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## Modelling Supply Chain Resilience and Organisational Performance for Selected Small and Medium Scale Enterprises

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### **Abstract:**

*The ability of a supply chain to prepare for, resist, and recover from disruption is defined by its level of resilience. In recent times, the focus on the improvement of supply chain resilience has been characterised by subjectivity and vagueness of the attributes of the organisations. While small and medium enterprises (SMEs) contribute substantial part of the GDP in many nations, research has been sparse on their supply chain resilience. This study is aimed at bridging the research gap by developing a model for measuring supply chain resilience of SMEs using the Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) and Fuzzy Inference System.*

*This study was carried out in three phases. Identification of critical attributes of supply chain resilience of SMEs was done in the first phase using Fuzzy-Analytic Hierarchy Process. In the second phase, a fuzzy inference system for measuring supply chain resilience levels was developed. Critical attributes were divided into 3 broad categories of preparedness, resistance, and response and recovery attributes which serve as inputs into the resilience fuzzy inference system. Data from seven (7) SMEs in the agricultural, water packaging, foods, and fabrication sectors were used to validate the system. The third phase of the study involved the identification of the relationship between supply chain resilience of the SMEs and organisational performance.*

*Seven attributes, financial capability, agility, recoverability, flexibility, redundancy, security, and awareness with percentage contribution of 17.0%, 13.6%, 10.8%, 10.5%, 9.9%, 9.1%, and 8.2% respectively were found to be critical to achieving more than 75% resilience of the supply chain for the SMEs. The resilience fuzzy inference system developed gave the supply chain resilience index of the selected SMEs. Resilience investments can be considered as sunk costs with benefits accruing at later dates.*

**Keywords:** Supply chain, resilience, fuzzy logic, fuzzy-AHP

### **1. Introduction**

A supply chain is often defined as the totality of all functions that are involved in the planning, production, storing and distribution of products and services to maintain the flow of information and goods from the suppliers to the end user often carried out by a network of organisations (Mentzer *et al.*, 2001, Janvier-James, 2012, Singh *et al.*, 2019). There are different functions carried out by different parties within a supply chain which may include forecasting, warehousing, and so on, however in the process of carrying out these functions, unforeseen disruptions that can affect the flow of goods and information often occur. (Qi *et al.*, 2017; Rajgopal, 2019). Behdani *et al.*, (2012) states that the effect of these disruptions in the supply chain network of small and medium enterprises (SMEs) is often faster than that of large enterprises.

Small and Medium Enterprises (SMEs), especially in developing countries like Nigeria, are often seen as agents that speed up the rate of economic growth. According to the survey carried out by National Bureau of Statistics (2017), the number of Micro, Small and Medium Enterprises (MSMEs) MSMEs as at December, 2017 in Nigeria stands at 41,593,028 why their contribution to the Gross Domestic Product stands at 49.78 percent. However, these enterprises are often faced with various challenges. Although the Nigeria micro and small enterprises had seen a significant growth of 12.1% and 4.6% respectively between 2013 and 2017, the medium enterprises had dropped significantly by 61% (Kale, 2019). According to Sama (2011) and Fasika *et al.*, (2014), some of the challenges faced may include but not limited to lack of competitive advantage, lack of flexibility in satisfying customers' demands, and lack of full supply chain integration. However, among these challenges, the effects of unforeseen disruptions cannot be overemphasized in the SMEs' supply chain. Large enterprises often face the challenges of disruptions more differently than the small and medium enterprise because of the large nodes of the supply chain they possess (Abdul-Malik *et al.*, 2014).

Supply chain disruptions are unanticipated occurrences that negatively affect the normal flow of goods and services within a chain thereby exposing the firms involved to risks (Craighead *et al.*, 2007; Vakharia and Yenipazarli, 2008). These disruptions which could be internal such as shortage of raw materials or externally caused by natural disasters often exert a significant effect on the enterprises and their supply chain performances (Abdul-Malik *et al.*, 2014; Murray, 2019). Adobor and McMullen (2018) opined that supply chain disruptions can have an obvious and significant economic impact. In a bid to mitigate the impact of disruptions on the supply chain, Sodhi (2014) emphasized on segmentation and regionalization of the supply chain which are mostly applicable in large enterprises and may be of no benefit to SMEs. For organisations to be able to withstand and absorb the shock of disruptions whenever they occur, there is a need for them to be resilient.

