complaints and fill rate. The weights of the performance measures for the commitment factors were determined to be 0.30 for the rate of complaints and 0.70 for the fill rate. Finally, let the satisfaction values for the average price in the market, the rate of complaints and the fill rate be 0.83, 1 and 0.95 respectively. The satisfaction level of the one-dimensional requirement is:

$$SL_{One-Dim.} = w_{price} w_{avg\ price} X_{avg\ price} + w_{commitment} w_{rate\ of\ complaints} X_{rate\ of\ complaints} + w_{commitment} w_{fill\ rate} X_{fill\ rate} \quad (12)$$

$$SL_{One-Dim.} = 0.75 * 1 * 0.83 + 0.25 * 0.30 * 1 + 0.25 * 0.70 * 0.95$$

$$SL_{One-Dim.} = 0.8638$$

3.3.3 Combining Requirement Types

The final step of this process is to combine the satisfaction level of each type of requirement to determine the overall customer satisfaction level for the supply chain. Since the attractive and must-be requirements do not affect the customer satisfaction level in a proportional manner, combining the satisfaction level of the different types of requirement is challenging. This problem is handled using fuzzy logic.

Fuzzy sets are needed to represent the satisfaction level of the types of requirement. As mentioned previously in section 2.4.1, each fuzzy set is defined by a membership function. Setting the membership function can be done by collecting ratings from customer surveys. Those ratings would reflect the satisfaction level corresponding to each linguistic term of satisfaction according to the customer. The linguistic terms of satisfaction could be set as very unsatisfied, neutral and satisfied among other terms. By combining those ratings, the degree of membership of the various linguistic terms of satisfaction for each requirement type can be identified.

The results of the customer surveys can be aggregated differently depending on the type of the membership function. The triangular and trapezoidal functions can be aggregated using the fuzzy aggregation method proposed by Chen, Lin and Huang in their fuzzy approach to evaluating and selecting suppliers in the supply chain management (Chen, et al., 2006). All the membership functions of this thesis will take the form of trapezoidal functions. Consider K trapezoidal fuzzy functions, where K is the number of customers who provided fuzzy ratings for a linguistic term of satisfaction. Let the fuzzy ratings of all customers be trapezoidal fuzzy numbers (a_k, b_k, c_k, d_k), $k = 1, 2, \ldots, K$. The set (a, b, c, d) composes the parameters of the aggregated fuzzy rating. Then the aggregation is done as follows:

$$a = \min_k(a_k) \tag{13}$$

$$b = \frac{1}{K} \sum_{k=1}^{K} b_k \tag{14}$$

$$c = \frac{1}{K} \sum_{k=1}^{K} c_k \quad (15)$$

$$d = \max_k(d_k) \quad (16)$$

The fuzzy function of a linguistic term of satisfaction would then be the following:

$$y = 0 \quad \text{for } x \leq a \quad (17)$$

$$y = \frac{x-a}{b-a} \quad \text{for } a \leq x < b \quad (18)$$

$$y = 1 \quad \text{for } b \leq x < c \quad (19)$$

$$y = \frac{d-x}{d-c} \quad \text{for } c \leq x < d \quad (20)$$

$$y = 0 \quad \text{for } d < x \quad (21)$$

where:

$$y = level\ of\ membership\ to\ linguistic\ term\ of\ satisfaction$$

$$x = satisfaction\ level\ calculated\ in\ section\ 3.3.2$$

Four sets of membership functions should be set to respectively represent the satisfaction levels of the three requirement types and the satisfaction level of the overall customer satisfaction. For each type of requirement, the customer should determine which satisfaction level is considered acceptable or even neutral. This implies that the customer should determine the set of membership functions for the satisfaction level of each of the type of requirements. The last set would represent the membership functions for the overall customer satisfaction level. Figure 3-1 depicts an example of a set of membership functions for the customer satisfaction level. The linguistic term of being very unsatisfied refers to a satisfaction level of 0 to 15 %. The linguistic term of being unsatisfied refers to a satisfaction level of 20 to 30%. The linguistic term of being neutral in terms of satisfaction refers to a satisfaction level of 45 to 55%. The linguistic term of being satisfied refers to a satisfaction level of 70 to 80%. Finally, the linguistic term of being very satisfied refers to a satisfaction level of 90 to 100%. All the intermittent satisfaction levels refer to

the two adjacent linguistic terms. For example, a satisfaction level between 15 and 20% will be associated to both the very unsatisfied and the unsatisfied linguistic terms.

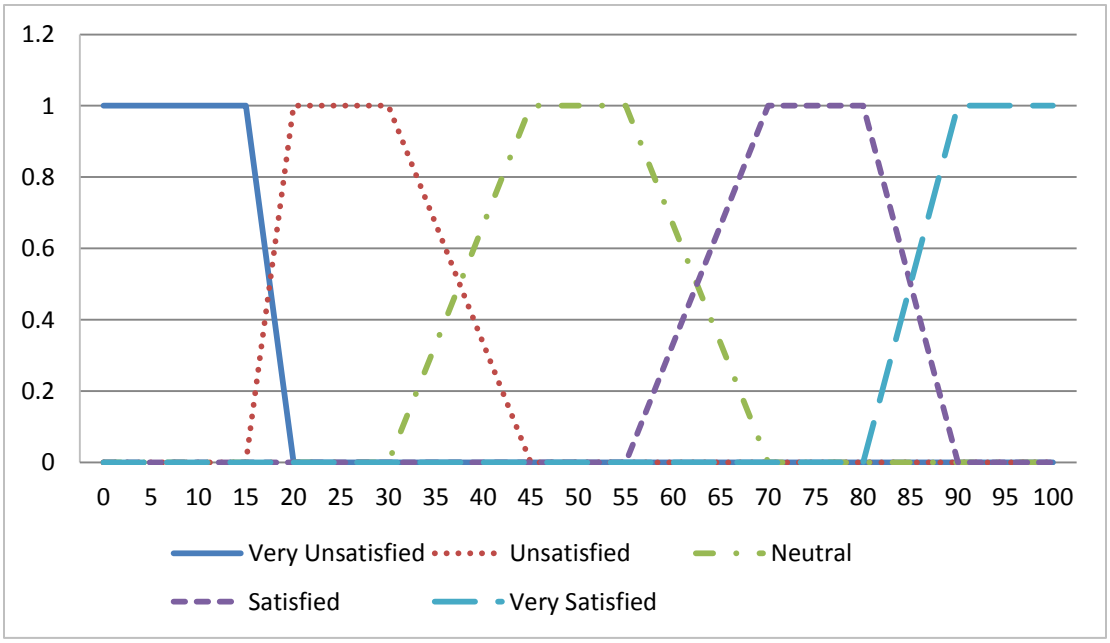


Figure 3-1: Membership Functions for Customer Satisfaction

In order to combine the satisfaction level of each type of requirements, a set of production rules need to be set to derive the overall customer satisfaction level of the supply chain. These rules will combine the linguistic terms obtained for the satisfaction levels of the requirement types from the sets of membership functions of the requirement types. The rules will return a linguistic term for the overall customer satisfaction level. They are given in Table 3-2. The production rules given in Table 3-2 were arbitrarily determined. When calculating the satisfaction level of a real supply chain, the production rules should be set by the customers of the supply chain. Lastly, the linguistic term for the customer satisfaction level will then be converted into a numerical value. This can be done by using the center of gravity formula (C) mentioned in chapter 2, section 2.4.1.

Table 3-2: Production Rules for Requirement Types to Customer Satisfaction Level

If	***and***	***and***	***Then***
Attractive Req	**Must be Req**	**One Dim. Req**	**Customer Satisfaction**
Neutral	Very Unsat.	Very Unsat.	Very Unsatisfied
Neutral	Very Unsat.	Unsatisfied	Very Unsatisfied
Neutral	Very Unsat.	Neutral	Unsatisfied
Neutral	Very Unsat.	Satisfied	Unsatisfied
Neutral	Very Unsat.	Very Satisfied	Neutral
Neutral	Unstatisfied	Very Unsat.	Very Unsatisfied
Neutral	Unstatisfied	Unsatisfied	Very Unsatisfied
Neutral	Unstatisfied	Neutral	Unsatisfied
Neutral	Unstatisfied	Satisfied	Unsatisfied
Neutral	Unstatisfied	Very Satisfied	Neutral
Neutral	Neutral	Very Unsat.	Very Unsatisfied
Neutral	Neutral	Unsatisfied	Unsatisfied
Neutral	Neutral	Neutral	Neutral
Neutral	Neutral	Satisfied	Satisfied
Neutral	Neutral	Very Satisfied	Very Satisfied
Satisfied	Very Unsat.	Very Unsat.	Very Unsatisfied
Satisfied	Very Unsat.	Unsatisfied	Unsatisfied
Satisfied	Very Unsat.	Neutral	Neutral
Satisfied	Very Unsat.	Satisfied	Neutral
Satisfied	Very Unsat.	Very Satisfied	Neutral
Satisfied	Unstatisfied	Very Unsat.	Unsatisfied
Satisfied	Unstatisfied	Unsatisfied	Unsatisfied
Satisfied	Unstatisfied	Neutral	Neutral
Satisfied	Unstatisfied	Satisfied	Neutral
Satisfied	Unstatisfied	Very Satisfied	Satisfied
Satisfied	Neutral	Very Unsat.	Unsatisfied
Satisfied	Neutral	Unsatisfied	Unsatisfied
Satisfied	Neutral	Neutral	Satisfied
Satisfied	Neutral	Satisfied	Satisfied
Satisfied	Neutral	Very Satisfied	Very Satisfied
Very Satisfied	Very Unsat.	Very Unsat.	Very Unsatisfied
Very Satisfied	Very Unsat.	Unsatisfied	Unsatisfied
Very Satisfied	Very Unsat.	Neutral	Unsatisfied
Very Satisfied	Very Unsat.	Satisfied	Neutral
Very Satisfied	Very Unsat.	Very Satisfied	Satisfied
Very Satisfied	Unstatisfied	Very Unsat.	Very Unsatisfied

If	***and***	***and***	***Then***
Attractive Req	**Must be Req**	**One Dim. Req**	**Customer Satisfaction**
Very Satisfied	Unstatisfied	Unsatisfied	Unsatisfied
Very Satisfied	Unstatisfied	Neutral	Neutral
Very Satisfied	Unstatisfied	Satisfied	Neutral
Very Satisfied	Unstatisfied	Very Satisfied	Satisfied
Very Satisfied	Neutral	Very Unsat.	Unsatisfied
Very Satisfied	Neutral	Unsatisfied	Neutral
Very Satisfied	Neutral	Neutral	Neutral
Very Satisfied	Neutral	Satisfied	Satisfied
Very Satisfied	Neutral	Very Satisfied	Very Satisfied

The one-dimensional/reverse requirement is the simplest of the three requirement types. The satisfaction level of the one-dimensional/reverse requirement type increases or decreases proportionally to the performance of its factors. Regarding the must-be requirements and the attractive requirements, the effect is conditional on a satisfaction level that a customer considers acceptable. The customer satisfaction level does not change once an acceptable level of satisfaction is reached for the must-be requirement satisfaction level. If the acceptable level is met, the must-be requirement satisfaction level should not be integrated in the calculation of the customer satisfaction level. If it is not, then the satisfaction level should be integrated in the calculation. Conversely, the customer satisfaction level changes only once when an acceptable level of satisfaction is reached for the attractive requirement satisfaction level. If the acceptable level is not met, the attractive requirement satisfaction level should not be integrated in the calculation of the customer satisfaction level. If it is met, then the satisfaction level should be integrated in the calculation.

