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To achieve sustainability in supply chain with Digital integration: A TISM approach

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Abstract: Conventional supply chain has been shown to be incapable of meeting the ever-increasing demands of customers as well as the requirements of innovation. Due to various uncertainty volatility, ambiguity, and intricacy, the sustainability of supply chain becomes a major topic for organisations. Now there is need to integrate the digital technologies like cloud computing, internet of things, artificial intelligence, big data analysis etc. which improve the performance of supply chain in efficient and responsiveness manner. Due to this digital integration, the system undergoes various changes at organisational, operational, performance and technological level. This study aims to identify nine major critical factors which are enablers to achieve the sustainability in digitally integrated supply chain. A TISM model is developed to address their interrelationship among them. The factors are classified as dependent and independent factors according to their driving and dependence power through the use of the MICMAC analysis. If is confirmed in MICMAC analysis that the factors Agile Organisational structure, Smart logistics Capabilities, Smart Manufacturing Process and financial planning enhance the sustainability of digitally enabled supply chain. This study provides a comprehensive list of enablers that are necessary to achieve sustainability of digitally integrated supply chains; nevertheless, the list is not exhaustive. This paper was written with the intention of contributing a pool of knowledge on achieving sustainability in digitally integrated supply chain. This study has the potential to make it possible for market specialists and executives to focus on critical elements that lead to tactical decisions and maximise value for companies. It establishes a baseline from which future studies can build.

Introduction

Over the past years, the world has witnesses various supply chain disruptions due to trade wars, tariff and pandemic and the world economy is facing uncertainty, volatility, ambiguity, and intricacy (Gomez-Trujillo and Gonzalez-Perez, 2021). Now achieving supply chain sustainability, visibility and resilience are the main the major discussion areas for the business communities (El Hilali and El Manouar, 2019). Over the past decade, the ideas of digitalization, potentiality, and sustainability have garnered significant interest in disrupted environments. Hence the organisations are forced to adapt digital integration with their system to mitigate the risks and challenges due to supply chain disruption (Dakhnovich et al., 2019). The digital integration with system can impact the sustainability as at the same time the system undergoes a chain of changes (Park et al., 2021; Sobb et al., 2020). The organisations are ready to invest in the digital transformation to achieve the sustainability in their supply chain and are preparing themselves to face the changes and threats (El Hilali and El Manouar, 2019). The digital transformation of supply chain leads to integration of new age digital technologies e.g., Machine Learning (ML), internet of things (IOT), cloud computing (CC), artificial intelligence (AI), big data analysis (BDA) etc. with the physical system. This physical and technological integration across the network, also termed as "SCM 4.0", enables the

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increased production, faster flow of material, more flexibility with real time planning and increased overall growth (Mckinsey, 2016). In fact, it allows for a more in-depth comprehension of market possibilities and anticipations, which aids in providing a more tailored and prompt response to the demands of SC Stakeholders. These technologies help in planning by optimization and simulation through collection of real time data from various environments (Kor et al., 2022). This research is carried out to focus on digital integration with conventional supply chain and studies the various factors which enables the supply chain to operate in a more environmentally and socially responsible manner, contributing to the attainment of sustainability goals. It explores how the digital integration provide an opportunity to incorporate sustainability at strategic level and improve firm efficiency by using data and information collection.

The previous researchers have mainly focused performance improvement concerning profits and discussion of implementation of digital technologies. Despite reams of research carried on digital transformation, few studies have analysed the sustainability in supply chain with digital integration in enterprises. The major aims of the study are (a) to identify the various enablers to achieve the supply chain sustainability with digital integration, and (b) to develop a Total Interpretive Structural Model (TISM) which signifies the inter-relationship among identified enablers.

To address the above research objectives nine critical success enablers related to sustainable digital supply chain are explored. A group of supply chain management expert is involved to fulfil the main sight of the study. A TISM approach is applied to investigate the critical factors (CFs) linkage. The past research confirms that TISM is very handful multi-criteria-decision-making tool which gives contribution into a theory development. The technique of TISM not only aids in identifying the connections between variables and constructing a hierarchical framework but also involves a qualitative evaluation of these linkages to uncover their underlying causes (Dubey et al., 2018). This study will help to the SC manager to take decision based on hierarchical structure framework developed by TISM approach. By representing nodes as factors and their direct and indirect interconnections, it becomes possible to elucidate the "what" and "how" of theory development.