According to Holling, (1973), resilience is the ability of any system to be able to adjust to changes. Resilience as a concept has been used in different fields of study. Supply chain resilience is often described as the ability of a supply chain to prepare for, respond to, and recover from any interruption when it occurs (Riberio and Babaso-Povoa, 2017; Hosseini, 2019). Ponomareva and Holcomb (2009) argued that resilient organisations are more likely to possess the capability to resist and/or withstand unforeseen disruptions. The question is, what are the major attributes that can make the supply chain of an SME resilient to disruptions, and does the resiliency of the supply chain affect the performance of the enterprise? In recent years, studies have been emerging that have shed light on different issues in the area of supply chain resilience. Among these studies are the works of Wicher *et al.*, (2015) and Ali *et al.*, (2017), nevertheless, research on this area is quite sparse. As a result of the chronic effects supply chain disruptions often have on the existence of small and medium enterprises especially in a developing country like Nigeria, this research focuses on identifying the attributes that impact the supply chain resilience of SMEs and develop a model for measuring the supply chain resilience index against disruption based on the identified attribute.

## 2. Research Objectives

The objectives of the study are:

- To identify the critical attributes that makes up the supply chain resilience of small and medium enterprises.
- To develop a fuzzy logic model for measuring supply chain resilience for SMEs and apply the model to measure supply chain resilience of selected SMEs.
- To determine the relationship between supply chain resilience and organisation performance.

### 2.1. Significance of Study

This research addresses a problem in the supply chain of SMEs which involves the identification of critical attributes that contribute to supply chain resilience and measuring of the resilience index of SMEs. The result of this research will help small and medium enterprises to make informed decisions that will help them to quickly bounce back to normal operations in case of any unexpected disruptions and also help them to focus on attributes that contribute to the resiliency of their supply chain. This, in turn, will enhance their organisation competitive strength and increase market share.

## 3. Literature Review

### 3.1. Supply Chain: Small and Medium Enterprises (SMEs)

Small and Medium Enterprises (SMEs) are often defined based on the number of workers and the annual turnover of independent businesses, however, these definitions differ from country to country (Kushnir, 2010). According to the Central Bank of Nigeria under the Credit Guarantee Scheme (2010), SMEs are enterprises that have between 11 and 300 staff and asset base of between ₦5 million - ₦500 million excluding land. However, according to a survey carried out by Small and Medium Enterprise Development Agency of Nigeria and the National Bureau of Statistics (2013), SMEs are defined as enterprises with staff between 10 to 199 and turnover between ₦5 million to less than ₦500million excluding land and buildings. For the purpose of this study, SMEs will be defined as enterprises that have staff between 10 and 250 and turnover between ₦5 million and ₦500 million excluding land and buildings. Although the focus has been on supply chain practices in large enterprises, SMEs have played a major role in adding values to supply chains (Hong and Jeong, 2006). Supply chain management adoption in SMEs presents a number of advantages some of which include; reduction of production time, increased flexibility etc. (Kot *et al.*, 2007). Nonetheless, many SME's have not been able to fully integrate the supply chain management concept into their practices (Chin *et al.*, 2012).

### 3.2. Supply Chain Resilience

In recent times, resilience has become a common concept among business owners, supply chain managers, and even researchers. Although several authors view supply chain in different dimensions, there exist some common elements. These elements include preparation, resistance, and recovery from disruptions when they occur. Table 1 shows some of the recent perspectives of supply chain resilience by different authors.

Authors	Perspective	Year
Brandon-Jones <i>et al.</i>	Supply chain resilience is viewed as the ability of a supply chain system to go back to its original state, after being disturbed within an acceptable period.	2014
Federal Emergency Management Agency (FEMA)	Supply chain resilience refers to the ability of a pre-existing network of demand and supply to deploy surviving capacity, and/or introduce new capacity, under severe duress.	2019
Hosseini <i>et al.</i>	Supply chain resilience is the capability of a network to withstand, adapt, and recover from disruptions to meet customer demand and ensure performance.	2019

Table 1: Perspectives to Supply Chain Resilience  
Source: Author

### 3.3. Components of Resilience in a Supply Chain

There appears to be no consensus on the attributes or factors that make up the resilience of any supply chain. Factors differ for different case studies. Stone *et al.*, (2015) highlighted some factors that can affect the resilience of the food supply chain. The vulnerabilities were listed to include; change in government policy, product hazards, the unreliability of partners within the chain while capabilities include; efficiency, assessment, financial strength among others. Pereira and Silva (2015) proposed internal and external factors that contribute to the resilience of a supply chain and they include; technologies, product flexibility, knowledge from backup, sourcing strategically among others.

### 3.4. Measuring Resilience; Fuzzy Logic

Fuzzy logic has gained increasing popularity among researchers in the field of supply chain. Fuzzy logic is an approach to computing that is mostly based on the degree or extent of truth (Margaret, 2016). It is a branch of soft computing in which imprecision is introduced in order to reduce the granularity of a problem. It helps explore the tolerance of imprecision in the real-world system, (Dote, 1995). The fuzziness of a problem is often expressed in words for example 'very fast, very slow', the question would be how fast or how slow? As a result of the subjectivity associated with resilience, most methods are constrained in fully assessing or measuring resilience (Greccoet *et al.*, 2013). Oladokunet *al.*, (2017) developed a fuzzy inference system that helps measures flood resilience. Three input factors used were inherent resilience, supporting facility and resident capacity. The study resulted in the generation of resilience index for households with a wide range of technological, socio-economic, and environmental factors. De Iuliiset *al.*, (2019) developed a fuzzy logic algorithm to determine the resilience of a building based on the input component of downtime of a building and damage level of the building.