3.3.4 Flow Chart of Methodology

The flow chart in Figure 3-2 illustrates all the necessary steps to evaluate the customer satisfaction level of a supply chain. The dotted lines in this flow chart represent the steps where the input of the customer is needed.

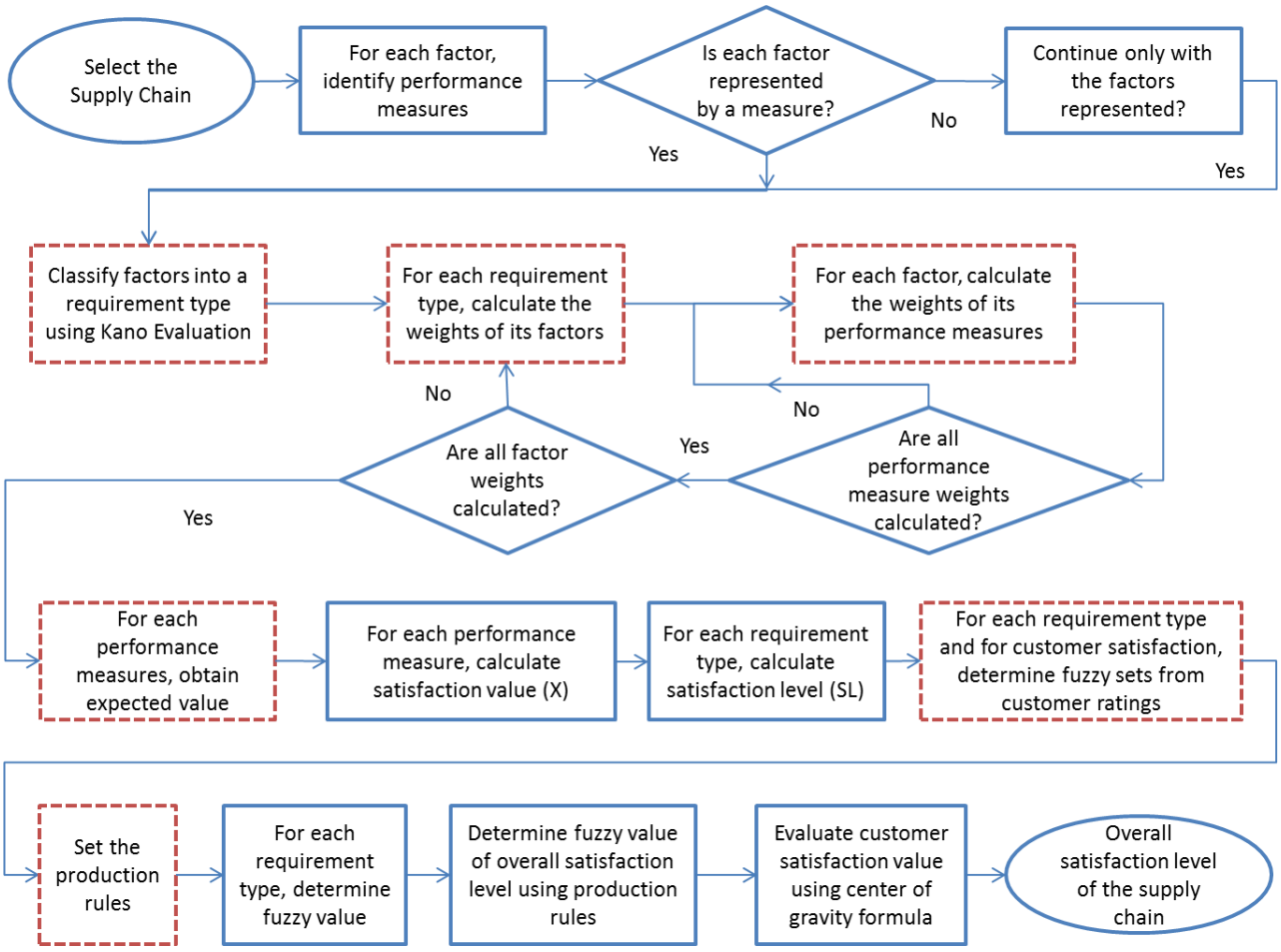


Figure 3-2: Flow Chart for Determining Overall Customer Satisfaction Level of the Supply Chain

3.4 Illustrative Example

This section presents an example of the application of the methodology described in sections 3.1, 3.2 and 3.3. It illustrates how the methodology should be used when all the factors are measured in the supply chain. For this example, we will assume that we are calculating the overall customer satisfaction level for the SONY Supply Chain, more specifically its 32 inch TVs. We will also assume that the supply chain collects performance measures to represent all the customer satisfaction factors listed in Table 3-3.

Table 3-3: Factors and Performance Measures

Factor	Performance Measures
Price	Average price
Brand	Company rank
Commitment	On-time delivery and fill rate
Response speed	Average delivery time
Process quality	Forecast accuracy
Product quality	Quality failure
Service quality	Shipping errors, rate of outage and time taken to resolve customer complaints

3.4.1 Data on Performance Measures and Factor

The brand rank of SONY was found on the "Ranking The Brands" website. From the "100-top CoreBrand Brand Power Ranking" of 2012, SONY was ranked 32nd. According to their site, CoreBrand tracks over 1200 of the world's best corporate brands and their ranking is based on 100-top scoring brands (SyncForce, 2013). Referring to Table 3-3, the price factor was

represented by the average price in the market for the product. Twelve prices were randomly generated between $250 and $650, which were assumed to be the range for 32 inch Televisions. On-time delivery rate and fill rate were used for the commitment factor. The random numbers for on-time delivery were generated from the arbitrarily chosen range of 75% to 99%, and for the fill rate, the range chosen was 90% to 99%. Average delivery time was chosen for the response speed factor and the times generated were between 1 and 28 days. Process quality was measured by the forecasting accuracy rate which was assumed to be in the range of 55% to 90%. Product quality was measured by the quality failure rate, which was presumed to be between 2% and 15%. Finally, the service quality factor was represented by three distinct performance measures. The rate of shipping errors was supposed to be in the range of 1% to 25%. The rate of outage was to be between 0.1% and 8%. Lastly, the time taken to solve a complaint was assumed to be between 1 day and 21 days. The complete data set used in the example is given in Table A-5 and Table A-6 of Appendix A.

Once the performance measures for each factor are collected, the customer classifies the factors into a type of requirement. Using Table 2-1, the customer answers a set of questions for each factor. For example, for the price factor, one functional and one dysfunctional question is asked such as:

Functional: *If the price is low, how do you feel?*

Dysfunctional: *If the price is high, how do you feel?*

Depending on the answer to the questions, meaning whether the customer likes (1), feels like it is a must-be (2), feels neutral (3), can live with (4) or dislikes the situation of each question, the intersection of the answers on Table 2-1 identifies the type of requirement for the

factor. The following table gives the answers to both questions and the resulting requirement type identified for each factor.

Table 3-4: Classification of Factors for Illustrative Example

Factor	Question	Answer	Requirement Type
Price	Functional	Like	One-Dimensional
	Dysfunctional	Dislike	
Brand	Functional	Like	Attractive
	Dysfunctional	Live With	
Commitment	Functional	Like	One-Dimensional
	Dysfunctional	Dislike	
Response Speed	Functional	Like	One-Dimensional
	Dysfunctional	Dislike	
Process Quality	Functional	Neutral	Must-be
	Dysfunctional	Dislike	
Product Quality	Functional	Must-be	Must-be
	Dysfunctional	Dislike	
Service Quality	Functional	Must-be	Must-be
	Dysfunctional	Dislike	

3.4.2 Weights and Satisfaction Values

The next step is to calculate the weights of each factor within each type of requirement and their respective performance measures. This is done by using the rating method as mentioned previously.

Weights for Factors

Assume the following ratings for each factor of the one-dimensional type: Price (9), Commitment (3) and Response speed (6). Assume the following ratings for each factor of the must-be type: Process quality (2), Product quality (8) and service quality (7). The weights for each are calculated as follow:

$$w_{price} = \frac{9}{9+3+6} = 0.5 \quad (22)$$

$$w_{commitment} = \frac{3}{9+3+6} = 0.1667 \quad (23)$$

$$w_{response\ speed} = \frac{6}{9+3+6} = 0.3333 \quad (24)$$

$$w_{process\ qual} = \frac{2}{2+8+7} = 0.1176 \quad (25)$$

$$w_{product\ qual} = \frac{8}{2+8+7} = 0.4706 \quad (26)$$

$$w_{service\ qual} = \frac{7}{2+8+7} = 0.4117 \quad (27)$$

There is only one factor for the attractive requirement type. Hence its weight is 1.