A systematic literature review has been concluded to identify the various critical factors which are enablers to attain sustainability in the supply chain through digital integration. The various published research articles from peer – reviewed database i.e. Scopus and Web of Science indexed has been studied for extensive research. Through a literature survey, A number of critical factors are identified, they are analysed and finally nine factors critical to achieve of supply chain sustainability with digital transformation are selected for the purpose of present study. These nine factors critical are explained in brief as follows

Smart/intelligent Manufacturing Process

The term "smart manufacturing," or "SM," refers to an approach that focuses on improving manufacturing operations by the integration of processes, the connecting of physical and cyber capabilities, and integration with many digital technologies e.g., 3D printing, IOT, CC, BDA, AI, BT (Moyne and Iskandar, 2017). With digital integration it is possible to collect massive amount of operational and processes conditions data generated across the network and it produces a data rich environment in which lot of data are shared and analysed across the network to manufacturing intelligence. BDA and IOT helps to develop an intelligent network that encompasses every phase of production and significantly alters how companies interact with society (Abubakr et al., 2020) and positively impacted the agility at organizational, technological and employee level (Vates et al., 2022). Adaptive Manufacturing (AM) and 3D printing technology are established to increase average production levels, to catch the process glitches timely, to meet the customer responsiveness and to deal the demand turbulence (Abdallah & Nabass, 2018). The application of this digital integration makes the smart manufacturing firms more flexible (Dixit and Raj, 2018), agile and responsive (Dubey and Gunasekaran, 2015) to achieve the sustainability in SC.

Smart logistics

The smart logistics is referred to application of barcodes, GPS (Global Positioning Systems), sensors, RFID (Radio Frequency Identification Technology), and other advanced network technologies for information processing and network communication purposes (Feng and Ye, 2021). Organisations need to implement smart logistics solutions with scalable, flexible, and future-oriented technologies to improve operations as conventional supply networks aren't enough; organisations need to get innovative solutions to compete and to achieve the supply chain sustainability. Smart logistics not only increase the efficiency of transport and warehousing, but it also allows the connectivity between various logistics networks, such as the exchange of transport orders between various parties and modes. The smart logistics make an organisation capable to manage

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logistics activities, including real time movement and delivery of goods (Shamsuzzoha et al., 2013), smart warehousing, optimising inventory level. It enhances the customer experience and boost the financial performance of the organisation (Shibin et al., 2017). Smart logistics implications include customer interface, value proposition, supply chain network, and financial structure and also three sustainability dimensions (Man and Strandhagen, 2017).

Information Sharing:

Information sharing among the stakeholders is one of the most important factors in digital integration to achieve sustainable supply chain (Sunmola, 2021). Proper information sharing enhances the supply chain capabilities and also increases the transparency between suppliers and customers (Ebinger and Omondi, 2020). With digital integration the information system, having huge generated data, is capable to share data in real time and it will impact positively on competency of sustainable supply chain (Shibin et al., 2017). Such information sharing helps in data analytics to create sustainable model in order to reduce risk in supply chain network (Xu et al., 2018).

Data Security and Trust Building

The digitally enabled supply chain relies on internet and network connectivity. This reliance may have cyber security implications for the efficacy of such systems (Sobb et al., 2020). The digital integration with system provides a transparency and information sharing along the supply chain. In some regards, this transparency and information sharing lead to major concerns about the data security of stakeholders (Ebinger and Omondi, 2020). Any misuse of data/information or any data breach due to cyber-attack may cause to lose trust among the partners (Pandey et al., 2020). Lack of trust may impact the agility and sustainability of supply chain. The management must develop a robust security infrastructure, which gives an assurance of privacy and security of data, to manage digital integration (Fernando et al., 2018).

