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Modelling Supply Chain Agility Antecedents Using Fuzzy DEMATEL

Anil Jindal[a*], Satyendra Kumar Sharma[b], Kuldip Singh Sangwan[c], Gajanand Gupta[d]

[a]*Department of Mechanical Engineering, Giani Zail Singh Campus College of Engineering and Technology MRSPTU, Bathinda-151001(India)*
[b]*Department of Management, Birla Institute of Technolgy and Science Pilani – 333031 (India)*
[c]*Department of Mechanical Engineering, Birla Institute of Technolgy and Science Pilani – 333031 (India)*
[d]*Department of Mechanical Engineering,Vellore Institute of Technolgy, Chennai- 632014 (India)*

* Corresponding author. Tel.:+91-9602214677; fax:+0-000-000-0000.*E-mail address:aniljindal1981@gmail.com*

Abstract

The era we live in today is full of uncertainty and varying customer demand. Firms are managing various difficulties including consistent change, shorter item life cycles, assorted client necessities and expanded vulnerability of interest. The purpose of this paper is to put forth the dimensions along which a firm can improve its performance and enhance its sustainability through supply chain agility. Supply chain agility is a key component of all successful firms today, be it in the services or in the manufacturing sector. It is believed that an agile company would tend to outshine its competitors, who have not adopted the agile principles. Seven dimensions of supply chain agility have been identified in this paper; and their effect on each other and on supply chain agility is assessed using Fuzzy DEMATEL. Four major factors- accessibility, alertness, flexibility and swiftness are identified as the key determinants of agility. It is found that the operational flexibility and analytical capabilities of a firm play the most crucial role in determining its agility as they had the maximum effect on the overall system. This study provides the management of companies with a clear guide map as to how they can improve their agility in today's highly competitive market and how one dimension of supply chain agility has an impact on another dimension. Identification of dimensions of agility and evaluating their impact on each other as well as on supply chain agility using Fuzzy DEMATEL is a new and unique contribution to the concept of agility.

Keywords: Supply Chain agility, Flexibility, Fuzzy DAMATEL

1. Introduction

The era we live in today is full of uncertainty and varying customer demand. Firms are managing a various difficulties including consistent change, shorter item life cycles, assorted client necessities and expanded vulnerability of interest [1-2]. This has caused the firms to become more alert, responsive, flexible and quick in order to cater such requirements of customers and win orders. Braunscheidel & Suresh [3] defined supply chain agility as "the capability of the firm, both internally and in conjunction with its key suppliers and customers, to adapt or respond in a speedy manner to marketplace changes as well as to potential and actual disruptions, contributing to the agility of the extended supply chain". This concept of developing agility within and between organizations has evolved over the years and is termed as Supply Chain Agility (SCA). SCA has become a very important topic for researchers, which is evident from the increasing number of articles that have been publishing lately [4-8]. "Supply chain agility has been identified by researchers and managers alike as one of the most important issues of current supply chain management" [9]. Various disruptions such as political changes, accidents, natural disasters and supplier failures can affect both the revenues and costs of the entire supply chain [10]. Supply chain agility and adaptability enhances the sustainability in logistics [11]. The integration of three perspectives agility, resilience and sustainability helps the firm in coping with unknown disasters like Covid 19

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[12]. Agility as a business concept originated in the domain of manufacturing, specifically in relation to flexible manufacturing systems. Later, the concept was extended into a wider business context and the concept of agility as an organizational trait was born [13]. The primary focus of agile supply chains is to maximize customer effectiveness, i.e. service levels and quality of product or service, which in turn will directly affect organizations' financial performance. Cicculo et al. [14] recognized that leanness, agility, and sustainability have received increased attention in the supply chain management literature. SCA depends on various factors involving flexibility and ability of a firm to detect changes in its environment and react suitably in order to satisfy its customers in a timely manner. In order to detect these changes, the firm must have access to required information through various internal and external sources. One such external source is its suppliers.