Weights for Performance Measures

Factors such as commitment and service quality, which have 2 and 3 representative performance measures (see Table 3-3) require the customer to rate the performance measure in order to calculate the measures' weight. Assume the following ratings for the performance measures: 1) on-time delivery rate (5) and fill rate (5) for commitment and 2) rate of shipping errors (9), rate of outage (5) and time taken to solve complaints (7) for service quality. The on-time delivery rate and fill rate weights are determined as follow:

$$w_{on-time\ delivery} = \frac{5}{5+5} = 0.5 \quad (28)$$

$$w_{fill\ rate} = \frac{5}{5+5} = 0.5 \quad (29)$$

The weights for the service quality performance measures are the following:

$$w_{shipping\ errors} = \frac{9}{9+5+7} = 0.4286 \quad (30)$$

$$w_{rate\ of\ outage} = \frac{5}{9+5+7} = 0.2381 \quad (31)$$

$$w_{time\ to\ solve\ complaints} = \frac{7}{9+5+7} = 0.3333 \quad (32)$$

The weights for all the single performance measures are one.

$$w_{avg\ price} = 1 \quad (33)$$

$$w_{company\ rank} = 1 \quad (34)$$

$$w_{avg\ delivery\ time} = 1 \quad (35)$$

$$w_{forecast\ accuracy} = 1 \quad (36)$$

$$w_{quality\ failure} = 1 \quad (37)$$

Once all the weights are calculated, the satisfaction value for each performance measure is calculated. For this, the expected value of the customer for each measure is needed. Considering the ten performance measures that were assumed to be collected, the expected values provided by the customer are given in Table 3-5. The actual performance values for the measures are the average of the twelve random numbers generated for the performance measures (see Table A-5 and Table A-6). The satisfaction values that were calculated are also provided in Table 3-5. For example, the satisfaction values of the average price in the market (minimize) and the on-time delivery rate (maximize) were determined respectively using equation (7) and equation (5) as follows:

$$X_{Avg\ Price} = 1 - \left|\frac{E-A}{Max-Min}\right| = 1 - \left|\frac{250-423.33}{800-200}\right| = 0.7111 \quad (38)$$

$$X_{On-time\ Del} = 1 - \left|\frac{E-A}{Max-Min}\right| = 1 - \left|\frac{100-89.93}{100-0}\right| = 0.8993 \quad (39)$$

Table 3-5: Satisfaction Values of performance measures for Illustrative example

Performance Measures	Expected Value (E)	Actual Value (A)	Range (Min-Max)	Satisfaction Value (X)
Average Price in Market ($)	250	423.33	200 - 800	0.7111
Brand Ranking	1	32	1 - 1200	0.9741
On-time Delivery Rate (%)	100	89.93	0 - 100	0.8993
Fill Rate (%)	100	95.44	0 - 100	0.9544
Average Delivery Times (days)	4	15.58	0 - 31	0.6265
Forecasting Accuracy (%)	90	68.06	0 - 100	0.7806
Quality Failure Rate (%)	2	10.29	0 - 100	0.9171
Shipping Errors Rate (%)	0.5	10.88	0 - 100	0.8962
Outage Rate (%)	1.5	4.31	0 - 100	0.9719
Time to Solve Complaints (days)	2	9.42	0 - 21	0.6467

3.4.3 Satisfaction Level for Requirement Types and for Customer Satisfaction

The next step of the methodology is to calculate the satisfaction level for each type of requirement. It is necessary to use the weights of the factors and the weights of the performance measures. Equation (11) is used to calculate the satisfaction levels as follows:

$$SL_{One-Dim} = w_{price}w_{avg\ price}X_{avg\ price} + w_{commitment}w_{on-time\ del}X_{on-time\ del} + w_{commitment}w_{fill\ rate}X_{fill\ rate} + w_{resp.\ speed}w_{avg\ del\ time}X_{avg\ del\ time} \quad (40)$$

$$SL_{One-Dim} = 0.5 * 1 * 0.7111 + 0.1667 * 0.5 * 0.8993 + 0.1667 * 0.5 * 0.9544 + 0.3333 * 1 * 0.6265 = 0.7189 \quad (41)$$

$$SL_{Attractive} = w_{brand} w_{rank} X_{rank} \quad (42)$$

$$SL_{Attractive} = 1 * 1 * 0.9741 = 0.9741 \quad (43)$$

$$SL_{Must-be} = w_{process\ qual} w_{forecast\ accuracy} X_{forecast\ accuracy} + w_{product\ qual} w_{qual\ failure\ rate} X_{qual\ failure\ rate} + w_{service\ qual} w_{shipping\ errors} X_{shipping\ errors} + w_{service\ qual} w_{outage\ rate} X_{outage\ rate} + w_{service\ qual} w_{time\ solving\ complaints} X_{time\ solving\ complaints} \quad (44)$$

$$SL_{Must-be} = 0.1176 * 1 * 0.7806 + 0.4706 * 1 * 0.9171 + 0.4118 * 0.4286 * 0.8962 + 0.4118 * 0.2381 * 0.9719 + 0.4118 * 0.3333 * 0.6467 = 0.8656 \quad (45)$$

The customer satisfaction level of the supply chain is finally determined by combining the satisfaction level of the three requirement types, one-dimensional, attractive and must-be. This is done with the use of fuzzy logic. The first step is to establish the membership functions for each type of requirement. Assume that the one-dimensional membership functions and the customer satisfaction membership functions are similar. As a result, the membership functions displayed in Figure 3-1 are used for both the one-dimensional requirement satisfaction level and the customer satisfaction level in the supply chain. The functions depicted in Figure 3-1 are provided in Table A-1 of Appendix A. To set the membership functions of the must-be requirements satisfaction level and the attractive requirements satisfaction level, the acceptable range for both must be determined.

The acceptable range of the attractive requirement is based on the customer's penchant on the brand factor compared to the one-dimensional factors. Similarly, the acceptable range of the must-be requirements is also based on the customer's preference of the process quality, product quality and service quality factors compared to the one-dimensional factors. The membership functions of both the attractive requirement satisfaction level and the must-be requirement level are depicted in Figure 3-3 and Figure 3-4 respectively. The functions are also provided in Table A-2 and Table A-3 of Appendix A.

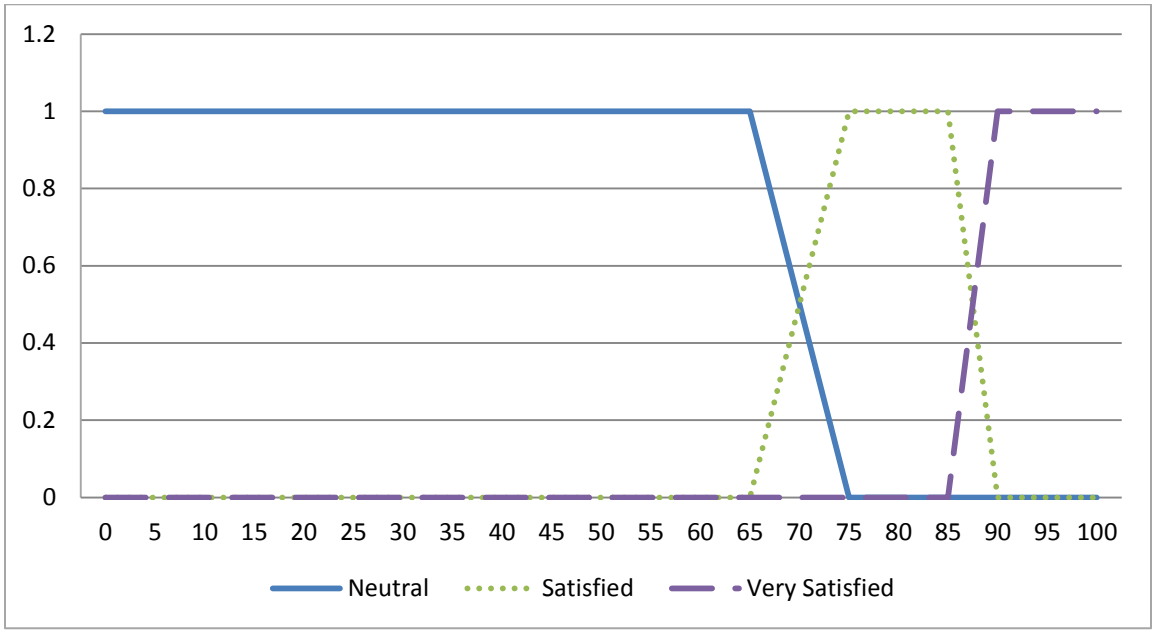


Figure 3-3: Attractive Requirement Membership Functions (example)

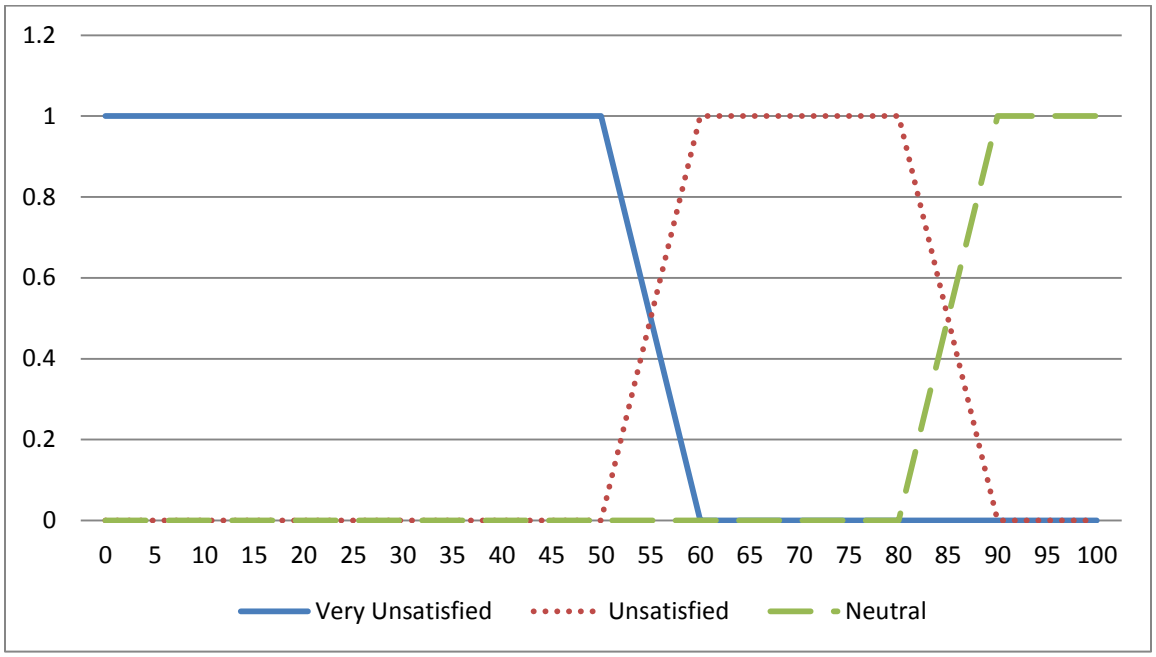


Figure 3-4: Must-be Requirement Membership Functions (example)