Agile Organisational structure

The digital integration process impacted organizations in every aspect and place enormous pressure on organisation to adapt these changes quickly. It is evident in study that the organizational structure is considered as a significant barrier to digital integration. Therefore it becomes essential for top management and supply chain managers to comprehend the implication of digital integration on their supply chain and their stakeholders (Agrawal and Narain, 2018). An agile organisation structure facilitates speedier decisions and encourages initiative and promotes an entrepreneurial spirit. The agility in organisation structure develops the organization's capability to respond quickly and creatively to new challenges, with the help of its people, departments, and other subsystems (Küffner et al., 2022). Modernization and digitization require major organisational restructuring for Facilitating novel processes that present both opportunities and challenges for enterprises and achieving resilience and sustainability (Choudhury et al., 2021).

Building Human Capital

For a paradigm shift to digital integration the organisations need to focus on continuous training & learning of the workers/employees as they must have a bundle of knowledge, talents, mindsets, approaches, and consciousness (Janssen et al., 2013). The goal here is to train individuals to become more proficient in their chosen fields and to develop the competencies as per requirement of digital integration with system (Bag et al., 2018). The digitalization of Supply Chains presents a multifaceted skill issue which may be hurdles to achieve the sustainability of supply chain pre and post implementation stages of digital integration. In contemplation of achieving the sustainability in digitally integrated supply chain, the supply chain managers must also aid and guide them as they gain these skills & competencies. To build a strong human capital the management need to focus not only technical competencies e.g. cloud computing, data analysis, artificial intelligence, data security etc., but also need to focus on their behavioural and related to their motivational, ethical and personality traits e.g., critical thinking, negotiation, leadership, communication, decision-making etc. (Ageron et al., 2020). Finally, it has become apparent that workforce need to be trained and equipped to actively analyse and address the complex ethical concerns, and inequalities associated to digital technologies and their data (Ross et al., 2022). Moreover, the trained and skilled workforce will also train and educate its SC partners and customers to ensure the supply chain's continued success in the modern digital era.

Financial Planning

The flow of financial transactions in the supply chain occurs apace with the movement of goods and information. Its integration with the physical supply chain is of the utmost decisive as it is identical to all other types of industrial supply networks. One of the major challenges is to achieve economic scale in business and to decrease the risk of financial instability in order to achieve the competitive edge (Ali and Govindan, 2021). The conventional Supply Chain is more matted and arduous due to delays of payment, additional cost of services of lawyers and bankers for contract arrangement (Fanning and Centers, 2016). The investments in digital integration, such as block chain technology, which is developed to identify critical and enduring barriers via diversified and developing supply chains that have traditionally relied on centralised governance models, amplify the coordination among all stakeholders enabling for direct and transparent transactions without longer delays or operational glitches (Saberi et al., 2019).

Customer Satisfaction

In order to achieve sustainability, the customer experience is also a major aspect to be considered in account to digital integration. In a volatile, uncertain, complex, and ambiguous (VUCA) world, in which the expectations of customers are escalating and where their loyalty and advocacy seem to be unstable and challenging to retain, all organisations need to stimulate innovative ideas and adopt the new realities that are driven by digital integration (Ageron et al., 2020). The value that customers place on the goods and services they receive increases as a result of increased personalization. With digital integration the customers will be increasingly incorporated into the creation of products and services, which will result in a modified consumer interface (Junge, 2019). It offers new potential for organizations to better enhance customer satisfaction (Reaidy et al., 2021) and allows to establish a long-term connection with customers to the extent of achieve the sustainability (Preindl et al., 2020).

Grievance Redressal Systems:

In contrast, grievance mechanisms are an essential instrument which capture highly localized issues in near real-time, it helps the companies to detect risks across their supply chain at a granular and comprehensive level. The management need to integrate digitally the company's grievance system for stakeholders i.e., suppliers, employees and customer. The digital integration develops an agile grievance mechanism to avoid the some key concerns in sustainable supply chain. If grievance is not handled effectively it may cause a disruption in supply chain and may also arises legal issues. An effective grievance mechanism improves the customer experience (Prajapat et al., 2018), motivate the employees, (Monish & Dhanabhakyam, 2022) and enhance suppliers' relations. The grievance process must be capable to for systematic handling of severe sustainability violations.

