STUDY OF SELECT ISSUES IN SUPPLY CHAIN DIGITALIZATION

A thesis submitted

in partial fulfilment for the Degree of

Doctor of Philosophy

by

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CERTIFICATE

This is to certify that the thesis entitled "**Study of select issues in supply chain digitalization"** submitted by **Deepu T.S.** to the Indian Institute of Space Science and Technology, Thiruvananthapuram, in partial fulfilment for the award of the degree of **Doctor of Philosophy** is a *bona fide* record of research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institution or University for the award of any degree or diploma.

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DECLARATION

I declare that this thesis entitled "**Study of select issues in supply chain digitalization"** submitted in partial fulfilment of the degree of **Doctor of Philosophy** is a record of original work carried out by me under the supervision of **Dr. V. Ravi.**, and has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgements have been made wherever the findings of others have been cited.

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ABBREVIATIONS

Code	Description
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ANP	Analytical Network Process
BDA	Big Data Analytics
BNR	Brand name reputation
CAP	Capabilities
CLS	Control linkages among SC partners
CPS	Cyber Physical Systems
CR	Customer Requirement
CSFs	Critical Success Factors
CSP	Commitment among SC partners
CULT	Cultural Alignment among partners
DBA	Data and Business Analytics
DEMATEL	Decision making trial and evaluation laboratory
DIKW	Data, Information, Knowledge and Wisdom
DMF	Decision Making Factors
DMSP	Decision making on short term perspective
DR	Design Requirement
DSC	Digital Supply Chain
DSP	Data Security and Privacy across networks
DT	Digital Twin
DTE	Digital technology enablers
EIIS	Enterprise and Inter-Enterprise Information Systems
EMRC	Employee’s reluctance to change
EOP	Ease of operations
e-SCM	Electronic Supply Chain Management
EXE	Extended Enterprise
FFS	Functional fit and future scalability
FRR	Financial resources required
FUNDS	Availability of Funds and Financial Investment
HOQ	House of Quality
ICT	Information and communication technology
INF	Information Sharing
INS	Information sharing across SC partners
IOIS	Inter-organizational information systems
IoT	Internet of Things
ISM	Interpretive Structural Modeling
IT	Information Technology
ITS	Intelligent Transportation System

LCSI	Lack of commitment from SC partners to share information
LEDT	Lack of education and technical know how
LFIR	Lack of financial resources
LFPM	Lack of framework and performance metrics for SCD
LIIS	Limited ICT infrastructure and systems
LMS	Long, medium and short term planning
LSIB	Lack of knowledge on SCD benefits
LTEM	Lack of training to employees
MBOI	Misalignment of business objectives with IT
MCDM	Multi Criteria Decision Making
MICMAC	Matriced'Impacts croises-multiplication applique' and classment
MSCP	Mistrust among SC partners
NERD	Non-encouragement of R & D
PCT	Project completion time
PI	Physical Internet
POCL	Poor organizational culture inhibiting cross functional interaction
PRO	Profitable information sharing model with SC partners
PSP	Post sales product support
QFD	Quality Function Deployment
QRC	Quality and risk control
RMS	Effective Risk Mitigation Strategies
RTD	Real Time Data Analytics
SAT	State of Art Technologies and Related Infrastructure
SC	Supply Chain
SCD	Supply Chain Digitalization
SCI	Supply Chain Integration
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SSIM	structural self-interaction matrix
TINS	Threats related to information security
TMC	Top Management Commitment and Support
TMCI	Top management commitment inadequacy
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VoC	Voice of the Customer

ABSTRACT

Supply chain management and supply chain digitalization are the dominant topics for research in the digital era. The research was conducted to address some of the vital problems in the domain of supply chain digitalization. The issues related to supply chain digitalization were considered in an Indian context by choosing representative case studies. Five problems were addressed in this research by developing suitable methodologies. The *first* problem of the research was to identify and prioritize the customer and design requirements for supply chain digitalization. An integrated analytic network process and quality function deployment methodology has been applied for prioritizing the customer and design requirements. The findings could be effectively used by the practicing managers and academicians in effective decision making during supply chain digitalization.

The digital transformation process is influenced by enablers and barriers. Hence, there exists a need to properly identify the enablers and remove the barriers for effective supply chain digitalization, which is considered as the *second and third* problems respectively. The hierarchical and contextual influences among the key enablers and the barriers affecting the digitalization process are found out using interpretive structural modelling and MICMAC approach. Grey-DEMATEL method was also applied to find out the cause-effect relationship among the enablers and barriers. Robustness of the methods used was verified using sensitivity analysis. The policy decision makers could consider the results of this analysis to identify and understand the interrelationships among the key enablers and barriers for effective digitalization of supply chain.

The development of a conceptual framework supply chain digitalization is considered as the *fourth* problem. A framework is developed by using a novel method which involves integrated systems model approach and Data, Information, Knowledge and Wisdom hierarchy and Decision Support System. This study aims to contribute to the literature on a better understanding of the relationship between the major decision making factors affecting digitalization and linking with integrated framework for digitalization. Interpretive Structural Modeling method is used to validate the framework through its evaluation in electronics supply

chain. The framework developed can also be used by the researchers for conducting a broader level of analysis of the decision making factors in another firm or industry.

The *fifth* problem addressed in the thesis is designing a model for selection of the most appropriate inter-organizational information systems alternative for supply chain digitalization. A novel model for selection is developed by using Analytic Hierarchy Process integrated TOPSIS method. The proposed method can also identify and select suitable inter-organizational information systems required by an organization to digitalize its business activities. This research also helps provide insights into the process of shortlisting criteria and selecting suitable IOIS alternatives. The decision model developed can be used by scholars and practicing managers for conducting a more comprehensive level of examination of the key decision making factors and selection of inter-organizational information systems in any industry or firm.

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INTRODUCTION

Supply chains have undergone tremendous change due to technological advancements over the last decade, enabling integration of operations among the supply chain (SC) partners. The application of advanced digital technologies makes the companies rethink the approach of SC design, as it alters the traditional ways of SC operations. The digital transformation allows the companies to achieve better operational efficiency and gain competitiveness. The drastic changes and options available have a heavy influence on effective digitalisation and Supply Chain Management (SCM). The transparency and real time access of data across the SC demands the firms to be more competitive and drives for supply chain digitalization (SCD). In order to effectively digitalize the supply chain, various aspects and dimensions of the digitalization process needs to be explored.

1.1. Supply Chain Management

Supply chains are becoming more complex due to drastic advancements in digital technologies. Digital technologies play a dynamic role in effective functioning of supply chain and enhancing firm's performance (Laaper, 2017). The application of information technology (IT) assists in accessing real time information which is one of the key factors in managing and designing digital supply chains. Studies have found out that SCD as one of the major factors that enhances SC performance. The global advancement and need to become competitive is forcing firms to digitalize the SC. The multidisciplinary nature of digitalization also finds emphasis in the literature.

SCM has become a dominant topic among academicians and practitioners in recent years (Ayoub et al., 2017). Traditional SC is considered as a rigid mechanism in which the processes are handled independently by the partners. The development in SC due to emerging technologies is transforming the businesses activities (Ben-Daya et al., 2019, Ivanov et al., 2019). The advancement in digital technologies has changed the nature of supply chains through closer collaboration and integration among partners. Accordingly, SCD has emerged as a strategic research topic for professionals and academicians in logistics and SCM communities.

The application of IT assists in accessing real time information which is one of the key factors in managing and designing digital supply chains. Advanced digital technologies and tools can be used in managing various supply chain functions through proper implementation and monitoring. Digital technologies and its applications in supply chains have revolutionized the traditional concept of SCM. The need for developing a responsive and innovative supply chain has made SCM operations a dominant topic of research among academicians and practitioners (Ayoub et al., 2017). Accordingly, supply chain integration (SCI) has become the central concept of SCM. SCD assumes importance from the concept of SCI.

SCI is defined as alignment, linkages and coordination of processes, people, information, knowledge, strategies and communication across the SC amongst all points of contact and making the efficient and effective movement of materials, information, money and knowledge as needed by the customer (Stevens and Johnson, 2016). The scope SCI covers entire functions and scope ranging from supplier to customer including the internal integration process. The two major components of an integrated SC are flow of goods and information (Fayezi et al., 2017). The application of information and communication technology tools for planning, forecasting and scheduling activities brings in more efficiency, visibility, accountability and transparency in supply chains.

SCI process has three levels of facilitators like information integration, coordination and information sharing and organizational relationship linkages. Information integration is the major component of the SCI process which is applicable to all business organizations. The future lies in the fact as to how digital transformation of supply chains would be managed (O'Marah et al., 2017. It demands addressing the factors like resource sharing, long term relationship, integration of planning and functional areas, ensuring availability of resources including IT systems to facilitate effective integration through digitalization. Digital technologies help in real time transmission of information and supports knowledge management practices (Wilkesmann and Wilkesmann, 2018). Application of advanced technologies allows the companies to gain competitive advantage through higher revenue and value addition (Buyukozkan and Gocer, 2018).

SCI process works on the basis of shared decision making, open communication, collaboration, shared vision, technology and trust among the partners. It aims at achieving accurate and timely flow of information, materials, money and processes for meeting customer requirements effectively and efficiently. The future of manufacturing depends upon the emergence of cyber-physical production systems based on digital technologies (Monostori et al., 2016) which is characterized by many networked entities (Scholz-Reiter et al., 2014). SCI can be done on both vertical and horizontal basis by using shared or standby infrastructure.

SCI can also be considered as a valuable tool for enhancing productivity and cost reduction, by effectively managing the real time processing of data and information for quick decision making. The two major components of an integrated supply chain are flow of goods and information (Fayezi et al., 2017). The technological advancement demands greater access to information and data management standards for better performance (Wilkinson et al., 2016). Data analytics helps in optimization of SC activities by visualizing the entire activities on a real time basis.

Organizations can reap benefits through proper integration by managing the data effectively using powerful digital technologies and methods (Pappas et al., 2018). The adoption of advanced technologies leads to automation and exchange of data across the SC, which leads to Industry 4.0 (Sprovieri, 2019). The advancements in digital technologies together with high expectations from SC partners have necessitated the requirement for a highly integrated SC. The studies have found out that SCI through digitalization is considered as one of the major factors that enhances supply chain performance.

Boehmer et al., (2020) explored the role of relational mechanisms of digital technologies in supply chains and have addressed the promising potential of internet of things technology as an enabler for manufacturers in the production process. Research in information systems has continued to evolve consistently in recent decades on various aspects like intellectual core, diversity and impact of information systems. It has advanced considerably over time whilst serving its core identity and strength (Jeyaraj and Zadeh, 2020). Marmolejo-Saucedo and Hartmann (2020) in their research have found that companies adopting technological advancements as Industrial revolution 4.0 will be able to survive in competitive business environments. They also state that digital transformation of SC requires proper organizing and planning of activities to meet various operational functions.

The use of digital technology and its ability to transform the information in user friendly format is a major invention for enhancing supply chain efficiency. Connectivity and information sharing under the mediating effect of top management commitment is positively related to Business Data and Predictive Analysis (BDPA) acceptance. Gunasekaran et al., (2017) in their study have found that assimilation of BDPA is positively related to Supply Chain Performance and Organizational Performance. Mahindroo et al., (2018) have investigated the application of selected information systems constructs for value creation. They have found that information systems play a crucial role in enhancing overall performance of SC and highlighted the impact of information systems on each of the constructs individually on the economic and operational performance of supply chains.

IT enabled supply chain helps in enhancing performance, competitiveness, collaboration, flexibility and cost reduction. The real time connectivity ensures the integration of all functional areas of the supply chains right from sourcing, manufacturing and delivery to the end users. Recent studies in the area of IT implementation reveal the benefits firms can gain through proper digitalization (Khan and Wisner, 2019). The implementation process requires support and commitment from the top management based on clear organizational objectives and investment justifications.

Research in the area of SCI has revealed that value creation can be done through partnership among SC partners (Jajja et al., 2018). The integration process works on basis of shared decision making, open communication, collaboration, shared vision, technology and trust among the partners (Flynn et al., 2010). A Digital Supply Chain can be defined as inter-organizational systems that firms implement to digitize the process of transaction and collaboration with their SC partners. (Xue et al., 2013).

1.2. Supply Chain Digitalization

The vast advancement in digital technology and internet enabled innovative technology demands for more research focussed on implementation and adoption process in SCM and networks focused on electronic solutions for commerce and data transfer (Kakhki and Gargeya, 2019). SCI involves flow of materials and information, coordination within partners, decision making and collaboration which smoothens the processes of the supply chain. SCI through IT requires money and time to leverage maximum benefits (Chakravorty et al., 2016). SCI involves collaboration of inter organizational and inter functional practices for enhancing supply chain performance. Integration of supply chain refers to the extent to which partners in the supply chain collaborate to achieve maximum efficiency and performance (Vanpoucke et al., 2017).

The need is for improving SC by shifting the priority from simple cost reduction and optimization of resources to supply chain restructuring based on technological advancement. The development in supply chain on account of the digitalization process allows the organization to manage the supply chain activities remotely (Lyall et al., 2018). Buyukozkan and Gocer (2018) in their study have found an upsurge in functions and application of digital technologies in various aspects of the supply chain. The impact of emerging technologies in the supply chain is transforming the businesses (Ivanov et al., 2019). The drivers and enablers affecting the process of SCI have been investigated, with little consensus on the process of integration of supply chain through digitalization (Hausberg et al., 2019).

1.3. Conceptual model of dimensions of supply chain digitalization

In recent times, IT is used by companies for interlinking the flow of information, material and money across the supply chain. The evolution of the internet has facilitated access to information across the supply chain on a real time basis. Further, software and applications like ERP systems have integrated the existing systems in areas such as inventory control, financial accounting, customer relations, etc. The advancements in Information and Communication Technology (ICT) tools have made the supply chains more dynamic and efficient. This has facilitated faster and real time communication among the SC partners.

In the context of SCM, researchers use various terms for Industry 4.0 (I 4.0), like digital supply network (DSN), e-Supply Chain, Supply Chain 4.0 etc. The concept of I 4.0 mainly concentrates on automating systems and processes, exchange of data and digitalization in industries. Adoption of I 4.0 concept can reduce lead time and respond effectively to changing customer demands and unexpected events facilitating to enhance system productivity. Overall, adoption of I 4.0 leads to advancement in SC, manufacturing and logistics systems. Implementation of I 4.0 enhances digitalization and automation in manufacturing by assisting interfaces among all stakeholders of a firm (Abdirad and Krishnan, 2021). I 4.0 concept impacts key elements of supply chains like integration, purchasing, operations and distribution resulting in productivity enhancement (Kayikci, 2018).

1.4. Supply chain digitalization in contemporary research

SCD is a broad term and the new watchword. SCM comprises three key areas, like supply chain optimization, cloud computing and storage and predictive analytics. The process of digitalization involves integrating physical processes with digital data to create a fully optimized supply chain. Further, the impact of globalization, boom in online transactions and higher customer expectations has made the supply chain more complex. Even though modern organizations are adopting tools like enterprise resource planning and customized software, these are not agile enough to ensure longevity and consistent growth. The technological advancements have resulted in the application and use of Software-as-a-Service (SaaS) which uses cloud for data storage and processing.

The recent development in ICT tools has made SCM a vital area for conducting businesses effectively. The technological advancements and the change in customer requirement has necessitated the need for an integrated supply management. ICT tools can be used for value addition to the products and services based on customer perceptions and demands which are to be considered while manufacturing the products. Thus the digital environment created by using ICT tools integrates seamlessly the activities that are to be carried out by various partners in the supply chain. The end-to-end SC thus developed through integration will expedite the processes and avoid possible roadblocks. The application of ICT tools in SCM will enhance information exchange among supply chain partners which facilitates in the reduction of overall costs.

1.5 Future trends in supply chain digitalization

Fatorachian and Kazemi (2021) highlighted the potential impact of Industry 4.0 due to technological advancements in enhancing business process and SC performance. They found that the adoption of Industry 4.0 enabling technologies facilitates SCI and information sharing, which brings transparency throughout the SC. Further, Industry 4.0 enhances overall operational functions through integration process, digitization and automation by bringing novel analytical capabilities.

Ageron et al., (2020) have highlighted the requirement of further research in the area of SCD in mobilizing various theoretical frameworks and combining qualitative and quantitative methods. Their study also stated that future research should be directed towards developing conceptual models and theoretical frameworks, original practices, case studies and projects for digital supply chain that could assist managers in making effective decisions on digitalization. This research was conducted to address some of the vital problems in the domain of SCD.

1.6. An overview of supply chain digitalization practices in India

Buyukozkan and Gocer (2018) in their study have found an upsurge in functions and application of digital technologies in various aspects of SC. This research is an attempt to study various digitalization aspects and its processes in a manufacturing firm in Indian context and would be useful for organizations in finalizing the requirements to be considered at various implementation levels. The stiff competition in the global market can be survived by adopting most innovative technologies in the day to day management of the organizations. A strong and real time communication is to be maintained with the supply chain partners for gaining competitive advantage. In this scenario, the electronics industry being one of the robust industries that has a very dynamic supply chain is considered in this study. The implementation of ICT tools gets affected by various factors, which are to be considered while designing a SC. Effective SCM by using ICT tools can be considered as a strategic weapon to improve the efficiency of SC through effective integration. An attempt has been made to identify the major dimensions and various factors which are having an influence on the implementation of ICT tools in the supply chain of an electronics firm.

The electronic industry faces various challenges such as rapid changes in technology, shorter product life cycle (Huang, et al., 2019), decreasing operating margins, uncertain demand and supply, outsourcing, warranty and service issues, outsourcing, etc. Digitalization of the SC helps in addressing these issues to some extent using advanced technologies. While designing and planning the SC, electronics manufacturers have to also consider content delivery. Thus, management of digital assets and digital rights becomes a critical aspect and design of appropriate Inter-Organizational Information Systems (IOIS) assumes importance.

The organizational requirements specific to the nature of business and the transactions involved are to be given due weightage. In order to achieve the targeted results, the implementation process should be considered by taking into account the strategic, tactical and operational objectives of the firm. Further the process of digitalization can be triggered by considering the organizational objectives and values, generation of suitable standards and assessment of the requirement of stakeholders. All these dimensions are to be considered and the implementation process is to be planned considering the time required in achieving the set targets. Further, feasibility, performance assessment and monitoring of the proposed digitalized SC should be completed. Continuous monitoring of the process and implementation will result in identifying the areas where modifications are required, which results in continual improvement.

1.7. Motivation for this research

Mendhurwar and Mishra (2019) have defined digital transformation, its potential impact on business, identified opportunities related to social and Internet-of-Things technology integration and challenges associated with convergence of technology focusing on cyber security challenges. FossoWamba et al., (2020) reviewed 149 peer–reviewed articles published during the period from 2010 - 2017 and also reviewed case studies related to application of digital technologies in the SC. They have found that the area of SCD needs better understanding of factors and challenges affecting the transformation process.

Studies on various aspects specific to a functional area or cross functional areas of SCI aiming at performance augmentation are found in the literature. Dimensions and measures relevant to integration of SC on a broad perspective in various contexts are also found. However, the studies pertaining to identifying the customer requirements and design requirements essential for the SCI process while adopting advanced digital technologies is not duly found. The lack of such a study in the digitized world needs to be addressed, which contributes to an understanding of various aspects of SCD.

Major challenges in the SCM area include cost reduction, risk management, customer loyalty, globalization and visibility. The challenges make the SC more complex and vulnerable (Abdel-Basset et al., 2019). Hence, it should be managed effectively through digitalization using advanced digital technologies. SCD leads to development of a smarter and transformed SC by combining management systems, networking and intellectualization using advanced technologies (Wu et al., 2016). As the research on SCM is booming, the process of SCD deserves more attention.