Based on the membership functions presented above, the fuzzy values of the must-be requirement satisfaction level, the attractive requirement satisfaction level and the one-dimensional requirement satisfaction level are determined. The attractive requirement and the one-dimensional requirement fuzzy values are easily evaluated. From the satisfaction levels of 0.9741 (97.41%) and 0.7189 (71.89%), the following fuzzy values were determined:

Attractive Requirements Fuzzy Value = 1 / Very Satisfied

One-Dimensional Requirements Fuzzy Value = 1 / Satisfied

Since the satisfaction level (86.56%) of the must-be requirement lies in between 80% and 90%, the fuzzy value is determined a little differently. Both the unsatisfied and the neutral linguistic level have positive values within that range. Thus, using the functions of both for that range, the must-be requirement fuzzy value is evaluated as follows:

$$Unsatisfied\ (86.56) = \frac{(90-x)}{10} = \frac{(90-86.56)}{10} = 0.344 \quad (46)$$

$$Neutral\ (86.56) = \frac{(x-80)}{10} = \frac{(86.56-80)}{10} = 0.656 \quad (47)$$

Must-be Requirements Fuzzy Value = 0.344 / Unsatisfied + 0.656 / Neutral

To determine the fuzzy value of the customer satisfaction level of the supply chain, the production rules presented in Table 3-2 are used. These rules combine the fuzzy values of the requirement types to produce the fuzzy value of the customer satisfaction level. Since the rules are all inclusive with the AND connector, the minimum of the values is the fuzzy value for the satisfaction level. Once all the rules are applied for this set of production rules, if the same linguistic is obtained multiple times, the maximum value is used as its final fuzzy value. The customer satisfaction fuzzy value is obtained below and then plotted in Figure 3-5.

Customer Satisfaction Fuzzy Value = 1/Very Satisfied AND 0.344/Unsatisfied AND 1/Satisfied + 1/Very Satisfied AND 0.656/Neutral AND 1/Satisfied

Customer Satisfaction Fuzzy Value = Min (1, 0.344, 1) / Neutral + Min (1, 0.656, 1) / Satisfied

Customer Satisfaction Fuzzy Value = 0.344 / Neutral + 0.656 / Satisfied

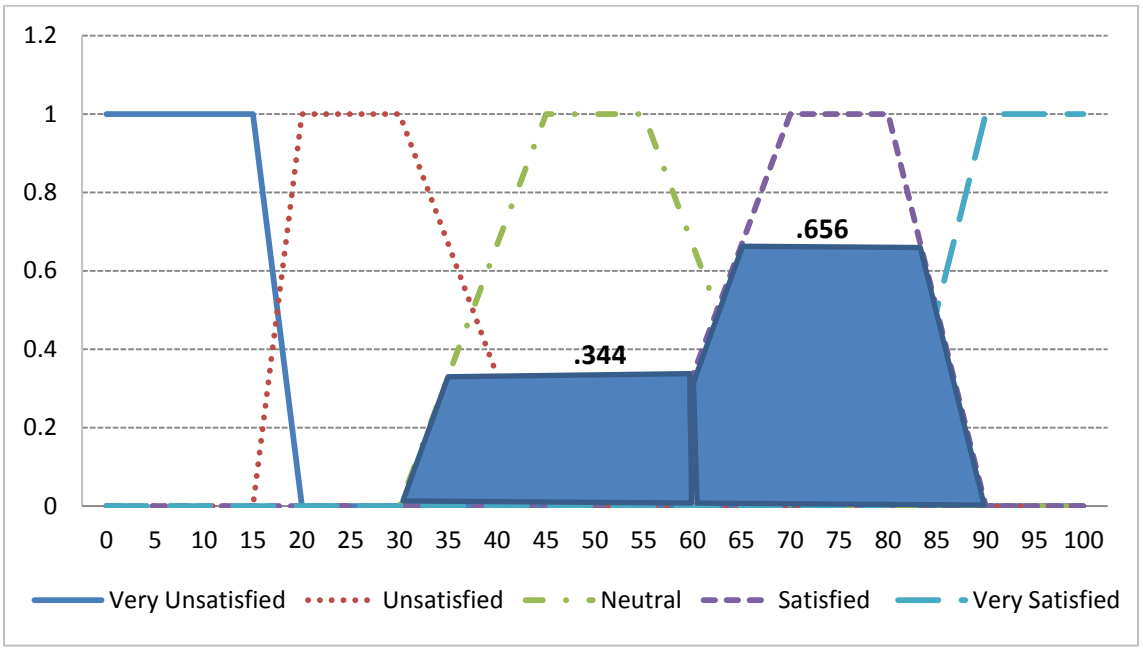


Figure 3-5: Customer Satisfaction Fuzzy Value Illustrative Example

In order to calculate the overall customer satisfaction level, the center of gravity of the shaded area in Figure 3-5 has to be evaluated. The points where the degree of membership changes are first determined. These points serve as the limits of the integration functions for the center of gravity formula. The overall satisfaction level is then calculated as follows:

Customer satisfaction =

$$\frac{\int_{30}^{35.16}\left(\frac{x-30}{15}\right)xdx+\int_{35.16}^{60.16}.344xdx+\int_{60.16}^{64.84}\left(\frac{x-55}{15}\right)xdx+\int_{64.84}^{83.44}.656xdx+\int_{83.44}^{90}\left(\frac{90-x}{10}\right)xdx}{\int_{30}^{35.16}\left(\frac{x-30}{15}\right)dx+\int_{35.16}^{60.16}.344dx+\int_{60.16}^{64.84}\left(\frac{x-55}{15}\right)dx+\int_{64.84}^{83.44}.656dx+\int_{83.44}^{90}\left(\frac{90-x}{10}\right)dx}$$

$$=\frac{1675.242}{26.1808}=63.9874 \qquad (48)$$

The customer satisfaction level of the supposed SONY supply chain was evaluated to be 63.99 %. In the linguistic terms, it was determined that the customer was somewhat satisfied and

somewhat neutral with regard to of the supply chain. The customer's opinion was of course based on the price of the product purchased, the ranking of the brand, the commitment and the response speed of the supply chain. It was also based on the quality of the process, the quality of the product and the quality of the service provided.

Chapter 4

Case Study

The last section of Chapter 3 demonstrated the application of the methodology when all factors are represented by performance measures. This chapter applies the methodology to a real company's supply chain. Data from the company was provided for this research. Unfortunately, not all the factors were represented by the performance measures provided. The customer satisfaction level was therefore evaluated based solely on the factors represented.

4.1 The Company

The company is a large consumer product company located in Pennsylvania. Once a luxury item for the wealthy, the product became affordable to all through mass production which lowered per-unit cost. As years passed, the company introduced new products and took advantage of growth opportunities by acquiring other companies. Today, the company's products are known all over the world and are marketed to approximately 70 countries. The company retail stores are not only located in the United States, but also can be found in Shanghai, Dubai and Singapore. The company is a make-to-stock company. This leads to big inventory and thus large inventory costs.

4.2 Performance Measures and Factor Types of Customer Satisfaction

To apply this research, company representatives were kind to offer some measurements recorded in the year 2012. Not all the desired information could be provided. This is due to confidentiality reasons and the lack of certain measurements. Additionally, no value- added

services were identified based on information provided by the company representative who supplied the data. The data provided was a combination of internal and external measures. The provided information can be described as follows:

Internal Measures of the Company (provided in weekly increments):

Case Fill: Cases ordered versus cases shipped

On-time Delivery: Appointment delivery to actual delivery

Dollar Fill: Dollars ordered versus dollars shipped

Net Dollar Fill: Includes any discounts or promotions applied to the items on the order

Gross Dollar Fill: Typically reported internally

External Customer Measures (provided in monthly increments):

Fill Rate: Cases ordered versus cases delivered

In-Stock/Service Level: Fill rate to stores from customer distribution centers or % of stock on retail shelf.

On-time Receipt: Requested delivery date/time to actual delivery date/time

The performance measures provided above were utilized as measures of the customer satisfaction factors. The net dollar fill as opposed to the gross dollar fill was used to represent the price factor. It was assumed that the customers' sentiment towards the price factor would only be affected based on what the customer ultimately paid. Since the net dollar fill is the price paid by the customers, the net dollar fill was thus used. Case fill and in-stock/service level measures were used as service quality measurements. The on-time delivery measure reflected the response speed factor. Finally, fill rate and on-time receipt were used to reflect the commitment factor. The measures used for the brand factor were obtained from the "Ranking The Brands" website.

Beside the previously mentioned “100-top CoreBrand Brand Power Ranking” list by CoreBrand, the “America’s Favorite Brands” list by 24/7 Wall St. was also used. Both ranking lists were for the year 2012. The CoreBrand list is based on the performance of 1200 of the world’s best corporate brands, where only the top 100 are reported. The 24/7 Wall St. list is based on the popularity of the brands within the American population. It was computed based on the population’s consumption patterns and only reports the top 10 most popular brand in the United States (SyncForce, 2013). The process quality and product quality factors were the only factors not represented. The data provided for the performance measures by the company can be found in Table A-7: 2012 Internal Measurements for Case Study Company and Table A-8: 2012 Customer Measurements (As reported by Case Study Company**)** of Appendix A. The rankings of the company can be found in Table 4-1: Satisfaction Values of Performance Measures for the Company.