In order to respond to market changes, a firm must have a strong management to decide on suitable course of action in a dynamically changing environment so that it can satisfy its customers. Brusset [15] mapped the relationship between different managerial resources and supply chain agility, and believed that the external and internal managerial processes to enhance agility. To implement the supply chain agility it is required to identify the antecedents of supply chain agility, and their effect on each other and the supply chain agility. From the literature review and discussion with experts seven dimensions of supply chain agility have been identified in this paper; and their effect on each other and on the supply chain agility is assessed using the Fuzzy DEMATEL. Fuzzy DEMATEL is one of the best technique to find the cause and effect relationship between assessed criteria in the evaluation process of any system or product [16]. It shows the "causal relationships as well as the influencing strength among elements by structural modelling techniques, and is thus suitable for identifying critical factors in the complex system i.e. modelling the antecedents of supply chain agility".

2. Literature review

There is numerous works explaining the concept of supply chain agility and modeling it. Several researchers have come at seemingly exhaustive list of parameters and metrics to quantify agility and develop meaningful models. Braunscheidel & Suresh [17] has provided a summary of the evolving definitions of supply chain agility. Gligor et al. [1] conducted a multidisciplinary literature review to clarify the differences and similarities between supply chain agility and resilience; and found the "six major dimensions of agility i.e. ability to quickly change direction, speed/accelerate operations, scan the environment/anticipate, empower the customer/customize, adjust tactics and operations (flexibility), and integrate processes within and across firms)". Agility is a market driven capability wherein firms respond market changes before market changes affect them whereas resilience in organization driven capability to help supply chains to restore. Braunscheidel & Suresh [17] proposed "internal integration measures, external integration with suppliers and customers, cultivation of external flexibility, and lean practices as the antecedents of supply chain". Abdallah & Nabass [18] revealed that supplier involvement, internal integration, and modularization of products positively and significantly affect agile manufacturing. Gligor et al. [19] identified alertness, accessibility of relevant data, decisiveness, swiftness and flexibility as the five dimensions of agility.

Chan et al. [7] investigated strategic flexibility and manufacturing flexibility as the critical antecedents to supply chain agility. Christopher [13] presented market sensitivity, information-based posture, fully linked network, and collaboration among partners as the four characteristics that are vital for agile supply chain. Agarwal et al. [20] found that "supply chain agility also depends on customer satisfaction, quality and cost improvements, delivery speed, new product introduction, and service level improvement". Yusuf et al. [21] identifies the automation, competing priorities, integration, and achieving manufacturing requirements in synergy as the drivers of agility and discusses the portfolio of competitive advantages that have emerged over time because of the changing requirements of manufacturing. Quinn et al. [22] view SCA as the ability to quickly switchover from the assembly of one product to the assembly of another product. Supplier innovativeness is defined as suppliers' ability to develop new processes or introduce new products [23]. Supplier innovativeness positively affects information sharing and supply chain agility. Both information sharing and strategic sourcing play a positive role on improving supply chain agility [6]. "Responsiveness to customers and markets is an indispensable requirement for all industries, like the fashion industry" [7, 24], and SCA plays the most crucial role in such dynamic market environments. Empirical examination by Jajja et al. [25] provided evidence that supplier and customer integration have positive impact on agility performance.

DeVOR et al. [26] defines agility as the ability of a firm to operate profitably in a dynamic environment of unpredictable change. This seems to be justified because of the way markets function. If a firm is not agile, its competitors will develop agile strategies to win orders from the customers and the firm will face decline in sales, and hence profits. Therefore, a clear indicator of a firm's agility is can be quantified through its financial reports, particularly when the industry is very volatile, like the fashion industry. Shekarian et al. [27] studied the impact of flexibility and agility on mitigating supply chain disruptions, through a numerical example solved with multi-objective mixed integer programming. Sangari et al.[28] developed a hybrid evaluation method that integrates fuzzy logic, DEMATEL (decision-making trial and evaluation laboratory), and ANP (analytic network process), to study the factors that contribute to achieving agility in supply chain. The proposed framework was implemented in an automotive company seeking to improve its supply chain agility. It provides a systematic approach to explore and analyze influential relationships between agile-enabling factors. Chirra & Kumar [29] proposed a Fuzzy DEMATEL to evaluate the supply chain flexibility in automobile industry. Si et al. [30] reviewed the applications of DEMATEL by reviewing 346 papers published from 2006 to 2016 in the international journals. Nejatian & Zarei [31] proposed balanced scorecard (BSC) and technique for order of preference by similarity to ideal solution (TOPSIS) for improving agility. Mangla et al. [32] proposed a flexible decision approach for analyzing the performance of sustainable supply chains under risks/uncertainty. In literature authors provided antecedents, enablers of SCA but research lack on modeling of information related enablers for achieving SCA.