Although literature reveals various ways and approaches for assessing the possibilities of digital supply chain, little research has been done on developing a model and framework for assessing the key enablers and barriers of SCD. This research attempts to bring insights to understand the process of SCD by identifying the requirements, analyzing the key enablers, barriers, designing a conceptual framework and developing a model for selection of suitable solutions for SCD. In this thesis, the issues related to SCD are discussed in Indian context.

1.8. Objectives of present research

This study has considered the main aspect that affects the process of digitalization. Five major problems associated with SCD are addressed in this research. *Firstly*, it has identified the customer and design requirements and its prioritization for effective digitalization. To the best of our knowledge, little research is found in literature on identifying the customer requirements and design requirements that are to be considered for SCI through the process of digitalization. For the effective prioritization of customer and design requirements, an integrated Analytic Network Process –Quality Function Deployment (ANP-QFD) methodology is proposed and is discussed in Chapter 3. The findings provide insights on various attributes that contribute to the process of SCD. The model developed can also be adjusted suitably to add more requirements specific to the industry for effective decision making.

The *second* and *third* objectives of the research, which are complementary, is to identify the contextual relationship among the enablers and barriers that influence the SCD process. The results reveal that there exist causal relationships among the key enablers and the barriers. It provides directions for managers and professionals in the field for SCD decision making processes. The influence and interrelationships among the key enablers identified is to be given due significance. Likewise, the key barriers identified need to be reduced for effective SCD. This would enhance SC efficiency and competitiveness of a firm. In this research we have used Interpretive structural modelling methodology to analyse the contextual relationships among the enablers and barriers affecting SCD, followed by validation of the results by applying Grey-DEMATEL method and performing sensitivity analysis of results. These are discussed in Chapter 4 and Chapter 5 of this thesis.

The *fourth* objective of the research was to develop a conceptual framework using an integrated systems model approach and DIKW (Data, Information, Knowledge and Wisdom) hierarchy. The inter relationships among key decision making factors were also identified and prioritized. The proposed framework can support the decision making process and development of appropriate design for digitalization. Detailed methodology and validation of the framework is discussed in Chapter 6.

The *fifth* objective of the research is development of a model and methodology for the selection of suitable inter-organizational information systems for SCD. The proposed method can be used to identify and select suitable information systems as required by an organization considering the key decision making factors for effective digitalization of business activities. This is discussed in Chapter 7 of this thesis.

1.9. Research methodology

The *first* problem (RP-1) identified for the research was the lack of study on the identification and prioritization of customer and design requirements for effective SCD. Findings of the study in identifying and prioritizing the customer and design requirements bridges the gap in literature which facilitates the professionals and managers in taking effective decisions while proceeding with SCD. An integrated Analytic Network Process (ANP) and Quality Function Deployment (QFD) methodology is applied for prioritizing the customer and design requirements.

The digital transformation process gets influenced by various enablers. In this study, key enablers influencing SCD in an electronic industry were identified from literature and in consultation with experts from the industry and academia. Accordingly, the *second* problem (RP-2) identified for the research includes development of a model showing interrelationships among the enablers that affects SCD process. The contextual relationships and analysis of the key enablers influencing the digitalization process are found using Interpretive Structural Modeling (ISM) and MICMAC approach. Further, Grey-DEMATEL method is used to verify the influence among the enablers and sensitivity analysis is also done to determine the robustness of the methods applied.

The digital transformation process gets affected by various barriers also. Hence, there exists a need to identify the key barriers that affect effective SCD. Accordingly, the *third* problem (RP-3) identified for the research includes development of a model showing interrelationships among the barriers that affects SCD process. The contextual relationships and analysis of the barriers affecting the digitalization process were found out using ISM and MICMAC approach. Accordingly, fifteen key barriers that affect the digitalization process were identified. The contextual relationship and influences among the barriers were analyzed by using Interpretive Structural Modelling and MICMAC approach. Further, Grey-DEMATEL method is used to verify cause effect relationship among the barriers and sensitivity analysis is also done to determine the robustness of the methods applied.

Further to the identification of customer and design requirements, enablers and barriers for SCD, it leads to the requirement of a framework for effective SCD, which is considered as the fourth problem (RP-4). The framework for SCD is developed by using a novel method which involves application of integrated systems model approach, Data, Information, Knowledge and Wisdom (DIKW) hierarchy and Decision Support Systems (DSS). The framework developed can be used by the researchers and practitioners for conducting a broader level of analysis of the decision making factors for effective SCD. Interpretive Structural Modeling method is used to validate the framework through its evaluation in electronics supply chain.

Efficient information systems have become the backbone of modern supply chains. The existing supply chain models available in the literature are insufficient to decide upon the process of SCD by using IOIS. Further, literature on developing a model for SCI through digitization is rarely found. The selection process and adoption of a suitable information system is a challenging task. The *fifth* problem (RP-5) addressed in the research is designing a model for selecting the most appropriate inter-organizational information systems alternative for SCD. A novel model is developed by considering the contents, scope and key decision making factors by using Analytic Hierarchy Process (AHP) integrated TOPSIS method.

AHP integrated TOPSIS method is used in the model for shortlisting of the alternatives of IOIS used for the integration process. AHP method is used to find out weights of decision criteria followed by application of TOPSIS method to rank the alternatives. Twelve decision making factors identified for IOIS were categorized under four major dimensions viz., technological, operational, application and innovative for effective decision making. The main focus of the study is on the selection of IOIS solutions for digitization of supply chain for effective management. The design proposition of the study is given in Figure 1.1.

1.10. Research overview

Based on the literature review, five major problems related to SCD have been considered in the present study. Research gaps were identified by reviewing many qualitative and quantitative works. It is found that more research is required in the real world case applications for digitalization of supply chain. The requirement of industry specific sub-framework for digitalization along with exploring the challenges was highlighted in the literature. Buyukozkan and Gocer (2018) have highlighted the requirement of further research for assessing the components and technologies of digital supply chain and its integration into the existing supply chain. SCD faces various challenges and opportunities during the process of design, analysis and identification of technologies for digitalization. However, as on date there has been few research in the area specific to SCD addressing these aspects. Hence, it is worthwhile and necessary to conduct research in the area of SCD with wider impact on the SC and organizational performance.

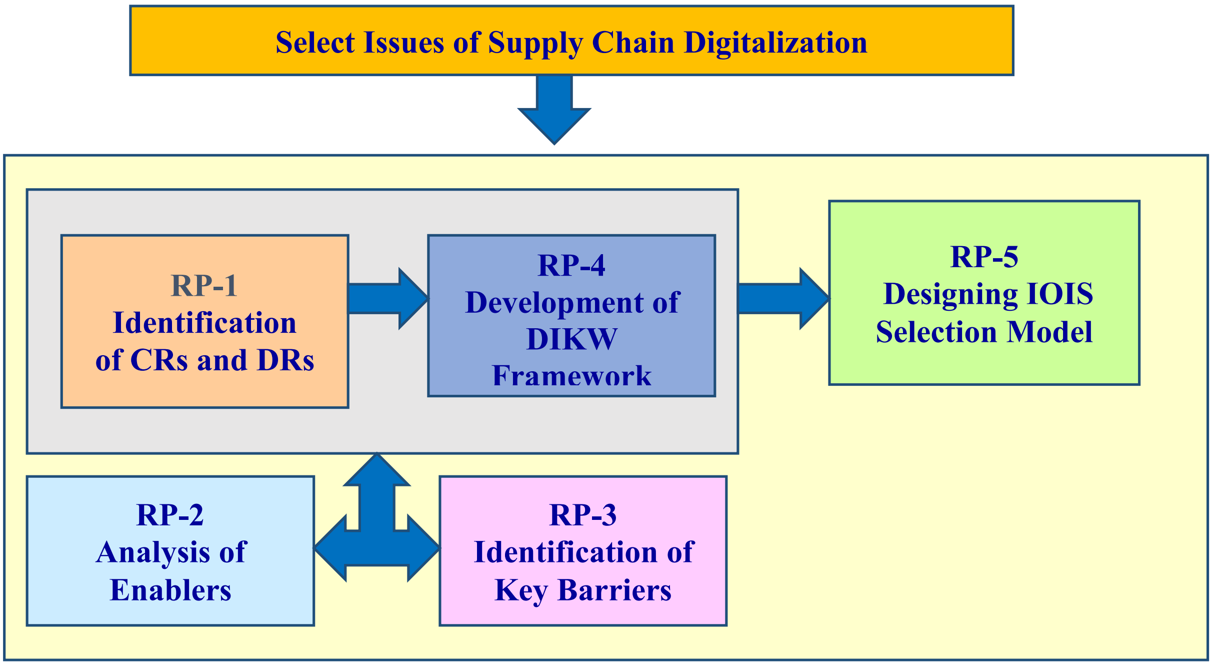


Figure 1.1. Design Proposition of the Study

The impact of emerging technologies in SC is transforming the businesses (Ivanov et al., 2019). Effective cooperation of SC partners in adopting technology for digitization helps in building an end-to-end SC expeditiously. Application of advanced technologies allows the companies to gain competitive advantage through higher revenue and value addition (Buyukozkan and Gocer, 2018). Literature reveals that there is a lack of knowledge in the procedure to be adopted for effective implementation and utilization of digital technologies.

In recent times, the process of SCD has emerged as a strategic topic for professionals and academicians in logistics and SCM communities. Ageron et al., (2020) have highlighted the requirement of further research in the area of SCD, in mobilizing various theoretical frameworks and combining qualitative and quantitative methods. Their study also stated that future research should be directed towards developing conceptual models and theoretical frameworks, original practices, case studies and projects for digital SC, that could assist managers in making effective decisions on digitalization. This study intends to fill this research gap.

1.11. Organization of the thesis

The study is timely and relevant due to the era of digitalization in SC, which leads to development of smart SC. It also contributes to the theory of SCI and digitalization process by providing insights to researchers in the field. The managers can take into account and weigh up the customer and design requirements, eliminate the barriers and give due significance to the enablers affecting the digitalization process. Further, the framework and the model selected for digitalization assists the managers and practitioners for effective decision making. Based on the nature of industry, the model developed can be adapted by considering the industry specific requirements for effective digitalization.

Introduction to SCM, SCI, SCD, dimensions of digitalization and background of the study is included in Chapter 1. Detailed literature review on SCD including the gaps identified from the literature would be included in Chapter 2. The details of customer and design requirements and its prioritization for SCD and its analysis will be elaborated in Chapter 3. The key enablers and barriers affecting the digitalization process identified are analyzed and would be elaborated in Chapter 4 and 5 respectively. Chapter 6 discusses the conceptual framework developed for SCD. The development of a model for selection of appropriate solutions for digitalization is discussed in Chapter 7. The conclusions, limitations and future scope of the study would be presented in Chapter 8.

A diagrammatic representation of the chapter organisation of thesis is given in Figure 1.2.A detailed review of the literature on SCD is provided in Chapter 2. Further, the details of the *five* problems addressed, related literatures, methodology and the case evaluations are briefly discussed in Chapters 3, 4, 5, 6 and 7. A detailed analysis of the findings and the related discussions followed by the concluding remarks, limitations and scope of future works for each of the *five* problems are elaborated in Chapter 8.

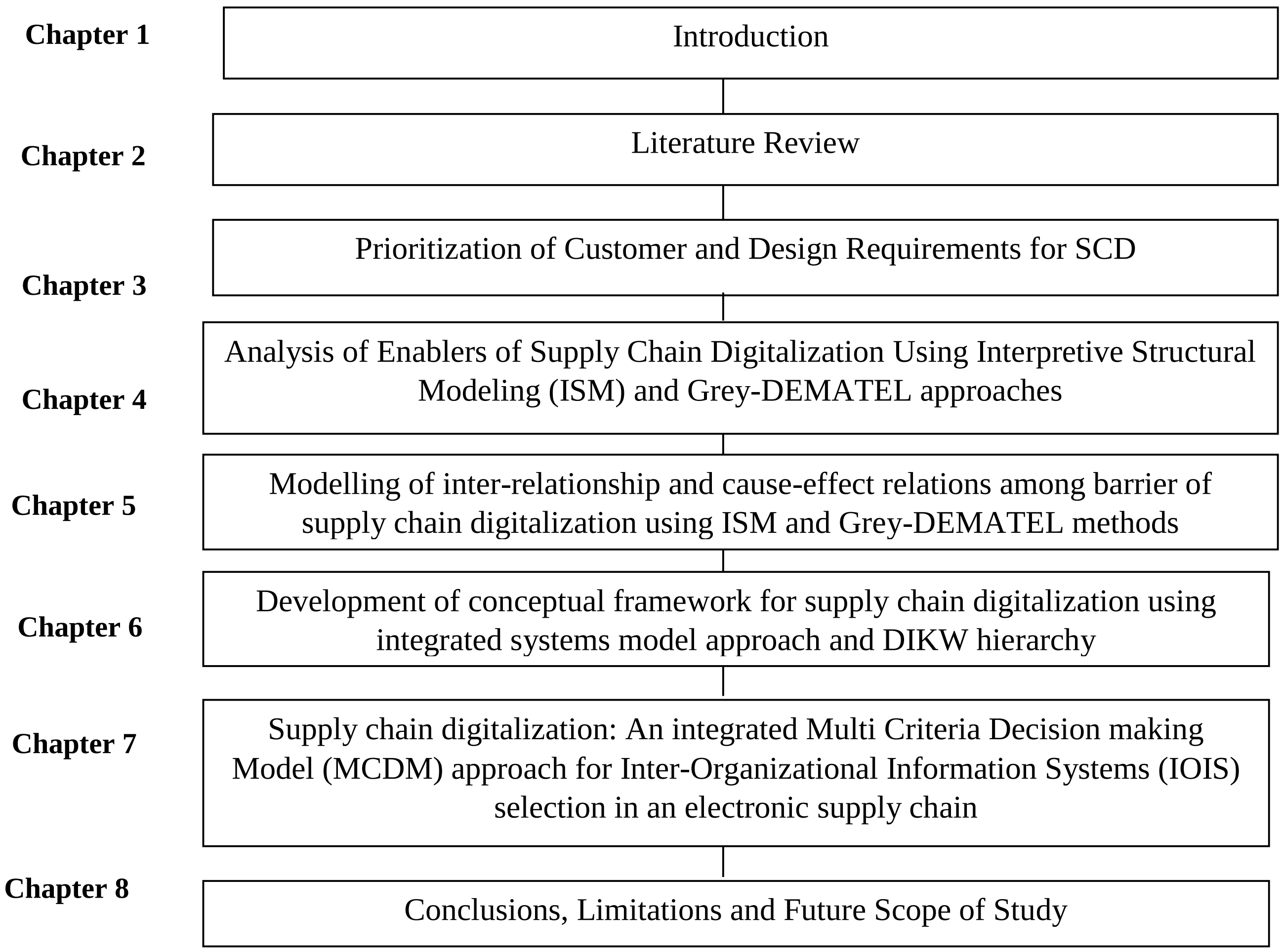


Figure 1.2: Chapters organization of the thesis

1.12. Conclusion

SCD enables the companies to effectively address the challenges in SC operations. Digitalization makes the SC to become more efficient, fast, flexible and accurate. The development of new business models enhances the supply chain flexibility resulting in creating economies of scale as well as economies of operations. The accuracy in supply chain operations decision making can be enhanced through end-to-end transparent supply chain. The real time availability of information across the SC allows the stakeholders to assess the situation and make decisions based on the data accessible on a real time basis.

The full potential of the digital supply chain can be leveraged through effective management of digital waste, which is one of the risks associated with the digitalization process. Ineffective data capturing and management is one of the sources of generation of digital waste. Further integrated process optimization between companies has to be leveraged fully resulting in enhanced potential created through transparency. In order to achieve this, the organizational setup, processes, governance and incentives need to be aligned within and between the supply chain partners. The future of the supply chain depends on big data and advanced analytics from automation.

In this chapter, introduction to SCM, SCD an overview of the context related to this research has been presented. The motivation and objectives of this research have also been presented in this chapter. The research methodologies to be used in this research followed by a summary of the entire research have been presented in the “Research Overview " section of this chapter. The next chapter deals with detailed literature review.

CHAPTER – 2
LITERATURE REVIEW

This chapter deals with review of literature on Supply Chain Integration (SCI) and Supply Chain Digitalization (SCD). It also deals with features of SCD, components and methods, benefits and challenges, framework for SCD, research streams and research gaps.

2.1 Introduction

SCD offers immense opportunity for researchers and practitioners in the area of operations and Supply Chain Management (SCM). The process of SCD involves the integration of all activities in the SC using advanced digital technologies to meet the customer demands. The digital information is used for decision making in intra and inter-organizational SC processes. This research provides an overview of the relevant literature in the area of SCD in which the digital and operational environments are merged for effective decision making. This research also focuses on the various concepts, technologies, dimensions and tools used for the process of digitalization of SC.

The traditional process of product development and manufacturing activities focus on a product as a class. The application of digital technologies assists in translating into a digital form of the physical product, making it feasible in continuous design change and modifications. Further the transformation also allows standardization and customization across all the products in a class so as to make adjustments based on the inputs received. The emerging practice of design remixing in additive manufacturing was highlighted in the literature (Friesike et al., 2019). Hedenstierna et al., (2019) have illustrated the operations mode for additive manufacturing facilitating pooling of capacities in a network of general purpose manufacturers. Heinen and Hoberg (2019) explored the opportunities created based on digitalization in the inventory management of spare parts and after sales operation.

Digitalization enriches the field and practices in the area of operations and SCM. The digital transformation process and the aspects to be considered challenges the researchers in bringing better insights in the SCD domain. Digital encapsulation represents a subset of the SCD, wherein the application of real time location systems, internet of things and cloud based platforms allows to effectively track, model and control each individual product. The process of digital encapsulation interfaces with various systems in the SC allowing real time sharing of information. Digital encapsulation facilitates autonomous operations by combining with artificial intelligence and assists the decision maker in operations and SCM. It empowers the firms in visualizing the demand and resources required to plan the production activities accordingly. The process of digital encapsulation is influenced by various factors. The interests of the SC partners, the industry standards, the flexibility of process and trust among the partners shall be considered during the process of encapsulation.

The control of an individual product's life cycle from design to production through effective engagement of firms in all the activities in product realization can be facilitated through digital encapsulation (Engel, Browning and Reich, 2017). The digital technology revolution is referred to as the fourth industrial revolution (I 4.0). Ben-Daya et al., (2019), Dolgui et al., (2019b), Frank et al. (2019), Gunasekaran et al. (2016), Ivanov et al. (2019), Tang and Veelenturf (2019) and Zennaro et al. (2019) have introduced various engineering and management frameworks of Industry 4.0 highlighting the customizable supply and manufacturing networks. The existing studies were pointing towards the formation of cyber-physical SCs (Ivanov et al., 2019; Panetto et al., 2019). Further the studies on the application of data analytics and its use for enhancing demand forecasting, production flexibility, SC visibility and transparency and its contribution to effective SCM was highlighted in the literature.

2.2 Supply Chain Integration

Integration of SC through digitalization involves the extent to which a company adopts digital technologies in their processes for conducting their day to day transactions. SCI aims at streamlining the flow of products, information and funds from suppliers to customers thereby ensuring efficiency and accuracy in SC processes (Sammuel and Kashif, 2013). Integration of SC is a building block consisting of joint collaborative network, coordination, shared vision, information and technical infrastructure among the SC partners (Flynn et al., 2010). In the globalized and highly competitive world, SC strategies and objectives shall be aligned with the business objectives to achieve maximum benefits. It adds value to the customer by gaining customer satisfaction and market share. The three main pillars of SCI framework are information integration, coordination and resource sharing and organizational relationship linkage.