To determine the influence of the factors on the customer satisfaction level of the company’s supply chain, the Kano Evaluation method was used to classify the factors in one type of requirement. The two questions relating to the functionality of the factors were asked and the requirement types for each factor was obtain based on the answers provided. The answers are similar to the ones of the illustrative example of Chapter 3. The requirement types remained the same. Therefore, price, commitment and response speed were one-dimensional factors. Brand remained an attractive factor and service quality a must-be factor.

4.3 Weights and Satisfaction Values

The influence of the factor within the requirement types is determined with the weights of the factors. The attractive and must-be types reflect only one factor each. Thus, the weights of their respective factor, the brand factor and the service quality factor, are equal to 1. The weights

of the one-dimensional factors are determined based on the rating the customer provides for each factor: price (9), commitment (7) and response speed (4).

$$w_{price} = \frac{9}{9+7+4} = 0.45 \quad (49)$$

$$w_{commitment} = \frac{7}{9+7+4} = 0.35 \quad (50)$$

$$w_{reponse\ speed} = \frac{4}{9+7+4} = 0.20 \quad (51)$$

The weights of the performance measures, within the factors, are determined similarly. Price and response speed are only represented by one performance measure. Therefore the weights of the net dollar fill and on-time delivery performance measures are equal to 1. The weights of the performance measures of the commitment, brand and service quality factors are based on the customer ratings. It is assumed that the ratings are as follows for each factor. The ratings for the brand factor are: 100-top CoreBrand Brand Power Rank (9) and America's Favorite Brand (4). The ratings for the commitment factor are: fill rate (9) and on-time receipt (7). The ratings for the service quality factor are: case fill (5) and in-stock/service level (8). The weights of these performance measures are then calculated.

The weights for the brand performance measures are the following:

$$w_{CoreBrand} = \frac{9}{9+4} = 0.6923 \quad (52)$$

$$w_{24/7\ Wall\ St.} = \frac{4}{9+4} = 0.3077 \quad (53)$$

The weights for the commitment performance measures are the following:

$$w_{fill\ rate} = \frac{9}{9+7} = 0.5625 \quad (54)$$

$$w_{on-time\ receipt} = \frac{7}{9+7} = 0.4375 \quad (55)$$

The weights for the service quality performance measures are the following:

$$w_{case\ fill} = \frac{5}{5+8} = 0.3846 \quad (56)$$

$$w_{in-stock} = \frac{8}{5+8} = 0.6154 \quad (57)$$

Once all the weights are calculated, the next step is to compute the satisfaction value of each performance measure. The satisfaction value is calculated using the actual measures of the performance measures and the expected values or goals that the customers expect. The external measures provided by the company included data from three customers, referred to as customer A, customer B and customer C. The evaluation of customer satisfaction was arbitrarily assumed to be of customer C. Therefore, only the external measures and goals provided by customer satisfaction C were utilized in the calculation of the satisfaction values. Additionally, the goals of the dollar fill measures were not available. Thus the expected value for the net dollar fill measure was assumed to be 100 percent. The goals of the brand ranking measures were also assumed to be 1st place. The satisfaction values of the performance measures were for three cases. Since measures for a whole year were provided by the company, the minimum values of each measure were used to represent the worst case scenario possible for the year 2012. The maximum values were used for the best case, and the average values were used as the expected customer satisfaction value for that year. The satisfaction values for all three cases were calculated using equations 5 through 8. When the actual value exceeded the goals or expectations of the customer, the satisfaction value was set as 1. Since the satisfaction values of the performance measures were calculated for the worst, the expected and the best scenarios, the customer satisfaction level of the supply chain for all three cases will be evaluated. The satisfaction values for all three cases are provided in Table 4-1.

Table 4-1: Satisfaction Values of Performance Measures for the Company

Performance Measures	**Expected Value (E)**	**Actual Value (A_{min}, A_{avg}, A_{max})**	**Range (Min-Max)**	**Satisfaction Value (X_{min}, X_{avg}, X_{max})**
Net Dollar Fill (%)	100	(97.18, 98.16, 99.23)	0 - 100	(.9718, .9816, .9923)
CoreBrand	1	2	1 - 1200	.9991
America's Fav. …	1	4	1 - 10	.6667
Fill Rate (%)	98	(94.70, 97.93, 98.70)	0 - 100	(.9670, .9993, 1)
On-time Rec. (%)	90	(73.80, 87.51, 95.90)	0 - 100	(.8380, .9751, 1)
On-time Del. (%)	95	(76.32, 90.07, 98.21)	0 - 100	(.8132, .9507, 1)
Case Fill (%)	98	(97.27, 98.27, 99.48)	0 - 100	(.9927, 1, 1)
In-Stock (%)	99	(99.10, 99.35, 99.50)	0 - 100	(1, 1, 1)

4.4 Evaluation of Customer Satisfaction Level in the Supply Chain

The satisfaction level of the requirement types are determined for all three cases based on the satisfaction values presented above. The weights of the factors as well as the weights of the performance measures are also used. The following equations are used to calculate the satisfaction level of the requirement types for all three cases.

$$SL_{One-Dim} = w_{price}w_{dollar\ fill}X_{dollar\ fill} + w_{commitment}w_{fill\ rate}X_{fill\ rate} + w_{commitment}w_{on-time\ rec.}X_{on-time\ rec.} + w_{resp.\ speed}w_{on-time\ del}X_{on-time\ del} \quad (58)$$

$$SL_{One-Dim} = 0.45 * 1 * X_{dollar\ fill} + 0.35 * 0.5625 * X_{fill\ rate} + 0.35 * 0.4375 * X_{on-time\ rec.} + 0.20 * 1 * X_{on-time\ del} \quad (59)$$

$$SL_{Attractive} = w_{brand}w_{CoreBrand}X_{CoreBrand} + w_{brand}w_{24/7W\ all\ St.}X_{24\ /7Wall\ St.} \quad (60)$$

$$SL_{Attractive} = 1 * 0.6923 * X_{CoreBrand} + 1 * 0.3077 * X_{24\ /7Wall\ St.} \quad (61)$$

$$SL_{Must-be} = w_{Service\ qual}w_{case\ fill}X_{case\ fill} + w_{Service\ qual}w_{In-stock}X_{In-stock} \quad (62)$$

$$SL_{Must-be} = 1 * 0.3846 * X_{case\ fill} + 1 * 0.6154 * X_{In-stock} \quad (63)$$

The satisfaction level of the attractive requirement type is the same for the three cases since only one ranking is provided for the year from both ranking sources. The satisfaction level of the attractive requirement type is thus calculated as:

$$SL_{Attractive} = 0.8968 \quad (64)$$

For the ***worst case*** scenario, the satisfaction levels of the one-dimensional requirement type and the must-be requirement type are:

$$SL_{One-Dim} = 0.9186 \quad (65)$$

$$SL_{Must-be} = 0.9972 \quad (66)$$

For the ***expected*** scenario, the satisfaction levels of the one-dimensional requirement type and the must-be requirement type are:

$$SL_{One-Dim} = 0.9779 \quad (67)$$

$$SL_{Must-be} = 1 \quad (68)$$

For the ***best case*** scenario, the satisfaction levels of the one-dimensional requirement type and the must-be requirement type are:

$$SL_{One-Dim} = 0.9965 \quad (69)$$

$$SL_{Must-be} = 1 \quad (70)$$

To combine the satisfaction levels of the three types of requirement, the production rules in Table 3-2 created for the illustrative example were used. The membership functions for the

satisfaction level of the attractive requirement type and of the must-be requirement type that were created for the illustrative examples were used for the company supply chain data. Thus, the set of membership functions depicted in Figure 3-3 represent the satisfaction level of the attractive requirement type. The set of membership functions depicted in Figure 3-4 represent the satisfaction level of the must-be requirement type. The set of membership functions representing the satisfaction level of the one-dimensional type of requirement as well as the customer satisfaction level of the supply chain is depicted in Figure 4-1. The functions depicted are provided in Table A-4 of Appendix A.

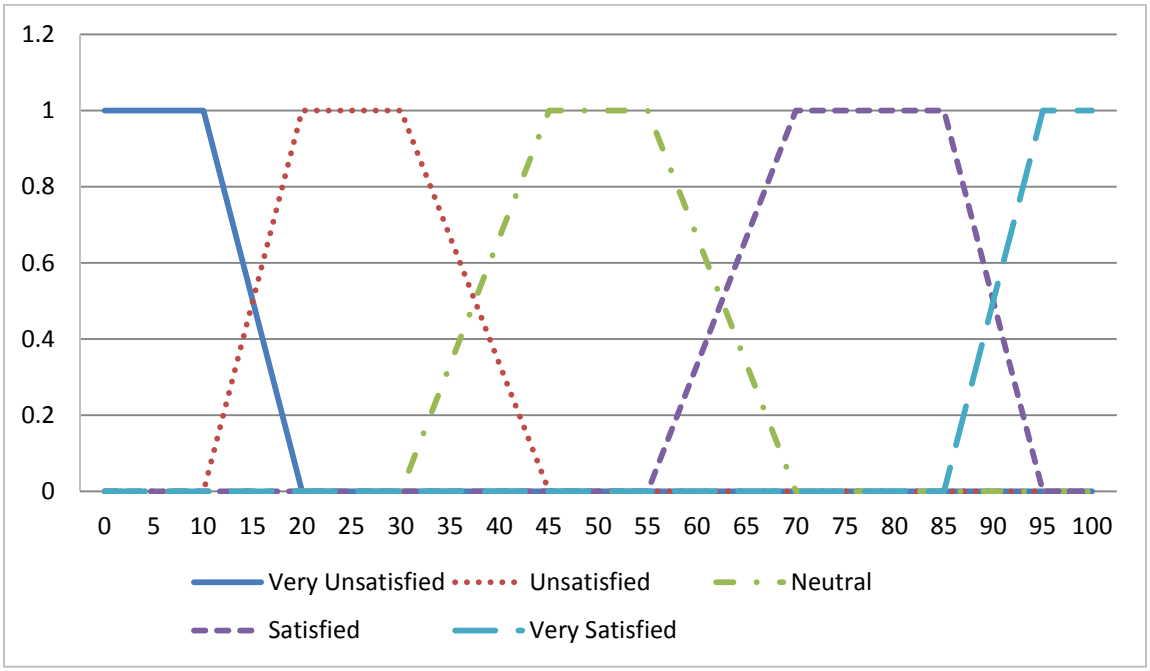


Figure 4-1: One-Dimensional Requirement and Customer Satisfaction Level Membership Functions

It is assumed that all four sets of membership functions were obtained from aggregating membership functions set by multiple customers of the company. This aggregation method was explained in section 3.4.3 and was used by Chen, Lin and Huang (Chen, et al., 2006). The sets of

membership functions used to depict the satisfaction levels of the requirement types are used to determine the corresponding fuzzy values for the satisfaction levels of the requirement types. The following values were determined for each requirement types.