Methodology

J. Warfield developed ISM in 1973. TISM is a general-purpose research and decision-support tool that offers a systematic approach to complicated circumstances. It creates a hierarchical flow from the most critical enabling to the least. In the ISM approach, the explanation of the interactive relationships depicted by directed links for the recognised factors is comparatively lacking, which could disrupt the decision-making method. Hence TISM could be a suitable strategy to overcome these problems in analysing the directed linkage in the structural model for the factors under consideration. TISM approach involves the following steps to a framework.

Step 1: In first step the nine critical factors are identified and explained in section 2 through literature survey.

Step 2: Establish contextual relationship among the CFs are established to create of a hierarchical structure by help of discussion and feedback from the experts. The Four symbols V, A, O, and X are used to establish the contextual relationship between two given CF. "V" stands that variable i influence j, the symbol "A" stands that variable j influence i, the symbol "X" stands that variable i influence j as well as variable j influence I, and the symbol "O" stands that variable i, j are not influencing each other.

Step 3: Structural Self Interaction Matrix (SSIM): A pairwise relationship among the CFs established in step 2 is framed in a matrix, as shown in table 1, called Structural Self Interaction Matrix (SSIM). The below matrix shows the relationship between row variable i and column variable j.

Step 4: Reachability Matrix (RM): A binary matrix, called initial reachability matrix, as shown in table 2 is developed from SSIM by replacing V, A, X, and O. Let S_{ij} and R_{ij} are the element of SSIM and RM. the substitute rule to develop binary matrix is as follows:

Table 1. Structural Self Interaction Matrix (SSIM).

Critical Factors (CFs)	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9
Smart Manufacturing Process (CF1)		X	V	V	A	V	V	V	O
Smart logistics (CF2)			V	V	A	V	V	V	O
Information Sharing (CF3)				X	A	A	O	V	V
Data Security and Trust Building(CF4)					A	A	A	V	O
Organisational structure (CF5)						V	V	V	V

Building Human capital (CF6)							A	O	V
Financial planning (CF7)								O	O
Customer Satisfaction (CF8)									X
Grievance Redressal Systems (CF9)									

"If the element Sij = V, Then Rij = 1and Rji = 0, If the element Sij = A, Then Rij = 0 and Rji = 1, If the element Sij = X, Then Rij = Rji = 1, and If the element Sij = O, Then Rij = Rji = 0. Subsequently the final reachability matrix as shown in table 3 is formed by applying transitivity rule (i.e., if the factor 1 is relating to factor 2 and factor 2 is relating 3 then factor 1 must relate factor 3) in the matrix."

Table 2. Initial Reachability Matrix (RM)

Factors	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9
CF1	1	1	1	1	0	1	1	1	0
CF2	1	1	1	1	0	1	1	1	0
CF3	0	0	1	1	0	0	0	1	1
CF4	0	0	1	1	0	0	0	1	0
CF5	1	1	1	1	1	1	1	1	1
CF6	0	0	1	1	0	1	0	0	1
CF7	0	0	0	1	0	1	1	0	0
CF8	0	0	0	0	0	0	0	1	1
CF9	0	0	0	0	0	0	0	1	1

Table 3. Final Reachability Matrix (RM).

Factors	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9	Driving Power
CF1	1	1	1	1	0	1	1	1	1	8
CF2	1	1	1	1	0	1	1	1	1	8
CF3	0	0	1	1	0	0	0	1	1	4
CF4	0	0	1	1	0	0	0	1	1	4
CF5	1	1	1	1	1	1	1	1	1	9
CF6	0	0	1	1	0	1	0	1	1	5
CF7	0	0	1	1	0	1	1	1	1	6
CF8	0	0	0	0	0	0	0	1	1	2
CF9	0	0	0	0	0	0	0	1	1	2
Dependence Power	3	3	3	7	7	1	5	4	9	9

Step 5: Level Partitioning: Based on reachability and antecedent sets of CFs obtained from final reachability matrix the CFs are separated at different level through a series of iterations. This process is known as level partition as shown in table 4. The partition is done at the point where the variables whose reachability and antecedent sets are same are separated and assigned level and again reachability and antecedent sets are determined and then where the variables whose reachability and antecedent sets are same are separated and assigned level. This process repeated until all the variables are divided into levels. These partition levels as shown in table 4 are used to create digraph and TISM model. A hierarchical directional structure is created among the variables and top level is ranked highest in the hierarchy.

