Evaluating the Flexibility Dimensions in a Supply Chain by Developing a Decision-Making Framework Through Fuzzy-TOPSIS Approach

A. B. M. Abdul Malek, Md. Farhad Hossain, and Md. Aminul Islam Tuhin
Department of Industrial and Production Engineering
Shahjalal University of Science and Technology
Sylhet, Bangladesh
abmmalek@gmail.com, farhadfaisal123@gmail.com, mdaminulislamtuhin4@gmail.com

Abstract

Supply chain flexibility means the ability to meet a growing diversity of consumer demands without incurring excessive costs, organizational disturbances, or performance losses. It's important for any company to assess its supply chain flexibility dimensions to manage its costs, resources effectively and effectively meeting customer demands. The aim of this study is evaluating the flexibility dimensions of a supply chain using Fuzzy TOPSIS method which uses MCDM approach. It aims to develop a decision-making framework which will assist any organization to evaluate their supply chain flexibility dimensions. This study focuses on five supply chain flexibility dimensions where each composes of four metrics. Five decision makers from a renowned RMG factory in Bangladesh were asked to rate the metrics with respect to each dimensions and rate the metrics from the perspective of overall supply chain performance point of view in linguistic terms. The study utilizes data obtained from the decision makers, interpreting the linguistic terms into fuzzy numbers. Fuzzy TOPSIS is used to calculate the CCi score of each dimension. Logistical processes flexibility obtained a CCi score of 0.758 and organizational structure flexibility obtained a CCi score of 0.301. Resource allocation for these two dimensions should be 26.20% and 10.46% respectively.

Keywords
Supply chain flexibility, Fuzzy TOPSIS, MCDM, Decision Framework, Resource allocation

1. Introduction
The present, highly competitive manufacturing climate is characterized by changing consumer needs and short lead time. Many companies that have previously relied on order winning through low-cost, standardized production have had to become more flexible in order to compete (Spring, 2007). The importance of flexibility in satisfying customer needs with is seen as a strategy (Fisher, 1994). Supply chain flexibility (SCF) is commonly regarded as one of the most important responses in raising market share in context with addressing unpredictability and competitiveness. SCF has grown increasingly relevant as the global rivalry has intensified and shifted to the supply chain level. A firm's capacity to adapt quickly to unanticipated changes in consumer needs and competition actions is referred as its flexibility. The flexibility related to machine, process, routing, part, worker and the like are all associated with a manufacturing or a production system. With the advent of the SC management concepts, business communities have realized that being flexible in a production system is not sufficient enough. Thus, flexibility concepts should be broadened from the perspective of a production system into an entire supply chain system (Pujawan, 2004). In contrast to industrial flexibility, Supply Chain Flexibility (SCF) implies the implied demand of adaptability inside and among all chain members. It is very crucial for modern supply chains that are characterized by increased global complexities to adjust to the changing demands and environments of businesses. It is, however, not an easy task to implement supply chain flexibility that comes with several challenges regarding its conceptualization and operationalization at the entire supply chain level. Supply chain flexibility embraces a unified process-based view that includes the core processes such as procurement, sourcing, distribution, and logistics. Hence, it envisages a much broader flexibility concept from the viewpoint of the entire value chain of supply chains. Supply chain flexibility follows a logical extension of manufacturing system flexibility. In supply chains, many sources of uncertainty have to be handled, such as market demand, supplier lead-time (LT), product quality and information delay. A supply chain management can be called sustainable if it is applied to all relevant supply chain aspects:

environmental product design, natural resource and energy efficiency, final product guarantee, after-sale service, ethical employment issues, reusing/recycling design and reverse logistics.

