Journal of Manufacturing Systems 52 (2019) 172–183

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Measuring Supply Chain Reconfigurability using Integrated and Deterministic Assessment Models

Pallab Biswas[a], Sameer Kumar[b,*], Vipul Jain[c], Charu Chandra[d]

[a] Department Of Mechanical Engineering, Ajay Kumar Garg Engineering College, Ghaziabad, Uttar Pradesh (India)
[b] Professor of Operations and Supply Chain Management, Opus College of Business, University of St. Thomas, 1000 LaSalle Avenue, Minneapolis, MN 55403-2005
[c] School of Management, Victoria Business School, Victoria University of Wellington, 23, Lambton Quay, Pipitea Campus, PO Box 600, Wellington 6140, New Zealand
[d] Department of Management Studies, College of Business Administration, University of Michigan – Dearborn, FCS 183, 19000 Hubbard Drive, Dearborn, Michigan 48126-2638, USA

ARTICLE INFO

Keywords:
Supply chain network
Reconfigurability index
Delphi technique
Additive weighting method
Kendall's coefficient concordance (W)
Total interpretive structural modeling (TISM)
Assessment models

ABSTRACT

The purpose of this paper is to assess supply chain reconfigurability in a global scenario. The paper attempts to measure comprehensive relative reconfigurability index (CRRI) in an automobile case supply chain by holistically considering fifteen enablers of reconfigurability. The present research evaluates CRRI by utilizing two distinct assessment models that calculate relative reconfigurability index (RRI). Firstly, a deterministic assessment model is developed from the total interpretive structural modeling (TISM) digraph, and secondly, an integrated assessment methodology that utilizes both the Delphi technique and the additive weighting method to calculate RRI. The uniqueness of the present research is to quantify reconfigurability in the case supply chain by a numerical index termed as CRRI. The paper analyzes the level of reconfigurability competence of the case supply chain in comparison with an ideal supply chain and thus facilitates structural flexibility. The proposed model for calculating CRRI, using two methodologies and comparing the results, is an innovative way of measuring supply chain reconfigurability. Supply chain's preparedness to structurally change in the present business environment of uncertainty and turbulence can be evaluated and it would act as an aide in decision making pertaining to reconfigurability in supply chains.

1. Introduction

Supply chain structures are subjected to variability, because the business environment has a fundamental difficulty fulfilling uncertain demands without compromising the product or service cost. Performance is adversely affected by variability since it adds to supply chain costs in the form of costly buffers, low capacity utilization and stock outs [1]. Supply chains in present-day business compete as the marketplace determines the success or failure of the supply chains. Today's global market is reasonably competitive and subjected to turbulence in market demand. To accommodate turbulence, supply chain reconfigurability incorporates structural flexibility capability in the designs of supply chains. Structural flexibility in supply chains focuses on combining the capability of being easily rearranged, timely and cost effective as per the real time demand scenario.

The emergence and growth of globalization require manufacturing enterprises to reconfigure their manufacturing systems and supply chains quickly and cost-effectively in response to market changes [2]. Reconfigurability is an ability that allows the addition, removal or rearrangement of manufacturing system components and functions to better cope with high product variety and significant fluctuations in market demand in a cost effective way [3].The dynamic market demand, the short product lifecycle and the flexibility need mark the transition from the traditional manufacturing systems to the so-called Next Generation Manufacturing Systems (NGMSs) [4].The reconfigurable manufacturing system (RMS) meets this challenge through the ability to rapidly and efficiently change capacity and functionality, which is the reason why it has been also widely labelled the manufacturing paradigm of the future [5].

The companies need to rapidly respond to new product introduction, mix and demand changes to stay competitive [6]. The Internet of Things (IoT) is also adopted in manufacturing to enable effective and adaptive planning and control of production systems [7].The demand for more personalized, smart, and sustainable products and the rapid growth of the industrial Internet and cyber-physical technologies have led to the development of several new paradigms for manufacturing in

* Corresponding author.
E-mail addresses: sameerkumar724@gmail.com (S. Kumar), Vipul.Jain@vuw.ac.nz (V. Jain), charu@umich.edu (C. Chandra).

https://doi.org/10.1016/j.jmsy.2019.05.008
Received 1 July 2018; Received in revised form 1 May 2019; Accepted 22 May 2019
Available online 30 July 2019
0278-6125/

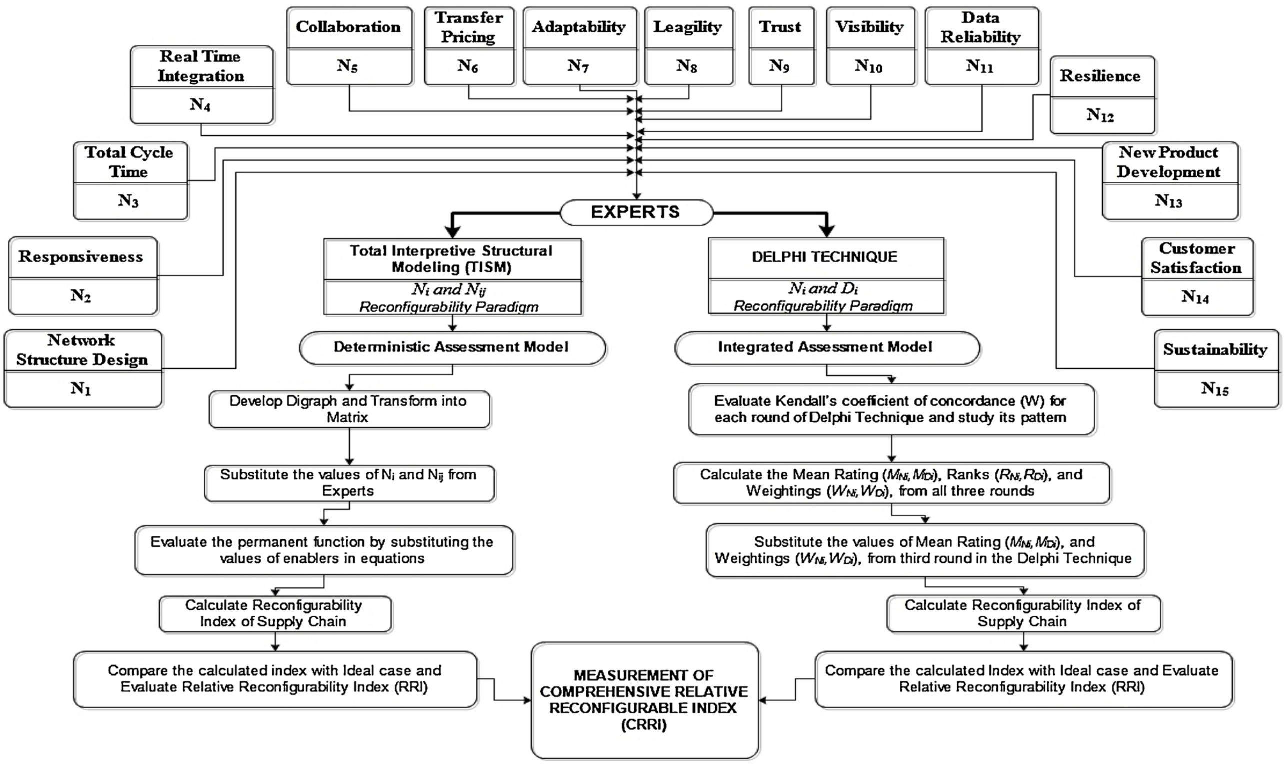

Fig. 1. Steps involved in measuring CRRI.

recent years [8].Product configuration system, is one of the effective tool to bridge the gap between customer requirements and product offerings, enables customer-centric product development in a cost-efficient way [9]. Improved methods for supply chain managers are needed to analyze factors pertaining to reconfigurability and to execute strategic decisions rapidly with specific structural adjustment in supply chains.

Reconfigurability is a multidimensional paradigm and can be achieved if certain features are engineered into a supply chain. This research attempts to classify those features, conduct an analysis and comparative study of the 'level of reconfigurability' and thus realize the scope of improvement. Consequently, the primary objective of this study is to propose a Relative Reconfigurability Index (RRI) to reflect the preparedness of companies and their supply chains towards market volatility.

1.1. Need for assessing supply chain reconfigurability

Supply chain reconfigurability is a paradigm that focuses on implementing structural flexibility by building flexible options into the design of supply chains. We need to move away from a focus on achieving the "lowest global cost" to serving the centres of gravity within a flexible supply chain structure [1]. Assessment of supply chain reconfigurability needs to be addressed, as it has not yet been attempted in the literature.