In the ***worst case*** scenario, the fuzzy values of the requirement types are:

$$Satisfied\ (89.68) = \frac{(90-x)}{5} = \frac{(90-89.68)}{5} = 0.064 \quad (71)$$

$$Very\ Satisfied\ (89.68) = \frac{(x-85)}{5} = \frac{(89.68-85)}{5} = 0.936 \quad (72)$$

Attractive Requirements Fuzzy Value = 0.064 / Satisfied + 0.936 / Very Satisfied

Must-be Requirement Fuzzy Value = 1 / Neutral

$$Satisfied\ (91.86) = \frac{(95-x)}{10} = \frac{(95-91.86)}{10} = 0.314 \quad (73)$$

$$Very\ Satisfied\ (91.86) = \frac{(x-85)}{10} = \frac{(91.86-85)}{10} = 0.686 \quad (74)$$

One-Dimensional Requirements Fuzzy Value = 0.314 / Satisfied + 0.686 / Very Satisfied

In the ***expected*** scenario, the fuzzy values of the requirement types are:

Attractive Requirements Fuzzy Value = 0.064 / Satisfied + 0.936 / Very Satisfied

Must-be Requirement Fuzzy Value = 1 / Neutral

One-Dimensional Requirements Fuzzy Value = 1 / Very Satisfied

In the ***best case*** scenario, the fuzzy values of the requirement types are:

Attractive Requirements Fuzzy Value = 0.064 / Satisfied + 0.936 / Very Satisfied

Must-be Requirement Fuzzy Value = 1 / Neutral

One-Dimensional Requirements Fuzzy Value = 1 / Very Satisfied

The fuzzy values obtained for the expected scenario and the best case scenario are similar. Thus, applying the production rules and defuzzifying these values will provide the same customer satisfaction level for the expected and the best case scenarios. The customer satisfaction Fuzzy Values are determined by using the production rules as follows.

Customer Satisfaction Fuzzy Value $_{\text{Worst Case}}$ =

0.064 / Satisfied AND 1 / Neutral AND 0.314 / Satisfied +

0.064 / Satisfied AND 1 / Neutral AND 0.686 / Very Satisfied +

0.936 / Very Satisfied AND 1 / Neutral AND 0.314 / Satisfied +

0.936 / Very Satisfied AND 1 / Neutral AND 0.686 / Very Satisfied

Customer Satisfaction Fuzzy Value $_{\text{Worst Case}}$ =

Max (Min (0.064, 1, 0.314), Min (0.936, 1, 0.314)) / Satisfied +

Max (Min (0.064, 1, 0.686), Min (0.936, 1, 0.686)) / Very Satisfied

Customer Satisfaction Fuzzy Value $_{\text{Worst Case}}$ = 0.314 / Satisfied + 0.686 / Very Satisfied

Customer Satisfaction Fuzzy Value $_{\text{Expected \& Best Case}}$ =

0.064 / Satisfied AND 1 / Neutral AND 1/ Very Satisfied +

0.936 / Very Satisfied AND 1 / Neutral AND 1/ Very Satisfied

Customer Satisfaction Fuzzy Value $_{\text{Expected \& Best Case}}$ =

Max (Min (0.064, 1, 1), Min (0.936, 1, 1)) / Very Satisfied

Customer Satisfaction Fuzzy Value $_{\text{Expected \& Best Case}}$ = 0.936 / Very Satisfied

The customer satisfaction level of the company's supply chain is then obtained by defuzzifying the customer satisfaction fuzzy value. This is done with the use of the center of gravity formula provided in equation (3). The worst case scenario customer satisfaction level of

the company's supply chain is determined by calculating the center of gravity of the shaded area in Figure 4-2. The expected or best case scenario customer satisfaction level of the supply chain is determined with the center of gravity of the shaded area in Figure 4-3.

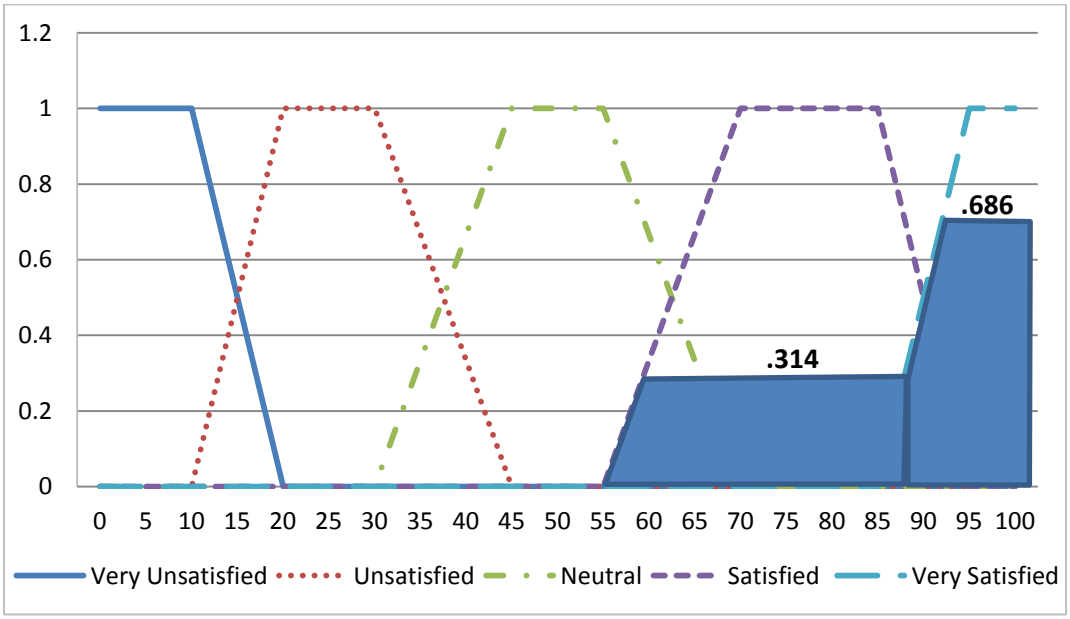


Figure 4-2: Worst Case Customer Satisfaction Fuzzy Value

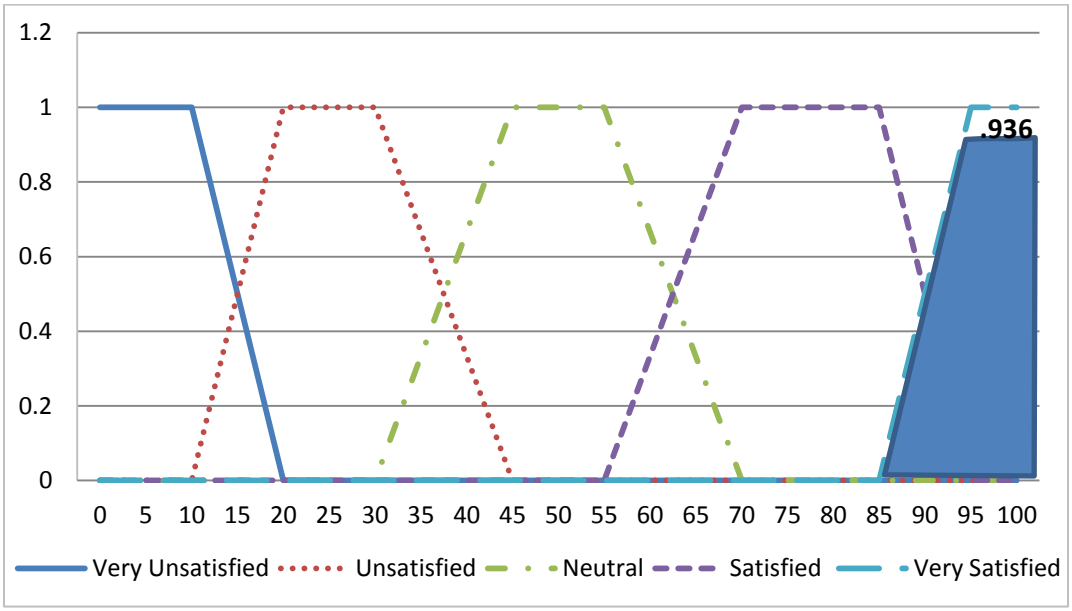


Figure 4-3: Expected and Best Case Customer Satisfaction Fuzzy Value

The customer satisfaction level for the worst case scenario is calculated as follows:

Customer satisfaction $_{\text{Worst Case}}$ =

$$\frac{\int_{55}^{59.71}\left(\frac{x-55}{15}\right)xdx+\int_{59.71}^{88.14}.314xdx+\int_{88.14}^{91.86}\left(\frac{x-85}{10}\right)xdx+\int_{91.86}^{100}.686xdx}{\int_{55}^{59.71}\left(\frac{x-55}{15}\right)dx+\int_{59.71}^{88.14}.314dx+\int_{88.14}^{91.86}\left(\frac{x-85}{10}\right)dx+\int_{91.86}^{100}.686dx}$$

$$=\frac{1406.4287}{17.1105}=82.1968 \quad (75)$$

The customer satisfaction level for the expected scenario and the best case scenario is calculated as follows:

Customer satisfaction $_{\text{Expected \& Best Case}}$ =

$$\frac{\int_{85}^{94.36}\left(\frac{x-85}{10}\right)xdx+\int_{94.36}^{100}.936xdx}{\int_{85}^{94.36}\left(\frac{x-85}{10}\right)dx+\int_{94.36}^{100}.936dx}$$

$$=\frac{912.6921}{9.6595}=94.4865 \quad (76)$$

The customer satisfaction level of the company was evaluated to be 82.20 % in the worst case scenario for the year 2012. The expected level of satisfaction for the year and the best case scenario customer satisfaction level were evaluated as 94.49 %. Using the linguistic terms of the set of membership functions of the customer satisfaction level, it was determined that the customer was “satisfied” in the worst case scenario. In the best case, and in general, the customer was determined to be slightly “satisfied” and considerably “very satisfied” in regards of the supply chain. The customer’s opinion of the company’s supply chain was based on the price of the product purchased, the ranking of the brand, the commitment and the response speed of the supply chain and of course the quality of the service provided.