Supply chain flexibility is emerging as a key competitive priority in the future business environment. Supply chain flexibility is important for several reasons. First, recent trends, such as mass customization, require supply chains to meet individual customer requirements without adding additional costs. Companies are allowing customers to provide specific product information needs and are producing products for specific customers. Mass production efficiencies thus are required for quantities of one. Second, certain industries, particularly high-tech industries, require upside and downside flexibility, which generally refers to the ability to rapidly increase or decrease production (by 20% or more) to a new unplanned level and then sustain that level. Third, in many innovative product categories, such as fashion apparel, like Ready-Made Garments (RMG) and electronic devices, the uncertainty of demand is a fact of life, and creating a responsive supply chain is one method of avoiding uncertainty. Finally, the always-changing business environment calls for the rapid launch of new products, rapid customer responses around the globe, and quick return on ordering for customers, which in turn requires a supply chain to be flexible to the core extent (Chuu, 2011). This research paper thus focuses on the flexibility dimensions and metrics of a supply chain which facilitates better decision making among the top management and supply chain representatives. Organizations where there is a consolidated supply chain department, top supply chain representatives are responsible for most of the flexibility decisions. Elsewhere, top management makes the flexibility decisions. In this paper, a decision making framework is developed which can be used to evaluate the flexibility dimensions of a supply chain by Fuzzy TOPSIS method using Multi-Criteria Decision Making approach. This decision making framework will greatly help managers to take decision regarding resource allocation.

2. Literature Review

2.1 Background of the Study

The present, highly competitive manufacturing climate is characterized by increasingly sophisticated consumers that demand customized products and short lead times. Many companies that have previously relied on order winning through low-cost, standardized production have had to become more flexible in order to compete (Spring, 2007). Authors have recognized the importance of flexibility in satisfying customer needs and enhancing responsiveness to the peak point where it is now referred to as a strategic capacity (Fisher, 1994). In the context of operations management, flexibility is most commonly associated with the literature on Manufacturing Flexibility which emerged in the 1980s and 1990s with seminal papers by Slack, Gerwin and Upton (Slack, Flexibility as a manufacturing objective, 1983) (Slack, The flexibility of manufacturing systems, 1987) (Gerwin, An agenda for research on the flexibility of manufacturing processes, 1987) (Gerwin, Manufacturing flexibility: a strategic perspective, 1993) (Upton, 1995). Several studies at this time reported positive effects of manufacturing flexibility on firm performance (Swamidass, 1987). While valuable, this literature confines the study of flexibility to intra-organizational components (such as supply chain flexibility dimensions and metrics flexibility) and to production environments. Companies are becoming more reliant on service providers and sources of supply as outsourcing grows, and they are becoming more aware of the need to manage and integrate the entire value chain from raw material provider to consumer, blurring conventional firm boundaries (Fisher, 1994). Supply chain flexibility (SCF) is commonly regarded as one of the most important responses to rising market unpredictability and competitiveness. SCF has grown increasingly relevant as the global rivalry has intensified and shifted to the supply chain level. A firm's capacity to adapt quickly to unanticipated changes in consumer needs and competition actions is referred to as SCF. The flexibility related to machine, process, routing, part, worker and the like are all associated with a manufacturing or a production system. With the advent of the SC management concepts, business communities have realized that being flexible in a production system is not sufficient enough. Thus, flexibility concepts should be broadened from the perspective of a production system into an entire supply chain system (Pujawan, 2004). In contrast to industrial flexibility, Supply Chain Flexibility (SCF) implies the implied demand of adaptability inside and among all chain members. It is very crucial for modern supply chains that are characterized by increased global complexities to adjust to the changing demands and environments of businesses. It is, however, not an easy task to implement supply chain flexibility that comes with several challenges regarding its conceptualization and operationalization at the entire supply chain level. Supply chain flexibility embraces a unified process-based view that includes the core processes such as procurement, sourcing, distribution, and logistics. Hence, it envisages a much broader flexibility concept from the viewpoint of the entire value chain of supply chains. Supply chain flexibility follows a logical extension of manufacturing system flexibility. In supply chains, many sources of uncertainty have to be handled, such as market demand, supplier lead-time (LT), product quality and information delay. A supply chain is said to have sustainability if it has addressed all relevant supply chain aspects: environmental product design, natural resource and energy efficiency, final product guarantee, after-sale service, ethical employment issues, reusing/recycling design and reverse logistics.

This research paper thus focuses on the flexibility dimensions and metrics of a supply chain which facilitates better decision making among the top management and supply chain representatives. Organizations where there is a consolidated supply chain department, top supply chain representatives are responsible for most of the flexibility decisions. Elsewhere, top management makes the flexibility decisions.