Diverse outlook and aims of SCI like collaborative advantage (Cao and Zhang, 2010); effective relational governance (Schoenherr and Swink, 2012); IT integration; knowledge exchange and trust (Chen et al., 2016); strategic achievement (Beske and Seuring, 2014); supplier involvement (Alam et al., 2014); SC performance (Flynn et al., 2016); lead time (Laureano Paiva et al., 2014); Quality (Gonzalvez-Gallego et al., 2015); competitive advantage (Pradabwong et al., (2017); Flexibility (Wong et al., 2017); cost reduction (Tseng and Liao, 2015) are found in literature. SCI process has three levels of facilitators, viz., (i) information integration (ii) coordination and information sharing and (iii) organizational relationship linkages (Alfalla-Luque et al., 2013).

The measures of SCI are information sharing and interdependence among SC members (Huang et al., 2014). Information sharing, decision making at inter organizational level and planning among partners in SC are considered as the key elements (Jayaram et al., 2010). The major dimensions identified for SCI are information sharing and operational coordination (Liu et.al.2013), collaboration and information sharing (Wu et al., 2014) and information and physical integration (Bruque-camara et al., 2016). Majority of the research papers in the area of SCI have focussed on the two dimensions of internal and external integration. Sundarakani et al., (2019) have developed a hybrid supply cloud model for integrating the infrastructure, resources and configurations of platforms for creating better flexibility and efficiency in SCM. Queiroz et al., (2019) has developed a framework for DSC capabilities consisting of seven basic capabilities and six main enabler technologies.

Digitalization of SC allows integration of data and information by assisting various functions of SC processes (Mussomeli et al., 2016). Digital technologies help in real time transmission of information and support knowledge management practices (Wilkesmann and Wilkesmann, 2018). The desire to adopt new technologies will bring in transformational effects on SC (Xue et al., 2013). Application of advanced technologies allows companies to gain competitive advantage through higher revenue and value addition (Buyukozkan and Gocer, 2018). There is a lack of knowledge in the procedure to be adopted for implementation and effective utilization of digital technologies. The development on account of the digitalization process allows organizations to manage their SC activities remotely (Lyall et al., 2018).

Information technology has immense significance in overall performance of SC in an organization. The impact of information technology attributes depends upon the nature of supply chain characteristics considered. Information technology integration is the most prominent attribute mentioned in the literature. Information technology integration refers to creation of a virtual SC by linking the information systems and sharing of information among SC partners. Seamless integration of partners across the SC is essential to reduce the costs. An efficient SC network can be established by means of implementing most modern information sharing systems and tools. Effective management of SC by using Information and communication technology tools aid in utilizing the firm's resource and capacity effectively. Information and communication technology implementation also helps in redesigning of SC (Lee et al., 2011). The innovations in Information and communication technology and its implementation have enabled the creation of effective and efficient information systems for effective management of SCs.

Perez-Lopez et al., (2019) have quantified the relationships among variables to be considered for adopting Information and communication technology in SCs. Seamless integration of partners across the SCI is required to reduce manufacturing and transactions costs. Hence, there exists a need to introduce an efficient SC network with execution of most modern information sharing systems and tools. In order to facilitate implementation of robust SCs using information technology tools, data and information transmitted across among the SCs partners is to be maintained in a repository and classified suitably for easy access and processing.

Integration process can be defined based on the cooperation, coordination and collaboration efforts made by SC partners for enhancing SC efficiency (Zhu, et.al., 2018). Integration of processes facilitates easy flow of materials and goods from the suppliers to the end customers at the right place and at the right time (Basheer, et al., 2019). Information and communication technology tools help in real time sharing of information across the SC network for on time decision making. It results in cost reduction and also in maintaining optimum inventory (Kwak et al., 2018).

The integration process has been transformed by the use of information technology in SCs, facilitating organizations to gain more market share. The process of digitalization of SCs has become an enabler. The influence of big data analytics for enhanced operational performance of organization is stated in the literature by integrating three major fields of management like entrepreneurship, operations management and information systems management. Dubey et al., (2020a) have developed a model that describes the role of entrepreneurial orientation on the adoption of big data analytics powered by artificial intelligence and operational performance. The drivers and enablers affecting the process of SCI have been investigated, with little consensus on the process of integration of SC through digitalization (Hausberg et al., 2019).

2.3. Supply chain digitalization

SCD can be defined as the extent to which advanced digital technologies are applied in the SC process and among the partners resulting in transformation of SC and gaining better operational and performance capabilities. SCD changes the way of collaborative practices and interaction among SC partners through a network of interconnected activities using novel technologies (Buyukozkan and Gocer, 2018). Establishment of collaborative practices across the SC has gained significance in SCM. Collaboration among partners in SC using advanced digital technologies is one of the key areas which is to be addressed for attaining competitive advantage. Research reveals that value can be created through partnership among SC partners (Jajja et al., 2018). Penthin et al., (2015) have addressed the differences between digital and non-digital SCs. The advancement in digital technologies has altered the way of communication and interaction among the professionals, and no exception in the case of SCs. The influence of the digitized world on the transactions and business process demands effective SCD.

Various factors like resource sharing, long term relationship, integration of planning and functional areas, ensuring availability of resources including information technology systems should be addressed to facilitate effective digitalization. Information technology enabled SC helps in enhancing performance, competitiveness, collaboration and flexibility and cost reduction. The hastened pace of digitalization has altered the dynamic business and market structure (Waluyo, 2019) and influenced the SCM process (Buyukozkan and Gocer, 2018). Nasiri et al., (2020) investigated the approach required to gain competitive advantage through digital transformation of SCs. Enhanced relationship performance can be achieved by coupling smart technologies while transforming digitally.

The need is for improving SC by shifting the priority from simple cost reduction and optimization of resources to SC restructuring based on technological advancement. It stresses addressing factors like resource sharing, long term relationship, and ensuring availability of resources including IT systems to facilitate effective integration through digitalization. SC managers need to examine, control and understand the entire operations in SCs by managing the information received from various sources (Ngai and Gunasekaran, 2007; Olson, 2018).

Advancements in information and communication technology together with high expectations from the SC partners have necessitated the need for a highly integrated SC. Information technology has drastically changed the way of defining the SCI process as the information can be shared online on a real time basis (Palomero and Chalmeta, 2014). Availability of timely and accurate information to partners facilitates effective coordination of activities and decision making in SC (Zhou et al., 2014). A diagrammatic representation of the evolution of digital supply chain is shown in Figure 2.1.

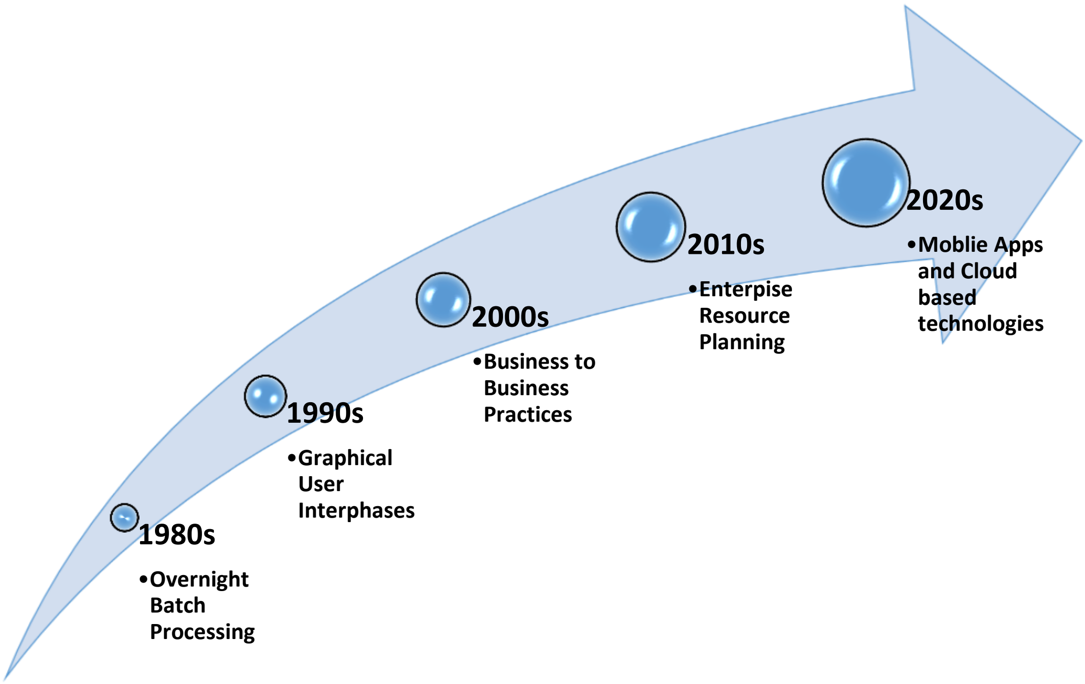


Figure 2.1: Evolution of Digital Supply Chain

Digital technologies play a dynamic role in effective SC functioning and enhancing firm's performance (Gurria, 2017; Laaper, 2017). There is a positive relationship between SCI and performance of the firm by comprising information, operational and relational integration (Leuschner et al., 2013). Studies on various aspects of SCI aiming at performance enhancement, dimensions and measures relevant to integration are also found in the literature. Drivers and enablers of SCI have also been investigated with little consensus on the process of SCI through digitalization (Hausberg et al., 2019). Inter-relationships among SC partners are to be established and recognized for effective design, alignment and execution of the strategy.

However, on account of advanced digital technologies, the implication and strategies to be framed and the procedure to be followed is not yet addressed.

The transformation of organizations into digital form is commonly known as Industry 4.0. It includes various types of technologies like internet of things, cloud based manufacturing, block chain, artificial intelligence and cyber physical systems. Further, in order to assess the readiness of organization for Industry 4.0, the six key ingredients identified are: the extent of digitization of SC, level of digitization of organization, readiness of organizational strategy, top management involvement and commitment, employee adaptability with Industry 4.0 and smart products and services (Sony and Naik, 2019). Belinski et al., (2020) have categorized the dimensions of Industry 4.0 under three main constructs: learning development, Industry 4.0 structure and technology adoption for easy management and implementation.

I 4.0 adoption affects entire operations in an organization. Manavalan and Jayakrishna (2019) have proposed a framework for evaluating the readiness of SCs for attaining sustainable growth to meet I 4.0 standards. Cagle et al., (2020) opined that benefits of I 4.0 adoption are seen across various functions in organizations as technology and process adoption, procurement and distribution, human resources and marketing business functions, etc. Kohtamaki et al., (2020) have investigated the effect of interaction between digitalization and servitization on the financial performance of manufacturing companies. Armengaud et al., (2020) have investigated opportunities for digitalization as well as the need for systems engineering including organization, tools, process and methods in case of automotive sector.

Sestino et al., (2020) have investigated business activities during digital transformation and have found that IoT and big data are the primary reengineering factors for business processes, products and services. The study presented appealing implications for managers in understanding transformations in business due to IoT and big data. The application of data in business marketing is facilitated through digitalization of which demands a great deal of attention. Ritter et al., (2020) defined digitization capability and have proposed how it interacts with business models by permitting data-enabled growth. The change in firms has happened due to advancements in ICT and the managers have to become accustomed to these changes in digital marketing (Guven, 2020).

Srinivasan and Swink (2018) have found that demand and supply visibility are associated with the development of analytics capability in a firm. The operational performance of a firm is closely associated with analytics capability. Managers considering investing in analytics capability should carefully evaluate their SC capabilities, organizational abilities and competitive value of sensing and responding to changing market conditions. Zekhnini et al., (2019) has developed a framework for SCM 4.0, which decomposes the connection between distinct parts in SC like digitalization, digital technologies and risk management. SCM 4.0 considers deployment of modern technologies like the internet of things, big data analytics, autonomous robotics, etc.

Literature has mentioned the need to identify the underlying technological challenges in the SCD process as a prerequisite. Zhao et al., (2020) have addressed about studying the crucial role and challenges associated with digital technologies in SC like process integration, strategic partnership, channel coordination and resource allocation. IT and sharing of information are the main drivers for the digital transformation of SC. Literature reveals that the process of adopting information technology alone does not provide competitive advantage. It also depends on technical competence, organizational capabilities and human resources.

Advanced digital technologies and tools can be used in managing various SC functions through proper implementation and monitoring of activities. SC in real time faces tribulations like mismatch between supply and demand, overstocking, stock outs and delay in delivery (Wu et al., 2016). Salam (2019) has investigated the impact of manufacturing strategies on Industry 4.0 supplier performance and found that improved quality and flexibility has a positive impact on performance of suppliers. Gupta et al. (2020c) have addressed the orientation of firms in adopting Industry 4.0 and Digital Supply Chain (DSC). Hastig and Sodhi (2020) have investigated the readiness of block chain technology for traceability in business requirements by including all the participants into the system. Existing systems should be integrated with the block chain based solution for facilitating effective implementation. Thus, traceability solutions for an industry can be hybrid in nature with block chain as a small but significant component of the overall system.

The effective use of Information and Communication Technology (ICT) by firms helps in gaining competitive advantage in a dynamic business environment. ICT is being used by firms for integrating various SC functions. SCD can be done effectively by using most advanced information technology (IT) tools by interconnecting partners in SCs. In a digital SC, firms integrate the processes through digitalization so as to facilitate transaction and collaboration among the SC partners (Zhu et al., 2020). The competition among the firms has necessitated making use of IT to gain competitive advantage by bringing in innovative products. SCD has become an enabler, whereas desired results from the process of digitalization cannot be achieved fully due to existence of various types of barriers and identifying the key enablers, methods and requirements for effective digitalization.

2.4 Features of SCD

The main aspect of SCD is the intensity of information sharing between the partners. Effective flow of information using information and communication technology tools provides a better platform for coordination, participation and result oriented activities in SC (Mackelprang et.al., 2014). Long term partnership in SC is fruitful only when the strategic information flow and trust is established among the partners (Fuller et al., 2016; Abdallah et al., 2017). In recent times, organization's strategies for SCD have changed drastically with emergence of big data, cloud computing, internet of things and artificial intelligence technologies.

The adaptability of the system with available Information Systems (IS) is another important aspect which is to be considered in digital transformation of SC. The integration of SC by using ICT needs to be considered in many areas, such as Supplier Relationship Management, Material Requirement Planning, Enterprise Resource Planning, Customer Relationship Management etc. In recent years, digital transformation of SC by using advanced ICT tools has gained greater significance.

The development of information technology has transformed the structure of SC by bringing organizations closer through collaboration and integration with SC partners (Chen, 2019). Real time access to data enables the firms to plan production activities considering products in the pipeline and anticipated problems, if any. Information and communication technology tools and its application in the process of planning, forecasting and scheduling of activities will bring in more transparency, visibility, accountability and efficiency in SC. The impact of revolution in SC due to emerging technologies is transforming the businesses (Ben-Daya, et al., 2019, Ivanov et al., 2019). Digitalization process in a company is a potential way to tackle uncertainties and customer demands effectively. Industry 4.0 and the concept of smart factories are gaining relevance in recent times (Liao et al., 2017; Xu et al., 2018).

Kong et al., (2018) considered Digital Twin (DT) technology as a combination of Industry 4.0, Cyber Physical Systems (CPS), Internet of Things (IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), Advanced Tracking and Tracing Technologies, wearables, Additive manufacturing etc. DT is one of the key compelling forces for hyper connected Physical Internet (PI). PI is defined as a hyper connected global logistics system that facilitates flawless open asset sharing and flow consolidation through standardized encapsulation, modularization, protocols and interfaces (Mervis, 2014). Researches highlighted the requirement of economic value addition and feasibility of PI technologies, quantitative evaluation of PI platform innovations and its methods (Joshi and Gupta 2019; Almohri et al., 2019).

The physical assets or the processes can be projected into the digital world to reflect the whole life cycle process through DT (Tao and Qi, 2019). Data driven optimization can be done based on the DT technologies, through data mining, analysing and modelling (Ivanov et al., 2019). Effective and successful deployment of DT and PI depends on integration of the intentions of both management and technology.

The process of traditional manufacturing systems can be changed towards a smart manufacturing system through the adoption of DT along with the internet of things, machine learning and application of technologies for data processing. The advantages and uses of acquisition of data on a real time basis and its processing based on simulation is demonstrated (Uhlemann et al., 2017a). It is found that adoption of smart manufacturing processes shows greater levels of automation, adaptability and flexibility to the entire process (Lohtander et al., 2018, Tolio et al., 2017). The application of DT framework based on machine learning for optimization of production in the petrochemical industry is also found in literature (Min, et al., 2019). Altogether the combination of DT with advanced technologies enhances the performances and automation process (Tolio et al., 2017).

Studies on various aspects of DT and PI aiming at performance enhancement are found in the literature. The importance of DT and PI is highlighted in the recent literature and has become a vital topic for research by industrialists and academicians. The process of adoption of DT and PI involves the extent to which the company adopts digital technologies in its processes to conduct their operations. The adoption of digital technologies increases customer databases, enhances SC performance and helps in building an end-to-end SC that expedites the processes.

Application of advanced technologies allows the companies to gain competitive advantage through higher revenue and value addition (Buyukozkan and Gocer, 2018). The desire to adopt the new technologies will bring in transformational effects on the SC (Xue et al., 2013). The quantum of data generated through digitalization of SC facilitates better performance, whereas the digitalization process is equally challenging. SCD assumes importance from the concept of SCI. The relevance of SCD is increasing day by day due to (i) increased distributed manufacturing, (ii) greater customer engagement, (iii) slow Industry 4.0 adoption (iv) artificial intelligence and advanced analytics coming to the fore. The integration process in industry has increased in light of Industry 4.0 trends resulting in creation of smarter end-to-end SC.

Advanced digital technologies and its applications in SC are recognized as an essential domain for SCD. The decision to be taken on SCD using information technology (IT) is a complex task, as it is influenced by internal and external factors which are to be analyzed in detail.

2.5 Components, technologies and methods for SCD

Research in information systems has continued to evolve consistently in recent decades on various aspects like intellectual core, diversity and impact of information systems. It has advanced considerably over time whilst serving its core identity and strength (Jeyaraj and Zadeh, 2020). The current business environments are challenged with dynamic emerging technological trends such as networks of entities and collaboration of computational entities surrounding the physical world as cyber-physical systems (CPS). These trends and technologies are equally challenging and have high potential (Liu et al., 2017).

Flexibility in operations and reduced cycle time are core components of digitalization of SC (Stank et al., 2019). The availability of more data on a real time basis helps in quick decision making by reducing uncertainty in SC. The literature on SCI deals with the social and technical aspects. Further, equally important aspects of information sharing and maintaining effective communication among SC partners is also addressed (Tseng and Liao, 2015, Prajogo, et al., 2016). The use of big data in predicting the technological innovation in SC and its performance is also found in the literature (Saleem, et al., 2020).

Enterprise information systems (EIS) are main components that play a key role in the Industry 4.0 era in realizing smart manufacturing systems (SMS). The limitations of traditional

EIIS identified are lack of seamless integration, business intelligence, value-driven processes and dynamic optimization, lack of complete information, etc., as these satisfy limited business needs. Qu et al. (2019) have developed a new integrative EIS items framework based on business process reengineering, intelligent management and lean thinking (Qu et al., 2019).

Ishtiaque et al., (2020) have developed a model that assists in understanding the relationships among ICT, operational responsiveness, integrative capabilities and dimensions of performance. They opine that the effective way to gain operational performance is by improving integrative capabilities through investment in ICT. SC responsiveness shall be configured from customer facing to supplier facing through integration. Dunke and Nickel (2020) investigated the use of collaborative IT applications in improving intra-organizational logistics processes. They found that vast improvements in logistics functions are attained using collaborative IT applications in track and tract IT solutions. Rached and Bahroun (2020) highlighted the need to raise awareness among SC partners for sharing of information by assessing the value in both upstream and downstream in a divergent SC. They found that maximum benefit was gained in the warehouse aspect and suggested implementing revenue sharing contracts for motivating and sharing information among SC partners. Gholipour et al., (2020) developed a bi-objective mixed linear integer programming model for designing a green SC network under certainty in case of automotive SC.