Thus, an innovative approach is proposed to design improved dynamic flexibility in supply chains by measuring the level of reconfigurability to manage volatility in this era of turbulence. The CRRI, a unique performance metric not attempted so far, is developed in this research to measure and compare supply chain reconfigurability. Evaluation of CRRI would facilitate the understanding of the reconfigurability level of any supply chain and thus pinpoint those specific areas which need improvement.

1.2. Objectives of research

Reconfigurability in supply chains is an emerging paradigm which needs to be measured through a specific index. Literature pertaining to the measurement of the supply chain resilience index [10], supply chain volatility index [1] and supply chain ecosilient index [24] is available in the literature, but measuring reconfigurability has not yet been attempted. Additionally, supply chain's readiness to change structurally in an uncertain business environment has not been attempted and recorded in literature.

The primary goal of this research can be summarized into three principal objectives. These objectives and their steps are summarized below.

- Objective 1: To assess the supply chain reconfigurability of the case supply chain using the Deterministic Assessment Model, which utilizes TISM and calculates the permanent of the matrix using a computer program.
- The steps involved in fulfilling this objective are as follows.
- Develop a digraph from TISM and transform it into the reconfigurable variable characteristic matrix (RVCM) incorporating the values of Ni and Nij obtained from experts.
- Generate the reconfigurable variable permanent matrix (RVPM).
- Select the interdependencies values among enablers with the help of experts using suitable scale (1–5).
- Evaluate the permanent function by substituting the values into the equation using a MATLAB R2015a program and then calculate the supply chain reconfigurability index.
- Calculate the Relative Reconfigurability Index (RRI) of the case supply chain by comparing the value with an ideal reconfigurability index value.
- Objective 2: To assess the supply chain reconfigurability of the case supply chain using an Integrated Assessment Model that utilizes the Delphi Technique and the Additive Weighting Method.
- The steps involved in fulfilling this objective are stated as follows.
- Evaluate Kendall's coefficient of concordance (W) for each round of

the Delphi Technique for dimensions and enablers and study the pattern.

- Obtain the mean rating, rank, and weighting from all the three rounds of the Delphi Technique for five reconfigurable dimensions (Di) and fifteen enablers (Ni).
- Substitute the values of Weightings (WDi, WNi) and Mean Ratings (MNi) from the final round and calculate the supply chain reconfigurable index.
- Calculate the Relative Reconfigurability Index (RRI) of the case supply chain by comparing the value with an ideal reconfigurability index value.
- Objective 3: To evaluate the Comprehensive Relative Reconfigurable Index (CRRI) combining the RRIs from both the methodologies.

The detailed process and steps for measuring the Comprehensive Relative Reconfigurability Index (CRRI) are clearly illustrated in Fig. 1.

2. Theory, methodology and model

The primary objective of this section is to propose the underlying theory, methodologies, and model formulation pertaining to the deterministic assessment model and integrated assessment model to evaluate reconfigurability index in supply chains. This section is divided into three sub sections to elucidate the supporting concepts.

2.1. Deterministic assessment model

The deterministic assessment model is utilized to evaluate the reconfigurability index, as the problem contains no random variables and consists of equations. Deterministic assessments are used in scientific research that includes engineering, chemistry and policy-making apart from studies related to population fields, climate development, and pollution. The model requires translating the interrelationships among enablers into a matrix form, which is a computer recognizable format. The steps involved are graphically explained below in Fig. 2.

2.1.1. Total interpretative structural modeling (TISM)

Total Interpretive Structural Modeling (TISM) is adopted in this research, as the relationships among reconfigurability enablers need to be logically established using a standard qualitative modeling technique. TISM is a novel qualitative modeling technique which is an extension of the ISM [11].

2.1.2. Reconfigurability enablers

Supply chain reconfigurability variables were identified from literature and fifteen enablers were used to measure readiness for structural changes in supply chains [12]. These fifteen variables were used to measure and quantify the reconfigurability preparedness of the researched supply chain. These enablers are discussed in detail in the literature; readers are therefore directed to refer to research pertaining to reconfigurability enablers. We specify fifteen enablers as follows.

N_1	*Network Structure Design*	N_9	*Trust*
N_2	*Responsiveness*	N_{10}	*Visibility*
N_3	*Total Cycle Time*	N_{11}	*Data Reliability*
N_4	*Real-Time Integration*	N_{12}	*Resilience*
N_5	*Collaboration*	N_{13}	*New Product Development*
N_6	*Transfer Pricing*	N_{14}	*Customer Satisfaction*
N_7	*Adaptability*	N_{15}	*Sustainability*
N_8	*Leagility*		

2.1.3. Digraph and matrix representation

A digraph, or directed graph is based on the principle that the nodes and the edges must represent the enablers and their interdependencies respectively. A digraph is preferred in this research, because the edges show directions and can be used as a form of visual representation to express interactions and interdependencies between two nodes. In this work, N_is represent the identified reconfigurability enablers, N_{ij}s account for the degree of dependency of the j^{th} enabler on the i^{th} enabler, and N_{ji}s account for the dependence of i^{th} enabler on j^{th} enabler. These can form edges in the opposite direction between two nodes and form a cycle. The fifteen broad enablers identified in the previous section form the reconfigurable digraph. The digraph for the reconfigurability enablers is developed by replacing the nodes in the digraph by interpretations provided in the interaction matrix. This digraph is transformed into a suitable matrix form for further processing.

2.1.4. Reconfigurable variable characteristic matrix (RVCM)

The visual representation helps the analysis to a certain extent; to establish equations for further processing the digraph is further represented in a matrix form. We consider a reconfigurable variable character matrix (RVCM). RVCM can be expressed as Y = [X-W], where X represents all diagonal elementsconsisting of N_is, and W accounts for all off-diagonal elements composed of N_{ij}s or N_{ji}s. TISM considers selective edges and interactions, resulting in a few of the diagonal elements as zero. The determinant of RVCM carries negative signs with

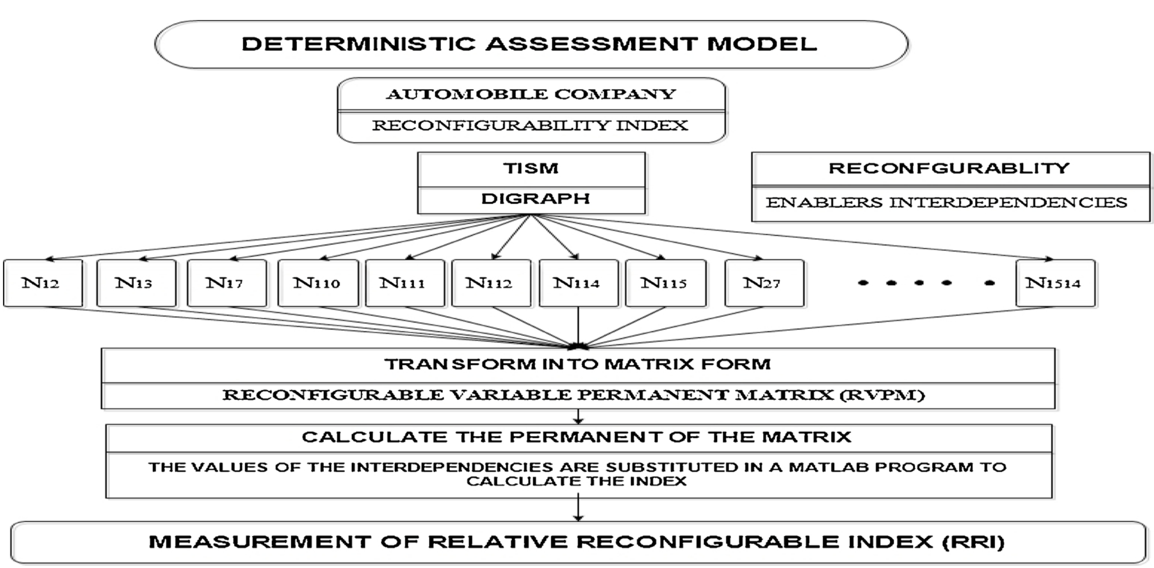

Fig. 2. Steps involved in measuring RRI by Deterministic Assessment Model.

some of its coefficients in the variable characteristic reconfigurability multinomial. The determinant of the reconfigurable variable characteristic matrix (RVCM) does not provide complete information concerning the reconfigurable environment, as some elements are lost due to the addition and subtraction of numerical values of diagonal and off-diagonal elements (i.e. N_is and N_{ij}s). To process the actual information, another matrix Z is introduced and is called reconfigurable variable permanent matrix (RVPM).