2.2 Flexibility in Supply Chain

A supply chain is a network that connects a corporation with its suppliers in order to manufacture and deliver a specific product to the end user. The generic principles for flexibility are (Hagström, 2015):

- Flexibility is multi-dimensional;
- Different elements of flexibility are more important in certain environments than in others, and
- Flexibility is a capability that does not have to be demonstrated.

Supply Chain Flexibility (SCF) can thus be defined as the supply chain's ability to be responsive, reactive and change in order for the organizations to meet the changes in market demand. This is a general concept that is being widely used by researchers and supply chain managers (Hagström, 2015).

2.3 Supply Chain Flexibility Dimensions & Metrics

Supply Chain Flexibility (SCF) being a complex and multi-dimensional concept, it is difficult to assess and far more difficult to narrow it down to few dimensions. There may be a lot of external factors or dimensions that affect the supply chain flexibility directly or indirectly. Five components or dimensions of supply chain flexibility, along with four metrics, have been identified from the literature on manufacturing flexibility, strategic flexibility and the writings on supply chain flexibility. They all make up an evaluation framework of supply chain flexibility. The framework is illustrated with a simple block diagram in Figure 1.

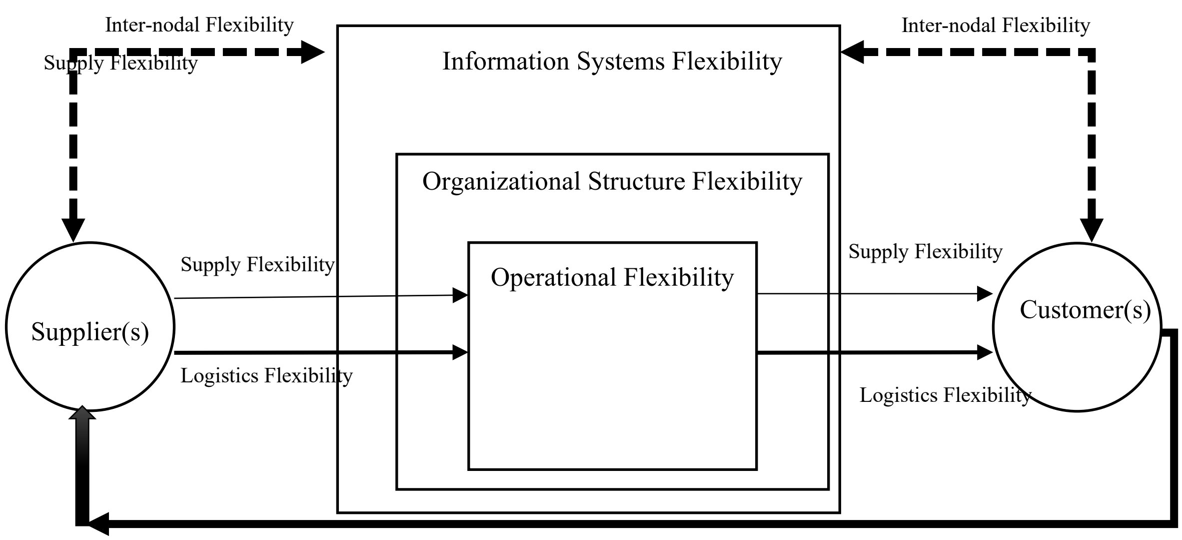

Figure 1. A conceptual frame work model of supply chain flexibility dimensions

Therefore, in this study five flexibility dimensions are taken into consideration:

1. Supply flexibility
2. Operations system flexibility
3. Logistical processes flexibility
4. Information systems flexibility
5. Organizational structure flexibility

3. Methodology

This section describes the methodology which was applied in this research. The proposed decision making framework is based on fuzzy triangular set theory and TOPSIS method. Figure. 2 shows the proposed decision making framework.