Sodhi and Tang, (2019) have found out process of disclosing information to the public as a mechanism for providing SC transparency. Dubey et al., (2020b) have developed a conceptual model for understanding of application of blockchain technology in the case of humanitarian SC. The model demonstrated that blockchain technology exercises positive and significant influence on operational SC transparency. Zangiacomi et al., (2020) presented a managerial perspective for the transformation towards I 4.0 in manufacturing value chain by investigating three major dimensions viz., investments in I 4.0 technologies, ability in perceiving the path towards digital transformation and knowledge sharing. Although the literature has mentioned the potential and benefits of SCD, a specific model on the key barriers that affects the SCD process is limited (Teniwut and Hasyim, 2020). This paves out the need for understanding the practices to be adopted and to analyze the barriers affecting SCD process.

Various types of decision support models for SC in the areas of production planning and scheduling, logistics planning and demand management are available. Simulation methods like

Monte Carlo simulation, agent-based and multi-agent simulation, discrete simulation, system dynamics, and visual simulation are also found for decision support in the area of SC management.

Integrity, interoperability and flexibility are the key characteristics of EIS in business processes. The basic problems which are affecting the transformation process can be categorized under business infrastructure and technical infrastructure EIS levels. Development in Enterprise Information Systems (EISs) is a never ending process as enterprises continue to evolve due to advancements in technology, emerging business models, legal regulations, optimization of internal solutions (Romero and Vernadat, 2016). EIIS facilitates exchange of information on a real-time basis across organizational boundaries through computer networks. EIIS can be described as an integrated data-sharing approach based on business collaboration between various enterprises and SC partners. EIIS is fundamentally an automated information system shared among the enterprises and SC partners for supporting business activities. The full potential of EIIS can be exploited through effective integration of EIIS with all the functional areas and among SC partners.

Inter-organizational information systems (IOIS) has emerged as one of the dominant topics in integration of SC based on advancement in technologies. Liu et al., (2019) have developed a model for IOIS adaptability based on organizational identity and found that organizational learning mechanisms and knowledge sharing have positive effects on the adaptability of IOIS. The process of digitalization involves sharing of data, resources and flow of information. Zangiacomi et al., 2020 have investigated the managerial practices for the adoption of Industry 4.0 technologies through multiple case studies in the manufacturing sector. Queiroz et al., 2020 have identified complexities of SPSs and main drivers for enhanced BPM. The process of transformation towards Industry 4.0 and further towards Industry 5.0 includes application of advanced digital technologies and its integration to SC performance. In this context, enterprise architecture is the ideal platform that can be used to enhance the flow of information and SCI.

One of the main features of the intertwined SC network is digitalization. The rapid advancements in the technologies have been utilized effectively in the area of SC research (Mourtzis and Vlachou, 2016; Panetto et al., 2019). The major technologies which can be used in the digital era includes additive manufacturing, data analytics, sensors, block chain, augmented reality, DT. Etc.

The decision support systems (DSS) developed in the field of SC is mainly based on numerical simulation approach (Gromov et al., 2019), followed by MCDM based techniques (Karthik et al., 2015). The DSS developed in SC has been used widely for supplier relationships (Sahu et.al., 2018), production (Gardas et al., 2019), transportation (Essien et al.,2018), construction (Guerlain et al., 2019), transactions (Brauner et al., 2019) and e-commerce. This paves the way for conducting further studies on the use of DSS in SC based on trends in IT. In the context of DIKW hierarchy, the data can be used and turned into information, followed by information to knowledge and finally leading to wisdom for decision making for effective digitalization.

Advanced digital technologies help in real-time transmission of information and support knowledge management practices (Wilkesmann and Wilkesmann, 2018). Delbrugger and Rossmann (2019) developed a model for production systems by combining system engineering and variability management to make DTs reconfigurable and modular. Boehmer et al., (2020) explored the role of relational mechanisms of digital technologies in SC and have addressed the promising potential of IoT technology as an enabler for manufacturers in the production process. Mendhurwar and Mishra (2019) have defined digital transformation, its potential impact on business, identified opportunities related to social and IoT technology integration and challenges associated with convergence of technology focusing on cyber security challenges.

Big data plays a crucial role in enhancing business value. Brinch et al., (2020) have identified the firm level capabilities required to create value from big data and have identified major capabilities as related to information technology, performance, processes, strategic, human and organizational practices. There is a positive relationship between SCI and performance of the firm by involving information, operational and relational integration.

FossoWamba et al., (2019) reviewed 149 peer–reviewed articles published during the period from 2010- 2017 and also reviewed case studies related to Bitcoin, block chain and FinTech concepts. They have found that the area of SCD needs better understanding of factors and challenges affecting the transformation process. Seyedghorban et al., (2020) have conducted a comprehensive review of the literature in the area of SCD, using both quantitative and qualitative review methods in the area of SCD. A review of the studies related to smart production systems (SPS) related issues in the context of Industry 4.0 covers areas as big data analytics (BDA), IoT, CPS and the potential of business process management (BPM) improvements.

AL-Shboul (2019) has studied main determinant logistical factors influencing adoption of cloud enterprise resource planning (ERP) among small and medium sized enterprises that provide insights to practicing managers while making investment decisions in cloud ERP. Block chain application; a disruptive internet based technology can be used to enhance the production processes and reduce costs (Pan et al., 2020). Ardito et al., (2019) have addressed the innovative efforts undertaken to develop digital technologies as an interface for SCM, marketing process and sustainable SCM from an information processing point of view. It provides insights about the application of digital technologies in enabling SCM marketing integration.

The competitiveness of an enterprise can be enhanced by developing intelligent manufacturing systems evolving a sensing, smart and sustainable enterprise (de Sousa, 2020). Balocco et al., (2019) proposed a lean framework to facilitate new ventures in the digital Business Model Change (BMC) process. BMC includes involvement of new ventures in a dynamic environment due to technological advancements facilitating digital transformation towards new business models. IOIS is a value added shared information system between the participants in the business process facilitating to generate, transform, communicate and store information across the boundaries of the firm. The process of implementing IOIS in an organization is a challenging task due to involvement of multiple participants, diverse culture, strategy and interests. In order to integrate the SC using digital technologies, the inter-organizational capabilities play a crucial role. Effective integration of SC using IOIS facilitates timely access to information required for forecasting, production planning and scheduling and collaborative planning. IOIS can be adopted to gain economies of scale, reducing risks, increasing competitiveness, overcoming barriers of investment and better communication to reap the benefits (Kakhki and Gargeya, 2019).

The significance of IT in integration of SC has been widely addressed in literature (Fulford and Standing, 2014). IOIS facilitates interconnection between enterprise information systems among firms using ICT tools (Naslund and Hulthen, 2012). The problem of heterogeneous enterprise information systems can be addressed through effective integration using IOIS enabled synchronization (Xu et.al, 2015). The areas like collaborative planning, SC visibility, logistics, vendor managed inventory and forecasting and replenishment are some of the areas that can be strengthened by using IOIS (Fulford and Standing, 2014).

In the case of a digitised SC, various types of software platforms are used by the companies to collaborate and drive SC activities. The selection of software platforms and their associated digital solutions varies among firms. It mainly depends upon the nature of business activities dealt by them. The selection of IS and methods for integration of SC should be compatible with the SC partners, failing which the firm would be facing gaps in SC visibility (Jeyaraj and Seth, 2010).

Digital technologies and its applications in SCs has revolutionized the traditional concept of SC management. Advanced digital technologies and tools can be used in managing various functions of the SC through proper implementation and monitoring. Information technology has drastically changed the way of defining the integration process as the information can be shared on a real time basis. It assists in gaining accesses of timely and accurate information to SC partners to coordinate various activities and decision making in SC (Zhou et al., 2014). Digital technologies play a vital role in the functioning of SC and enhance performance of the firms (Gurria, 2017).

Blomkvist et al., (2020) highlighted the application of DT to automate monotonous activities which can be prone to human error, allowing the resources to be centred on more value-added activities. The benefits gained from DT were categorized under descriptive value, analytical value, diagnostics value and predictive value. Cooperation of partners in the SC in adopting DT and PI helps in building an end-to-end SC that expedites the process by avoiding obstacles. The process of information sharing facilitates collaboration, competitiveness and transparency results in better performance of the SC (Flynn et al., 2016). DT has a significant role to play in various functional levels and operations in SC. The process of product life cycle management, process automation and information flow gets influenced with the application of DT (Qi et al., 2018; Zutshi and Grilo, 2019). The models created based on DT can be used for virtualization of real conditions during the operations and manufacturing of the product (Kritzinger et al., 2018). It helps in continuous improvement of the manufacturing systems, facilitates innovations resulting in advancement of business activities. DT enables transparency, visibility and provides a simulated environment of various scenarios to optimize the performance of SC. Thus the entire activities in the SC can be modified considering various scenarios for enhancing the performance.

DT approach has become a significant element in product lifecycle management and major organizations are integrating the DT approach into the entire lifecycle from designing of the product and assembly to usage monitoring (Qi et al., 2018). DT facilitates way for cyber-physical integration resulting in creation of virtual models of the physical objects to simulate their behaviours (Hochhalter et al., 2018). The full potential of DTs can be unlocked through enabling technologies like 3D simulation, IoT, and AI which facilitates physical and virtual models to work concurrently by providing powerful and agile computing capabilities.

DT technology is also used in the area of aircraft maintenance, and its role and requirement on the conventional industry is also addressed (Tammaro et al., 2017). DT can also be applied from design phase to after sales service after sales service, which is one of the main resources of a company. The overall performance of the product can be tracked and requisite of maintenance can be decided. It also helps in control of production activities and planning of manufacturing activities along with services (Qi et al., 2018). Feedback can be obtained from customers to improve brand loyalty and address the requirements of the customers (Zutshi and Grilo, 2019).

DT is considered as the core solution for enhancing digital monitoring systems through various interconnected devices resulting in a more autonomous system (Liu et al., 2019). It helps in increasing the extent of horizontal and vertical integration of the manufacturing system (Stark et al., 2019). DT is also used in predictive maintenance based on various modelling techniques. The data that is acquired continuously helps in forecasting the predictive maintenance (Diez-Olivan et al., 2019).

The PI is a broader concept which merges various relevant areas of logistics and SCM resulting in disruption of current logistics and SC management practices. Treiblmaier (2020) defined PI as a comprehensive and measurable SC framework based on a network of physical components, which are standardized as well as optimized and exchange information to improve the efficiency, effectiveness and sustainability of SCM operations. PI has the capability to become a disruptive innovation which assists in solving several business and social problems by transforming extant logistics and SCM practices. Kache and Seuring (2017) highlighted the aim of PI as to optimize logistics and SCM processes in order to create more effective, efficient and sustainable SCs, ultimately leading to innovations in SC models and strategies.

PI process visibility has emerged in the case of application of PI in the solar cell industry (Lin and Cheng, 2018). Ben Mohamed et al., (2017) has studied the urban transportation problem in a PI-enabled setting by using various types of vehicles. The benefits and performance of PI compared to the conventional logistics systems was also studied (Fazili et al., 2017). Tran-Dang et al., (2017) has proposed a solution that has the ability to facilitate containers equipped with wireless sensor nodes by detecting errors and providing updates for determining node relationships in their neighbourhood. Yang et al., (2017) used a PI environment of interconnected logistics to study the impact of disruptions on hubs and factory plants and to assess inventory model resilience. A framework which guides practitioners to build a robust data-driven agri-food SC through proper planning of investments was developed. In order to achieve data analytics capability and sustainable performance, the framework identified SC resources and SC visibility as the main driving forces (Kamble et al., 2020b).

Yang et al, 2017, investigated the resilience of inventory models in the PI using interconnected logistics services. A simulation based optimization model was developed to determine inventory control decisions and found that the PI inventory model which is having greater agility and flexibility outperforms the traditional inventory models. The performance dimensions to be considered for planned investments in smart manufacturing systems adoption are also addressed (Kamble et al., 2020d). Literature found that industry 4.0 enabled smart manufacturing systems to offer more competitive benefits compared to traditional manufacturing systems. Tortorella et al. (2020) addressed the mediating role of organizational learning capabilities at different contextualization between Industry 4.0 technologies and operational performance. It is found that companies which systematically foster learning and knowledge sharing can obtain greater benefits from Industry 4.0 adoption.

Information technology adoption process has gained significance due to advancement in digital technologies (Khemili and Belloumi, 2018). SCI works on the basis of shared decision making, open communication, collaboration, shared vision, technology and trust among the partners. The real time connectivity across SC partners facilitates easy access of data for quick and effective decision making. The connection between cyber-physical production systems and machines by storing data in the cloud i.e. industrial internet of things is gaining prominence (Boyes et al., 2018). Flexibility in operations and reduced cycle time are the core components of digitalization of SC (Stank et al., 2019).

Buer et al., (2020) have stated that manufacturing digitalization is considered as a key enabler for gaining competitive advantage. They had investigated application of digital technologies in different production environments like shop floor digitalization and technologies for vertical and horizontal integrations. Singh and Bhanot (2020) investigated the challenges involved in adoption of smart devices and have also analyzed barriers of implementation of Internet of Things (IoT) in the manufacturing sector.

Literature reveals that IOIS is one of the key factors that helps in maintaining inter-organizational relationships (Rahman, 2017). Firms involved in integration of SC using IOIS can share technologies and exchange information on a real time basis for effective decision making (Haseeb et al, 2019). Dynamism of SC can be measured based on introduction of new products and its revenue share in the total business volume, frequency of innovation for new products and rate of operating processes for innovation (Lee et al., 2016). Information sharing, trust and collaboration are some of the key forms of inter-organisational competencies in relationship based SC (Mirkovski et al., 2016; Abdallah et al., 2017).

2.6 Benefits and challenges for SCD

The process of digitalization of SC creates value opportunities and savings for companies (Ehret and Wirtz, 2017; Grubic and Jennions, 2018). The DSC also provides flexibility in business processes and economies of scale (Gerpott and May, 2016). Integration of the SC can be done by using digital technologies with the help of IoT theories and physical systems (Luz Martin-Pena et al., 2018).

Figure 2.2: Key benefits of SCD

SC and the risks involved can be managed effectively with the application of DT technology. DT facilitates in redesigning the complex data-driven systems based on understanding on how various aspects of SC are interrelated. Organizations can plan for initiating advance actions for probable disruptions resulting in enhancing the performance, reliability and efficiency. Thus, the development and application of DT models is attaining significance in real case scenarios.

Figure 2.3: Challenges in SCD

There are various types of risks involved in the process of decision making for digitisation of SC. It needs consideration of various conflicting criteria (qualitative and quantitative), that makes it a challenging task for SC managers. There is a lack of knowledge in the procedure to be adopted and for effective integration of SC by using IOIS. Multi Criteria Decision Making methodologies could judicially be used in these circumstances to model a solution to the problem. Model for SCI proposed in this paper aims to bring in flexibility, capability, adaptability and quick response to SC processes.

2.7 Framework for SCD

SCD involves the process of creating computer powered processes to handle value chain activities in a SC. Visibility in SC can be established by providing access to information in SC for effectively planning the flow of information in both upstream and downstream. The process of adoption of IT has gained vide significance based on the advancement in digital technologies (Khemili and Belloumi, 2018). Li et al., (2019c) investigated the impact of structured and unstructured information sharing on strategic coordination and SC performance through effective operational coordination. A conceptual framework of digital supply chain is shown at Figure 2.1.

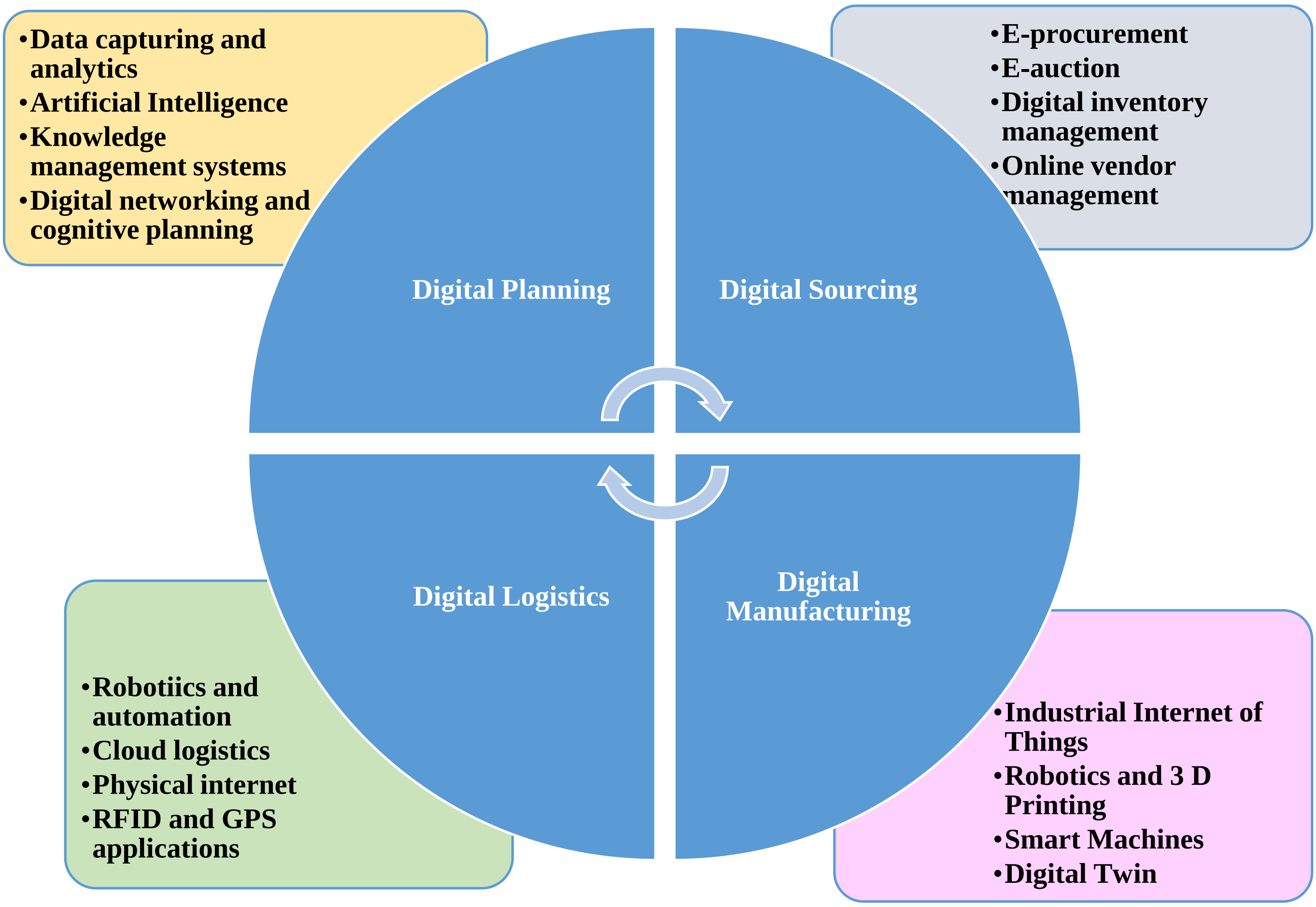


Figure 2.4: Conceptual framework of supply chain digitalization

Sarkis et al., (2000) presented a framework on traditional and emerging digitalization to leverage SC sustainability. They highlighted potential trade-offs and variance of greening and digitalization. The fourth industrial revolution facilitates restructuring of organizations through formation of a more connected digital ecosystem. Seyedghorban et al., (2020) have highlighted the importance of data SCI enabled SCM, SC agility, Omni-channel and humanizing manufacturing through digital strategies.