2.1.5. Reconfigurable variable permanent matrix (RVPM)

The reconfigurable variable characteristic matrix (RVCM) does not provide us with a complete quantitative value. Therefore, we define a reconfigurable variable permanent matrix (RVPM) as Z = [X + W], where X represents all diagonal elements consisting of N_is and W represents all off-diagonal elements consisting of N_{ij}s or N_{ji}s. The reconfigurable variable permanent matrix (RVPM) corresponds to the nodes and edges of the digraph. The matrix X includes diagonal elements, which are considered critical factors in achieving reconfigurability, and is represented by fifteen enablers of reconfigurability. The matrix W consists of off-diagonal elements that represent interdependencies among the enablers.

2.1.6. Permanent assessment and index calculation

The digraph and matrix representations cease to be distinctive as they can alter if we amend the labelling of the nodes, and a solution is required which will evaluate the results independent of the labelling. A permanent function Per (N^*) of the reconfigurable variable permanent matrix (RVPM) independent of labelling is therefore assessed. Permanent function of matrices is used in combinatorial mathematics and is a standard matrix function recognized by researchers [13,21]. This standard function is used to determine index and is composed of mathematical equations [14]. This standard function transforms a matrix into a set of standard equations and eradicates the loss of information as it does not contain negative sign coefficients. Expert opinions are sought to evaluate quantitative values of reconfigurability elements of the supply chain. These values include values pertaining to critical factors and interdependencies and are gathered from the reconfigurable variable permanent matrix (RVPM). The permanent function Per (N^*) of RVPM corresponding to the fifteen-enablers is given in Eq. (1) [10].

$$
\begin{aligned}
&Per(N^*) = A + B + C + D + E\\
&Where\\
&A = \prod_{i=1}^{15} Ni\\
&B = \sum_{1,2,3...15} (N_{12}N_{21})N_3\,N_4......N_{15}\\
&C = \sum_{1,2,3...15} (N_{12}N_{23}N_{31} + N_{13}N_{32}N_{21})N_4N_5......N_{15}\\
&D = \sum_{1,2,3...15} (N_{12}N_{21})(N_{34}N_{43})N_5N_6......N_{15}\\
&E = \sum_{1,2,3...15} (N_{12}N_{23}N_{34}N_{45}N_{51} + N_{15}N_{54}N_{43}N_{32}N_{21})N_6N_7......N_{15}
\end{aligned} \tag{1}
$$

The permanent of the matrix is a mathematical expression in symbolic form. The reachability matrix from TISM represents the critical factors and interdependencies and is considered in formation of RVPM to evaluate the permanent function Per (N^*).The assignment of numerical values to quantify N_i and N_{ij} is done through proper interpretation by experts [15]. Table 1 shows the scale used by experts to measure interdependencies of enablers on each other.

The permanent of the RVPM is obtained through a program written in MATLAB R2015a. The program inputs the matrix from the user and calculates the minor of the matrix. The recursive logic is then used to obtain the permanent function of the matrix using Eq. (1), and the value obtained is the Reconfigurability Index. The ideal value of the Reconfigurability Index is obtained by substituting the maximum possible values designated for N_i and N_{ij}. The actual value of the index can now be compared with the ideal value of the reconfigurability index, and a level can be ascertained as the percentage of attainment or deficit in preparedness of reconfigurability functionality in a supply chain. This percentage attainment/preparedness with respect to the ideal value is termed as Relative Reconfigurability Index (RRI).

Table 1
Quantification of Reconfigurability Enabler Interdependencies.

Qualitative Measure of Interdependencies	Assigned Value (N_{ij})
Very Weak	*1*
Weak	*2*
Medium	*3*
Strong	*4*
Very Strong	*5*

2.2. Integrated assessment model

An integrated assessment model is used for scientific knowledge integration from two or more domains where existing theory seems inadequate. In the proposed research, the model accounts for five dimensions of reconfigurability and an integration of them as domains are required to assess reconfigurability index. Integrated approach in assessment is extensively used as scientific models by environmentalists for policy-related research.

Numerical models are utilized for the evaluation by integrating the reconfigurability dimensions and their respective enablers of the case supply chain. The steps involved are shown in Fig. 3.

2.2.1. Delphi technique

The Delphi technique is a highly formalized method of communication that is designed to extract the maximum amount of unbiased information from a panel of experts [16]. Several studies pertain to the determination of numerous forms of indices in supply chain management, i.e. Fragility Index in supply chains [17]; Risk Assessment Index [18,22]; and Supply chain performance index [23].

Nineteen experts were invited, who have extensive research backgrounds from academia and industry expertise from the case supply chain, to participate in our research. After the invitation process, six out of eleven and four out of eight experts from academia and industry respectively agreed to collaborate in this process. Virtual web-based interviews (using the website www.welphi.com) were conducted with the academic and industry experts, firstly to validate the reconfigurability dimensions and enablers considered, and secondly to rank them according to their importance to structural changes in supply chains.

2.2.2. Statistical results and Consensus analysis of Delphi Technique after three rounds

Statistical tool IBM SPSS Statistics V22.0 is used in this study to calculate all of the statistical results. We performed Kendall's W test within the non-parametric tests for k-related samples to analyze the ranks received for reconfigurability dimensions and enablers from ten experts. These results were analyzed for stability and convergence as clear criterion prior to any study. Stability and convergence are two key elements identified for this study. The consistency of the ratings across three rounds and the experts' degree of agreement with each other can be summarized as stability and convergence respectively.

The coefficient is calculated for all k-related variables rather than calculating for each one separately in Kendall's coefficient of concordance and is considered a broad-brush statistical tool [20]. Siegel and Castellen [24], mentioned that the convergent degree of variation in the average ranks assigned by the experts to each category is the basis for calculating Kendall's coefficient of concordance. The probability is observed by p-value or level of significance of the test [20].

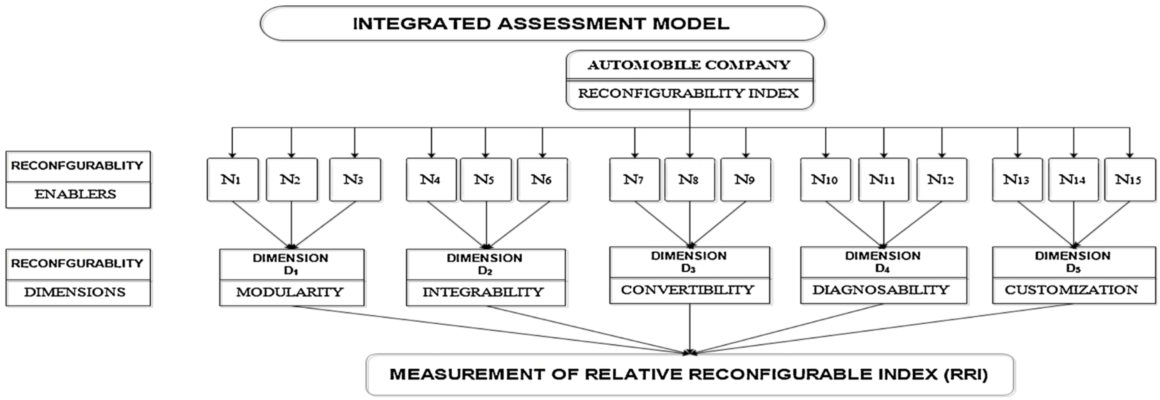

Fig. 3. Steps involved in measuring RRI by Integrated Assessment Model.

2.2.3. Weighting, mean-rating, and rank determination

In this study, an assessment of a series of weightings of reconfigurability dimensions and their corresponding enablers were carried out. The assessment of the relative impacts of reconfigurability dimensions and enablers are scored 1–9, and their qualitative status is suggested in Table 2.

The mean ratings of reconfigurability dimension and enablers are represented by M_{Di}, and M_{Ni}, and they are calculated on the ratings gathered from the experts. The weighting for reconfigurability dimensions and their corresponding enablers, namely their importance in attaining reconfigurability in supply chains, Eq. (2) & (3) show the expression for computing these weightings(Yeung et al., 2007).

$$W_{Di} = \frac{M_{Di}}{\sum_{i=1}^{5} M_{Di}} \quad (2)$$

$$W_{Ni} = \frac{M_{Ni}}{\sum_{i=1}^{15} M_{Ni}} \quad (3)$$

Where:

- W_{Di} and W_{Ni} represent the weighting of dimension i (i = 1,2, …5) and enabler i (i = 1,2,…15) respectively.
- M_{Di} and M_{Ni} represent the mean rating of dimension i (i = 1,2, …5) and enabler i (i = 1,2,…15) respectively.