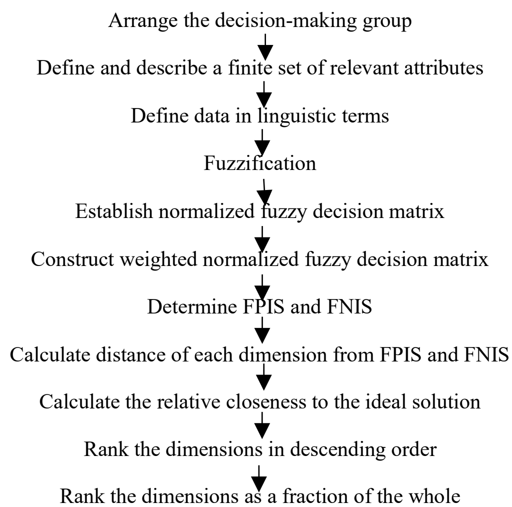

Figure 2 Proposed decision-making framework

Step 1: Arrange the decision making group

A group of five DMs (Decision Makers) was constituted to express their subjective preferences (priority importance) in linguistic terms in order to evaluate the importance grade (priority extent) of individual assessment indices at different levels (very low to very high).

Step 2: Define and describe a finite set of relevant attributes

Conversion scales are used to convert linguistic terms into fuzzy numbers. Typically, a scale of 1 to 9 is used to rate the criteria and alternatives. The intervals are chosen so that the fuzzy triangular numbers used for the five linguistic ratings have a uniform representation from 1 to 9.Similarly, the decision-making group has also been instructed to use the five point linguistic terms (very low to very high) shown in the following table to express their subjective judgement against importance grade of each dimensions. Furthermore, the proposed model assumes a group of K experts (E1,E2, . . . ,EK) are responsible for assessing the degree of SCF. In this case, which is five decision makers.

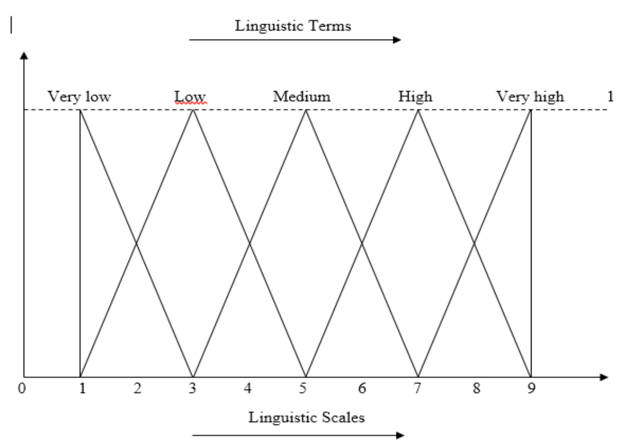

Figure 3. Linguistic variables for importance grade

Table 1. Five linguistic terms and their corresponding fuzzy representations

Linguistic terms for importance grade	Fuzzy representation
Very Low (VL)	(1,1,3)
Low (L)	(1,3,5)
Medium (M)	(3,5,7)
High (H)	(5,7,9)
Very High (VH)	(7,9,9)

Step 3: Define data in linguistic terms

In this step, the decisions makers were asked to rate the metrics with respects to each dimension and rate each metrics from the perspective of overall supply chain performance.

Step 4: Fuzzification of data

In this step, the linguistic ratings of each correspondent elements rated by Decision Makers are transformed into fuzzy scale; which are called fuzzified value of the ratings.

Step 5: Aggregate fuzzy ratings of each dimensions

Now the fuzzy ratings of dimensions are aggregated with respect to each metrics. Here, the fuzzified values are represented as, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$

Where, $a_{ij} = \min_k \{ a_{ij}^k \}$

$$b_{ij} = \frac{1}{K} \sum_{k=1}^{K} b_{ij}^k$$

$$c_{ij} = \max_k \{ c_{ij}^k \}$$

K = no. of decision makers, i = row number, j = column number

Step 6: Aggregate fuzzy weights of each metrics

The weights given to SCF metrics by each decision makers are aggregated to generate aggregated weights of metrics.

Here, the fuzzified values are represented as, $\widetilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$

Where, $w_{j1} = \min_k \{ w_{i1}^k \}$

$$w_{j2} = \frac{1}{K} \sum_{k=1}^{K} w_{i2}^k$$

$$w_{j3} = \max_k \{ w_{i3}^k \}$$

K = no. of decision makers, i = row number, j = column number

Step 7: Establish combined decision matrix

In this step, the aggregated fuzzy ratings of each dimensions and the aggregated fuzzy weights of each metrics are combined together to form a fuzzy combined decision metrics.