### 3.5. Fuzzy Analytic Hierarchy Process (Fuzzy-AHP)

Fuzzy-AHP is an integration between fuzzy with fuzzy numbers and Analytic Hierarchy Process (AHP) (Yuce, 2016). Fuzzy-AHP is a multi-criteria decision-making tool that is an extension of AHP. It is used to cater for situations where data cannot be precisely assessed (Ozdogoghu and Ozdogoghu, 2017). It helps to rank and weigh attributes or criteria in relation to an overall goal. Imprecision is often associated with data in relation to attributes/criteria. This imprecision may be as a result of unquantifiable data, incomplete information, or partial ignorance (Oguztimu, 2011).

### 3.6. Organisation Performance

Organisation performance measures refer to metrics by which each and different areas of an organisation can be measured (James, 2012). Moullin (2007) defines performance measurement as the evaluation of how well organisations are managed and values that are being delivered to customers and stakeholders. CIMA (2008) viewed performance measurement as monitoring the effectiveness of organisation in relation to pre-determined goals or the requirement of stakeholders. Barr (2012) opined that performance measure is quantifying the degree with which a performance result re-occurs.

### 3.7. Further Studies on Supply Chain Resilience

Ghafamifaret *al.*, (2018) designed a resilient competitive supply chain network under distribution risk by examining supply chains from a producer and reseller point perspective, while putting into consideration risks associated with uncertainties. A bi-level multi-objective programming approach was used. Rajesh (2019) observed that most of supply chain attributes are qualitative with respect to resilience. Given this, fuzzy logic was used to develop a model for supply chain resilience.

Bukowski (2015) proposed an expert fuzzy logic (partial) resilience model considering recoverability, survivability, and security as attributes. The impact of changes in input parameters and their effects on the output were determined through simulation. Though the system can be used to monitor and predict the output of the resilience level of a supply chain, the resilient output will be limited by the number of attributes considered. Mohammaddust *et al.*, (2017) developed a mixed integer model for supply chain design using risk reduction strategies to increase the organisational resilience. Mustafa (2015) viewed the improvement in supply chain resilience as one relating to a significant decrease in the time it takes the supply chain system to recover from disruptions. A simulation-based decision support approach was utilized to assess the resilience of the supply chain under study. The evaluation of cost trade-offs due to resilience was

adopted for different mitigation strategies in an uncertain environment. Though the study combined risk assessment and evaluation with simulation, it is observed that the factors considered as contributing to resilience are inventory and demand which are at best partial factors required to determine the overall state of the supply chain resilience.

Based on the aforementioned, much more needs to be done in identifying attributes that impact resilience in SMEs which are often constrained on organisation leverage.

#### 4. Methodology

This study is divided into 3 phases: The Critical attributes Selection Phase, the Resilience Index Determination Phase, and the Resilience-Performance relationship phase

##### 4.1. Phase 1: Selection of Critical Attributes Using Fuzzy Analytic Hierarchy Process (AHP)

For this study, ten attributes selected from the literature were analysed using the fuzzy analytic hierarchy process approach. This was to get the ranking of these factors, based on their relative weights; the attributes that made up to 75% of the resilience weights were selected for further analysis of the supply chain resilience. The selected resilience attributes include; agility, redundancy, robustness, collaboration, visibility, flexibility, awareness, security, recoverability, and financial capability. Table 2 shows the selected attributes and their associated metrics.

Attributes	Metrics
Agility	- Production lead time; - Total Cost
Redundancy	- Extra Workers; -Multiple equipment; -Extra Warehouse; -Safety Stock
Robustness	- Change in product specification; -Change in Government Policy
Collaboration	- On-time Delivery; -Share Losses; -Close accurate Forecast
Visibility	- Immediate Strategic Decision; -Availability of Mitigation plans
Flexibility	- Prompt response to input change; -Prompt response to output change; -Total Cost
Awareness	- Demand forecast; -Knowledge of upcoming disruption
Security	- Transportation Security; -Access Restriction
Recoverability	- Lead time after disruption; -Supplier Sourcing after Disruption
Financial Capability	- Customer's loyalty; Brand competitiveness

Table 2: Attributes and Metric  
Source: Adapted from Singh et al., 2019

##### 4.1.1. Pairwise Comparison of Criteria

The importance of each of the criteria was measured against one another using linguistic terms. This comparison was based on the perception of the experts used. The main goal was to get the relative importance of each criterion with respect to each other as perceived by the experts. To achieve this, an importance scaling system (1 to 9) proposed by Satty (1980) was adopted.