The rank assessment of the dimension and enablers pertaining to reconfigurability is worked out on the basis of the weightings, and it provides the position of how important a dimension or enabler is to attain reconfigurability in a supply chain perspective.

2.2.4. Additive weighting method

The research uses the additive weighting method out of various linear methods for aggregation. The linear method is used assuming that there are no synergy or conflict effects among the dimensions and enablers [25], and the variables are independent of each other [26,27].

Table 2
Quantification of Reconfigurability Enablers.

Qualitative Measure of Enablers	Assigned Value (N_i)
Exceptionally Low	*1*
Very Low	*2*
Low	*3*
Below Average	*4*
Average	*5*
Above Average	*6*
High	*7*
Very High	*8*
Exceptionally High	*9*

This type of aggregation also implies that poor performance in some variables can be compensated by sufficiently high values of other indicators [25]. To evaluate Reconfigurability Index for the supply chain, this approach is appropriate as the boundaries of a phenomenon are not only unclear, but there is also no control over the behavioural events [28].

2.2.5. Index calculation

To assess the Reconfigurability Index, the weights of each dimension are multiplied with the summation of mean rating multiplied by weights of their respective enablers and divided by the number of enablers pertaining to that dimension. The values mean rating and weightings are substituted from the third round of the Delphi technique. They are then aggregated to calculate the reconfigurability index as shown in Eq. (4).The ideal value of Reconfigurability Index is obtained by substituting maximum possible values designated for M_{Di} and M_{Ni} and keeping the evaluated weightings intact. The expression shown below is used to compute the Reconfigurability Index for the actual and the ideal cases.

$$\begin{aligned} ReconfigurabilityIndex= & \left[W_{D1} \times \frac{\sum_{i=1}^{3} W_{Ni} \times M_{Ni}}{n}\right] + \left[W_{D2} \times \frac{\sum_{i=4}^{6} W_{Ni} \times M_{Ni}}{n}\right] + \left[W_{D3} \times \frac{\sum_{i=7}^{9} W_{Ni} \times M_{Ni}}{n}\right] \\ & + \left[W_{D4} \times \frac{\sum_{i=10}^{12} W_{Ni} \times M_{Ni}}{n}\right] + \left[W_{D5} \times \frac{\sum_{i=13}^{15} W_{Ni} \times M_{Ni}}{n}\right] \end{aligned} \quad (4)$$

Where:

- W_{Di} and W_{Ni} represent the weighting of any dimension i (i = 1,2, …5) and enabler i (i = 1,2,…15) respectively.
- Each dimension is attained through three enablers.
- M_{Ni} represents the mean rating of the enabler i (i = 1, 2,…15).
- n is the number of companies considered in the supply chain, in our case $n = 1$.

The reconfigurability index for the actual case and ideal cases are compared to compute the relative reconfigurability index (RRI).

2.3. Measurement of comprehensive relative reconfigurable index (CRRI)

To assess the Comprehensive Relative Reconfigurable Index (CRRI), the relative reconfigurability index from both the methodologies, i.e. deterministic assessment model and integrated assessment model, is aggregated. The value is expressed as a percentage and will reflect the level of reconfigurability attained by the supply chain. This will help the supply chain managers investigate key areas where improvements are required to make the supply chains structurally flexible.

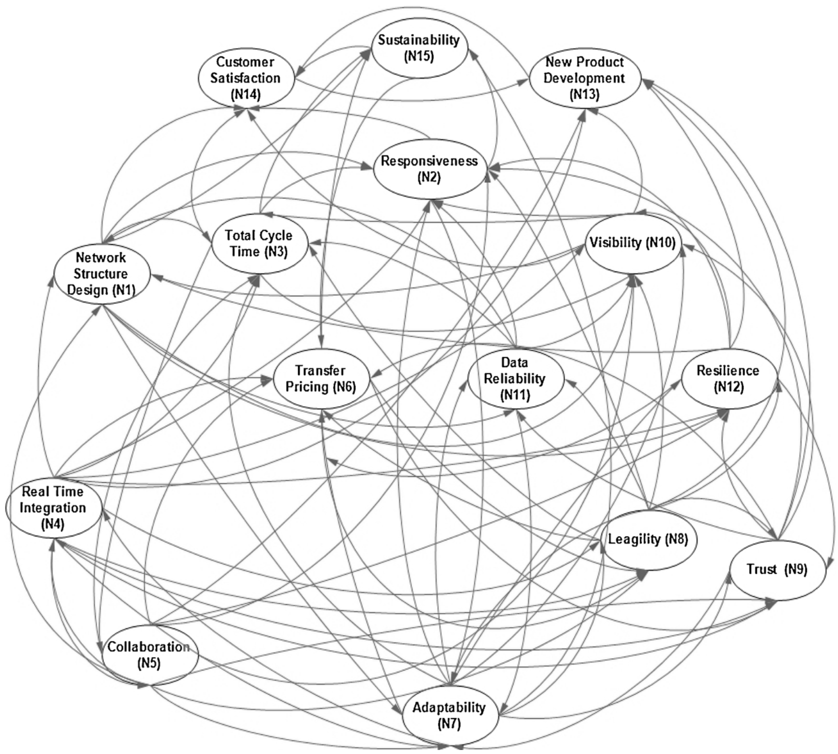

Fig. 4. Digraph of Reconfigurability Enablers.

3. Case study

A multi-national automobile supply chain case study was selected to enquire the preparedness of the company towards the reconfigurability paradigm. For the purpose of confidentiality, the company is referred to as XYZ. This multinational corporation was established in 1981, to meet the demand of personal mode of transport in India. XYZ has a total market share of total 46.8% with 9.6% in the passenger cars segment, 38.4% in the utility vehicle segment, 11.2% in the vans segment, and 11.5% in the passenger vehicle segment from 2015-16. The profit before tax is Rs. 516,732 million with a growth rate of 34.2%. The production planning was executed after the real demand was received from the dealers.

We identified altogether ten experts from the case supply chain and academia working in the supply chain management (SCM) domain for the Delphi and TISM methodologies. Expert opinion was sought to carry out the ratings of the dimensions, enablers, and interdependencies among enablers. A detailed execution and implementation of theory and methodologies for the research model pertaining to the case supply chain are described in the following subsections.

3.1. Deterministic assessment model

The model is designed to capture the relationships among the enablers pertaining to reconfigurability paradigm.

3.1.1. Digraph and matrix representation

The digraph depicts the interrelationships between the enablers on causal thinking and is shown in Fig. 4.

3.1.2. Reconfigurable variable characteristic matrix (RVCM)

The digraph is considered for defining RVCM. We consider a reconfigurable variable character matrix (RVCM) which is shown below as Eq. (5)

$$
\begin{matrix}
N_1 & -N_{12} & -N_{13} & 0 & 0 & 0 & -N_{17} & 0 & 0 & -N_{110} & -N_{111} & -N_{112} & 0 & -N_{114} & -N_{115} \\
0 & N_2 & 0 & 0 & 0 & 0 & -N_{27} & 0 & 0 & 0 & 0 & 0 & 0 & -N_{214} & -N_{215} \\
0 & -N_{32} & N_3 & 0 & -N_{35} & 0 & 0 & 0 & 0 & -N_{310} & 0 & 0 & 0 & -N_{314} & -N_{315} \\
-N_{41} & -N_{42} & -N_{43} & N_4 & -N_{45} & -N_{46} & -N_{47} & -N_{48} & -N_{49} & -N_{410} & 0 & -N_{412} & -N_{413} & 0 & 0 \\
-N_{51} & -N_{52} & -N_{53} & -N_{54} & N_5 & -N_{56} & -N_{57} & -N_{58} & -N_{59} & -N_{510} & 0 & -N_{512} & -N_{513} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & N_6 & 0 & -N_{68} & -N_{69} & -N_{610} & 0 & 0 & 0 & 0 & -N_{615} \\
0 & -N_{72} & -N_{73} & -N_{74} & 0 & -N_{76} & N_7 & -N_{78} & -N_{79} & -N_{710} & -N_{711} & -N_{712} & 0 & 0 & -N_{715} \\
0 & -N_{82} & -N_{83} & -N_{84} & 0 & -N_{86} & -N_{87} & N_8 & -N_{89} & -N_{810} & -N_{811} & -N_{812} & -N_{813} & 0 & 0 \\
0 & -N_{92} & 0 & -N_{94} & 0 & -N_{96} & -N_{97} & 0 & N_9 & -N_{910} & -N_{911} & -N_{912} & -N_{913} & 0 & 0 \\
-N_{101} & -N_{102} & -N_{103} & 0 & 0 & 0 & 0 & 0 & 0 & N_{10} & 0 & 0 & -N_{1013} & -N_{1014} & 0 \\
-N_{111} & -N_{112} & -N_{113} & 0 & 0 & 0 & -N_{117} & 0 & 0 & -N_{1110} & N_{11} & 0 & 0 & 0 & 0 \\
-N_{121} & -N_{122} & 0 & 0 & 0 & -N_{126} & 0 & 0 & -N_{129} & -N_{1210} & 0 & N_{12} & -N_{1213} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & N_{13} & -N_{1314} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -N_{1413} & N_{14} & 0 \\
0 & 0 & 0 & 0 & 0 & -N_{156} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -N_{1514} & N_{15}
\end{matrix}
$$

Table 3
Results of Index Calculations (Deterministic Assessment).