Step 8: Establish normalized fuzzy decision matrix

To compute the normalized fuzzy decision matrix, the cell values of combined decision matrix are normalized according to the respective cost and benefit criteria.

For benefit criteria, $\tilde{r}_{ij} = (\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*})$ and $c_j^* = \max_i\{c_{ij}\}$

For cost criteria, $\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right)$ and $a_j^- = \min_i\{a_{ij}\}$

In this study, the SCF metrics are all considered to be beneficial criteria because the maximum value is expected from them. So, no cost criteria is considered.

Step 9: Construct weighted normalized fuzzy decision matrix

To construct and compute the weighted normalized fuzzy decision matrix, the value of each cells of normalized fuzzy decision matrix (Table 4.26) are multiplied with the respective weight of each metrics.

Here, $\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j$

This follows the fuzzy multiplication rule, where

$\widetilde{A_1} \otimes \widetilde{A_2} = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2) = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2)$

Step 10: Determine FPIS and FNIS

An FPIS (Fuzzy Positive Ideal Solution) is composed of the best performance values for each dimension whereas the FNIS (Fuzzy Negative Ideal Solution) consists of the worst performance values for each dimension. Here, FPIS and FNIS of the studied problem are calculated.

For FPIS, $A^* = (\widetilde{v_1}^*, \widetilde{v_2}^*, \dots, \widetilde{v_n}^*)$, where $\widetilde{v_j}^* = \max_i\{v_{ij3}\}$

For FNIS, $A^- = (\widetilde{v_1}^-, \widetilde{v_2}^-, \dots, \widetilde{v_n}^-)$, where $\widetilde{v_j}^- = \min_i\{v_{ij1}\}]$

Step 11: Calculate distance of each dimension from FPIS and FNIS

Next up, the distance of each dimension is calculated from the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) respectively. The distances are calculated as:

$d(\tilde{x}, \tilde{y}) = \sqrt{\frac{1}{3}\,[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]}$ (E. Roghanian, 2010)

Here, (a_1, b_1, c_1) = the fuzzified value of the targeted cell

(a_2, b_2, c_2) = the value of the FPIS or FNIS cell

Step 12: Calculate the relative closeness to the ideal solution

Next, the sum of total distance is calculated for both Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS).

For FPIS, $d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*)$

For FNIS, $d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-)$

Where, d_i^* = the sum of distances from the FPIS cell.

d_i^- = the sum of distances from the FNIS cell.

Step 13: Rank the dimensions in descending order

The SCF dimensions are then ranked in descending order of the value of CC_i which represents the relative closeness coefficient value of each dimension. The highest CC_i value is ranked first to the lowest CC_i value which is ranked last.

Step 14: Rank the dimensions as a fraction of the whole

The importance percentage are then determined by fractioning the CC_i values. This is used to determine how much priority should be given to each dimensions to attain the expected degree of supply chain flexibility.

Percentage (%) importance given to dimension = $\frac{CC_i}{\sum_{i=1}^{n} CC_i}$

Here, CC_i = closeness coefficient of the i^{th} dimensions.

4. Data Collection

The rating of each metrics with respect to each supply chain flexibility dimension and the rating of each metrics with respect to overall supply chain performance by five decision makers DM1, DM2, DM3, DM4, and DM5 respectively. They put their opinion on a Likert Scale: low to very high. Table 2 shows the overall matric of the parameters in Fuzzified form.

Table 2. Fuzzified ratings of metrics with respect to each of the dimensions

Dimensions	Metrics	Fuzzification of importance grade assigned by decision makers				
		DM1	DM2	DM3	DM4	DM5
Supply Flexibility	Efficiency	(1,3,5)	(7,9,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Responsiveness	(3,5,7)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)
	Versatility	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Robustness	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)	(7,9,9)
Operations Systems Flexibility	Efficiency	(1,3,5)	(5,7,9)	(3,5,7)	(7,9,9)	(7,9,9)
	Responsiveness	(3,5,7)	(7,9,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Versatility	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Robustness	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(7,9,9)
Logistical Processes Flexibility	Efficiency	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Responsiveness	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,9)	(7,9,9)
	Versatility	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Robustness	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(7,9,9)
Information Systems Flexibility	Efficiency	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Responsiveness	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
	Versatility	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,9)
	Robustness	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(7,9,9)
Organizational Structure Flexibility	Efficiency	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)
	Responsiveness	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)
	Versatility	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)
	Robustness	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,9)	(5,7,9)