3. Model and Methodology

Given the substantial evidence that the SCA depends on various factors concerning the firms' capability to be responsive to the changing market environment, SCA can be described as a factor of four determinants - accessibility, alertness, flexibility and swiftness. The four factors considered in this study are shown in Fig 1 with their associated dimensions. The associated dimensions are interdependent that will be explored through Fuzzy DEMATEL.

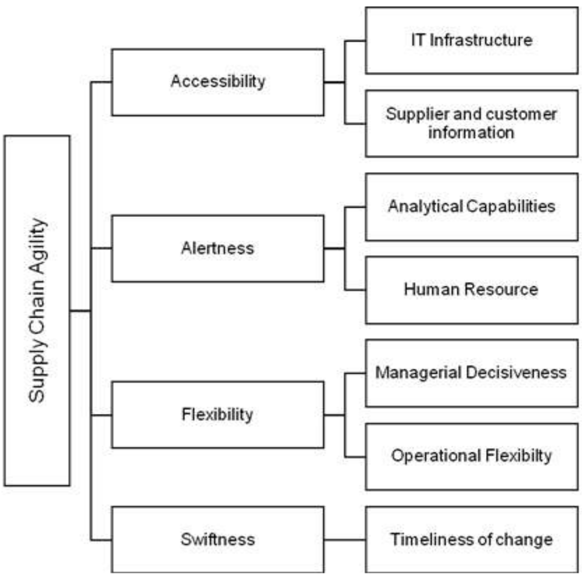

Fig. 1. SCA determinants and dimensions

In reality decision making is subjective and imprecise therefore, the concepts of fuzzy set theory introduced by [33] is used along with Decision Making Trial and Evaluation Laboratory (DEMATEL) to develop a relationship between criteria and creates a network relation map between the dimensions of Supply Chain Agility (SCA). It is a well-known and comprehensive method to obtain a structural model that provides casual relationships between complex real-world problems.

"This method not only converts the interdependent relationships into a cause and effect group via matrixes but also finds the critical factors of a complex structure. Due to its advantages and capabilities, DEMATEL has received a great deal of attention in the past decade and many researchers have applied it for solving complicated system problems in various areas" [30]. Si et al. [30] reviewed the applications of DEMATEL by reviewing 346 papers published from 2006 to 2016 in the international journals. In addition, the Fuzzy DEMATEL has been extended for better decision making under different environments including imprecise and uncertain information.

The steps of fuzzy DEMATEL are explained below:

3.1 Data Collection

From literature review and discussion with the experts, the seven dimensions of supply chain agility are identified and are mentioned in Table 1 along with their evaluating criteria.

Table 1. Dimensions of SCA and their criteria

Dimension	Criteria	Representation
IT Infrastructure	IT systems availability and robustness	C1
Supplier and customer information	Extent and ease of information sharing from suppliers and customers	C2
Analytical Capabilities	Data processing models availability and reliability	C3
Human Resource	Employees to develop meaningful models	C4
Managerial Decisiveness	Competency and capability of the top management	C5
Operational Flexibility	Ability of the firm to accommodate change in specification or size of orders	C6
Timeliness of change	How quickly the firm identifies and implements changes	C7

The computation of Fuzzy DEMATEL method is based on inputs from industry experts in the form of questionnaire on relationship between the various dimensions of SCA. Each respondent is made to evaluate the direct influence between any two factors by linguistic numbers as given in Table 2

Table 2. Fuzzy Linguistic scale

Linguistic term	Influence score	Triangular fuzzy number
No influence	0	(0, 0, 0.25)
Very low influence	1	(0, 0.25, 0.50)
Low influence	2	(0.25, 0.50, 0.75)
High influence	3	(0.50, 0.75, 1)
Very high influence	4	(0.75, 1, 1)

For each respondent, a 7x7 non-negative matrix is established. The notation of x_{ij} indicates the degree to which the respondent believes factor i affects factor j.