Assessment Model	Reconfigurability Index (Calculated)	Reconfigurability Index (Ideal)	Relative Reconfigurability Index (**RRI**) %
Deterministic Assessment Model	**3.9086 × 10** [19]	**5.0244 × 10** [19]	**77.7924**

Table 4
Kendall's coefficient of concordance (W) Reconfigurability Dimensions.

DimensionsD_i	Statistics		
	First round	Second round	Third round
Number (n)	*10*	*10*	*10*
Kendall's coefficient of concordance (W)	*0.094*	*0.104*	*0.134*
Level of significance (p)	*0.437*	*0.386*	*0.254*

Table 5
Kendall's coefficient of concordance (W) for Reconfigurability Enablers.

EnablersN_i	Statistics		
	First round	Second round	Third round
Number (n)	*10*	*10*	*10*
Kendall's coefficient of concordance (W)	*0.088*	*0.102*	*0.109*
Level of significance (p)	*0.578*	*0.431*	*0.358*

(5)

To process the actual information, another matrix Z is introduced and is called the reconfigurable variable permanent matrix (RVPM).

3.1.3. Reconfigurable variable permanent matrix (RVPM)

We define a reconfigurable variable permanent matrix (RVPM) as Z = [X + W], where X represents all diagonal elementsconsisting of N_is and W represent all off-diagonal elements consisting of N_{ij}s or N_{ji}s. The RVPM is shown as follows as Eq. (6).

N_{1}	N_{12}	N_{13}	N_{14}	N_{15}	N_{16}	N_{17}	N_{18}	N_{19}	N_{110}	N_{111}	N_{112}	N_{113}	N_{114}	N_{115}
N_{21}	N_{2}	N_{23}	N_{24}	N_{25}	N_{26}	N_{27}	N_{28}	N_{29}	N_{210}	N_{211}	N_{212}	N_{213}	N_{214}	N_{215}
N_{31}	N_{32}	N_{3}	N_{34}	N_{35}	N_{36}	N_{37}	N_{38}	N_{39}	N_{310}	N_{311}	N_{312}	N_{313}	N_{314}	N_{315}
N_{41}	N_{42}	N_{43}	N_{4}	N_{45}	N_{46}	N_{47}	N_{48}	N_{49}	N_{410}	N_{411}	N_{412}	N_{413}	N_{414}	N_{415}
N_{51}	N_{52}	N_{53}	N_{54}	N_{5}	N_{56}	N_{57}	N_{58}	N_{59}	N_{510}	N_{511}	N_{512}	N_{513}	N_{514}	N_{515}
N_{61}	N_{62}	N_{63}	N_{64}	N_{65}	N_{6}	N_{67}	N_{68}	N_{69}	N_{610}	N_{611}	N_{612}	N_{613}	N_{614}	N_{615}
N_{71}	N_{72}	N_{73}	N_{74}	N_{75}	N_{76}	N_{7}	N_{78}	N_{79}	N_{710}	N_{711}	N_{712}	N_{713}	N_{714}	N_{715}
N_{81}	N_{82}	N_{83}	N_{84}	N_{85}	N_{86}	N_{87}	N_{8}	N_{89}	N_{810}	N_{811}	N_{812}	N_{813}	N_{814}	N_{815}
N_{91}	N_{92}	N_{93}	N_{94}	N_{95}	N_{96}	N_{97}	N_{98}	N_{9}	N_{910}	N_{911}	N_{912}	N_{913}	N_{914}	N_{915}
N_{101}	N_{102}	N_{103}	N_{104}	N_{105}	N_{106}	N_{107}	N_{108}	N_{109}	N_{10}	N_{1011}	N_{1012}	N_{1013}	N_{1014}	N_{1015}
N_{111}	N_{112}	N_{113}	N_{114}	N_{115}	N_{116}	N_{117}	N_{118}	N_{119}	N_{1110}	N_{11}	N_{1112}	N_{1113}	N_{1114}	N_{1115}
N_{121}	N_{122}	N_{123}	N_{124}	N_{125}	N_{126}	N_{127}	N_{128}	N_{129}	N_{1210}	N_{1211}	N_{12}	N_{1213}	N_{1214}	N_{1215}
N_{131}	N_{132}	N_{133}	N_{134}	N_{135}	N_{136}	N_{137}	N_{138}	N_{139}	N_{1310}	N_{1311}	N_{1312}	N_{13}	N_{1314}	N_{1315}
N_{141}	N_{142}	N_{143}	N_{144}	N_{145}	N_{146}	N_{147}	N_{148}	N_{149}	N_{1410}	N_{1411}	N_{1412}	N_{1413}	N_{14}	N_{1415}
N_{151}	N_{152}	N_{153}	N_{154}	N_{155}	N_{156}	N_{157}	N_{158}	N_{159}	N_{1510}	N_{1511}	N_{1512}	N_{1513}	N_{1514}	N_{15}

Table 6
Weighting, mean-rating, and rankfor Reconfigurability Dimensions.

Dimensions D_i		Statistics								
		First round			Second round			Third round		
		Mean RatingM_{Di}	RankR_{Di}	WeightingW_{Di}	Mean RatingM_{Di}	RankR_{Di}	WeightingW_{Di}	Mean RatingM_{Di}	RankR_{Di}	WeightingW_{Di}
D_1	Modularity	7.60	2	0.21	7.50	1	0.21	6.80	4	0.19
D_2	Integrability	6.90	4	0.19	7.10	2	0.20	7.40	3	0.20
D_3	Convertibility	7.80	1	0.22	6.80	3	0.19	7.90	1	0.22
D_4	Diagnosability	6.60	5	0.18	7.50	1	0.21	6.70	5	0.18
D_5	Customization	7.30	3	0.20	6.20	4	0.18	7.60	2	0.21

Table 7
Weighting, mean-rating, and rankfor Reconfigurability Enablers.

Enablers N_i		Statistics								
		First round			Second round			Third round		
		Mean Rating M_{Ni}	Rank R_{Ni}	Weighting W_{Ni}	Mean Rating M_{Ni}	Rank R_{Ni}	Weighting W_{Ni}	Mean Rating M_{Ni}	Rank R_{Ni}	Weighting W_{Ni}
N_1	Network Structure Design	7.60	3	0.071	6.80	9	0.063	7.40	5	0.069
N_2	Responsiveness	7.40	5	0.069	6.90	8	0.064	6.80	10	0.064
N_3	Total Cycle Time	7.50	4	0.070	7.80	2	0.072	7.20	7	0.067
N_4	Real- Time Integration	7.10	8	0.066	6.60	11	0.061	7.70	2	0.072
N_5	Collaboration	7.00	9	0.065	7.30	6	0.068	6.50	11	0.061
N_6	Transfer Pricing	6.20	14	0.058	7.50	4	0.070	6.20	12	0.058
N_7	Adaptability	6.60	12	0.062	7.40	5	0.069	7.70	2	0.072
N_8	Leagility	6.50	13	0.061	7.60	3	0.071	7.30	6	0.068
N_9	Trust	6.90	10	0.064	6.70	10	0.062	6.80	10	0.064
N_{10}	Visibility	7.20	7	0.067	7.50	4	0.070	6.20	12	0.058
N_{11}	Data Reliability	7.30	6	0.068	7.10	7	0.066	7.60	3	0.071
N_{12}	Resilience	7.60	3	0.071	7.90	1	0.073	7.10	8	0.067
N_{13}	New Product Development	6.80	11	0.063	6.80	9	0.063	6.90	9	0.065
N_{14}	Customer Satisfaction	7.80	1	0.073	7.60	3	0.071	7.50	4	0.070
N_{15}	Sustainability	7.70	2	0.072	6.20	12	0.058	7.80	1	0.073

Table 8
Integrated data for Reconfigurability Index Calculation (Actual).