##### 4.1.2. Model Development

The notations that were used in this study are as follows:

$n$	=	Number of criteria/attributes
$X_{ij}$	=	Relative scale importance of attributes in row $i$ against attributes in column $j$
$i$	=	roll 1 to $n$
$j$	=	column 1 to $n$
$\check{A}$	=	Membership function with membership numbers
$U_{\check{A}}$	=	Fuzzy value associated with membership function $\check{A}$
$l$	=	lower fuzzy number for membership function $\check{A}$
$m$	=	middle fuzzy number for membership function $\check{A}$
$u$	=	upper fuzzy number for membership function $\check{A}$
$Gm_i$	=	Fuzzy geometric mean across roll $i$
$W_n$	=	Fuzzy Weight.
$\hat{W}_n$	=	De-fuzzified Weight
$N\hat{W}_n$	=	Normalized Weight
$T\hat{W}_n$	=	Total De-fuzzified Weight

##### 4.1.3. Pairwise Comparison Matrix

The number of pairwise comparisons to be carried out is given in equation 4.1

$$\text{Number of Pairwise Comparisons} = \frac{n*(n-1)}{2} \quad (4.1)$$

A matrix was formulated and the relative importance of the pairwise comparison carried out. The pairwise comparison matrix data collection sheet for attributes is given in Figure 1. The consistency ratio of the pairwise comparison should be less than or equal to 0.1 as proposed by Satty (1980).

Attributes	Agility	Redundancy	Robustness	Collaboration	Visibility	Flexibility	Awareness	Security	Recoverability	Financial Capability
Agility	1									
Redundancy		1								
Robustness			1							
Collaboration				1						
Visibility					1					
Flexibility						1				
Awareness							1			
Security								1		
Recoverability									1	
Financial Capability										1

Figure 1: Pairwise Comparison Data Collection Sheet  
Source: Author

4.1.4. Fuzzification; Linguistic Terms to Membership Functions

The linguistic terms used in the scaling system were converted into membership functions. For this study, the triangular membership function was used as shown in Figure 2. The fuzzy value used was represented as;

$$U_{\tilde{A}}(x) = \tilde{A} \tag{4.2}$$

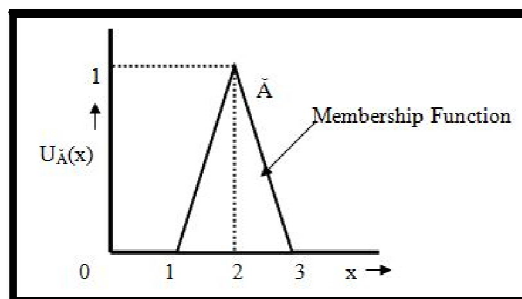


Figure 2: Triangular Membership Function  
Source: Author

For every membership function, there are associated fuzzy numbers that represent the lower, middle, and upper part of the triangle membership function. The purpose of fuzzification that is, assigning a lower, upper and medium number to represent the single scale number as used in the scaling system for the linguistic terms is to cater for the vagueness that may not be well represented by a single number. Table 3 shows the fuzzy membership functions for each linguistic term, associated fuzzy numbers and intermediate values used in this study.

Importance (Linguistic terms)	Scale	Associated Fuzzy Numbers
Equally Important	1	(1,1,1)
Moderately Important	3	(2,3,4)
Strongly important	5	(4,5,6)
Very Strongly Important	7	(6,7,9)
Extremely Important	9	(9,9,9)
Intermediate Value	2	(1,2,3)
Intermediate Value	4	(3,4,5)
Intermediate value	6	(4,5,6)

Table 3: Linguistic Terms and Associated Fuzzy Number

Equation (4.3) gives the fuzzy numbers associated with the inverse number on the scale.

$$\check{A}^{-1} = (l, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right) \tag{4.3}$$

4.1.4.1. Fuzzy Geometric Mean Calculation

After each crisp value of the scale of importance has been converted to fuzzy numbers, the fuzzy geometric mean across the rows was calculated using the equation proposed by Buckley (1985).

$$Gm_i = ((l_1 \times l_2 \times \dots \times l_n)^{1/n}, (m_1 \times m_2 \times \dots \times m_n)^{1/n}, (u_1 \times u_2 \times \dots \times u_n)^{1/n}) \tag{4.4}$$