Table 4. Level Partitioning of Reachability Matrix

Factors	Reachability set	Antecedent set	Intersection Set	Level
Iteration 1				
CF1	1,2,3,4,6,7,8,9	1,2,5	1,2	
CF2	1,2,3,4,6,7,8,9	1,2,5	1,2	
CF3	3,4,8,9	1,2,3,4,5,6,7	3,4	
CF4	3,4,8,9	1,2,3,4,5,6,7	3,4	
CF5	1,2,3,4,5,6,7,8,9	5	5	
CF6	3,4,6,8,9	1,2,5,6,7	6	
CF7	3,4,6,7,8,9	1,2,5,7	7	
CF8	8,9	1,2,3,4,5,6,7,8,9	8,9	I
CF9	8,9	1,2,3,4,5,6,7,8,9	8,9	I
Iteration 2				
CF1	1,2,3,4,6,7	1,2,5	1,2	
CF2	1,2,3,4,6,7	1,2,5	1,2	
CF3	3,4	1,2,3,4,5,6,7	3,4	II
CF4	3,4	1,2,3,4,5,6,7	3,4	II
CF5	1,2,3,4,5,6,7	5	5	
CF6	3,4,6	1,2,5,6,7	6	
CF7	3,4,6,7	1,2,5,7	7	
Iteration 3				
CF1	1,2,6,7	1,2,5	1,2	
CF2	1,2,6,7	1,2,5	1,2	
CF5	1,2,5,6,7	5	5	
CF6	6	1,2,5,6,7	6	III
CF7	6,7	1,2,5,7	7	
Iteration 4				
CF1	1,2,7	1,2,5	1,2	
CF2	1,2,7	1,2,5	1,2	
CF5	1,2,5,7	5	5	
CF7	7	1,2,5,7	7	IV
Iteration 5				
CF1	1,2	1,2,5	1,2	V
CF2	1,2	1,2,5	1,2	V

CF5	1,2,5	5	5	
Iteration 6				
CF5	5	5	5	VI

Step 6: Digraph Construction

All the critical factors from the final reachability matrix are positioned and shown by nodes and linkage which represents the directional relationship between two factors. In Figure 1, we may see a digraph with meaningful connections and useful transitive relationships. The diagraph also represents prominent relations of the TISM model.

Step 7: Interpretive Matrix

With the help of diagraph shown in figure1, an interpretive matrix shown in table 5 is formed. This interpretive matrix provides the interpretation for each directive and transitive cell between the variables of TISM model. This interpretive matrix is useful in framing Total Interpretive Structural Model.

Step 8: MICMAC Analysis

MICMAC means Matrice d'Impacts croises-multipication appliqu'ean classification analysis as shown in figure 2 is done classify the all CFs in four quadrants according to their driving and dependence power. The key objective of MICMAC analysis is to look into the driving and the dependencies strengths of the CFs. It also examines the strength and reliance of the CFs and categories them into four groups. The variable lies in these four quadrants are named as (i) Autonomous (low driver power and low dependence), (ii) Linkage (high driver power and high dependence), (iii) Dependent (low driver power and high dependence) and (iv) Independent (high driver power and low dependence)