Dimensions D_i		Weighting W_{Di}	Enablers N_i		Mean Rating M_{Ni}	Rank R_{Ni}	Weighting W_{Ni}
D_1	**Modularity**	0.19	N_1	Network Structure Design	7.4	1	0.346
			N_2	Responsiveness	6.8	3	0.318
			N_3	Total Cycle Time	7.2	2	0.336
D_2	**Integrability**	0.20	N_4	Real- Time Integration	7.7	1	0.377
			N_5	Collaboration	6.5	2	0.319
			N_6	Transfer Pricing	6.2	3	0.304
D_3	**Convertibility**	0.22	N_7	Adaptability	7.7	1	0.353
			N_8	Leagility	7.3	2	0.335
			N_9	Trust	6.8	3	0.312
D_4	**Diagnosability**	0.18	N_{10}	Visibility	6.2	3	0.297
			N_{11}	Data Reliability	7.6	1	0.364
			N_{12}	Resilience	7.1	2	0.340
D_5	**Customization**	0.21	N_{13}	New Product Development	6.9	3	0.311
			N_{14}	Customer Satisfaction	7.5	2	0.338
			N_{15}	Sustainability	7.8	1	0.351

Table 9
Integrated data for Reconfigurability Index Calculation (Ideal).

Dimensions D_i		Weighting W_{Di}	Enablers N_i		Mean Rating M_{Ni}	Rank R_{Ni}	Weighting W_{Ni}
D_1	**Modularity**	0.19	N_1	Network Structure Design	9.00	1	0.33
			N_2	Responsiveness	9.00	1	0.33
			N_3	Total Cycle Time	9.00	1	0.33
D_2	**Integrability**	0.20	N_4	Real Time Integration	9.00	1	0.33
			N_5	Collaboration	9.00	1	0.33
			N_6	Transfer Pricing	9.00	1	0.33
D_3	**Convertibility**	0.22	N_7	Adaptability	9.00	1	0.33
			N_8	Leagility	9.00	1	0.33
			N_9	Trust	9.00	1	0.33
D_4	**Diagnosability**	0.18	N_{10}	Visibility	9.00	1	0.33
			N_{11}	Data Reliability	9.00	1	0.33
			N_{12}	Resilience	9.00	1	0.33
D_5	**Customization**	0.21	N_{13}	New Product Development	9.00	1	0.33
			N_{14}	Customer Satisfaction	9.00	1	0.33
			N_{15}	Sustainability	9.00	1	0.33

Table 10
Results of Index Calculations (Integrated Assessment).

Assessment Model	Reconfigurability Index (Calculated)	Reconfigurability Index (Ideal)	Relative Reconfigurability Index (**RRI**) %
Integrated Assessment Model	**7.1528**	**9.0000**	**79.4751**

$$
\begin{matrix}
N_{1} & N_{12} & N_{13} & 0 & 0 & 0 & N_{17} & 0 & 0 & N_{110} & N_{111} & N_{112} & 0 & N_{114} & N_{115} \\
0 & N_{2} & 0 & 0 & 0 & 0 & N_{27} & 0 & 0 & 0 & 0 & 0 & 0 & N_{214} & N_{215} \\
0 & N_{32} & N_{3} & 0 & N_{35} & 0 & 0 & 0 & 0 & N_{310} & 0 & 0 & 0 & N_{314} & N_{315} \\
N_{41} & N_{42} & N_{43} & N_{4} & N_{45} & N_{46} & N_{47} & N_{48} & N_{49} & N_{410} & 0 & N_{412} & N_{413} & 0 & 0 \\
N_{51} & N_{52} & N_{53} & N_{54} & N_{5} & N_{56} & N_{57} & N_{58} & N_{59} & N_{510} & 0 & N_{512} & N_{513} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & N_{6} & 0 & N_{68} & N_{69} & N_{610} & 0 & 0 & 0 & 0 & N_{615} \\
0 & N_{72} & N_{73} & N_{74} & 0 & N_{76} & N_{7} & N_{78} & N_{79} & N_{710} & N_{711} & N_{712} & 0 & 0 & N_{715} \\
0 & N_{82} & N_{83} & N_{84} & 0 & N_{86} & N_{87} & N_{8} & N_{89} & N_{810} & N_{811} & N_{812} & N_{813} & 0 & 0 \\
0 & N_{92} & 0 & N_{94} & 0 & N_{96} & N_{97} & 0 & N_{9} & N_{910} & N_{911} & N_{912} & N_{913} & 0 & 0 \\
N_{101} & N_{102} & N_{103} & 0 & 0 & 0 & 0 & 0 & 0 & N_{10} & 0 & 0 & N_{1013} & N_{1014} & 0 \\
N_{111} & N_{112} & N_{113} & 0 & 0 & 0 & N_{117} & 0 & 0 & N_{1110} & N_{11} & 0 & 0 & 0 & 0 \\
N_{121} & N_{122} & 0 & 0 & 0 & N_{126} & 0 & 0 & N_{129} & N_{1210} & 0 & N_{12} & N_{1213} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & N_{13} & N_{1314} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & N_{1413} & N_{14} & 0 \\
0 & 0 & 0 & 0 & 0 & N_{156} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & N_{1514} & N_{15}
\end{matrix}
$$

(6)

The fifteen enablers that play a critical role in creating reconfigurability are the diagonal elements, and the interdependencies of each enabler with other enablers are represented by off-diagonal elements.

(7)

These are the actual representations from the reconfigurability digraph and are shown in Eq. (7).

3.1.4. Index calculation

The values for each element in RVPM were obtained from experts' opinions, and a mean rating of the interdependencies was taken, and as the diagonal elements are assumed to be critical factors for reconfigurability attainment, it is considered as maximum possible value. The actual RVPM denoted by N* and Eq. (8) is used for evaluation of the reconfigurability index by calculating the permanent Per (N*).

$$
\begin{matrix}
9 & 4 & 4.2 & 0 & 0 & 0 & 3.9 & 0 & 0 & 3.9 & 4.3 & 4.1 & 0 & 4.1 & 4.3 \\
0 & 9 & 0 & 0 & 0 & 0 & 3.6 & 0 & 0 & 0 & 0 & 0 & 0 & 4.1 & 4.2 \\
0 & 3.9 & 9 & 0 & 3.9 & 0 & 0 & 0 & 0 & 4.3 & 0 & 0 & 0 & 4.1 & 3.9 \\
3.8 & 3.8 & 4.4 & 9 & 4.2 & 4.1 & 3.7 & 3.8 & 4.2 & 3.7 & 0 & 4 & 4.1 & 0 & 0 \\
3.9 & 3.8 & 4.1 & 4.1 & 9 & 3.8 & 4.1 & 4.2 & 4.1 & 3.9 & 0 & 3.7 & 4.1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 9 & 0 & 4.2 & 3.9 & 3.9 & 0 & 0 & 0 & 0 & 4.3 \\
0 & 4.1 & 3.9 & 3.8 & 0 & 3.8 & 9 & 4.4 & 4.2 & 4.1 & 3.7 & 3.8 & 0 & 0 & 4.2 \\
0 & 3.7 & 3.8 & 4.2 & 0 & 3.7 & 4 & 9 & 4.1 & 3.9 & 3.8 & 4.1 & 4.1 & 0 & 0 \\
0 & 3.8 & 0 & 4.1 & 0 & 4.2 & 4.1 & 0 & 9 & 3.9 & 3.9 & 3.8 & 3.8 & 0 & 0 \\
4.4 & 4.2 & 4.1 & 0 & 0 & 0 & 0 & 0 & 0 & 9 & 0 & 0 & 3.7 & 3.8 & 0 \\
4.2 & 3.7 & 3.8 & 0 & 0 & 0 & 4.2 & 0 & 0 & 3.7 & 9 & 0 & 0 & 0 & 0 \\
4 & 3.8 & 0 & 0 & 0 & 4.2 & 0 & 0 & 3.7 & 4 & 0 & 9 & 4.1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 9 & 3.9 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.8 & 9 & 0 \\
0 & 0 & 0 & 0 & 0 & 4.1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4.1 & 9
\end{matrix}
$$

(8)

The matrix is transformed into equations stated earlier in Eq. (1). The permanence of the RVPM is obtained through a program written in MATLAB R2015a. The Reconfigurability Index is obtained by substituting maximum possible values designated for N_{ij} in RVPM.