There are four respondents to this survey:

1. Procurement head at Maruti plant in Gurugram
2. Supply chain head at Volkswagen in Pune
3. An expert in supplier development in Denso
4. IT specialist at Volkswagen

3.2 Data Analysis

Following steps are involved to evaluate these responses:-

Table 3. Average Direct Relationship Matrix

(0,0,0.25)	(0.25,0.50,0.75)	(0.44,0.69,0.94)	(0.19,0.44,0.69)	(0.19,0.44,0.69)	(0.44,0.69,0.94)	(0.13,0.38,0.63)
(0.13,0.38,0.63)	(0,0,0.25)	(0.44,0.69,0.94)	(0.31,0.56,0.81)	(0.19,0.44,0.69)	(0.44,0.69,0.94)	(0.38,0.63,0.88)
(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0,0,0.25)	(0.38,0.63,0.88)	(0.38,0.63,0.88)	(0.44,0.69,0.94)	(0.38,0.63,0.88)
(0.25,0.50,0.75)	(0.06,0.31,0.56)	(0.06,0.31,0.56)	(0,0,0.25)	(0.13,0.38,0.63)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
(0.19,0.44,0.69)	(0.19,0.44,0.69)	(0.31,0.56,0.81)	(0.19,0.44,0.69)	(0,0,0.25)	(0.19,0.44,0.69)	(0.19,0.44,0.69)
(0.25,0.50,0.75)	(0.38,0.63,0.88)	(0.31,0.56,0.81)	(0.38,0.63,0.88)	(0.5,0.75,0.88)	(0,0,0.25)	(0.5,0.75,0.88)
(0.19,0.44,0.69)	(0.19,0.44,0.69)	(0.06,0.31,0.56)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.13,0.38,0.63)	(0,0,0.25)

Step 1: Compute the average matrix.

To incorporate all opinions from the four respondents, the average matrix A is calculated as:

$$\mathrm{A} = 1/\mathrm{N}\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{X_i} \quad (1)$$

Before applying the above equation the linguistic number are converted into their respective triangular fuzzy number using Table 2. The average matrix is shown in Table 3.

Step 2: Defuzzfying the average direct relationship matrix.

Due to the simplicity and ease of use, centroid method is used to defuzzify the triangular fuzzy number into its crisp values. Equation (2) shows the "centroid method, where b represents the obtained crisp value, and r, m, n denote the parameters in the triangular fuzzy number". After the defuzzification of the linguistic evaluation, defuzzified matrix-B (Table 4) is constructed, where b_{ij} represents the transformation value of the direct impact that factor b_i exerts on factor b_j.

$$\mathrm{b_{ij}} = \frac{(\mathrm{r}-\mathrm{m})+(\mathrm{n}-\mathrm{m})}{3} + \mathrm{m} \quad (2)$$

Table 4. Defuzzified average direct relationship matrix

0.08	0.50	0.69	0.44	0.44	0.69	0.38
0.38	0.08	0.69	0.56	0.44	0.69	0.63
0.50	0.50	0.08	0.63	0.63	0.69	0.63
0.50	0.31	0.31	0.08	0.38	0.50	0.50
0.44	0.44	0.56	0.44	0.08	0.44	0.44
0.50	0.63	0.56	0.63	0.71	0.08	0.71
0.44	0.44	0.31	0.50	0.50	0.38	0.08

Step 3: Normalize direct-relation matrix D is obtained by using the following formula and is shown in Table 5.

$$\mathrm{D} = \frac{\mathrm{B}}{\max\left[\max\sum_{\mathrm{i}}^{\mathrm{n}} \mathrm{y_{ij}}, \max\sum_{\mathrm{j}}^{\mathrm{n}} \mathrm{y_{ij}}\right]} \quad (3)$$

Table 5. Normalized direct-relation matrix

0.02	0.13	0.18	0.11	0.11	0.18	0.10
0.10	0.02	0.18	0.15	0.11	0.18	0.16
0.13	0.13	0.02	0.16	0.16	0.18	0.16
0.13	0.08	0.08	0.02	0.10	0.13	0.13
0.11	0.11	0.15	0.11	0.02	0.11	0.11
0.13	0.16	0.15	0.16	0.19	0.02	0.19
0.11	0.11	0.08	0.13	0.13	0.10	0.02

Step 4: Calculate the total relation matrix.