Result and Discussion

Our study aimed to understand the sustainability in digital integrated supply chain, research gaps, and key performance factors to achieve the sustainability. A TISM technique is used to establish direct and transitive linkage which is shown by digraph as shown in figure 1. The customer satisfaction (CF1) and Grievance Redressal Systems (CF9) placed at first level, Data Security & Trust Building (CF4) and Information Sharing (CF3) are placed at second level, Building Human capital (CF6) is placed at third level, financial planning (CF7) is placed at fourth level, Smart logistics Capabilities (CF2) and Smart Manufacturing Process (CF1) are placed at fifth level and at the last and sixth level Agile Organisational structure (CF5) is placed in the hierarchical structure. The factors placed at bottom influence the factors placed at top. This structure indicates that the customer satisfaction and Grievance Redressal Systems are at top level for sustainability and it can be achieved by combined effort of all other factors placed at lower level in hierarchy. In the MICMAC analysis as shown in figure 2 there is no autonomous variables, so all the factors picked are significant. The critical factor Building Human Capital is found a linkage variable which has high dependency and driving power. Hence it becomes sensitive element as

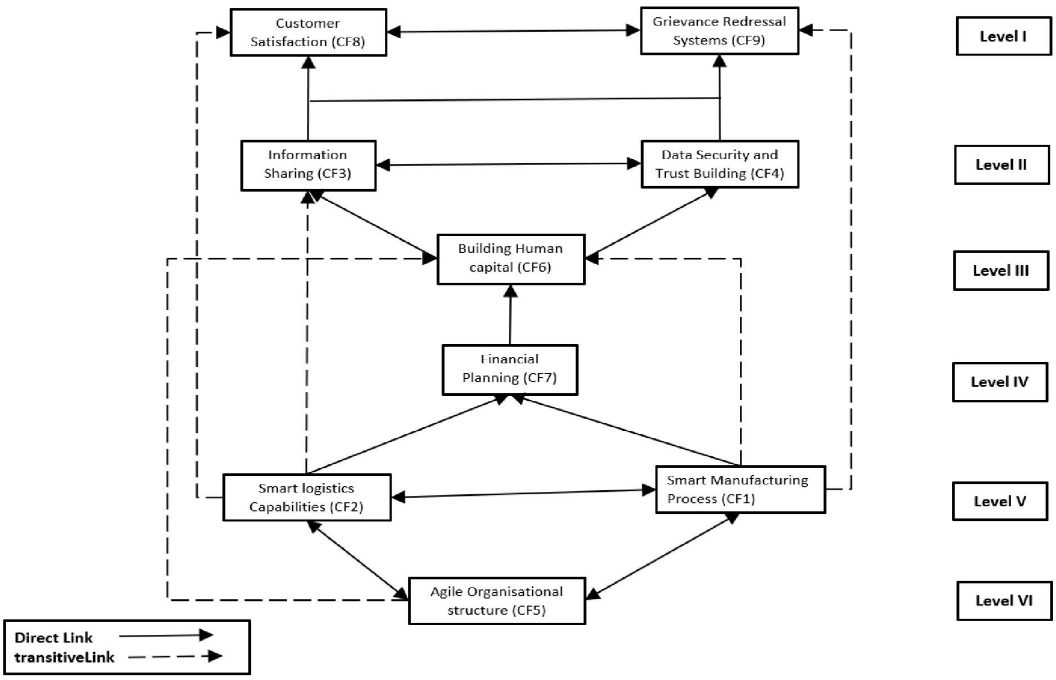

Figure 1. Digraph representing prominent relations of the TISM model.

Table 5. Interpretive matrix

Factors	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9
CF1		Integration of digital technologies				A tech-driven strategy requires skilled labour assets	Integration of financial to sustainable developent		Digital integration develops an agile grievance
CF2	High responsiveness and agility		Increased visibility and coordination				reduce cost and time results in financial improvement	Both RFID and GPS transit tracking improves SC responsiveness	
CF3				to build trust among the SC partners				Better collaboration with the customer by digital communication	Better information flow and transparency
CF4			Mitigate the risk of sharing information						
CF5	Smart investment in innovative technologies	Agile operating models improve planning and inventory sync.				Improved culture and talent development			
CF6			Improves confidence and trust	Team works and connectivity					
CF7						improvement in talent retention			
CF8									Anticipating user preferences improves customer experiences.