Chapter 5

Conclusion

As was explained at the start of this thesis, the customer is the most important element of a supply chain. In order for a company to be successful, customer satisfaction is a necessity. To ensure customer satisfaction, a company must be aware of its customers' needs and of the factors influencing customer satisfaction.

In this thesis, the factors which influence customer satisfaction across all supply chains were focused upon. Measures reflecting the performance of these factors were used to evaluate customer satisfaction and in turn, monitor the progress of supply chains in satisfying their customers. As was mentioned in the introduction, this research had three distinct goals. The first was to identify the factors which directly or indirectly relate to customer satisfaction. The second was to identify the degree to which each factor affects customer satisfaction. The last goal was to create a methodology to help measure customer satisfaction in supply chain based on the factors identified.

The first goal of identifying the factors affecting customer satisfaction in supply chain was accomplished with a literature review. Out of several studies, factors pertinent to this research were selected due to their relation to customer satisfaction in supply chain. Price, brand, quality, commitment and response speed were the factors that were picked. The measures reflecting the performance of each factor were also selected from the literature. The second goal of identifying the degree to which each factor affects customer satisfaction in supply chain is achieved by requesting the input of the customer. The customer needed to identify which type of requirement the factors represent. By classifying the factors between the six types of customer

requirements, the customer helps with the understanding of how the factors affect customer satisfaction. The degree to which the factors influence customer satisfaction is determined only to a certain extent, since the weights of each factor were calculated within each type of requirement.

The last goal of this research was to measure the level of customer satisfaction in supply chain. This was done by calculating a satisfaction value for each performance measure, calculating the level of satisfaction within each type of requirement and then combining the level of satisfactions of the requirement to obtain the final customer satisfaction level. Combining the satisfaction level of each type requirement proved to be challenging since the attractive and must-be requirements do not affect the customer satisfaction level in a proportional manner. Fuzzy set theory, a tool capable of handling uncertainty and vagueness in terms, was proposed as a suitable method to deal with this issue.

The methodology proposed in the thesis has the customer satisfaction value mostly depend on the set of membership functions of the requirement types and on the set of membership functions of the customer satisfaction. Therefore, it is imperative that the customers of the supply chain being evaluated are used to determine all sets of membership functions of satisfaction levels. The evaluation of the customer satisfaction level for the case study was accomplished based on assumed sets of membership functions due to the lack of access to the actual customers. A more accurate satisfaction level would be possible if the membership functions were set from ratings collected from the company's customer surveys. The degree of membership of the various levels of each requirement type and of the customer satisfaction ultimate value would then suitably reflect the customers feeling towards the supply chain.

In this research, combining the satisfaction values of the different type of requirements was accomplished with the use of fuzzy logic. Since fuzzy logic introduces a certain amount of imprecision in the customer satisfaction evaluation, it would be advantageous to discover a new method of combining the satisfaction value of the type of requirements. Thus future work could

be focused on determining whether or not a correlation exists between the satisfaction levels of the requirement types. If a correlation does exist, the use of fuzzy logic may no longer be appropriate.

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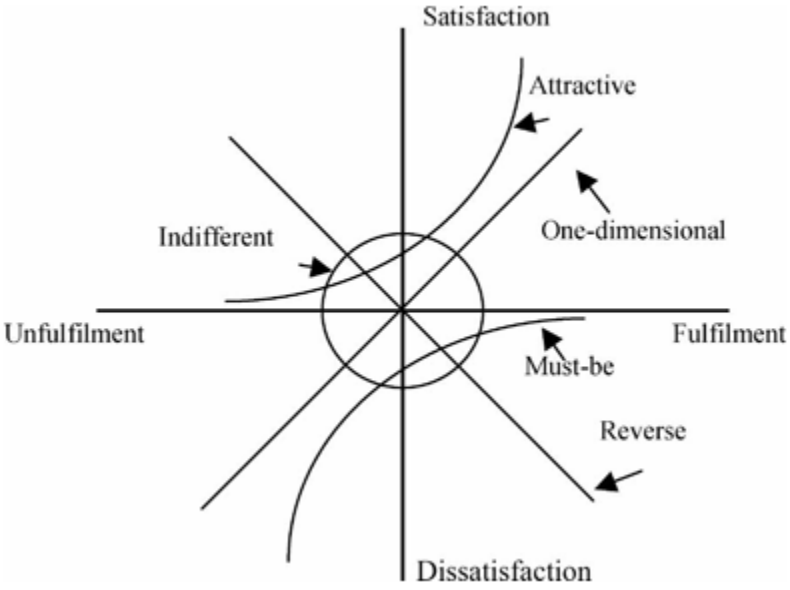
Appendix

Appendix A

Tables and Data



(Yang, 2005)

Figure A-1: Kano's Model Quality of Attributes

Table A-1: Membership Functions for Satisfaction Level of One-dimensional Requirement Type and Customer Satisfaction Level for Illustrative example

Linguistic Term	**Mu(x)**	**Range**
Very Unsatisfied	**1**	**0 to 15 %**
Very Unsatisfied	(20 - x) / 5	15 to 20 %
Unsatisfied	(x - 15) / 5	
Unsatisfied	**1**	**20 to 30 %**
Unsatisfied	(45 - x) / 15	30 to 45 %
Neutral	(x - 30) / 15	
Neutral	**1**	**45 to 55 %**
Neutral	(70 - x) / 15	55 to 70 %
Satisfied	(x - 55) / 15	
Satisfied	**1**	**70 to 80 %**
Satisfied	(90 - x) / 10	80 to 90 %
Very Satisfied	(x - 80) / 10	
Very Satisfied	**1**	**90 to 100 %**

Table A-2: Membership Functions for Satisfaction Level of Attractive Requirement Type

Linguistic Term	**Mu(x)**	**Range**
Neutral	**1**	**0 to 65 %**
Neutral	(75 - x) / 10	65 to 75 %
Satisfied	(x - 65) / 10	
Satisfied	**1**	**75 to 85 %**
Satisfied	(90 - x) / 5	85 to 90 %
Very Satisfied	(x - 85) / 5	
Very Satisfied	**1**	**90 to 100 %**

Table A-3: Membership Functions for Satisfaction Level of Must-be Requirement Type

Linguistic Term	**Mu(x)**	**Range**
Very Unsatisfied	**1**	**0 to 50 %**
Very Unsatisfied	(60 - x) / 10	50 to 60 %
Unsatisfied	(x - 50) / 10	
Unsatisfied	**1**	**60 to 80 %**
Unsatisfied	(100 - x) / 10	80 to 90 %
Neutral	(x - 90) / 10	
Neutral	**1**	**90 to 100 %**

Table A-4: Membership Functions for Satisfaction Level of One-dimensional Requirement Type and Customer Satisfaction Level for the case study

Linguistic Term	**Mu(x)**	**Range**
Very Unsatisfied	**1**	**0 to 10 %**
Very Unsatisfied	(20 - x) / 10	10 to 20 %
Unsatisfied	(x - 10) / 10	
Unsatisfied	**1**	**20 to 30 %**
Unsatisfied	(45 - x) / 15	30 to 45 %
Neutral	(x - 30) / 15	
Neutral	**1**	**45 to 55 %**
Neutral	(70 - x) / 15	55 to 70 %
Satisfied	(x - 55) / 15	
Satisfied	**1**	**70 to 85 %**
Satisfied	(95 - x) / 10	85 to 95 %
Very Satisfied	(x - 85) / 10	
Very Satisfied	**1**	**95 to 100 %**

Table A-5: Performance Measure data for Illustrative Example (1)

	Price	Commitment		Response Speed	Process Quality
	Average in Market($)	On time Delivery (%)	Fill rate (%)	Average Delivery times (days)	Forecasting Accuracy (%)
	259	89.47	97.37	6	67.75
	342	93.82	97.27	18	74.44
	356	86.21	94.99	17	61.75
	483	95.36	98.51	1	62.96
	426	89.97	91.64	19	76.9
	339	75.52	96.6	20	65.97
	642	98.38	98.13	27	55.31
	376	81.85	92.43	1	73.11
	503	96.4	95.37	10	56.42
	307	81.94	93.49	19	63.71
	458	92.39	96.99	27	80.81
	589	97.87	92.45	22	77.53
Average	**423.33**	**89.93**	**95.44**	**15.58**	**68.06**
Max	**642.00**	**98.38**	**98.51**	**27.00**	**80.81**
Min	**259.00**	**75.52**	**91.64**	**1.00**	**55.31**

Table A-6: Performance Measure data for Illustrative Example (2)

	Product Quality	Service Quality		
	Quality Failure Rate (%)	Rate of shipping Errors (%)	Rate of outage (%)	Time taken to solve complaints (days)
	12.97	16.23	0.11	6
	12.73	23.61	1.92	12
	6.51	9.66	7.72	8
	5.77	4.04	7.61	8
	14.75	13.04	4.31	3
	12.21	4.41	5.21	1
	2.91	6.2	2.6	15
	9.63	4.74	3.01	3
	8.81	2.07	4.15	17
	9.51	10.14	5.63	7
	13.45	15.32	7.92	21
	14.21	21.15	1.54	12
Average	**10.29**	**10.88**	**4.31**	**9.42**
Max	**14.75**	**23.61**	**7.92**	**21.00**
Min	**2.91**	**2.07**	**0.11**	**1.00**