Autry and Moon (2016) have defined various perspectives and dimensions of SCI. In addition, uncertainty (Flynn et al., 2016); supplier's involvement & relationship (Alamet al., 2014); market complexity (Wong et al., 2015); competitive approach (Cao et al., 2015); organization culture (Yunus and Tadisina, 2016); human capital (Huo et al., 2016); market and technological turbulence (Arora et al., 2016); trust (Abdallah et al., 2017) are the other dimensions and variables driving SCI that are addressed in literature.

The availability and sharing of information on a real time basis helps in reducing costs and shortages in inventories (Kwak et al., 2018). The advanced ICT tools will help in real time tracking of goods and access to information, which makes the SC more efficient. The relevance of SCD is increasing day by day due to (i) increased distributed manufacturing, (ii) greater customer engagement, (iii) slow industry4.0 adoption, (iv) agility and responsiveness as top priorities and (v) artificial intelligence, machine learning and advanced analytics coming to the fore (Ivanov et al., 2019). Lin and Lin, (2019) have investigated the processes influencing the application of cloud computing services in SCM which facilitates transmission and exchange of data among the SC partners.

Case studies conducted on the relationship among the SC partners has identified that effective implementation of IT and communication provides a better platform for coordination, participation and result oriented activities (Mackelprang et al., 2014). The impact and control on SC can be enhanced by adopting IT for business activities (Khemili and Belloumi, 2018). The extent of communication among the partners determines the symmetry and strategic transmission of information across SC. The main aspect of SCD is the intensity of sharing information between the partners. Martinez-Caro et al., (2020) studied the role of IT integration on the performance of firm in business to business scenario by considering the link between information technology and the absorptive capacity of the firm and how improvement can be done in potential and realized absorptive capacity.

The methods adopted for interconnection among the partners in the SC has changed considerably in the recent decades. The long term partnership has become fruitful (Hensler, 2015). Strategic information flow can be established only when trust is established among the partners (Fuller et al., 2016). The extent of use and benefits of SCD are explained by taking into account IT infrastructure, IT personnel, IT re-configurability and IT knowledge (Kausar et al., 2017). The impact of dimensions of business-IT strategic alignment on organizational performance was also studied (Ilmudeen et al., 2019).

The adoption of advanced technologies leads to automation and exchange of data in various processes across the SC, which leads to Industry 4.0 (Sprovieri, 2019). It is found that research on implementation, benefits and design of SC is scarce (Hofmann and Rusch,2017). The literature on SCD focused on technologies like cloud computing, big data analytics and its applications with respect to a specific industry (Kache and Seuring,2017). The integrated SC can be considered as a business ecosystem with specific governance model and defined roles for each partner. Klumpp and Zijm (2019) have emphasized the importance of empowering the human work force in the SC during the process of digitalization. The characteristics of Industry 4.0 like customer-centric, proactive, automated, transparent and interconnected needs to be addressed.

2.8. An overview of supply chain digitalization in Indian Space Research Organization (ISRO) context

The supply chain for the space industry could support its inspirational plan for interplanetary explorations and other research activities. The initiatives by the Government of India especially with respect to Indian Space Research Organization (ISRO) in enhancing the national capability by unlocking India's potential in the space sector is one of the core areas to be considered. The supply chain partnerships and opening up of the space sector for participation of private industry demands enhancement in the supply chain capability The application of digital technologies in the space sector through effective research and development brings in innovation across the supply chain activities in the space sector. The enhanced number of launches and opening up of the space sector indicates a much higher demand for effective logistics and supply chain management in the space sector. It helps in the use of advanced supply chain technology to achieve the best and to harvest the undiscovered.

2.8.1 Digitalization of space supply chains in global context

The global competition and advancements in space technology and businesses offers significant potential for the supply chain partners in the space industry in India. In the United States, the public fund is utilized mainly for rating more on ambitious exploration, space militarization and climate change, whereas the private industries are growing in other areas in the space business. Even the countries with less well-established space programs are venturing into developing and launching satellites and launch services. Hence, based on the space sector reforms in India, Indian firms have the opportunity to explore the businesses and emerge as successful players globally in gaining national achievement by utilizing digital technology and services. It also helps the businesses to capture the international market and widen its revenue streams.

The space transportation and allied activities involved in the supply chain is a complex task. The challenges faced during the pandemic in the supply chain space sector, especially in the satellite industry can be managed with the application of digital technologies. The global nature of satellite industry and application of technology connects the people and supply chain partners. The application of digital technology in the supply chain in the space sector enables remote installation in pandemic conditions. The COVID-19 pandemic situation has necessitated the requirement of online support and guidance in various space related activities. The complex remote systems were provided with real time installation and support guidance, using equipment set up in the labs, which mimics the set up at the remote place. Hence, it is high time for ISRO to also focus on digital transformation of satellite design, manufacturing and other related services to become more competitive in the global scenario.

2.8.2. Supply chain digitalization in ISRO

The involvement of private giants in the space sector will boost the manufacturing and services operations for space related programs by contributing to the innovation of related technologies. The reuse of components in the launch services highlights the significance of the streamlining various inbound and outbound logistics operations. Thus the supply chain and operations management and application of digital technology can be used in supply of materials including supply of food, travel of humans to work in space, requirement of fuel to support the renewable energy sources, spare parts, supply of oxygen to support the life and other life support activities required during the mission. Effective space logistics and supply chain management activities will be realized in effective delivery.

2.8.3. Scope of digitalization in space supply chain

The space based supply chain is the largest supply chain network which delivers humans and technology to outer space with high operational cost and risk. The application of digital technologies in the space supply chain makes the supply chain for space exploration sustainable. It facilitates inter planetary resource utilization accessible to earth by providing new sources. This necessitates the requirement of working on space-earth supply chain technology concepts, which makes it sustainable space exploration. The level of competition can be enhanced through application of new technology, scientific research, human capital and creating new supply chains and logistics for effectively delivering the material.

The opening up of Indian space sector will witness improvements in the space industry with the participation of diverse supply chain partners. It adds value to the supply chain network by creating an innovative atmosphere in the research and development supply chain, its management and evolving new supply chain technology. The trade study conducted by Dassault systems in partnership with the global space market places at search found out that there are significant opportunities for new space sector participants for realising end-to-end satellites and launch vehicles. Even though digitalization was identified as one of the key drivers for commercial success in Indian space sector, the Indian companies are lagging in adoption of digital technologies. Further an interconnected development ecosystem and manufacturing work flow is essential for realizing the business opportunities offered by the changed Indian space sector.

The adoption of digital technologies assists in managing the extended supply chain wherein various different space-grade, radiation hardened components are produced by the manufacturers spread across the world. The management of supply chain on a real time basis by keeping track of the product level data, logistical information and documentation resulting in gaining more benefits can be done with the help of digital technologies.

Digital technology can also be used in the designing and manufacturing phase wherein the engineering workflows can be managed digitally from the development stage of design, engineering and to automated testing procedures. Literature reveals that there is immense scope for growth in the space sector business by harnessing digital tools resulting in creating connected and integrated approach for developing space technology. The firm can reach the next level of growth through transition from the part of industry's manufacturing back bone to creating proprietary technologies. The supply chain partners in the space sector require a business platform that integrates various departments and information by providing digital capabilities to enhance design and manufacturing of satellites and launch vehicles, utilizing advanced simulation capabilities as well. The firms in Indian space sector can become competitive by reducing the gap between the real and virtual world. The abundant young talent, required provisions and the evolving infrastructure availability in India added along with the supply chain digitalization makes Indian space sector as a global leader in the space arena.

The design, engineering, development and testing is one of the major aspects of the space supply chain. The application of advanced virtual simulation capabilities and its integration with product development lifecycle, i.e. from the in-orbit operations and eventual de-orbiting will accelerate the time to market new innovations. The simulation capabilities allow companies to improve testing and validation of new space technologies and configurations. All these advancements through supply chain digitalization will be very crucial in enabling the Indian companies to expand the manufacturing expertise and creating proprietary systems and sub-systems for space programmes.

The SCD process in the space sector could be a real asset for the foreign firms willing to engage in Indian space sector business as well as for the Indian companies to explore the global business opportunities by figuring their own position in the global space supply chain. Digitalization assists in the development of new products and services. These technologies can be applied in all the activities starting from product development to manufacturing. The recent developments in the space sector and opening up of business opportunities to private sectors enable the companies to use digital technologies in the activities for development of new products and services. The application of digital technologies leads to development of business platforms which shortens the lead time for realization of rockets, satellite development and production.

The business platform developed enables integration of various departments and supply chain partners resulting in real time sharing of information. It ensures reliability and quality of very high standards and enhances design and manufacturing. The data available from the previous projects can be used to create appropriate business platforms while designing rockets and satellites. The stakeholders concerned can collaborate in design development on a real time basis resulting in development of innovative and sustainable products. Digital technologies can also be used in simulation, testing and validation processes. The advanced virtual simulation of complex space systems reduces launch and quality risks, as it can be assessed earlier, resulting in gaining agility and significant competitive advantage. The virtual twin of the products, services and physical operations can be applied to assess the impact of various decisions before final implementation of any changes or plans. It is found that there is enough scope and opportunity for application of digital technologies in the Indian space ecosystem. The wider level of application of digital technologies results in development and support of intellectual property for innovative products and services addressing the requirements of various stakeholders globally.

Supply chain digitalization allows the companies to share information across the supply chain safely by ensuring transparency. The emergence of companies from new regions across the globe to capture the Indian space business market can be facilitated with the application of digital technologies. The requirements of interplanetary explorations and delivery of supplies for the mission enhances the scope and roles of operations and supply chain management industry. The initiative made by NASA in releasing a request for proposal for seeking innovative ideas to transport, store and handle supplies by developing a deep space supply chain reveals the significance and wide scope for further research and development in the area of space supply chains. Thus innovations in the space supply chain with the application of digital technologies in the traditional supply chains and use of research and development activities to enhance the businesses ensures development of technically viable and competent space supply chains.

2.9 Research streams on SCD

The topic of digitalization of SC by using advanced information and communication technology (ICT) tools has become one of vital topics in recent times. The process of digitalization involves adoption of digital technologies such as machine learning, internet of things (IoT), big data, block chain, etc., for enhancing operational and SC performance. Digitalization has turned out to be vital for enterprises to integrate its SC effectively by devising suitable strategies. A digitally integrated SC will help in timely exchange of information across SC partners resulting in cost reductions and gaining better manufacturing efficiency. The need to be responsive and innovative has made SCM a critical topic for research (Ayoub et al., 2017). SCD adopting Enterprise and Inter-Enterprise Information Systems (EIIS) has become vital in the modern industrial world. Effective digitalization of SC using IT assists the enterprises to enhance its market share and profit. However, the desired results from the digitalization process could not be achieved due to the existence of various types of EIIS barriers.

Based on the detailed literature review, we propose future research directions to generate innovative knowledge and theories in SCD. It is noted that there is limited research in the area of implementation and operational dimensions of SCD and this study tries to fill this gap in the literature. This study assumes importance in the digital era and would be helpful for effective SCD in dynamic environments. Lots of challenges involved while adoption of digital technologies and thus this study has focused on understanding and implementation and operational dimensions affecting the process of digitalization. From a practical point of view, the findings from the study can help practicing managers to effectively digitalize the SC. Further, results of this research add knowledge to the literature and may help academicians and researchers in the field.

The application and use of advanced technologies have allowed companies to gain competitive advantages (Buyukozkan and Gocer, 2018). The impact of digital revolution in SC due to emerging technologies is transforming the SC rapidly (Ben-Daya et al., 2019).

Traditional SC is considered as a rigid mechanism in which the SC process is handled independently by different trading partners. Digitalization allows integration of data and information from various sources facilitating various functions of the SC process (Mussomeli et al., 2016). An effectively digitalized SC will help in timely exchange of information across SC partners, resulting in cost reduction and better manufacturing efficiency.

The dominant and significant technological area for research in the context of Industry 4.0 is DT (Uhlemann et al., 2017b). DT creates a virtual model of the physical asset by using advanced digital technologies including IoT sensors. Strategic and operational decisions can be taken based on the data gathered by DT (Negri et al., 2017). An actionable DT was initially developed by NASA in 2011 to foresee the structural behaviours of aircrafts by simulating and analysing the digital models (Lu et al., 2020). The management of SCs has gained significance in the recent period due to Covid-19 pandemic and disruptions occurred in SCs. The involvement of multiple partners and activities in the SCs has made management of SCs even more complex.

2.10 Research gaps arising out of literature review

The literature review on DSC denotes a gap between theoretical studies and its practical applications. The benefits reaped from the digitalization process are an encouraging sign for the firms who are willing to proceed with SCD. However, from the literature, it is noted that the gap between the industries that adopted most advanced technologies for SCD compared to the industries which are yet to adopt digitalization is growing. It is seen that industries, especially in the manufacturing sector are lagging during the pilot phase of digitalization. Thus, for effective digitalization and to achieve proper return on investments, a roadmap for SCD has to be planned. This study tries to fill the gap in the existing theory of SCD, being an emerging topic in SC.

Researches pertaining to implementation and decision making process with respect to DSC are very limited. The scope for further research in the area of how knowledge management and digitization influences SC digital performance was also highlighted (Schniederjans et al., 2020). The current era leads to the digital and autonomous world and SCI through digitalization which forms the core area of SC. The existing studies are generic in nature without focusing on a particular industry. Research on various challenges and factors, interrelationships among the factors, framework and model for SCD are not duly found in literature for the electronics industry, particularly in the case of the Indian context. Hence, more insights and research to understand them could lead to better management of the electronics SC. SCD using advanced technologies while compared with the conventional SC managements differs drastically on account of management of knowledge, information and emerging technologies. From the literature, it is found that the area of SCI through digitalization is a less explored area.

The studies on SCD examine the extent of digitalization and also asserts that SCD focused primarily on integration of information technology, automation and usage of data rather than concentrating on a comprehensive approach for SCD. It leads to the fact that there is still scope for further studies on SCD.

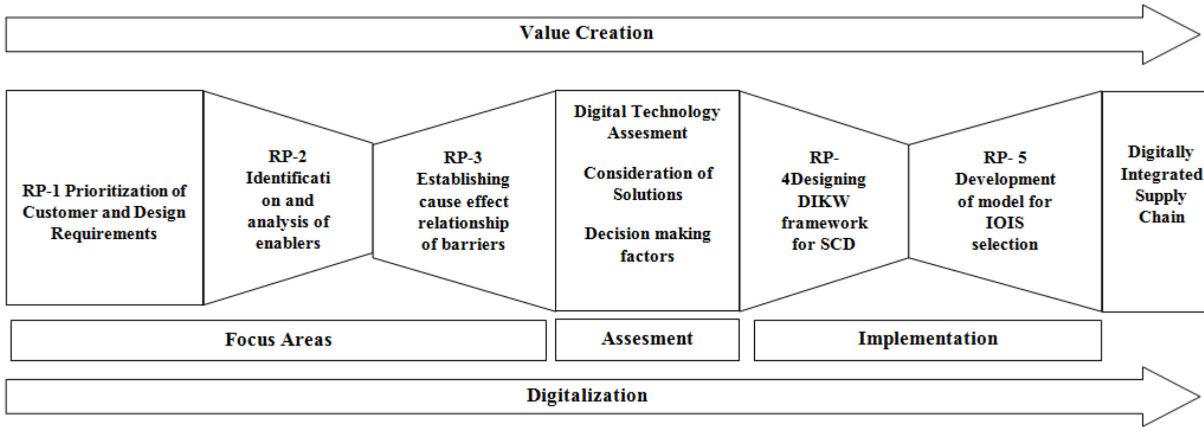


Figure 2.5: Integrated conceptual framework of the thesis.

Literature reveals various ways and approaches for assessing the possibilities of DSC, whereas, little research has been done on developing a framework by considering the customer requirements (CRs) and design requirements (DRs) for SCD. Based on the advent of advanced technologies and its practical implications, this study has great relevance in the digital era. Hence, identifying the key CRs and DRs, its interrelationship and prioritizing the requirements would facilitate successful digitalization of SC. The process of adoption of digitalization in SC affects various functional areas like quality, maintenance, inventory management, production planning, etc. The decision on SCD should be taken considering factors like availability of advanced digital technologies, various requirements, its impact and willingness of SC partners to adopt such technologies. Hence, a study on the prioritization of CRs and DRs is much necessitated, as the organizations are competing to transform by adopting DSC, which is considered as the *first* research problem (RP 1).

The role and process of digitalization in SC is yet to be fully explored through proper understanding of the SCD process. The existing studies on integration of SC through digitalization are generic in nature without focusing on a particular industry. The existing literature also lacks study on SCD and identification of key enablers and its prioritization for effective integration. Hence, more insights and research to understand the enablers influencing SCD deserves attention. In order to integrate the SC effectively through digitalization, a study on analysis of the key enablers affecting integration process is necessitated. This gap has motivated us to conduct a study in this area with specific emphasis to electronics SC which is considered as the *second* research problem (RP 2). It provides guidance to the professionals and managers in the field of SC by providing insights for effective integration of the SC through digitalization. The research also addresses the relevance of considering the key enablers for SCD with respect to an electronics SC, which have not been considered in earlier research.

The competition among firms and the globalized business scenario has motivated the firms to gain competitive advantage through digitalization. Research done in the area of implementation of IT in SC is not exhaustive. While proceeding with digitalization, organizations face various types of challenges both internally and externally. As the benefits of SCD outweigh the investments required in infrastructure, the key barriers affecting the process of digitalization needs to be addressed effectively. Organizations can gain much better benefits through SCD by addressing the barriers effectively. Majority of the literature on SCD has been widely disorganized without much importance on the identification and analysis of key barriers affecting the process of digitalization. In order to digitalize SCs effectively, a study on the analysis of major barriers affecting the digitalization process is necessitated, which is considered as the *third* research problem (RP 3). The digitalization barriers and the interrelationships considered in the study were not given due attention by researchers and practitioners.

The current era leads to the digital and autonomous world and SCI through digitalization which forms the core area of SC. SCI using advanced technologies while compared with the conventional SCM differs drastically on account of management of knowledge, information and emerging technologies. The available literature on the topic consists of a variety of conceptual frameworks (Kritzinger et al., 2018) without addressing the key driving factors and challenges affecting the transformation process. Further, a detailed methodology based on concrete theoretical background is also not found. A specific model on account of advancement of IT tools and its application in the SC for decision making for SCD is also not found in literature (Teniwut et al., 2020). This research proposes a framework for SCD by classifying the DMFs based on Data -Information-Knowledge –Wisdom (DIKW) hierarchy. Thus, this research tries to fill the gap in the existing theory of SCI through digitalization, being an emerging topic by developing a framework and identifying the key DMFs, which is considered as the *fourth* problem (RP 4).

Further, the advancement in technologies can be utilised to its fullest potential only through an efficient model for decision making in digitalization. Thus, the real solution lies in developing and implementing a model that could help managers for an effective decision making process. From the literature, it is found that even though there are papers on digitalization, a model for SCI by using IOIS is rarely found. The field of transition of SC processes to digitalization is still in its infancy. Hence, there is a need to find out the theoretical gaps, its conceptualization and development of a model for IOIS adoption in SC. There exists a limited knowledge on the decision making methodology for SCI using IOIS. It also denotes a gap in literature due to increased complexity in SC network and its management which demands further investigation by researchers in IOIS adoption and model development, which is considered as the *fifth* research problem (RP 5). A study on this aspect will contribute to the theoretical knowledge and its practical applications in SC

Thus, this research seems to be significant in the era of SCD as it considers the customer requirements and design requirements, enablers, barriers, developing a framework and IOIS selection model by contributing to the theory of digitalization of SC. This research tries to address the concerns of the scholars and decision makers due to the uncertainties in SCD. The research gaps identified have motivated us to conduct studies with specific emphasis to electronics SC. An electronics firm is considered due to the vast potential for growth and acceptance of the products. The firm can tap full market potential by devising suitable strategies to strengthen the SC using advanced digital technologies at various functional levels which helps in effective planning and production.