CF9								Reduces discrepancy in material and information flow in SC	

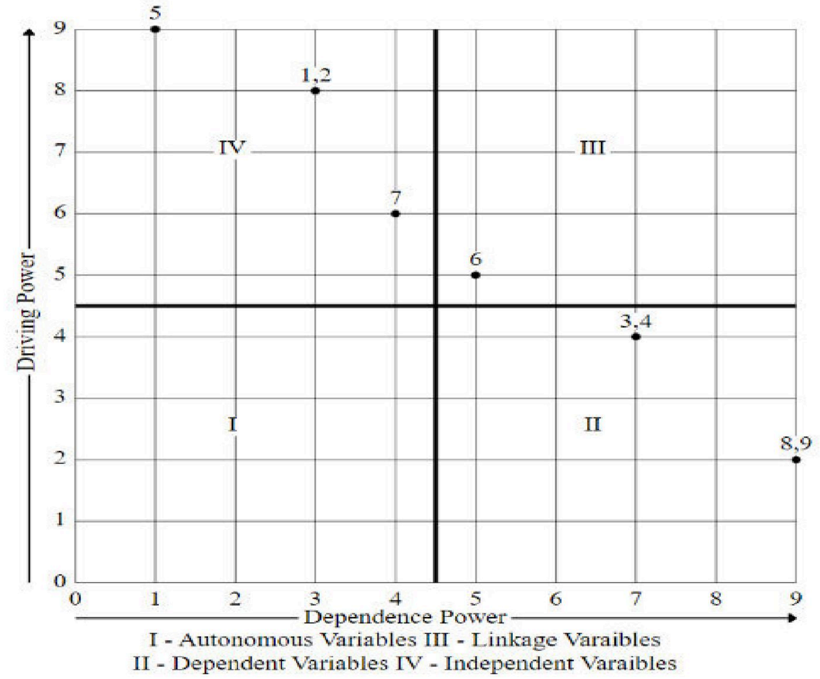

Figure 2. MICMAC analysis of the CFs

minor change may affect others elements also and can disturb the supply chain sustainability. Digitally integrated supply chain requires the skilled employees and when they are trained, they become a capital to an organisation. Losing the skilled employees may impact the performance of the digitally integrated supply chain. Agile Organisational structure, Smart logistics Capabilities, Smart Manufacturing Process and financial planning are grouped in independent variables having high driving power to affect the system and they have a positive impact on the on the sustainability performance of the supply chain, which, in turn, will assist enterprises in achieving an advantage over their competitors. Customer Satisfaction and Grievance Redressal Systems, Data Security & Trust Building and Information Sharing are grouped as dependent variables having high dependence power.

Conclusion, limitations and future scope of the study

Digital technology would streamline, modularize, and standardise products and solutions. Businesses will have learned to develop novel revenue streams, create valuable product lines, and be responsive to changes in consumer preferences. Integrating digital technology into the supply chain would lead to transformative shifts and radical changes which also may affect the sustainability of supply chain. In the era modern industry, digital integration also provides a boost to the supply chain capabilities to meet the organisation expected growth which may cause an impact on sustainability of supply chain. It becomes important to study sustainability of supply chain integrated with recent technologies e.g. Artificial Intelligent (AI), Cloud Computing (CC), and the Internet of Things (IoT). This paper enlightens the factors those plays a vital and critical role to achieve sustainability with digital integration. MICMAC analysis is done to find dependency and driving capacity of defined CFs.

This study has a few caveats, despite providing substantial insight into the inter linkages among the success factors of a DSC. Due to the reliance on the opinions of professionals in the field, this discussion is inherently subjective. In addition, the qualitative nature of this research makes it difficult to draw strong managerial conclusions about the interplay of the various factors that were taken into account.

Other than these nine CFs which are discussed in this study, more several factors can also be explored and analysed in future research. Statistical validation of the model can be achieved through the application of Structure Equation Modelling (SEM). It can reduce the subjectivity of experts' knowledge. The framework should be interpretable to provide managers confidence and effective operationalization.

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