Table A-7: 2012 Internal Measurements for Case Study Company

Calendar year / week	Case Fill	Gross Dollar Fill	Net Dollar Fill	On-Time Delivery
01/2012	98.74 %	98.71 %	98.70 %	92.17 %
02/2012	98.67 %	98.74 %	98.73 %	94.41 %
03/2012	98.70 %	98.58 %	98.56 %	93.44 %
04/2012	99.09 %	99.06 %	98.93 %	90.67 %
05/2012	99.28 %	99.20 %	99.15 %	91.62 %
06/2012	98.90 %	98.73 %	98.73 %	93.16 %
07/2012	98.84 %	98.83 %	98.78 %	91.26 %
08/2012	98.99 %	98.74 %	98.72 %	92.41 %
09/2012	99.48 %	99.26 %	99.23 %	85.63 %
10/2012	98.60 %	98.95 %	98.94 %	91.72 %
11/2012	98.60 %	98.99 %	98.94 %	87.52 %
12/2012	98.55 %	99.01 %	98.99 %	90.64 %
13/2012	98.08 %	98.72 %	98.65 %	90.73 %
14/2012	97.67 %	98.12 %	98.08 %	90.74 %
15/2012	98.28 %	98.28 %	98.24 %	93.13 %
16/2012	98.09 %	97.79 %	97.78 %	93.82 %
17/2012	99.30 %	98.92 %	98.90 %	94.71 %
18/2012	99.18 %	98.99 %	98.93 %	93.82 %
19/2012	98.77 %	98.24 %	98.23 %	91.60 %
20/2012	98.86 %	98.50 %	98.47 %	92.28 %
21/2012	98.65 %	98.72 %	98.62 %	90.81 %
22/2012	98.12 %	98.50 %	98.48 %	91.05 %
23/2012	98.13 %	98.24 %	98.20 %	89.54 %
24/2012	97.84 %	98.11 %	98.04 %	92.77 %
25/2012	98.04 %	98.61 %	98.55 %	88.74 %
26/2012	98.67 %	98.65 %	98.63 %	90.52 %
27/2012	98.44 %	98.32 %	98.25 %	89.55 %
28/2012	98.00 %	98.14 %	97.99 %	91.14 %
29/2012	97.27 %	97.58 %	97.44 %	90.57 %
30/2012	98.40 %	98.23 %	98.21 %	93.72 %
31/2012	97.96 %	97.65 %	97.60 %	87.93 %
32/2012	98.27 %	98.10 %	98.08 %	82.95 %
33/2012	98.07 %	97.86 %	97.81 %	89.68 %
34/2012	97.69 %	97.76 %	97.58 %	85.93 %
35/2012	97.33 %	97.43 %	97.35 %	84.99 %
36/2012	98.50 %	98.11 %	98.08 %	89.86 %
37/2012	97.96 %	97.20 %	97.18 %	90.80 %
38/2012	97.85 %	97.58 %	97.53 %	88.71 %

Calendar year / week	Case Fill	Gross Dollar Fill	Net Dollar Fill	On-Time Delivery
39/2012	98.00 %	97.48 %	97.47 %	90.02 %
40/2012	98.23 %	97.57 %	97.54 %	89.81 %
41/2012	98.00 %	97.81 %	97.76 %	89.50 %
42/2012	97.44 %	97.55 %	97.50 %	91.79 %
43/2012	97.87 %	97.78 %	97.73 %	88.02 %
44/2012	97.53 %	97.71 %	97.61 %	76.32 %
45/2012	97.72 %	97.95 %	97.90 %	89.46 %
46/2012	98.10 %	97.76 %	97.72 %	89.22 %
47/2012	98.51 %	98.32 %	98.28 %	90.49 %
48/2012	97.93 %	97.78 %	97.75 %	89.16 %
49/2012	97.45 %	97.57 %	97.51 %	92.19 %
50/2012	97.94 %	97.55 %	97.44 %	95.11 %
51/2012	97.76 %	97.60 %	97.52 %	87.63 %
52/2012	98.32 %	98.33 %	98.30 %	98.21 %
Overall Result (Average)	98.27 %	98.21 %	98.16 %	90.07 %
Maximum	99.48 %	99.26 %	99.23 %	98.21 %
Minimum	97.27 %	97.20 %	97.18 %	76.32 %
Goals	98.00 %	N/A	N/A	95.00 %

Table A-8: 2012 Customer Measurements (As reported by Case Study Company)

	Customer A			Customer B			Customer C		
	Fill Rate	In-Stock	On-time Receipt	Fill Rate	In-Stock	On-time Receipt	Fill Rate	In-Stock	On-time Receipt
Jan	98.80%	97.30%	72.60%	98.40%	96.80%	97.20%	97.70%	99.10%	91.90%
Feb	99.00%	96.90%	83.50%	98.80%	95.70%	95.40%	98.70%	99.40%	90.90%
Mar	99.10%	97.70%	86.60%	99.00%	96.50%	97.40%	98.30%	99.10%	95.90%
Apr	98.90%	98.40%	76.10%	99.00%	96.00%	90.50%	94.70%	99.20%	95.00%
May	97.80%	98.50%	77.00%	97.40%	96.30%	94.10%	98.00%	99.50%	95.50%
Jun	97.20%	95.30%	81.00%	95.70%	96.10%	93.20%	97.80%	99.30%	89.30%
Jul	98.40%	97.90%	83.20%	99.40%	97.20%	97.80%	98.60%	99.40%	91.30%
Aug	98.60%	97.60%	65.30%	99.10%	95.50%	77.40%	98.30%	99.50%	75.00%
Sep	98.10%	97.80%	79.80%	99.30%	97.70%	95.50%	98.70%	99.20%	73.80%
Oct	98.20%	97.80%	62.20%	98.40%	98.20%	92.00%	98.50%	99.50%	84.70%
Nov	98.30%	97.80%	65.90%	98.50%	98.20%	93.90%	98.40%	99.50%	80.60%
Dec	98.60%	97.70%	65.90%	99.90%	96.80%	91.10%	97.50%	99.50%	86.20%
Avg	98.42%	97.56%	74.93%	98.58%	96.75%	92.96%	97.93%	99.35%	87.51%
Max	99.10%	98.50%	86.60%	99.90%	98.20%	97.80%	98.70%	99.50%	95.90%
Min	97.20%	95.30%	62.20%	95.70%	95.50%	77.40%	94.70%	99.10%	73.80%
Goals	98.00%	95.90%	85.00%	96.00%	95.00%	96.00%	98.00%	99.00%	90.00%

Appendix B

SERQUAL

DIRECTIONS: This survey deals with your opinions of _____ services. Please show the extent to which you think firms offerings _____ services should possess the features described by each statement. Do this by picking one of the seven numbers next to each statement. If you strongly agree that these firms should possess a feature, circle the number 7. If you strongly disagree that these firms should possess a feature, circle 1. If your feelings are not strong, circle one of the numbers in the middle. There are no right or wrong answers – all we are interested in is a number that best shows your expectations about firms offering _____ services.

E1. They should have up-to-date equipment.

E2. Their physical facilities should be visually appealing.

E3. Their employees should be well dressed and appear neat.

E4. The appearance of the physical facilities of these firms should be in keeping with the type of services provided.

E5. When these firms promise to do something by a certain time, they should do so.

E6. When customers have problems, these firms should be sympathetic and reassuring.

E7. These firms should be dependable.

E8. They should provide their services at the time they promise to do so.

E9. They should keep their records accurately.

E10. They shouldn't be expected to tell customers exactly when services will be performed. (-)*

E11. It is not realistic for customers to expect prompt service from employees of these firms. (-)

E12. Their employees don't always have to be willing to help customers. (-)

E13. It is OK if they are too busy to respond to customer requests promptly.

E14. Customers should be able to trust employees of these firms.

E15. Customers should be able to feel safe in their transactions with these firm's employees.

E16. Their employees should be polite.

E17. Their employees should get adequate support from these firms to do their jobs well.

E18. These firms should not be expected to give customers individual attention. (-)

E19. Employees of these firms cannot be expected to give customers personal attention. (-)

E20. It is unrealistic to expect employees to know what the needs of their customers are. (-)

E21. It is unrealistic to expect these firms to have their customers' best interests at heart. (-)

E22. They shouldn't be expected to have operating hours convenient to all their customers. (-)

DIRECTIONS: The following set of statements relate to your feelings about XYZ. For each statement, please show the extent to which you believe XYZ has the feature described by the statement. Once again, circling a 7 means that you strongly agree that XYZ has that feature, and circling 1 means that you strongly disagree. You may circle any of the numbers in the middle that show how strong your feelings are. There are no right or wrong answers – all we are interested in is a number that best shows your perceptions about XYZ.

P1. XYZ has up-to-date equipment.

P2. XYZ's physical facilities are visually appealing.

P3. XYZ's employees are well dressed and appear neat.

P4. The appearance of the physical facilities of XYZ is in keeping with the type of services provided.

P5. When XYZ promises to do something by a certain time, it does so.

P6. When you have problems, XYZ is sympathetic and reassuring.

P7. XYZ is dependable.

P8. XYZ provides its services at the time it promises to do so.

P9. XYZ keeps its records accurately.

P10. XYZ does not tell customers exactly when services will be performed. (-)

P11. You do not receive prompt service from XYZ's employees.

P12. Employees of XYZ are not always willing to help customers. (-)

P13. Employees of XYZ are too busy to respond to customer requests promptly. (-)

P14. You can trust employees of XYZ.

P15. You feel safe in your transactions with XYZ's employees.

P16. Employees of XYZ are polite.

P17. Employees get adequate support from XYZ to do their jobs well.

P18. XYZ does not give you personal attention. (-)

P19. Employees of XYZ do not give you personal attention. (-)

P20. Employees of XYZ do not know what your needs are. (-)

P21. XYZ does not have your best interests at heart. (-)

P22. XYZ does not have operating hours convenient to all their customers. (-)

*A seven-point scale ranging from "Strongly Agree: (7) to "Strongly Disagree" (1), with no labels for the intermediate scale points (i.e., 2 through 6), accompanied each statement. Also, the statements were in random order in the questionnaire. A complete listing of the 34-item instrument used in the second stage of data collection can be obtained from the first author.

*Ratings on these statements were reverse-scored prior to data analysis. (Parasuraman, et al., Spring 1988)