This research provides guidance to the professionals and managers in the field of SC by providing insights for effective SCD. The research also addresses various issues for SCD with respect to an electronics SC, which have not been considered in earlier research. This study tries to bring out a theoretical background of the process of digitalisation in SC for its practical implementation and integration of the process. The research further addresses what organisations have to consider for the process of digitalisation facilitating overall performance improvement of the SC. Thus a detailed study on the research gaps identified in the area of SCD is noteworthy to provide insights to practitioners and academicians to improve firm's performance through effective digitalization. The details of the *first* research problem addressed, related literature, methodology and the case evaluation are discussed in Chapter 3.

CHAPTER 3

PRIORITIZATION OF CUSTOMER AND DESIGN REQUIREMENTS FOR SUPPLY CHAIN DIGITALIZATION

3.1 CR and DRs for SCD

SCD can be done productively by considering SC requirements and adopting suitable implementation procedures. In order to effectively integrate SC, this research tries to analyse various CRs and DRs affecting the digitalization process. Literature review has identified various factors of SCI as collaborative planning (Barratt, 2004); competitive capability (Kim, 2009);long-term relationship (Prajogo and Olhager, 2012); dependence and trust with customer and supplier (Zhang and Huo, 2013); SC planning and trust (Laureano Paiva et al., 2014); SC relationship (Wu et al., 2016); shared IT infrastructure (Bernon et al., 2013); technology adoption (Tseng and Liao, 2015); inter-organizational communications (Jacobs et al., 2016) and people involvement (Pradabwong et al., 2017).

Ghosh et al., (2019) have investigated the practices and policies that are unique to high-tech manufacturing start-ups in emerging economies and related technologies through Industry 4.0. The three constructs affecting performance and competitiveness of high-tech manufacturing firms are upstream operations issues, production-based issues and downstream operations issues. Kumar et al., (2020b) have studied the role of ICT in agri-food SC and impact on SCM practices on firm's performance. It is found that ICT and SCM practices are significantly related. Further, SCM practices like information sharing, supplier relationship and logistics integration have a significant and positive impact on organization's performance.

Literature reveals that no prior works found for identifying CRs and DRs influencing the process of SCI through digitalization. Studies on identifying the requirements of SCD in the context of electronics SC have also not received due attention. As the role of digitalization in SC is yet to be fully explored, proper understanding of the process of SCD is necessitated. Hence, more insights and research to understand the CRs and DRs to be considered for SCD merits attention. The key CRs and DRs were identified and shortlisted based on existing literature and in consultation with three experts in the industry and one expert from academia.

Details of abbreviations used in the study are given in Appendix A. Some of the recent studies highlighting the core area in SCD are given in Table 3.1.

Table 3.1: Literature Review on SCD

Sl.No	Author & Year	Area of study	Remarks
1	Feibert et al., 2017	Digitalization in shipping SC	Integrated digitalization and business process management perspective for enhancing SCP in shipping companies.
2	Kersten et al., 2018	DSC	New Business ecosystems create challenges for all partners and developed a road map for digital SC.
3	Buyukozkan et al., 2018	DSC	Review of DSC and identified its key limitations and prospects of future researches in this area.
4	Hein et al., 2019	Digital products and services	Technology management, economics and information systems has different perspective on digital platform ecosystems.
5	Sundaram et al., 2020	Digital transformation business models	Studied the need for incorporating digital transformations in business models.
6	Nasiri et al., 2020	Performance in DSC	Smart technologies mediation between digital transformation and relationship performance.
7	Marmolejo-Saucedo and Hartmann, 2020	DSC	Studied the evolution of SC in digital context of operational functions.
8	Hennelly et al., 2020	DSC	Production digitalization and its role in performance improvement in SC.

3.2 ANP and QFD in Supply Chain Management

Quality Function Deployment (QFD) is a quantitative tool that can be used to translate CRs into DRs. The dynamic and diversified requirements of customers' needs to be addressed actively. Customers get utmost value for money, if the CRs are considered. Organizations are adopting QFD to consider the CRs called voice of customer, while designing products and services. The advantages of identifying requirements or expectations prior to design and manufacture results in meeting customer demands to the maximum possible extent. QFD method helps in realistically communicating the requirements of customers at each production level, starting from marketing, design, quality, manufacturing, sales, after sales service, etc.

The Analytic Network Process (ANP) is a multi-criteria decision making (MCDM) methodology that considers the interdependence among various alternatives and criteria. It helps in transforming the qualitative judgment of decision makers into quantitative values. ANP differs from the Analytical Hierarchy Process (AHP) wherein the later deploys a hierarchical relationship among the criteria, whereas the former enables to identify the interrelationships among the clusters and its elements.

Researchers have applied the QFD method in a number of areas. Karsak et al., (2002) have used a combination of ANP and zero one goal programming approach in determining technical requirements for designing the product. The requirements of SMEs in SC planning has been addressed through a hybrid QFD, Interpretive Structural Modeling (ISM), Zero one goal programming and ANP approach (Thakkar et al., 2011). Morteza (2013) has addressed SCM design using QFD and ANP approaches. Chang et al., (2019) have used a combination of ANP and QFD methodologies for mitigation of bullwhip effect by deploying agility in SC.

3.3 The proposed ANP-QFD Methodology

3.3.1 Analytic Network Process

ANP method is used in this study as it is feasible for modelling within complex situations and relations. An advantage of ANP is that it considers all relations and interactions among different levels of decision making and it also creates a network structure (Saaty, 2004). It also determines the relative importance of criteria and prioritizes alternatives that are available with decision makers. ANP method is effective in real world case applications when decision criteria and alternatives are interdependent. It can be applied to find out solutions for real world problems considering tangible as well as intangible criteria.

3.3.2 QFD

Quality Function Deployment (QFD) is a quantitative tool that can be used to translate CRs into DRs. In reality, the demand and requirements of the customers are dynamic and diversified in nature and these need to be addressed effectively. In order to gain competitive advantage, CRs have to be considered prior to launching products. QFD is a tool that organizations are adopting to consider the requirements of customers called as the voice of the customer (VoC) while designing products and services. The advantage of having the requirements or expectations prior to designing and manufacturing helps them in meeting customer demands as close as possible. QFD has been successfully applied in service sectors like hotels and airline (Zawati and Dweiri, 2016), e-commerce sector (Waterworth and Eldridge, 2010), e-banking (Shahin et al., 2016), web interface (Hamilton and Selen, 2004) and construction sector (Gilbert –III et al., 2016, Moghimi et al., 2017).

QFD method helps in effectively communicating the CRs at each level of production process initiating from the design, manufacturing, quality, marketing, sales and after sales service. The key benefits of adopting the QFD method are as follows.

(a) Focus on Customer: Focus on customers is given utmost importance in QFD. Organizations are considering the perceived demands and CRs rather than producing and marketing the products which they feel the customer wants.

(b) Voice of Customer: QFD process involves comparing competitive products in order to design a product that meets the voice of the customer. The voice of customers is transformed into technical requirements which provide valuable insights in product development and in rendering service.

(c) Less development time and cost: Adoption of the QFD tool results in reducing development time and cost. This is because development of the product is done based on the CRs. A well-tailored QFD methodology helps in effectively using the resources for development of better products and services.

(d) Structure and Documentation: QFD method provides a well-structured documentation of data collected that helps in product development and decision making process.

3.3.3 Proposed QFD based integrated SCM framework

The procedure of adoption and digitalization through QFD has many benefits (Murali et al., 2016). It expedites the design process and brings breakthrough innovation (Vinodh et al., 2008). It also reduces cost, design and rework changes and failure risks (Gonzalez et al., 2004). Application of QFD augments overall operational performance of the firm by meeting the CRs and DRs influencing the process of digitalization. QFD assumes the linear relationships between the CRs and DRs which are considered as an abridged version of reality. QFD method aggregates both quantitative and qualitative data. The QFD process could be improved by integrating quantitative techniques like Analytical Hierarchy Process (AHP) to minimize subjective weakness (Dai and Blackhurst, 2012). A diagrammatic representation of the House of Quality construction using QFD method is shown in Figure 3.1.

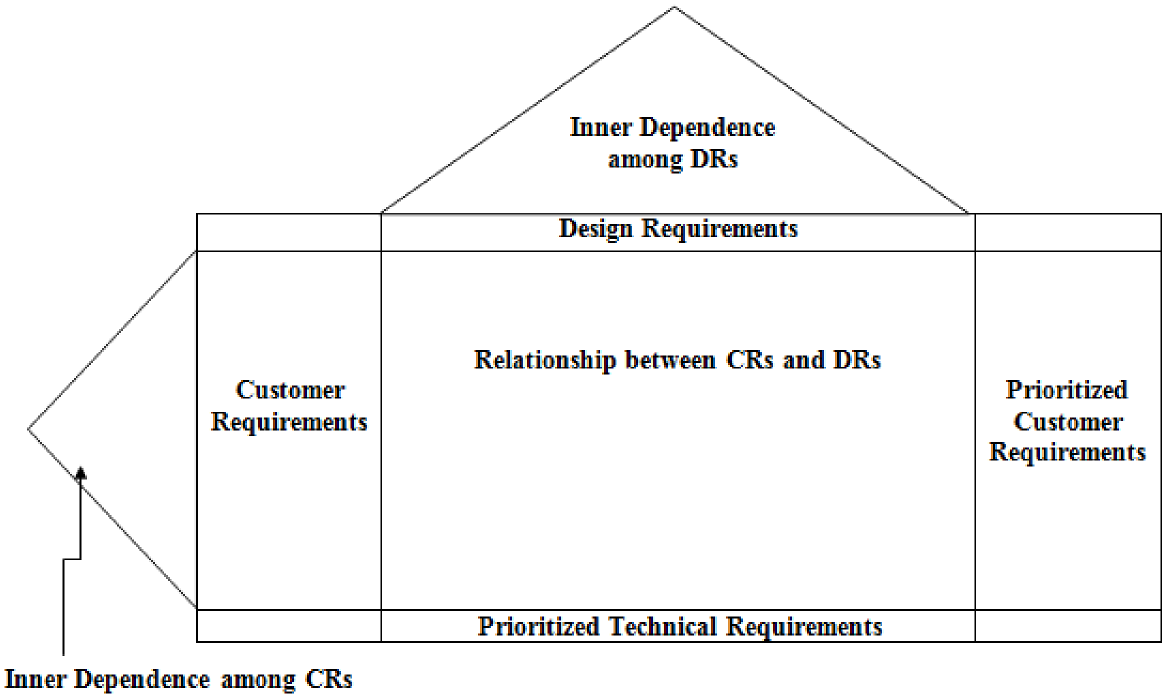


Figure 3.1: The House of Quality

3.4 Integrated ANP approach in QFD

The Analytic Network Process (ANP) is a multi-criteria decision making (MCDM) process that considers the interdependence among various alternatives and criteria. Further, it helps in transforming the qualitative judgment of decision makers into quantitative values. Chang et al., (2019) have used a combination of QFD-ANP approaches to determine the vital agility factors for mitigating the bullwhip effect. The integrated QFD-AHP method through pairwise comparison helps in overcoming disadvantages and reduces the subjectivity bias of decision makers (Kwong and Bai, 2003). QFD–ANP method used in this study helps to outline and relate CRs and DRs for SCD. The activities can be planned effectively by prioritizing the requirements for effective decision making.

3.4.1 Steps to be followed in the proposed ANP-QFD Framework

The steps in the proposed framework for making the HOQ is given in Figure 3.2.

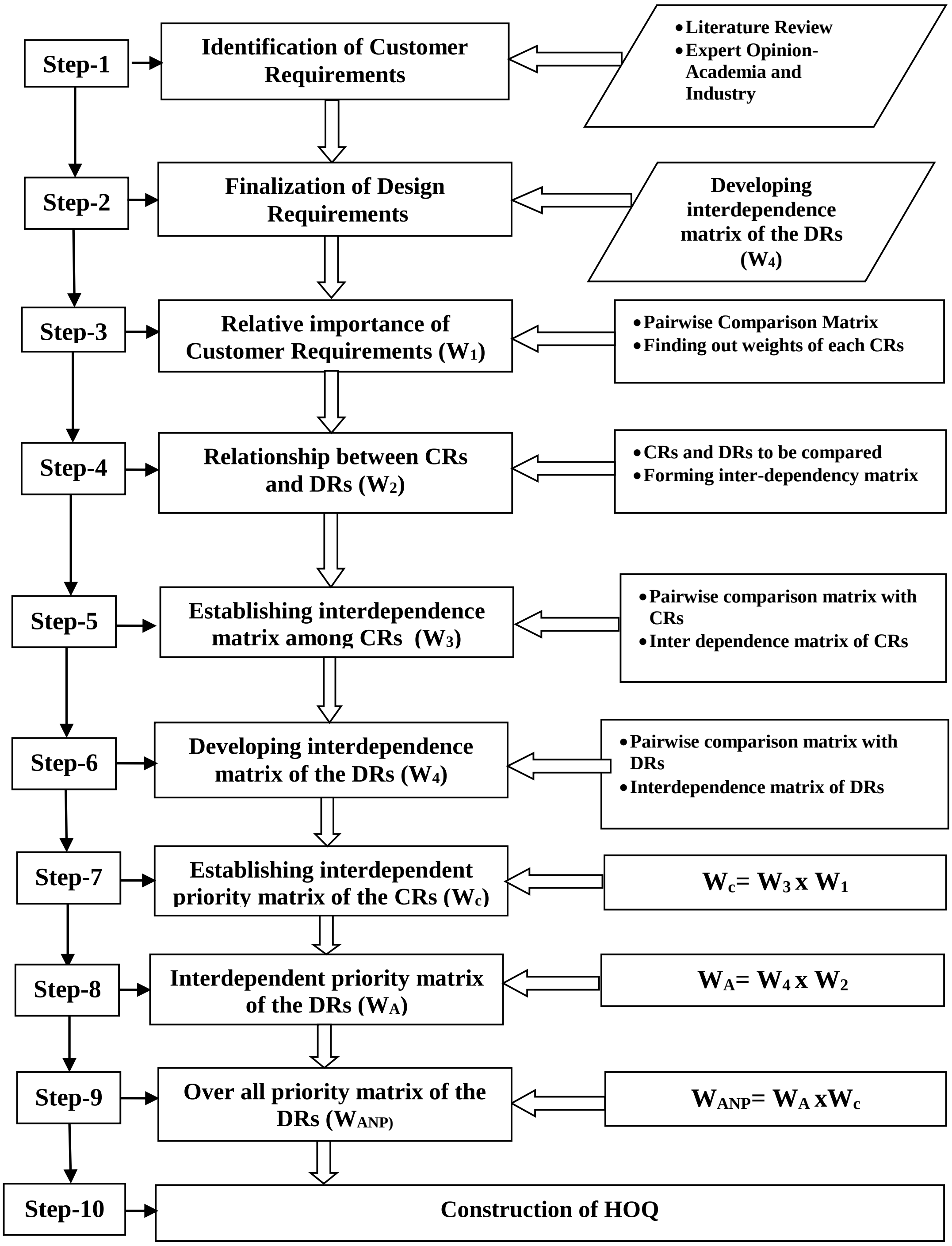


Figure 3.2: Steps in the proposed Framework for completing HOQ

3.4.2 Completing HOQ

A HOQ which relates CRs and DRs can be constructed using the QFD method. HOQ reflects the prioritization of CRs and DRs so as to meet perceived requirements of the organization contemplated in this study. A four phase model of building a HOQ that conveys the voice of customer (WHATs) to design modifications (HOWs) and in meeting customer expectations needs to be developed. The priority of CRs and DRs are determined by formulating the super matrix of HOQ network model which consists of following steps (Buyukozkan and Berkol, 2011):

Step 1. Identification of CRs: The CRs are identified from literature review and shortlisted based on opinion of experts in industry and academia through brainstorming sessions.

Step 2. Finalization of DRs: The DRs are finalized by considering the CRs identified in Step 1 above, through brainstorming sessions with the experts in the electronics industry.

Step 3. Relative importance of CRs (W_1): The relative importance of CRs is found out by framing a pair wise comparison matrix among the CRs.

Step 4. Relationship between CRs and DRs(W_2): In order to develop a HOQ, CRs and DRs are compared and their relative importance are established by forming an inter-dependency matrix.

Step 5. Establishing inner dependence matrix among CRs (W_3): The CRs identified may have inner dependence and may support or affect the achievement of other CRs. The inner dependence matrix of the CRs is constructed by a pair-wise comparison matrix within CRs.

Step 6. Developing inner dependence matrix among DRs (W_4): The inner dependence matrix of DRs is established by constructing a pair-wise comparison matrix within the DRs which forms the roof of HOQ called correlation matrix.

Step 7. Establish inter dependent priority matrix of CRs (Wc): The interdependent priority matrix of the CRs is obtained by using the following relation, $W_C = W_3 * W_1$.

Step 8.* Establish inter dependent pri*ority matrix among DRs (W_A): The interdependent priority matrix of DRs is obtained by using the relation, $W_A = W_4 * W_2$

***Step 9. Finding out the overall priority of DRs*:** The overall priorities of DRs, reflecting the interrelationships within HOQ, are obtained by using the relation, $W_{ANP} = W_A * W_C$.

3.5. Illustration of Proposed Methodology to an Electronic Company

The methodology proposed in this study is applied in the SC of an XYZ company in electronics industry, which is dealing with consumer electronics having an annual turnover of INR 128 billion. The CRs and DRs for the XYZ company is finalised based on literature review and in consultation with experts in the company and academia. The experts identified were chosen based on case study methodology adopted by Bouzon et al., (2018) and Seker et al., (2017). These experts consulted were senior managers who are having an industrial experience of over 25 years in the electronics industry responsible for Information Technology, Product Life Cycle Management and Operations Management in the firm. The academic expert was an Associate Professor in a reputed University engaged in research for over twenty years in various areas of Operations and SCM. He was also associated with many industrial consultancies related to automation of SC projects. All these experts in the study were quite experienced and familiar with digital transformations of SCs happening in electronic industries. All these experts were asked to evaluate the CRs and DRs based on their knowledge in the industry and experience.

As the methodology involves construction of matrices for pairwise comparison for each CR and DR, only a limited number of matrices for pairwise comparison of CRs and DRs are shown. However, the detailed methodology for calculating the pairwise comparison matrices for each CRs and DRs is explained. The step by step procedure of application of methodology is mentioned as follows.

***Step 1*: Identification of CRs**

In order to build a HOQ, the first step is to identify CRs. In this study, CRs were identified from literature review and refined based on the opinion from experts in electronics industry and academia.

The CRs are identified based on various studies in the area of integration of SC using information systems. Accordingly, the case company identified nine major CRs as follows: (i) Cost, (ii)Quality, (iii)Flexibility, (iv)Data Privacy, (v)Responsiveness, (vi)Functional Fit to the System, (vii)Vendor Reputation, (viii) After Sales Service and (ix)Ergonomic design. Details of CRs identified and the relevant literature are given in Table 3.2.

3.6. Definitions of CRs

3.6.1 Cost (CR1, CST): Cost analysis is pertinent to find out the impact of processes costs in SC. The available resources of the SC should be used in the most efficient way to provide competitive goods and services. The overall cost in SC can be reduced by adopting innovative IT tools (Lapinskaite et al., 2014; Wronka, 2016). Assessing the production and distribution costs enables the management to determine the products which are viable and cost effective. Thus, understanding the costs involved in SC has a significant role in improving a company's profit and its viability.