4.1.4.2. Fuzzy Weight

The fuzzy weight of each of the attributes are calculated using equation (4.5)

$$W_i = Gm_i \times (Gm_1 + Gm_2 + \dots + Gm_n)^{-1} \tag{4.5}$$

$$Gm_1 + Gm_2 + \dots + Gm_n = (l_1 + l_2 + \dots + l_n), (m_1 + m_2 + \dots + m_n), (u_1 + u_2 + \dots + u_n) \tag{4.6}$$

4.1.4.3. De-Fuzzification of Fuzzy Weights

Using the Centre of Area (COA)

$$\hat{W}_n = \frac{l+m+u}{3} \tag{4.7}$$

4.1.4.4. Normalization of Weights

As a result of some inconsistency that may occur, the weights are normalized such that the total weights are equal to 1 (see 4.8).

$$NW_n = \frac{\hat{W}_n}{\sum \hat{W}_n} \tag{4.8}$$

The attributes are ranked according to the weights and the critical factors are selected.

4.2. Phase 2: Resilience Determination Using Fuzzy Logic

All attributes that have been identified in phase 1 with respect to their weights and cumulatively contribute 75% of supply chain resilience were selected and categorised to span through the different stages in the resiliency of a supply chain. The attributes were grouped to serve as input into the Fuzzy Inference System. The categories are: Preparedness Attributes, Resistance Attributes, Response and Recovery Attributes. Figure 3.6 shows the relationship of the input factors and a resilient supply chain output

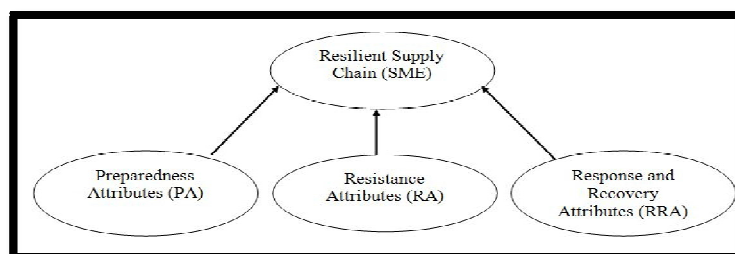


Figure 3: Attributes That Contributes to Supply Chain Resilience of SME's  
Source: Author

4.2.1. Preparedness Attributes (PA)

These are attributes of supply chain resilience that help a supply chain to anticipate changes, prepare for these changes, and taking precautionary measures when expecting a potential disruption. The constituent of this include the ability of a supply chain to forecast change in demand and supply, general knowledge of upcoming disruptions, general knowledge of the consequences of disruptions, etc. for the purpose of this study, the selected attributes that fall in this category are Visibility, Awareness, and Security.

4.2.2. Resistance Attributes (RA)

These are attributes of supply chain resilience that focus on resisting the negative effects that both foreseen and unforeseen disruption might have on a supply chain before their occurrence. Some of the constituents include the availability of safety stock, extra workers, multiple equipment, loss sharing plan, and the ability to respond to both input and output changes amongst others. The attributes in this category include; Flexibility, Redundancy, Collaboration, and Robustness.

4.2.3. Response and Recovery Attributes (RRA)

These are attributes of supply chain resilience that help a supply chain to mitigate the negative impact of disruptions on the supply chain when they occur. They include actions that can help a supply chain to respond to disruptions such that it can quickly recover from the impacts of these disruptions. Consequently, a quick, sufficient and

accurate response can help a supply chain to quickly resume its normal operation and even have a higher performance than it was. The attributes in this category include; Agility, Financial Capability, and Recoverability.

**4.2.4. Model Conversion to Equivalent Fuzzy Inference System**

The Mandani Fuzzy Inference System (FIS) was used to create the control system needed. A fuzzy inference system comprises linguistic variables, membership functions, and set of control rules. The Mandani FIS is used because of its ability to synthesise set of linguistic rules obtained from human inputs and it is a generally used and accepted attribute. Also, the rules can be easily understood and interpreted. Table 4 shows the list of the linguistic variables, membership function and term set used in this study. In order to exclusively exhaust the different scenarios that may come up based on the proposed term set, about 27 rules were used as the basis for the FIS. The number of rules was obtained by raising the number of membership functions to the power of the number of inputs.

Input	Linguistic Variables	Membership functions	Term Sets
INPUT 1	Preparedness Attributes (PA)	Trapezoidal	Inadequate
		Trapezoidal	Marginal
		Trapezoidal	Adequate
INPUT 2	Resistance Attributes (RA)	Trapezoidal	Low
		Trapezoidal	Average
		Trapezoidal	High
INPUT 3	Response and Recovery Attributes (RRA)	Trapezoidal	Poor
		Trapezoidal	Good
		Trapezoidal	Very Good
OUTPUT	Resilience	Trapezoidal	Poor
		Gaussian	Average
		Sfunction	Excellent

Table 4: Linguistic Variables, Membership Functions, and Term Sets  
Source: Author

**4.2.5. Scoring and Generation of Crisp Input value for FIS**

For the purpose of this study, the scoring sheet system is used and it is adapted from Oladokun *et al.*, (2017). This scoring sheet system is designed to make use of a checklist where an assessor ticks the number associated with the linguistic words used to describe the attitude of the assessor to what is being assessed. In order to be able to get the crisp number that was needed as input into the FIS from the scoring system, more computations are needed. This scoring system can be used both by expert and non-expert. Table 5 shows the adapted score sheet.