This ideal value allows us to compare with the actual value and understand the level of reconfigurability attained by the supply chain and is termed as Relative Reconfigurability Index (RRI). The RRI calculated from the deterministic assessment model was found to be 77.79% as shown above in Table 3.

3.2. Integrated assessment model

In the present research, the model accounts for five dimensions of reconfigurability and an integration of them as domains are required to assess reconfigurability index.

3.2.1. Statistical results and Consensus analysis of Delphi Technique after three rounds

We performed Kendall's W test in the non-parametric tests for k-related samples to analyze the ranks received for reconfigurability dimensions and enablers from ten (n) number of experts. IBM SPSS Statistics V22.0 is used in this study to compute the Kendall's coefficient of concordance (W).

Kendall's coefficient of concordance (W) increased for dimensions (0.094, 0.104, and 0.134) from the first to third round shown above in Table 4. The value of W also increases for enablers (0.088, 0.102, and 0.109); therefore the stop criterion was reached in the third round, because its value became statistically significant for $p < 0.05$ as shown in Table 5.

3.2.2. Weighting, mean-rating, and rank determination

The weighting (W_{Di}, W_{Ni}) for reconfigurability dimensions and their corresponding enablers were computed using Eq. (2) and Eq. (3), which were stated earlier. The mean ratings of reconfigurability dimension and enablers are represented by M_{Di}, and M_{Ni}, and are calculated based on the ratings gathered from the experts.

The rank signifies how important of dimension, and the enabler is to attain reconfigurability in a supply chain perspective. These result dimensions and enablers are shown above in Tables 6 and 7, respectively. The ranks (R_{Di}, R_{Ni}) were assessed for the dimension and enablers pertaining to reconfigurability.

3.2.3. Index calculation

To assess the Reconfigurability Index, the weights of each dimension are multiplied with the summation of mean rating multiplied by weights of their respective enablers and divided by the number of enablers pertaining to that dimension. The values of mean rating and

Table 11
Result of Comprehensive Relative Reconfigurability Index (CRRI) %.

Assessment Model	Reconfigurability Index (Calculated)	Reconfigurability Index (Ideal)	Relative Reconfigurability Index (**RRI**) %	Comprehensive Relative Reconfigurability Index (**CRRI**) %
Deterministic Assessment Model	**3.9086 × 10** [19]	**5.0244 × 10** [19]	**77.7924**	**78.6337**
Integrated Assessment Model	**7.1528**	**9.0000**	**79.4751**	

Table 12
Sensitivity Analysis with Minimum Diagonal Values.

Plot Number	Reconfigurabilty Enablers	Minimum Index Value
1	Network Structure Design	4.3429E+13
	Responsiveness	4.3429E+13
	Visibility	4.3429E+13
	Data Reliability	4.3429E+13
	Resilience	4.3429E+13
	Sustainability	4.3429E+13
2	Transfer Pricing	5.9456E+13
3	Total Cycle Time	6.1092E+13
4	Trust	6.1997E+13
5	New Product Development	7.6914E+13
	Customer Satisfaction	7.6914E+13
6	Real Time Integration	9.9999E+13
	Collaboration	9.9999E+13
7	Adaptability	1.1779E+14
	Leagility	1.1779E+14

weightings are substituted from the third round of the Delphi technique. They are then aggregated to calculate the reconfigurability index using Eq. (4) and are shown in Table 8.

$$\begin{aligned} Re\,configurabilityIndex(Actual) &= \left[0.19 \times \frac{7.14205}{1}\right] + \left[0.20 \times \frac{6.86176}{1}\right] + \left[0.22 \times \frac{7.28532}{1}\right] \\ &+ \left[0.18 \times \frac{7.01483}{1}\right] + \left[0.21 \times \frac{7.41891}{1}\right] \\ &= [1.35699] + [1.37235] + [1.60277] + [1.26266] + [1.55797] \\ &= 7.15275 \end{aligned} \tag{9}$$

The ideal value of Reconfigurability Index is obtained by substituting maximum possible values designated for M_{Di} and M_{Ni} and keeping the evaluated weightings of dimensions intact and shown in Table 9. The reconfigurability index for actual cases and ideal cases are compared to compute the relative reconfigurability index (RRI).

$$\begin{aligned} ReconfigurabilityIndex(Ideal) &= \left[0.19 \times \frac{9.00}{1}\right] + \left[0.20 \times \frac{9.00}{1}\right] + \left[0.22 \times \frac{9.00}{1}\right] \\ &+ \left[0.18 \times \frac{9.00}{1}\right] + \left[0.21 \times \frac{9.00}{1}\right] \\ &= [1.71] + [1.80] + [1.98] + [1.62] + [1.89] \\ &= 9.0000 \end{aligned} \tag{10}$$

Relative Reconfigurability Index (RRI) is calculated by dividing the results obtained from Eq. (9) by Eq. (10). The result is presented in Table 10 below.

3.3. Measurement of comprehensive relative reconfigurable index (CRRI)

The Comprehensive Relative Reconfigurable Index (CRRI) is evaluated by taking the average of the two RRIs calculated from the deterministic and integrated assessment models. The details of the measurement of RRI and CRRI are shown in Table 11.

The calculated value is expressed as a percentage and reflects the level of reconfigurability attained by the supply chain.

4. Research finding and implications

The relative reconfigurability index obtained from the deterministic assessment model shows a 77.79% attainment of reconfigurability paradigm and the supply chain is deficient by 22.21% in the attainment of reconfigurability. To better understand the results, sensitivity analysis of the relative reconfigurability index obtained from the deterministic assessment model is obtained. The ideal value of the reconfigurability index was obtained from the RVPM by taking the maximum value of the diagonal elements (N_1–N_{15}). Now for each enabler, all sets of values from minimum (1) to maximum (9) are substituted and results obtained, keeping the values of other enablers and their relationship the same as the ideal index. Thus, for all the possible nine values of each enabler the corresponding sets of values of RRI are obtained. We grouped the enablers depending upon the obtained minimum values of the reconfigurability index by substituting (1) in the diagonal element pertaining to that enabler of the RVPM; these are shown in Table 12.

There are seven plots in which the variations are observed. The results are plotted as shown in Fig. 5.

This analysis provides an exhaustive picture of the variation of reconfigurability in relation to each enabler. The analysis shows that minimum variation of RRI is obtained for two enablers of supply chain i.e. adaptability and leagility. The maximum variation is obtained for network structure design, responsiveness, visibility, data reliability, resilience and sustainability. Transfer pricing, total cycle time, and trust vary independently.

The comprehensive relative reconfigurability index is calculated to be 78.63% and can be improved further by closely analyzing the enablers which lack in the ratings. These results will help managers improve the actual value of reconfigurability by focussing on the weak links and addressing the barriers in attaining them. The utility of this index is the ability to handle the subjectivity involved, which would not have been obtained through network analysis models.

This research provides a deeper knowledge of how supply chain characteristics increase or decrease reconfigurability and consequently, affect structural flexibility in the supply chain. The research supports firms in measuring and analyzing supply chain reconfigurability and supports supply chain decision-making.

5. Conclusions and scope for further study

The proposed model for measuring reconfigurability in supply chains is a new effort altogether in the area of supply chain management. The novelty of this research lies in its combination of two methods to evaluate a single index, considering the dimension, enablers and their interdependencies in an automobile supply chain.