Table 3.2: CR for SCI through Digitalization

Ref No.	Ref. Code	Customer Requirements	Relevant Literature	Remarks
CR1	CST	Cost	Lapinskaite et al., 2014; Wronka, 2016	Overall cost can be reduced by adopting innovative methods
CR2	QLT	Quality	Kushwaha et al., 2010; Sharma et al., 2012	Improving quality results in better resource utilization and process efficiency
CR3	FLX	Flexibility	Stevenson et al., 2009; Palandeng et al., 2018	Ability to respond quickly to rapid changes
CR 4	DPY	Data Privacy	Kolluru et al., 2001; Ulhaq et al., 2016	Data privacy is required for obtaining trust among supply partners.
CR 5	RSP	Responsiveness	Hayat et al., 2012; Sinha et al., 2015	Responsiveness is the ability to understand market situations and adapt to CRs
CR 6	FFS	Functional Fit to the System	Marinagi et al., 2014; Aithal, 2016	Aligning functions to achieve the organizational goals.
CR 7	VNR	Vendor Reputation	Haridasan et al., 2018; Yadavalli et al., 2019	Helps in achieving SC objectives.
CR 8	AFS	After Sales Service	Gaiardelli et al., 2007; Gilaninia et al., 2012	Vendor reputation retains customers and increases business volume.
CR 9	ERD	Ergonomic Design	Farooq and Grudin, 2016, Zunjic et al., 2018; Wei et al., 2019	Designing and effective implementation using digital technologies

3.6.2 Quality (CR2, QLT): One of the most important factors to be considered by the companies in their relationship between suppliers and customers is quality. Improving the quality of all SC processes results in (i) reduced costs (ii) better resource utilization and increased process efficiency. Firms can gain competitive advantage by providing innovative products and services at better price, quality and on time supply (Kushwaha et al., 2010; Sharma et al., 2012). Firm's performance can be evaluated through financial and operational performance. Thus, there is a direct and positive relationship between quality and SCM. Based on the dynamic changes that are happening in the SC, quality concept and its implication is gaining relevance. Firms need to adhere to quality policy that meets the CRs and standards for manufacture of products.

3.6.3 Flexibility (CR3, FLX): Flexibility in SC means the potential of the firm to improve efficiency and performance by quickly responding to the rapid changes. A firm's performance depends upon the flexibility dimensions among SC partners (Stevenson et al., 2009; Palandeng et al., 2018). Flexibility is strategically important to SC as it includes operational flexibility, resource flexibility and demand flexibility. The specific inter-firm practices used to achieve flexibility and how these affect SC is of greater significance.

3.6.4 Data Privacy (CR4, DPY): The dimensions of power distance, uncertainty avoidance and collectivism actively support information protection practices in SCM. Protection of data is necessary while it is transmitted across SC partners and privacy should be ensured. Organizations should evolve strategies and procedures to improve security and privacy of information transmitted across the SC (Kolluru et al., 2001; Ulhaq et al., 2016).

3.6.5 Responsiveness (CR5, RSP):SC responsiveness refers to how rapidly an organization can understand the market situations and adapt to CRs. IT plays a major role in gathering and transmitting information across the SC, which enhances SC responsiveness. Top management plays a major role in ensuring SC responsiveness, as it involves financial investment (Mehrjerdi, 2009; Hayat et al., 2012). Proper planning in SC activities enables the SC to be more responsive and efficient. Responsive SC ensures meeting customer demands and requirements on time.

3.6.6 Functional Fit to the System (CR6, FFS): Functional fit to the system is the process of aligning the functions of an organization in achieving organizational goals. This attribute is necessary is to ensure that the customer demands are met to avoid uncertainty, if any. Achieving functional fit to the system ensures trust and mutual co-operation among internal and external SC partners. Maintaining functional fit to the system ensures accurate forecast of the demand and supply, availability of resources, proper designing of SC, alignment of goals resulting in achieving the overall objectives of organization (Gurumurthy et al., 2013).

3.6.7 Vendor Reputation (CR7, VNR): The vendors participating in SC play an important role in achieving SC objectives (Hemalatha et al., 2015; Mani et al., 2018). Continuous improvement and development of vendors to meet the requirements of the firm helps in(i) reducing wastages, (ii) improving quality and (iii) reducing lead time. Reputation of a vendor depends upon the technical competence, financial soundness, production capacity etc.

3.6.8 *After Sales Service (CR8, AFS):* Customer satisfaction and retention of customers depends upon after sales service indices provided by the firm viz. product delivery, installation and warranty. In the case of an electronics industry, income earned from repairs and maintenance accounts for a major share in the overall turnover of the company. Providing proper after sales service will help in retaining customers and increasing business volume. The feedback received from customers can be used in developing improved products with better quality that suits CRs (Kumar, 2012; Gilaninia et al., 2012). Coordination between suppliers and customers are required for managing SC effectively through proper communication and information sharing. Monitoring of after sales service can be met by identifying proper service performance criteria and frequent auditing so as to make corrective measures for providing better service.

3.6.9 *Ergonomic Design (CR9, ERD):* Ergonomic design facilitates in achieving a unified experience through interaction between humans and machines through digital solutions (Farooq and Grudin, 2016). It helps in analyzing the opportunities that enhance the existing design through in-depth integration, resulting in realizing greater competitive advantage. Application of ergonomic principles in SC facilitates solving various problems through designing and effective implementation (Zunjic et al., 2018). Hence the segments of SC in which ergonomics can provide significant contributions should be identified for better integration (Wei et al., 2019). The application of ergonomics in SC should be a multidisciplinary approach with specific emphasis on designing information in compliance with ergonomic principles for quick absorption, understanding and effective execution.

These CRs along with relevant literature are summarized in Table 3.2. Further, the CRs identified were grouped based on the nature of functions to be performed in the SC like Transaction Execution, Collaboration and Decision Support (Auramo et al., 2005). This is illustrated in figure 3.3.

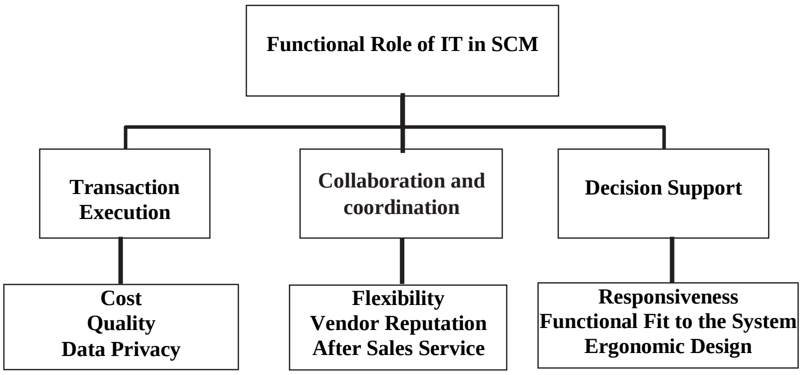


Figure 3.3: CRs for SCI through digitalization

3.7 Step 2: Finalization of DRs

The DRs were identified from literature review and finalized based on expert opinion.

Table 3.3: Design Requirement used in the study for SCI through Digitalization

Ref No.	Ref. Code	DRs	Relevant Literature	Relevance to SCD
DR1	SMS	Simplification and Standardization	Sanchez-Rodrıguez et al., (2006), Stajniak and Kolinski (2016).	Positive impact on business performance through coordination and simplifying processes.
DR2	OTS	Outsourcing	Tsay et al., (2018); Pankowska et al., (2019)	Helps to focus on core areas and bring flexibility
DR3	ITA	IT Automation	Almuiet and Salim, 2014; Kothari et al., (2018)	Results in robustness and efficiency by information exchange on real time basis
DR4	QLS	Quality Standards	Sharma et al., (2012); Gu et al.,(2017)	Adds value to products and service
DR5	PRM	Process management	Croxton et al., (2001); Lockamy III, et al., (2004)	Assists in measuring performance and continual improvements
DR6	RAD	Research and Development	ShahmariChatghieh et al., (2013), Jordan (2014)	Results in evolution of innovative methods for effective SCM
DR7	KLM	Knowledge Management	Almuiet and Salim (2014); Perez-Salazar et al., (2017)	Includes acquisition, integration, protection and dissemination of knowledge
DR8	SMC	Smart Contracts	Law (2017); Schutte et al., (2018); Hu et al.,(2019)	Reduces complexity through automated verification and execution
DR9	EIM	E-intermediation	Wollschlaeger et al., (2017); Mostafa et al., (2019)	Integrated system of physical and virtual world for communication, computing and control
DR10	AUD	Auditability	LeBaron et al., (2017); Daghfous et al., (2017)	Independent objective assurance and consulting activity to add value to improve operations
DR11	ITI	IT Integration	Marinagi et al., (2014), Samadi et al., (2016); Pachayappan (2018)	Enhances collaboration and provides timely, accurate and reliable information.
DR12	DDI	Data Driven Innovation	Padmos (2016); Spanaki et al., (2018)	Creates better value by providing reliable inputs in planning and other activities.
DR13	IVN	Intelligent Value Chain Networks	Kothari et al., (2018), Goswami et al., (2013); Hanifan et al., (2014)	Provides visibility through real time continuous synchronization
DR14	ICS	ICT security	Kolluru et al., (2001); Ulhaq et al., (2016)	Reduces risk of loss of data, misuse, fraud and tampering of data
DR15	DBA	Data and Business Analytics	Tiwari et al., (2017); Mishra et al., (2018), Spanaki et al., (2018); Roy (2018)	Quick processing of data for effective decision making and enhancing business process.
DR 16	DFM	Design for Manufacturing	Srinivasan et al., 2018; Bogers et al., 2018; Roscoe et al., 2019	Application of digital solutions and integration of product design in the production process

Sixteen major DRs identified are (i) Simplification and Standardization, (ii)Outsourcing, (iii)IT Automation, (iv) Quality Standards, (v)Process Management, (vi) Research and Development, (vii) Knowledge Management, (viii)Smart Contracts, (ix)E-intermediation, (x)Auditability, (xi)IT Integration, (xii) Data Driven Innovation, (xiii) Intelligent Value Chain Networks, (xiv)ICT Security(xv) Data and Business Analytics and (xvi) Design for Manufacturing. Details of the DRs identified and the corresponding literature are given in Table 3.3.

3.7.1 Simplification and Standardization (DR, SMS): Simplification and standardization is the process of adopting standard procedures, materials parts and process in manufacturing of product or providing service. Simplification and standardization procedure has a positive effect on business performance (Sanchez-Rodrıguez et al., 2006) as it facilitates in bulk production. It also helps in coordinating and simplifying processes among SC partners leading to overall reduction of cost and raw materials (Stajniak and Kolinski, 2016). The effects of information systems and its role in process improvements needs to be considered while proceeding with adoption of simplification and standardization process.

3.7.2 Outsourcing (DR2, OTS): Outsourcing of non-core activities to specialized third parties allows an organization to focus on its core areas. It gives flexibility in operating and maintaining SC (Tsay et al., 2018; Pankowska et al., 2019). IT outsourcing chain partners are mutually dependent due to globalization and rapid innovation in IT. Outsourcing allows firms to concentrate on a narrower range of operations and reduces the need for internal flexibility.

3.7.3 IT Automation (DR3, ITA): The process of IT automation can be centralized, distributed and agent based. The Internet has allowed collaboration among SC partners to become automated, by providing access to real-time information (Almuiet and Salim, 2014, Kothari et al., 2018). IT automation of SC results in robustness and efficiency through real time sharing of information across the SC. It helps in planning and collaboration of SC activities and enhances SC performance and efficiency.

3.7.4 Quality Standards (DR4, QLS): Quality standards are a prominent factor to be considered in the whole process of SC. The concept of total quality management should be carried out to add value in products and services (Sharma et al., 2012). Quality is one of the most important factors to be considered by suppliers and customers that enhance customer database and reputation. The areas of production, delivery and after sales services should be given due priority and monitored by using quality management tools (Gu et al., 2017).

3.7.5 Process Management (DR5, PRM): The process management includes implementation of a set of processes to enhance SC performance and efficiency. Effective process management tools can be used for measuring performance and continual improvement efforts (Croxton et al., 2001; Lockamy III et al., 2004). It includes defining the process, measuring and controlling the activities that bring consistency and richness across the organization. Gaining maturity in the process management process will result in continuous improvement and in attaining new maturity levels, i.e. from an internal perspective to an externally focused perspective that results in a higher level of process capability for a firm.

3.7.6 Research and Development (DR6, RAD): *R*&D is a competitive tool that contributes to a great extent in the success of a company. The process of R&D requires information related to specific areas in higher level of research and innovation (ShahmariChatghieh et al., 2013). R&D results in fruition of innovative methods for managing SC processes that result in better performance (Jordan, 2014).

3.7.7 Knowledge Management (DR7, KLM): Knowledge Management (KM) is one of the strategic activities in SC which includes acquisition of knowledge, integration of knowledge, its protection and dissemination. The era of globalization has necessitated the need for managing information and knowledge to survive in the highly competitive and turbulent environment. Effective knowledge management helps in identifying new trade-offs and developing new models which helps in quick decision making to gain competitive advantage (Perez-Salazar et al., 2013; Almuiet and Salim, 2014). Knowledge and information being the core areas for effective integration and coordination of SC activities, building effective tools for knowledge management will enhance the firm's capabilities.

3.7.8 Smart Contracts (DR8, SMC): *S*mart contracts are digital agreements that are written in computer code and deployed to the blockchain, where they will self-execute when predetermined conditions are met. They reduce complexity in SC through automated verification and execution of the multiple business transactions involved. It ensures that all the stakeholders have equal access to the information which can be accessed on a need base that in turn helps in building trust among the SC partners (Law 2017; Schutte et al., 2018; Hu et al., 2019). Smart contracts help in bringing in transparency, efficiency and traceability of SC activities. It also helps in evaluating the performance of the contracts on a real time basis.

3.7.9 E-intermediation (DR9, EIM): E-intermediation involves an integrated system for communication, computing and control which integrates the physical and virtual world of an organization. The development of robust communication technologies like cloud computing, mobile internet and internet of things (IoT) enables for interaction among the SC partners (Wollschlaeger et al., 2017; Mostafa et al., 2019). Applying the concepts of IoT and Industry 4.0 helps in developing smart products and services.

3.7.10 Auditability (DR10, AUD): Auditing is an independent objective assurance and consulting activity framed to add value to improve the operations in an organization. Auditing helps an organization in achieving the objectives through systematic and well planned approach to enhance the efficiency of an organization. It also assesses whether the predetermined rules and procedures were deviated from the standards set. Effective auditing adds value to the organization and stakeholders by evaluating the efficiency, economy and effectiveness of activities. The plan, policy and procedures followed in the organization should be examined (LeBaron et al., 2017; Daghfous et al., 2017).

3.7.11 IT Integration (DR11, ITI): IT Integration a critical factor to enhance the SC performance. The recent advancements in IT have provided timely, accurate and reliable information for enhancing collaboration and integration among SC partners. It has also improved agility and flexibility among firms (Sabbaghi et al., 2008). The information should be shared both upstream and downstream for improving the integration and planning related activities in SC processes (Samadi et al., 2016; Pachayappan, 2018).

3.7.12 Data Driven Innovation (DR12, DDI): ICT tools help the organizations in focusing on data driven decision making based on the real time data availability. The innovation based on the data accessed plays a significant role in transforming and enhancing SC functions. Organizations are concentrating more on developing capabilities to access and analyze the data to enhance their technical and organizational capabilities. New digital business models are increasingly more complex and companies that are able to effectively manage that complexity gains competitive advantage (Padmos, 2016). Effective data driven innovation helps in creating better value by providing reliable inputs in planning the activities of an organization (Spanaki et al.,2018).

Companies have to frame and develop data strategies and information and data management disciplines to gain full potential of SCD.

3.7.13 Intelligent Value Chain Networks (DR13, IVN): The significance of collaborative technologies makes improvements in sharing of information, trust and commitment among SC partners. It helps in coordinating activities to overcome uncertainties by providing visibility of the manufacturing process in real time through continuous synchronization between demand and supply. Analysis of the real time information through intelligent value chain networks helps in meeting the demands of customers. It also reduces manufacturing cost, which is of the top priority of SC relationships (Kothari et al., 2018; Goswami et al., 2013; Hanifan et al., 2014). SC information systems are critical for synchronizing information among SC partners in order to carry out a systematic evaluation and selection of such applications.

3.7.14 ICT security (DR14, ICS): The information that an organization communicates with its SC partners is one of the most critical assets (Kolluru et al., 2001; Ulhaq et al., 2016). The need for securing information should be made aware to all SC partners. It helps in attaining control on the information to be transmitted and accessed across the SC. Organizations should ensure security at sender and receiver level for the information transmitted over a publicly accessible medium such as the Internet. ICT security helps in reducing organizations risk of loss of data, misuse, fraud and tampering of data by providing protection from both external and internal threats.

3.7.15 Data and business Analytics (DR15, DBA): Data and business analytics are used for effectively processing different types of data for proper decision making. Data and business analytics has the potential to outperform and transform traditional SCM practices by providing better insights for improving processes, operational efficiency, cost reduction and quick decision making (Mishra et al., 2018; Tiwari et al., 2017). It also helps in enhancing the business process and methodology by analyzing the information related to various processes and partners involved in the SC (Spanaki et al., 2018; Roy, 2018).

3.7.16: Design for Manufacturing (DR 16, DFM): The process of digital transformation should consider the integration of design for manufacturing to translate the design into a final product. The application of digital solutions and integration of product design in the production process adds value. The operational capability in the digital manufacturing process needs effective management of knowledge for better performance (Roscoe et al.,2019). Consideration of design for manufacturing during digitalization process by taking into account of information required for manufacturing, usage and delivery results in effective decision making (Srinivasan et al., 2018). Further, features of products are affected due to uncertainty and designs selected for the production process (Bogers et al., 2018). Hence, design for manufacturing should be given due consideration.