Attribute a	Attributes Metrics j	Rating for Input factor Metrics					Max Score	Actual Score
		Very Poor	Poor	Fair	Good	Very Good		
		1	2	3	4	5		
1. Agility	1. Production lead time				✓			
	2. Total Cost		✓					
	Aggregate Score of Agility						10	S <sub>11</sub>
2. Redundancy	1. Availability of Extra Workers			✓				
	2. Availability of Multiple equipments				✓			
	3. Availability of Extra Warehouse				✓			
	4. Availability of Safety Stock				✓			
	Aggregate Score of Redundancy						10	S <sub>21</sub>
3. Robustness	1. Change in product specification			✓				
	2. Change in Government Policy				✓			
	Aggregate Score of Robustness						10	S <sub>31</sub>

Table 5: Sample; Scoring Sheet System for Attributes  
Source: Author

The maximum Score assignable to each input is 10.

In computing, the actual and aggregate scores associated with each input attribute, the following equations were used:

$$A_{aj} = \frac{R_{aj}}{5} \times M_{aj} \quad (4.9)$$

$$S_{ai} = \sum_{j \in a} A_{aj} \quad (4.10)$$

$$W_i = \frac{\sum_{a \in i} S_{ai}}{\sum_{a \in i} N_{ia}} \times 10 \quad (4.11)$$

Where;

i	=	Index describing inputs
a	=	Index describing attributes
j	=	Index describing attributes metric
R <sub>aj</sub>	=	Likert scale rating for attribute a with metric j e.g. R <sub>22</sub> = 4 (Availability of Multiple Equipment rated good)
A <sub>aj</sub>	=	Actual score assigned to attribute i with respect to metric j
M <sub>aj</sub>	=	Maximum score assignable to attribute a with respect to metric j e.g. M <sub>32</sub> = 4 (Change in Government Policy under Factor Robustness)
N <sub>ia</sub>	=	Maximum score assignable to input i with respect to attribute a
S <sub>ai</sub>	=	Aggregate score of attribute a with respect
W <sub>i</sub>	=	Aggregate Score of Input i

#### 4.3. Phase 3: Organisation Performance Measurement

Performance measures refer to metrics by which the performance of each selected organisation was measured. For the purpose of this study, three performance measures were analysed for each of the selected SMEs. The performance measures are profitability, profit margin and productivity. The measures are given below.

$$\text{Profitability Ratio} = \frac{(\text{Total Revenue} - \text{Total Cost})}{\text{Total Revenue}} \times 100 \dots\dots\dots (4.12)$$

$$\text{Profit} = \text{Total revenue} - \text{Total Cost} \dots\dots\dots (4.13)$$

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \dots\dots\dots (4.14)$$

For this study, the output and input used in measuring productivity are the total number of sales as output and the total number of marketing staff for one productivity measure and the total number of distribution channels for the other productivity measure.

#### 4.4. Assumptions

The following assumptions were made for the purpose of this study;

- Each SME produces or sells one type of product.
- The data used for performance span over a year.
- Total cost consists of the cost of production.
- Where total cost is not known, the total cost is assumed to be 63% of the total revenue.

### 5. Results and Discussion

The results of this study are in 3 phases. Each of the phases is summarized below.

#### 5.1. Phase 1: Ranking of Critical Attributes

In the first phase, the attributes that are critical to the supply chain resilience of small and medium enterprises were identified. This was done by selecting 10 attributes from the literature which were subjected to pairwise comparison by selected experts. The inputs of these experts were analysed and the inputs that satisfied the consistency (ratio) criterion were selected. The selected inputs were subjected to Fuzzy-AHP model and normalized weights were gotten for each of 10 attributes. The first 7 attributes that contributed to more than 75% of the total weight were selected for further analysis. The attributes are financial capability, agility, recoverability, redundancy, flexibility, security, and awareness. Figure 4 shows the weighted contribution of each attributes with respect to the overall supply chain resilience.