The comprehensive relative reconfigurable index (CRRI) obtained is quite generic and may be helpful for supply chain practitioners and entrepreneurs to evaluate their concerned supply chains to compete in an era of turbulence. This research will serve as an essential framework

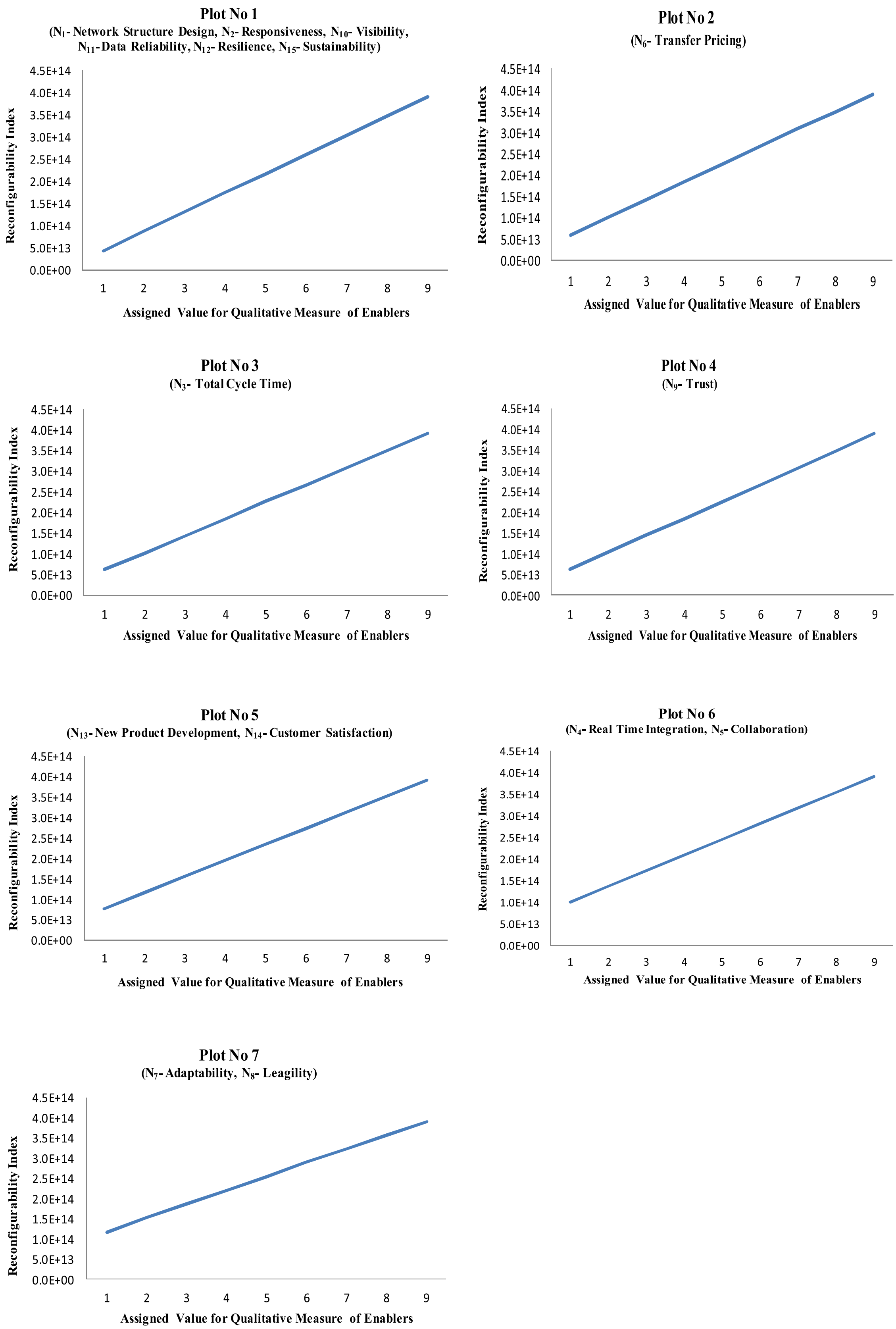

Fig. 5. Sensitivity Analysis.

for supporting strategic decision making to transform supply chains into reconfigurable supply chains.

This research can be further extended by doing a certain level pair-wise comparison between the two distinct supply chain companies, evaluating the coefficient of similarity and dissimilarity, and anticipating them in numerical values. Future research can also include a number of companies ($n > 1$) in the same supply chain and then, a reconfigurability index can be evaluated.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jmsy.2019.05.008.

References

[1] Christopher M, Holweg M. "Supply Chain 2.0″: managing supply chains in the era of turbulence. Int J Phys Distrib Logist Manag 2011;41(1):63–82.
[2] Guo Weihong, Tian Qi, Jiang Zhengqian, Wang Hui. A graph-based cost model for supply chain reconfiguration. J Manuf Syst 2018;48(Part B):55–63.
[3] Maganha Isabela, Silva Cristovao, Ferreira Luis, Miguel DF. Understanding reconfigurability of manufacturing systems: an empirical analysis. J Manuf Syst 2018;48(Part A):120–30.
[4] Bortolini M, Galizia FG, Mora C. Reconfigurable manufacturing systems: literature review and research trend. J Manuf Syst 2018;49:93–106.
[5] Andersen Ann-Louise, Brunoe Thomas Ditlev, Nielsen Kjeld, Rösiö Carin. Towards a generic design method for reconfigurable manufacturing systems: analysis and synthesis of current design methods and evaluation of supportive tools. J Manuf Syst 2017;42:179–95.
[6] Renna Paolo. Decision-making method of reconfigurable manufacturing systems' reconfiguration by a gale-shapley model. J Manuf Syst 2017;45:149–58.
[7] Mourtzis Dimitris, Vlachou Ekaterini. A cloud-based cyber-physical system for adaptive shop-floor scheduling and condition-based maintenance. J Manuf Syst 2018;47:179–98.
[8] Moghaddam Mohsen, Cadavid Marissa N, Kenley CRobert, Deshmukh Abhijit V. Reference architectures for smart manufacturing: a critical review. J Manuf Syst 2018;49:215–25.
[9] Zheng Pai, Xu Xun, Yu Shiqiang, Liu Chao. Personalized product configuration framework in an adaptable open architecture product platform. J Manuf Syst 2017;43(Part 3):422–35.
[10] Soni Umang, Jain Vipul, Kumar Sameer. Measuring supply chain resilience using a deterministic modeling approach. Comput Ind Eng 2014;74:11–25.
[11] Yadav Neetu. Total interpretive structural modelling (TISM) of strategic performance management for Indian telecom service provider. Int J Product Perform Manag 2014;63(4):421–45.
[12] Biswas Pallab. Modeling reconfigurability in supply chains using total interpretive structural modeling. J Adv Manag Res 2017;14(2):194–221.
[13] Jurkat WB, Ryser HJ. Matrix factorizations of determinants and permanents. J Algebra 1996;3:1–27.
[14] Jense JB, Gutin G. Digraph theory, algorithms and organisations. London: Springer; 2000.
[15] Wani MF, Gandhi OP. Development of maintainability index for mechanical systems. Reliab Eng Syst Saf 1999;65(3):259–70.
[16] Chan APC, Yung EHK, Lam PTI, Tam CM, Cheung SO. Application of Delphi method in selection of procurement systems for construction. Constr Manag Econ 2001;19(7):699–718.
[17] Stonebraker PW, Goldhar J, Nassos G. Weak links in the supply chain: measuring fragility and sustainability. J Manuf Technol Manag 2009;20(2):161–77.
[18] Rao T, Schoenherr T. Assessing and managing risks using the supply chain risk management process (SCRMP). Supply Chain Management 2011;16(6):474–83.
[19] Gunasekaran A, Patel C, Tirtiroglu E. Performance measures and metrics in a supply chain environment. Int J Oper Prod Manage 2001;21(1/2):71–87.
[20] Azevedo Susana G, Govindan Kannan, Carvalho Helena, Cruz-Machado V. Ecosilient Index to assess the greenness and resilience of the upstream automotive supply chain. J Clean Prod 2013;56:131–46.
[21] Harary F, Maybee JS. "Graphs and applications: Proceedings of the first colorado symposium on graph theory". Hoboken, New Jersey: John Wiley & Sons; 1985.
[22] Gaudenzi B, Borghesi A. "Managing risks in the supply chain using the AHP method". The International Journal of Logistics Management 2006;17(1):114–36.
[23] Nunlee M, Qualls W, Rosa JA. "Antecedents of supply chain management: a performance measurement model". In: American Marketing Associationeditor. Conference Proceedings 2000 AMA. 2000. pp. 354-360.
[24] Siegel S, Castellen NJ. "Nonparametric Statistics for the Behavioural Sciences". second ed. New York: McGraw-Hill; 1988.
[25] Nardo M, Saisana M, Saltelli A, Tarantola S. "Tools for Composite Indicators Building". European Commission; 2005.
[26] Farmer TA. "Testing the robustness of multi attribute utility theory in an applied setting". Decision Sciences 1987;18(2):178–93.
[27] Curwin J, Slater R. "Quantitative Methods for Business Decisions". sixth ed. International Thomson Business Press; 2008.
[28] Rowley J. "Using case studies in research". Management Research News 2002;25(1):16–27.