Table 3. Fuzzified ratings of each of the metrics

Metrics	Fuzzification of importance grade of metrics assigned by decision makers				
	DM1	DM2	DM3	DM4	DM5
Efficiency	(1,3,5)	(7,9,9)	(3,5,7)	(5,7,9)	(7,9,9)
Responsiveness	(3,5,7)	(7,9,9)	(3,5,7)	(3,5,7)	(7,9,9)
Versatility	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
Robustness	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)

Table 3 shows the summary of the fuzzified conversion of decision makers' ratings for the sought dimensions in each flexibility measures.

5. Results & Discussion

This section exhibits the results and outcomes of the conducted research including numerical results, graphical results and proposed improvements.

5.1 Numerical Results

Table 4. Ranking of dimensions and resource allocation

Dimensions	CC_i	Rank	Percentage (%)
Supply Flexibility	0.629	2	21.74
Operational Flexibility	0.581	4	20.08
Logistical Flexibility	0.758	1	26.20
Information Flexibility	0.624	3	21.57
Organizational Structure Flexibility	0.301	5	10.41

According to the descending order of the crisp scores (CC_i), also called ranking function value, of individual SCF dimensions, the ranking order of various dimensions were determined and shown in Table 4. By this way, the important dimensions of supply chain flexibility network can be identified which require future attention and a significant amount of emphasis should be given to these dimensions in order to boost up overall supply chain flexibility. That will result in better response to customer demands and a smoother flow of supply chain in case of situations when supply chain uncertainties occur due to numerous reasons. It is seen that among the five dimension of SCF, Logistical processes flexibility came out first (CC_i score of 0.758) and all the way to organizational structure flexibility, which is last (CC_i score of 0.301).

5.2 Graphical Results

From the below graph it is observed that the resource allocation, importance or emphasize percentage (%) for each of the flexibility dimension should be as follows and is presented with Figure 5.

1. Logistical Processes Flexibility – 26.20%
2. Supply Flexibility – 21.74%
3. Information Systems Flexibility – 21.57%
4. Operations System Flexibility – 20.08%
5. Organizational Structure Flexibility – 10.41%