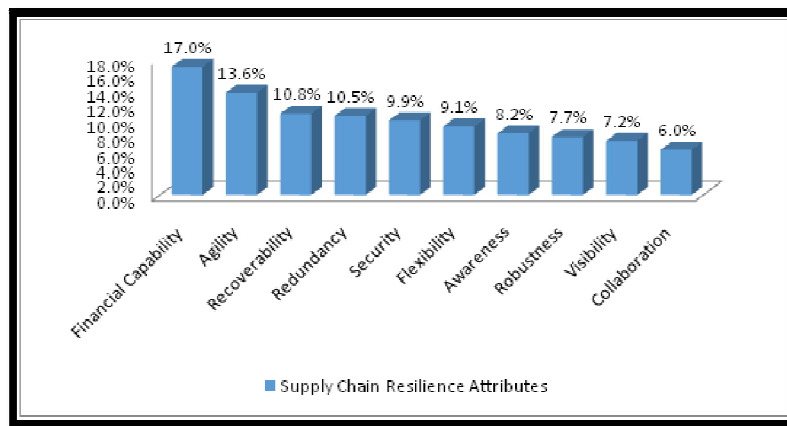


Figure 4: Ranks of Supply Chain Resilience Attributes  
Source: Author

5.2. Phase 2: Resilience Index of Selected SMEs

In the second phase of this work, a fuzzy inference system was designed that helps to measure the supply chain resilience index. Figures 5.2, 5.3, and 5.4 show the fuzzy inference system plot, the surface plot of the fuzzy inference system rules, and an example of a 3-dimensional plot of the output surface respectively. The selected attributes mentioned earlier were divided into 3-broad categories: preparedness attributes, resistance attributes, response and recovery attributes. The set of attributes served as inputs into the FIS. The output is the supply chain resilience index.

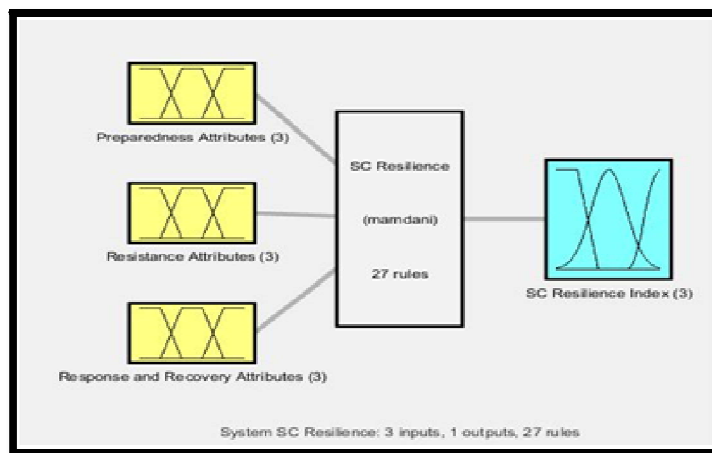


Figure 5: Plot of Fuzzy Inference System  
Source: Author

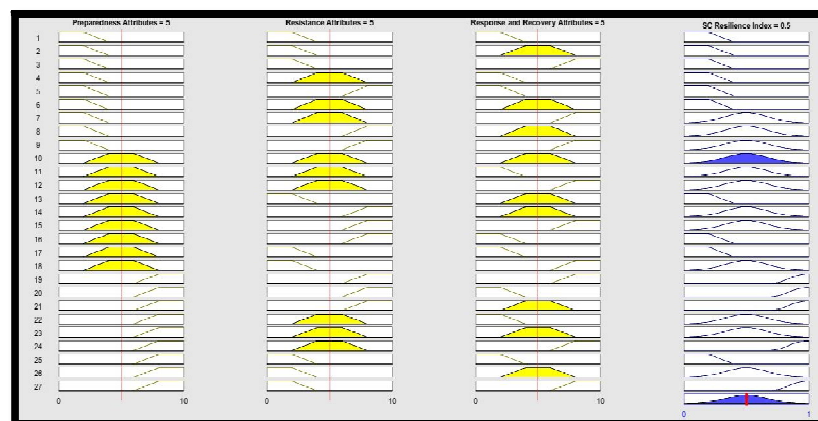


Figure 6: Surface Plot of Fuzzy Inference System Rules  
Source: Author

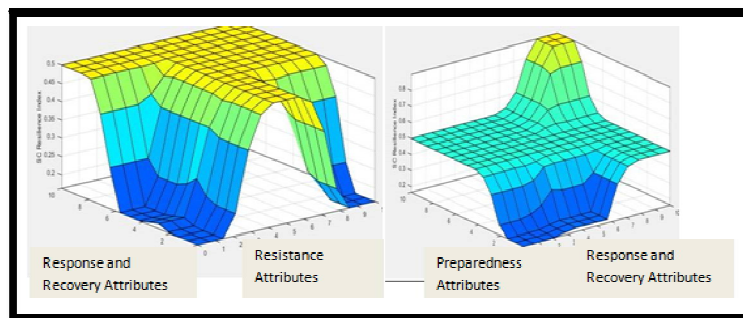


Figure 7: Example of Supply Chain Resilience 3-Dimensional Output Surface Plot

Source: Author

SMEs were selected from four industries which include agriculture, foods (Bakery), water packaging, and fabrication. The data obtained from each SME were used as input values into the system and their resilience indices determined. The SME with the highest resilience index was from the agriculture industry (Agric-Z) with a resilience index of 0.67 while the SME with the lowest resilience index was from the food industry (Bakery-M) with a resilience index of 0.50. Table 6 gives the result of the supply chain resilience index of each SME under study.