The total relation matrix T (Table 6) reflects the indirect relationship between elements. T can be calculated using the following equation:

$$T = \mathrm{D} + \mathrm{D2} + \mathrm{D3} + \cdots + \mathrm{Dn} = \sum_{i}^{\infty} D^{i} = D(I-D)^{-1} \quad (4)$$

where I is the 7 x 7 identity matrix.

Table 6. Total relationship matrix of factors affecting SCA

0.52	0.63	0.72	0.67	0.67	0.76	0.69
0.63	0.56	0.75	0.74	0.70	0.79	0.77
0.67	0.67	0.63	0.76	0.76	0.81	0.79
0.52	0.48	0.53	0.47	0.54	0.60	0.59
0.53	0.54	0.62	0.59	0.50	0.62	0.61
0.69	0.72	0.78	0.79	0.81	0.70	0.84
0.50	0.51	0.53	0.57	0.57	0.57	0.49

In Table 7, r and c are represents the row and column matrices respectively; and are defined as the sum of rows and sum of columns of the total relation matrix T, respectively. Suppose "ri be the sum of ith row in matrix T, then ri summarizes both direct and indirect effects given by factor i to the other factors. If cj denotes the sum of jth column in matrix T, then cj shows both direct and indirect effects to factor j from the other factors. For the diagonal elements, when j = i, the sum (ri + cj) shows the total effects given and received by factor i".

Thus, (ri + cj) indicates the "degree of importance for factor i in the entire system". On the contrary, the difference (ri - cj) represents the net effect that factor i contributes to the system. Specifically, if (ri - cj) is positive the factor i is a net cause, while if (ri - cj) is negative factor i is a net receiver. Table 7 summarises these results.

Table 7. The direct and indirect effects of seven dimensions

Dimension	r	c	r+c	r-c
IT Infrastructure	4.66	4.06	8.72	0.60
Supplier and Customer Information	4.94	4.11	9.05	0.83
Analytical Capabilities	5.09	4.56	9.65	0.53
Human Resource	3.73	4.59	8.32	-0.86
Managerial Decisiveness	4.01	4.55	8.56	-0.54
Operational Flexibility	5.33	4.85	10.18	0.48
Timeliness of Change	3.74	4.78	8.52	-1.04

Step 5: Plot the digraph

With R + C being the horizontal axis, and R − C the vertical axis, a causal diagram is constructed to analyze the importance of each factor to supply chain agility (Figure 2). Deng at al. [34] explained that when the value of (R-C) is positive, it means that this factor is a net causer. In contrast, “when the value of R-C is negative, the factor is a net receiver and grouped in the effect cluster. Effect factors are affected by cause factors, influencing it the supply chain agility directly”.

Since the matrix T provides information on how one factor affects another, it is necessary to set up a threshold value to filter out some negligible effects. The threshold value is obtained by the average of all elements in matrix T. Hence, calculate the average of all 49 elements of the matrix T and leave only the elements which are greater than this average value in the matrix and convert all remaining elements to zero. Since the average of the matrix T is 0.64, we find the modified version of T, as T’ in Table 8.