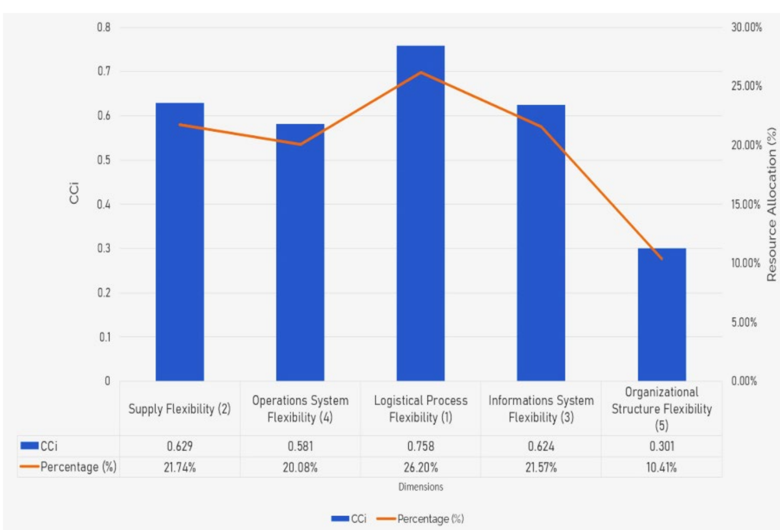

Figure 5. Ranking of supply chain flexibility dimensions

5.3 Proposed Improvements

In order to obtain flexibility, it is not enough to simply buy it. It must be planned and managed in accordance with changing circumstances in order to reap its benefits. This is only achievable if a broad view of flexibility is considered and analyzing all of the key flexibility characteristics for that situation at the same time, rather than one at a time. As a result of the research, a group decision-making structure model of flexibility in Supply Chain Management (SCM) has been developed. This research proposes a framework for assessing Supply Chain Flexibility (SCF) dimensions using the Fuzzy Triangular Number (TFN) approach based on Fuzzy TOPSIS method, as well as an assessment hierarchy with flexibility dimensions and related metrics, and an evaluation scheme that evaluates SCF using a fuzzy logic foundation. Using the proposed fuzzy-based flexibility appraisal paradigm, managers will be able to diagnose and deploy supply chain flexibility techniques more effectively. On the basis of the ranking of the supply chain flexibility dimensions, the proposed framework can also be used to evaluate the various possibilities for exploiting or acquiring flexibility methods. From the perspective of the studied company, it was observed that among the five supply chain flexibility dimensions, Logistical Processes Flexibility was ranked first based on the Closeness co-efficient Index (CC_i) score. It has scored a CC_i score of 0.758 and it requires 26.20% resource allocation of the whole. So, it is advisable that managers can exploit this dimension by allocating necessary resources (e.g. time, capital, effort, importance etc.) in order to achieve the highest possible degree of supply chain flexibility (SCF).

6. Conclusion

Due to trends in the area of globalization, technology improvements and innovations, and changes in the demand patterns and expectations of customers, organizations are dealing with constantly changing, and uncertain settings. Firms seek for flexibility in order to cope with an increasingly uncertain and rapidly changing environment. The method described above, which uses a group decision-making structure in the presence of various dimensions and related multiple metrics to assess SCF dimensions, is quite effective in supply chain development. A panel of experts and interactive consensus analysis are used in this study's model to evaluate SCF dimensions. As a result, the evaluation outcomes are more objective and unbiased than those that are evaluated separately. Logistical processes flexibility obtained a CCi score of 0.758 and organizational structure flexibility obtained a CCi score of 0.301. Resource allocation for these two dimensions should be 26.20% and 10.46% respectively. However, providing supply chain flexibility is far more complex than narrowing it down to only five dimensions. There may be a lot of external factors or other dimensions that affect the supply chain flexibility as a whole, which can be explored in different ways. Future study can be done in industries where the impact of supply chain flexibility is more rigorous. The methodology should be refined by applying it to various supply chains and a framework for evaluating Supply Chain Flexibility (SCF) should be developed based on the experiences of more supply chain assessments to reach more precise conclusions.

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Biography

Dr. A. B. M. Abdul Malek is a Professor in the Department of Industrial and Production Engineering at Shahjalal University of Science and Technology (SUST), Bangladesh. He completed both of his B.Sc. in Mechanical Engineering and M.Sc. in Industrial and Production Engineering, both from Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. He holds a Ph.D. from Higher Institution Centre of Excellence (HICoE) named UM Power Energy Dedicated Advanced Centre (UMPEDAC) at University of Malaya, Kuala Lumpur. Dr. A.B.M. Abdul Malek is actively engaged in the area supply chain management, economic and environmental assessment of renewable energy projects. His special interest is on energy, economic and environmental analysis of renewable energy based power generation systems. In the arena of supply chain management he is interested on inventory control systems. Dr. A. B. M. A. Malek is a regular course teacher in Supply Chain Management, Engineering Economy, Operations Management, Machine Tools, Productivity Management, and Energy Management. He has published a number of good articles in the prestigious journals like, Journal of Cleaner Production, Renewable and Sustainable Energy Reviews, Solar Energy, Clean Technologies and Environmental Pollution, Energy and Environment, etc. He was awarded the Dean's Research Excellence Award, 2020 from School of Applied Sciences and Technology.

Md. Farhad Hossain has completed his B.Sc. in Industrial and Production Engineering from Shahjalal University of Science and Technology (SUST), Bangladesh. He was a regular student in this department from 2017 to 2021. He completed his HSC from Ispahani Public School & College in 2016 and SSC from the same institution in 2014.

Md. Aminul Islam Tuhin has completed his B.Sc. in Industrial and Production Engineering from Shahjalal University of Science and Technology (SUST), Bangladesh. He was a regular student in this department from 2017 to 2021. He completed his HSC from MC College in 2016 and SSC from Sylhet Govt. Pilot High School in 2014.