Industries	SMEs	Preparedness Attributes	Resistance Attributes	Response and Recovery	Resilience Index
Agriculture	Agric-Z	7.50	6.00	7.67	0.67
	Agric-A	7.00	6.00	7.00	0.57
Foods (Bakery)	Bakery-U	6.40	7.30	6.20	0.52
	Bakery-M	4.30	6.20	5.13	0.50
Water Packaging	Water-U	7.20	6.40	6.87	0.57
	Water-H	6.90	6.50	6.33	0.53
Fabrication	Fabric-A	6.30	6.40	7.00	0.52

Table 6: Supply Chain Resilience Index of Selected SMEs

Source: Author

### 5.3. Phase 3: Organisation Performance Measurement and Resilience Index

The selected organisation performance measures were used to assess the performance of the SMEs. The performance measures include profit margin, productivity with respect to total sales per marketing staff per year, and productivity with respect to total sales per distribution channel per year. It was observed that SMEs with lower profit margins in two of the industries have higher supply chain resilience and this was attributed to their investment in redundancy which may have led to increasing cost. However, there is a pay off in the long run as these SMEs are likely to have a stronger resistance to the effect of disruptions. In the evaluation of supply chain resilience index and productivity relating to total sales per marketing staff per year, it was observed that SMEs with the highest resilience index in Agricultural and Water packaging industries have the highest productivity level. This was attributed to the fact that resilience attributes such as agility and flexibility as built in the supply chain of these SMEs, are also built in their staff as the marketing staff area key part of the chain. On supply chain resilience index and productivity with respect to total sales per distribution channel per year, it was observed that some of the paired SMEs in the same industries have the SMEs with the lowest resilience index having the highest productivity level. It was deduced that it is necessary to seek to obtain a balance between supply chain resilience, total cost, and organization performance by focusing on the optimal number of distribution channels. Table 7 gives a summary of each performance measure and resilience indices for the SMEs under study.

Industries	SMEs	Profit Margin (%)	Productivity (Sales/Marketing Staff/Year)	Productivity (Sales/Channels/Year)	Resilience Index
Agriculture	Agric-Z	22.9	3,333	2,857	0.67
	Agric-A	37.0	1,000	19	0.57
Foods (Bakery)	Bakery-U	25.9	1,759	503	0.52
	Bakery-M	72.1	5,400	720	0.50
Water Packaging	Water-U	32.1	70,000	7,000	0.57
	Water-H	25.2	63,300	16,231	0.53
Fabrication	Fabric-A	31.0	62	186	0.52

Table 7: Summary of Organisation Performance Measures and Resilience Indices

Source: Author

Essentially, with the inputs of preparedness attributes, resistance attributes, and response and recovery attributes, the system is able to give as output the supply chain resilience index of an enterprise according to the level of inputs. Also, it aids in determining how a level of input affects the total supply chain resilience. The knowledge of the impact of each resilience inputs on the overall supply chain resilience will help SMEs understand where they stand and what attributes are needed to be improved in order to achieve a higher resilience level.

With respect to the relationship between organisational performance and supply chain resilience level, it can be inferred that in order to improve supply chain resilience, certain trade-offs are required. However, this trade-off may later become an advantage as supply chains may spend less time to recover from the effect of any disruptions as a result of the resilience investments that have been made.

## 6. Conclusion

Measuring Supply chain resilience is an integral part of the supply chain management that will not only help large enterprises but will also assist small and medium enterprises to prepare for, resist and recover from disruptions that can negatively impact their supply chain. To help improve the supply chain resilience of small and medium enterprises, this study has identified the critical attributes that SMEs need to focus on in order to improve supply chain resilience levels. These critical attributes include financial capability, agility, recoverability, redundancy, security, flexibility, and awareness. Using the fuzzy logic inference system developed for measuring supply chain resilience, resilience indices of the SMEs were determined. The design of a fuzzy logic inference system provided an approach for measuring the resilience through quantification of the subjective and vagueness characteristics of supply chain resilience attributes. It can be inferred that in order to improve supply chain resilience, certain trade-offs such as the increase in total cost has to be made. However, this trade-off may later become an advantage as less time is spent to recover from the effect of any disruptions. Resilience investments can therefore be considered as sunk costs with benefits accruing at later dates.

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