Table 8. Modified T’

0	0	0.72	0.67	0.67	0.76	0.69
0	0	0.75	0.74	0.70	0.79	0.77
0.67	0.67	0	0.76	0.76	0.81	0.79
0	0	0	0	0	0.60	0
0	0	0	0	0	0.62	0
0.69	0.72	0.78	0.79	0.81	0.70	0.84
0	0	0	0	0	0	0

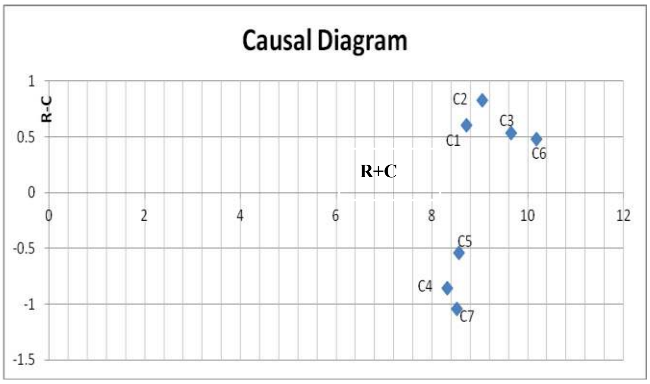

Fig. 2. Digraph of the seven dimensions of SCA

The digraph is created by mapping the dataset of (r+c, r-c) from Table 8. Figure 2 depicts the digraph to visually indicate the casual relationship between the seven dimensions. Positive (r+c) values indicate the causal factors and negative (r-c) values indicate the outcome/leaf factors. This provides a framework to managers for effective implementation of SCA. Manager’s decisiveness and operational flexibility can only be gained through information access and analytical capabilities.

4. Discussion and Managerial Implication

The SCA of a firm is observed to be a factor of four determinants- accessibility, alertness, flexibility and swiftness, which themselves depend on seven dimensions. These dimensions have been evaluated using fuzzy DEMATEL method to find the casual relationships between them and their affect on SCA. Generally, the values of “(R + C) and (R − C) are used to examine the degree of importance of each factor on the system objective and the interdependence among factors. But these two parameters alone may likely lead to analysis that are not consistent with the practical situation. Therefore, the value of R and C should be considered when critical elements are to be determined, in order to synthesize the impact of elements on system goals” [34-35]. Specific analysis is made in the following sections in accordance with Table 7 and Figure 2.

Cause Cluster

Operational flexibility, IT infrastructure, analytical capability and supplier-customer information are net causes of the system since they have a positive (r – c) value. Further operational flexibility and analytical capability of a firm have the maximum effect on the system of these seven dimensions as they have the maximum (r + c) value.

Effect Cluster

Managerial decisiveness, human resource and timeliness of change are net receivers of the system since they have a negative (r – c) value.
The data points on the digraph and Table 8 provides the following key insights:

- Operational flexibility and analytical capability have an effect on all the remaining six dimensions, which is the highest compared to all other dimensions.
- Timeliness of change and human resource is a result of all the remaining five dimensions and are not causes of any significant relationship.
- IT infrastructure and supplier and customer information sharing, although don’t have a direct dominant impact on agility, but are significant causes affecting both the analytical capability and operational flexibility, which in turn, are the dominant dimensions of SCA. Thus, IT infrastructure and SC information sharing indirectly play an important role in affecting the overall system.

Possible explanation of the observations – Analytical capability is important for agility because it helps the firm to predict uncertainty using robust models. Operational flexibility, on the other hand, enhances agility by it helping the firm address the variability in order size and specifications, if needed. This research provides insights on the understanding of cause and effect factors for the implementation of SCA From the cause and effect relation i.e. from Fig (2), it’s evident that decision power of managers depends on the timely and right information with analysis.

5. Conclusion

From the aforementioned observations and visual aid of the digraph, it can be concluded that the operational flexibility and analytical capability of a firm play the most important role in determining a firm’s SCA. Although IT infrastructure and supplier & customer information sharing stand amongst the remaining five dimension in terms of its total affect on the agility, they indirectly have a dominant effect due to the fact that both these dimensions have a substantial effect on the operational flexibility as well as the analytical capability which in turn are the most dominant dimensions affecting agility. Analytical capability enhances predictability for the firm, thus enhancing its SCA, while the operational flexibility takes care of addresses the variability in order size and specification, if such a situation arises. Hence, these two dimensions together play the most crucial role in determining the agility of a firm and any firm can work on strengthening these aspects in order to become more agile and remain competitive in the dynamic marketplace they operate in.

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