3.8 Step *3*: Relative importance of CRs (W_1)

The relative importance of CRs are identified by finding out the answer to “Which CR should be given more priority while designing a digitally integrated SC and to what extent? The following eigenvector is calculated by assuming that there is no dependency among the CRs, which is obtained by doing pairwise comparison with respect to the goal of achieving the better design.

$$W_1 = \begin{pmatrix} 0.2913 \\ 0.1994 \\ 0.1478 \\ 0.1216 \\ 0.0776 \\ 0.0663 \\ 0.0337 \\ 0.0304 \\ 0.0319 \end{pmatrix} = \begin{pmatrix} \text{CR 1} & \text{CST} \\ \text{CR 2} & \text{QLT} \\ \text{CR 3} & \text{FLX} \\ \text{CR 4} & \text{DPY} \\ \text{CR 5} & \text{RSP} \\ \text{CR 6} & \text{FFS} \\ \text{CR 7} & \text{VNR} \\ \text{CR 8} & \text{AFS} \\ \text{CR 9} & \text{ERD} \end{pmatrix}$$

Table 3.4: Relative importance of the DRs for Quality

	DRs	**DR1**	**DR3**	**DR4**	**DR5**	**DR6**	**DR8**	**DR10**	**DR14**	**DR15**	**DR 16**	**Weight**
DR1	**SMS**	1.00	4.00	5.00	5.00	6.00	8.00	7.00	6.00	2.00	9.00	0.316
DR3	**ITA**	0.25	1.00	3.00	3.00	3.00	5.00	6.00	6.00	7.00	8.00	0.199
DR4	**QLS**	0.20	0.33	1.00	3.00	2.00	3.00	3.00	4.00	2.00	8.00	0.115
DR5	**PRM**	0.20	0.33	0.33	1.00	3.00	2.00	3.00	4.00	3.00	9.00	0.102
DR6	**RAD**	0.17	0.33	0.50	0.33	1.00	2.00	3.00	3.00	2.00	9.00	0.078
DR8	**SMC**	0.13	0.20	0.33	0.50	0.50	1.00	2.00	2.00	2.00	4.00	0.051
DR10	**AUD**	0.14	0.17	0.33	0.33	0.33	0.50	1.00	2.00	2.00	6.00	0.047
DR14	**ICS**	0.17	0.17	0.25	0.25	0.33	0.50	0.50	1.00	2.00	2.00	0.034
DR15	**DBA**	0.50	0.14	0.50	0.33	0.50	0.50	0.50	0.50	1.00	2.00	0.043
DR 16	**DFM**	0.11	0.13	0.13	0.11	0.11	0.25	0.17	0.50	0.50	1.00	0.016

Table 3.5: The column eigenvectors with respect to each CRs

	W_2	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
DR1	**SMS**	0.4697	0.3162	0.2687	0.2858	0.3429	0.2733	0.0000	0.3777	0.3041
DR2	**OTS**	0.2414	0.0000	0.0000	0.1386	0.1496	0.1675	0.3327	0.1721	0.1463
DR3	**ITA**	0.0000	0.1985	0.2030	0.1903	0.1429	0.1418	0.0000	0.1598	0.1282
DR4	**QLS**	0.0000	0.1150	0.0000	0.1169	0.1145	0.0000	0.2412	0.1120	0.1074
DR5	**PRM**	0.0000	0.1022	0.1524	0.0848	0.0822	0.1045	0.0000	0.0578	0.0804
DR6	**RAD**	0.1211	0.0781	0.1207	0.0000	0.0000	0.0753	0.1726	0.0000	0.0526
DR7	**KLM**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0498	0.0000	0.0000	0.0349
DR8	**SMC**	0.0761	0.0512	0.0718	0.0673	0.0589	0.0000	0.1207	0.0719	0.0000
DR9	**EIM**	0.0000	0.0000	0.0693	0.0000	0.0440	0.0354	0.0000	0.0000	0.0223
DR10	**AUD**	0.0000	0.0465	0.0000	0.0431	0.0000	0.0000	0.0720	0.0000	0.0000
DR11	**ITI**	0.0000	0.0000	0.0474	0.0357	0.0248	0.0274	0.0000	0.0000	0.0000
DR12	**DDI**	0.0000	0.0000	0.0284	0.0000	0.0000	0.0189	0.0390	0.0000	0.0203
DR13	**IVN**	0.0000	0.0000	0.0236	0.0214	0.0231	0.0163	0.0000	0.0000	0.0140
DR14	**ICS**	0.0588	0.0338	0.0000	0.0162	0.0000	0.0000	0.0217	0.0260	0.0000
DR15	**DBA**	0.0000	0.0429	0.0000	0.0000	0.0000	0.0000	0.0000	0.0227	0.0000
DR16	**DFM**	0.0330	0.0156	0.0146	0.0000	0.0171	0.0134	0.0000	0.0000	0.0134

3.9 *Step 4*: Relationship between CRs and DRs(W_2).

In this step, interdependence of DRs with respect to each CR is found out, assuming that there is no dependence among the DRs. For example, the calculation of interdependence of DRs with respect to CR; quality is given in Table 3.4. What is the relative importance of DR2 (IT Automation) when compared to DR5(Process Management resulting in 3 as depicted in Table 3.4? Further, degree of relative importance of DRs for the remaining CRs calculated in the same way and is presented in Table 3.5. The transpose of the data shown in Table 3.5 will be represented in the body of the House of Quality.

Table 3.6: The inner dependence of CRs against Quality

CRs		CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR 9	Weight
CR1	**CST**	1.00	5.00	2.00	4.00	5.00	8.00	7.00	6.00	1.00	0.3076
CR3	**FLX**	0.20	1.00	3.00	2.00	4.00	7.00	8.00	8.00	0.20	0.2073
CR4	**DPY**	0.50	0.33	1.00	3.00	2.00	8.00	6.00	7.00	0.50	0.1664
CR5	**RSP**	0.25	0.50	0.33	1.00	2.00	6.00	7.00	6.00	0.25	0.1253
CR6	**FFS**	0.20	0.25	0.50	0.50	1.00	4.00	3.00	3.00	0.20	0.0736
CR7	**VNR**	0.13	0.14	0.13	0.17	0.25	1.00	2.00	3.00	0.13	0.0392
CR8	**AFS**	0.14	0.13	0.17	0.14	0.33	0.50	1.00	3.00	0.14	0.0332
CR9	**ERD**	0.17	0.13	0.14	0.17	0.33	0.33	0.33	1.00	0.17	0.0281
CR 2	**QLT**	0.13	0.14	0.17	0.14	0.25	0.33	0.50	0.33	0.13	0.0193

3.10 Step 5: Establishing inner dependence matrix among CRs (W_3).

Further, interdependence among CRs is arrived by finding out the impact of each CR on other CRs by using pairwise comparisons. The CRs which do not have an impact are not included in the comparison matrix. For example, the relative importance of Cost when compared to Responsiveness in achieving quality is mentioned as 5.00 as mentioned in Table 3.6. Accordingly, eigenvectors obtained from pairwise comparisons for other CRs are mentioned in Table 3.7. Zero is assigned to the eigenvector weights for CRs that are independent.

Table 3.7: The inner dependence matrix of CRs (W_3)

CRs		CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR 9
CR1	**CST**	0.0349	0.3076	0.0000	0.5702	0.0000	0.4237	0.5527	0.4484	0.4415
CR2	**QLT**	0.2706	0.0193	0.2451	0.2786	0.2377	0.2566	0.1966	0.2297	0.2383
CR3	**FLX**	0.0000	0.2073	0.0524	0.0000	0.2965	0.1337	0.0000	0.0000	0.1316
CR4	**DPY**	0.3009	0.1664	0.3164	0.0396	0.1834	0.0803	0.1003	0.0000	0.0000
CR5	**RSP**	0.0000	0.1253	0.1951	0.0000	0.0283	0.0455	0.0724	0.1368	0.0856
CR6	**FFS**	0.2548	0.0736	0.1298	0.1116	0.0000	0.0273	0.0000	0.0000	0.0450
CR7	**VNR**	0.0000	0.0392	0.0000	0.0000	0.1155	0.0000	0.0319	0.0839	0.0000
CR8	**AFS**	0.0752	0.0332	0.0000	0.0000	0.0899	0.0000	0.0461	0.0468	0.0327
CR 9	**ERD**	0.0637	0.0281	0.0612	0.0000	0.0488	0.0330	0.0000	0.0544	0.0252

***Step 6*: Developing inner dependence matrix of the DRs (W4).**

In the next step, dependence among the DRs is determined. For this pairwise comparison among DRs are done to find out the inner dependency. For example, the relative importance of DR1 SMS when compared to DR3 ITA resulting in 7 is illustrated in Table 3.8. Accordingly, the relative importance of the weights obtained from pairwise comparisons are presented in Table 3.9.

Table 3.8: The inner dependence matrix of DRs with respect to Quality Standards

DRs		DR1	DR3	DR5	DR11	DR13	DR14	DR4	DR 16	Weight
DR1	**SMS**	1.00	2.00	7.00	7.00	7.00	5.00	9.00	8.00	0.3760
DR3	**ITA**	0.50	1.00	3.00	3.00	4.00	4.00	7.00	4.00	0.2030
DR5	**PRM**	0.14	0.33	1.00	5.00	4.00	4.00	4.00	6.00	0.1537
DR11	**ITI**	0.14	0.33	0.20	1.00	2.00	3.00	3.00	3.00	0.0821
DR13	**IVN**	0.14	0.25	0.25	0.50	1.00	2.00	2.00	7.00	0.0742
DR14	**ICS**	0.20	0.25	0.25	0.33	0.50	1.00	2.00	3.00	0.0518
DR16	**DFM**	0.11	0.14	0.25	0.33	0.50	0.50	1.00	2.00	0.0329
DR4	**QLS**	0.13	0.25	0.17	0.33	0.14	0.33	0.50	1.00	0.0265

Step 7: Establishing inter dependent priority matrix of the CRs (Wc). The interdependent priorities of the CRs are obtained by using the relation $W_C = W_3 \times W_1$.

$$W_c = \begin{array}{c} 0.2152 \\ 0.2116 \\ 0.0841 \\ 0.1942 \\ 0.0675 \\ 0.1272 \\ 0.0204 \\ 0.0395 \\ 0.0402 \end{array} = \begin{pmatrix} \text{CR 1} & \text{CST} \\ \text{CR 2} & \text{QLT} \\ \text{CR 3} & \text{FLX} \\ \text{CR 4} & \text{DPY} \\ \text{CR 5} & \text{RSP} \\ \text{CR 6} & \text{FFS} \\ \text{CR 7} & \text{VNR} \\ \text{CR 8} & \text{AFS} \\ \text{CR 9} & \text{ERD} \end{pmatrix}$$

Table 3.9: The inner dependence matrix of the DRs

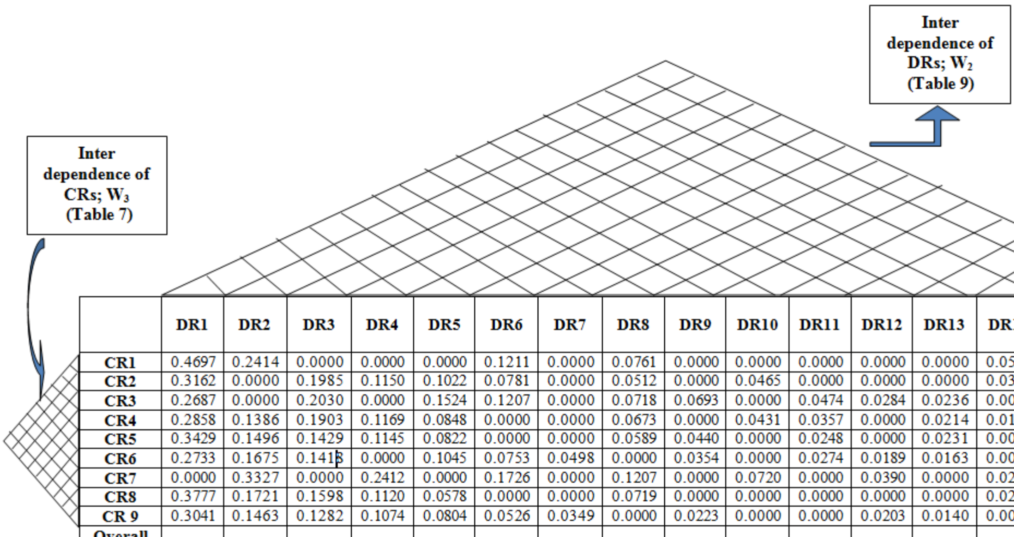
DRs		DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10	DR11	DR12	DR13	DR14	DR15	DR 16
DR1	**SMS**	0.014	0.454	0.258	0.376	0.336	0.355	0.000	0.308	0.294	0.000	0.265	0.312	0.242	0.306	0.000	0.257
DR2	**OTS**	0.267	0.030	0.000	0.000	0.135	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.207
DR3	**ITA**	0.212	0.000	0.015	0.203	0.155	0.000	0.340	0.262	0.216	0.398	0.182	0.196	0.187	0.259	0.344	0.150
DR4	**QLS**	0.145	0.232	0.189	0.026	0.122	0.170	0.210	0.158	0.000	0.296	0.130	0.141	0.146	0.000	0.000	0.090
DR5	**PRM**	0.091	0.182	0.138	0.154	0.019	0.000	0.000	0.108	0.142	0.160	0.070	0.113	0.094	0.127	0.000	0.076
DR6	**RAD**	0.056	0.000	0.000	0.000	0.082	0.018	0.154	0.000	0.000	0.000	0.000	0.072	0.082	0.000	0.207	0.054
DR7	**KLM**	0.000	0.000	0.101	0.000	0.000	0.153	0.018	0.064	0.139	0.077	0.060	0.058	0.059	0.000	0.156	0.044
DR8	**SMC**	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.069	0.000	0.039	0.000	0.050	0.094	0.000	0.000
DR9	**EIM**	0.041	0.000	0.064	0.000	0.058	0.000	0.000	0.000	0.018	0.000	0.032	0.037	0.039	0.080	0.000	0.034
DR10	**AUD**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.039	0.000	0.000	0.030	0.000	0.106	0.000
DR11	**ITI**	0.026	0.000	0.051	0.082	0.039	0.124	0.100	0.044	0.044	0.000	0.064	0.000	0.022	0.075	0.000	0.024
DR12	**DDI**	0.000	0.000	0.042	0.000	0.031	0.077	0.076	0.000	0.032	0.000	0.025	0.018	0.020	0.000	0.070	0.018
DR13	**IVN**	0.020	0.000	0.033	0.074	0.000	0.051	0.042	0.036	0.025	0.000	0.018	0.000	0.012	0.032	0.064	0.018
DR14	**ICS**	0.000	0.000	0.018	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.016	0.027	0.000	0.000
DR15	**DBA**	0.000	0.066	0.000	0.000	0.000	0.029	0.037	0.000	0.000	0.030	0.000	0.033	0.014	0.000	0.026	0.014
DR 16	**DFM**	0.015	0.036	0.016	0.033	0.022	0.023	0.023	0.000	0.020	0.000	0.015	0.022	0.011	0.000	0.028	0.013

Step 8: Inter dependent priority matrix of the DRs (WA). The interdependent priorities of the DRs, W_A are calculated as follows: $W_A = W_4 \times W_2$

$$
W_A=\begin{pmatrix}
0.2089 & 0.1911 & 0.2236 & 0.2288 & 0.2279 & 0.2093 & 0.3590 & 0.2162 & 0.2095 \\
0.1394 & 0.1013 & 0.0952 & 0.0918 & 0.1106 & 0.0948 & 0.0100 & 0.1137 & 0.0991 \\
0.1398 & 0.1670 & 0.1383 & 0.1498 & 0.1473 & 0.1147 & 0.1225 & 0.1476 & 0.1260 \\
0.1596 & 0.1354 & 0.1428 & 0.1542 & 0.1420 & 0.1512 & 0.1588 & 0.1463 & 0.1373 \\
0.1050 & 0.0943 & 0.0828 & 0.1178 & 0.1152 & 0.0886 & 0.1295 & 0.1172 & 0.0979 \\
0.0302 & 0.0371 & 0.0344 & 0.0246 & 0.0287 & 0.0363 & 0.0059 & 0.0305 & 0.0332 \\
0.0249 & 0.0462 & 0.0597 & 0.0302 & 0.0279 & 0.0360 & 0.0420 & 0.0243 & 0.0273 \\
0.0255 & 0.0166 & 0.0199 & 0.0166 & 0.0198 & 0.0149 & 0.0048 & 0.0187 & 0.0140 \\
0.0251 & 0.0350 & 0.0382 & 0.0322 & 0.0312 & 0.0298 & 0.0032 & 0.0313 & 0.0276 \\
0.0000 & 0.0064 & 0.0007 & 0.0023 & 0.0007 & 0.0005 & 0.0028 & 0.0024 & 0.0004 \\
0.0357 & 0.0467 & 0.0484 & 0.0370 & 0.0358 & 0.0367 & 0.0481 & 0.0345 & 0.0380 \\
0.0100 & 0.0209 & 0.0273 & 0.0120 & 0.0114 & 0.0216 & 0.0141 & 0.0102 & 0.0162 \\
0.0205 & 0.0311 & 0.0237 & 0.0243 & 0.0241 & 0.0177 & 0.0317 & 0.0258 & 0.0232 \\
0.0016 & 0.0104 & 0.0046 & 0.0107 & 0.0092 & 0.0032 & 0.0131 & 0.0093 & 0.0081 \\
0.0199 & 0.0050 & 0.0049 & 0.0107 & 0.0104 & 0.0161 & 0.0304 & 0.0119 & 0.0135 \\
0.0190 & 0.0173 & 0.0167 & 0.0189 & 0.0202 & 0.0195 & 0.0245 & 0.0201 & 0.0205
\end{pmatrix}
$$

Step 9: Finding out the overall priority of DRs.: The overall priorities of the DRs (W_{ANP}), reflecting the interrelationships within the HOQ, are obtained by multiplying W_A and W_C.

$$
W_{ANP}=\begin{pmatrix}
0.2149 \\ 0.1055 \\ 0.1441 \\ 0.1483 \\ 0.1027 \\ 0.0312 \\ 0.0354 \\ 0.0185 \\ 0.0306 \\ 0.0021 \\ 0.0398 \\ 0.0161 \\ 0.0242 \\ 0.0070 \\ 0.0122 \\ 0.0188
\end{pmatrix}
=
\begin{pmatrix}
\text{DR1} & \text{SMS} \\
\text{DR2} & \text{OTS} \\
\text{DR3} & \text{ITA} \\
\text{DR4} & \text{QLS} \\
\text{DR5} & \text{PRM} \\
\text{DR6} & \text{RAD} \\
\text{DR7} & \text{KLM} \\
\text{DR8} & \text{SMC} \\
\text{DR9} & \text{EIM} \\
\text{DR10} & \text{AUD} \\
\text{DR11} & \text{ITI} \\
\text{DR12} & \text{DDI} \\
\text{DR13} & \text{IVN} \\
\text{DR14} & \text{ICS} \\
\text{DR15} & \text{DBA} \\
\text{DR 16} & \text{DFM}
\end{pmatrix}
$$



	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10	DR11	DR12	DR13	DR14	DR15	DR 16	Relative weight of CRs
CR1	0.4697	0.2414	0.0000	0.0000	0.0000	0.1211	0.0000	0.0761	0.0000	0.0000	0.0000	0.0000	0.0000	0.0588	0.0000	0.0330	**0.2913**
CR2	0.3162	0.0000	0.1985	0.1150	0.1022	0.0781	0.0000	0.0512	0.0000	0.0465	0.0000	0.0000	0.0000	0.0338	0.0429	0.0156	**0.1994**
CR3	0.2687	0.0000	0.2030	0.0000	0.1524	0.1207	0.0000	0.0718	0.0693	0.0000	0.0474	0.0284	0.0236	0.0000	0.0000	0.0146	**0.1478**
CR4	0.2858	0.1386	0.1903	0.1169	0.0848	0.0000	0.0000	0.0673	0.0000	0.0431	0.0357	0.0000	0.0214	0.0162	0.0000	0.0000	**0.1216**
CR5	0.3429	0.1496	0.1429	0.1145	0.0822	0.0000	0.0000	0.0589	0.0440	0.0000	0.0248	0.0000	0.0231	0.0000	0.0000	0.0171	**0.0776**
CR6	0.2733	0.1675	0.1418	0.0000	0.1045	0.0753	0.0498	0.0000	0.0354	0.0000	0.0274	0.0189	0.0163	0.0000	0.0000	0.0134	**0.0663**
CR7	0.0000	0.3327	0.0000	0.2412	0.0000	0.1726	0.0000	0.1207	0.0000	0.0720	0.0000	0.0390	0.0000	0.0217	0.0000	0.0000	**0.0337**
CR8	0.3777	0.1721	0.1598	0.1120	0.0578	0.0000	0.0000	0.0719	0.0000	0.0000	0.0000	0.0000	0.0000	0.0260	0.0227	0.0000	**0.0304**
CR 9	0.3041	0.1463	0.1282	0.1074	0.0804	0.0526	0.0349	0.0000	0.0223	0.0000	0.0000	0.0203	0.0140	0.0000	0.0000	0.0134	**0.0319**
Overall priorities of DR	**0.2149**	**0.1055**	**0.1441**	**0.1483**	**0.1027**	**0.0312**	**0.0354**	**0.0185**	**0.0306**	**0.0021**	**0.0398**	**0.0161**	**0.0242**	**0.0070**	**0.0122**	**0.0188**	

Figure 3.4: House of Quality for case electronics company

The results from the ANP indicate that the most significant DR is simplification and standardization with a relative importance value of 0.2149 followed by quality standards and IT Automation with a relative importance of 0.1483 and 0.1441 respectively. The HOQ thus obtained from the steps outlined above is illustrated in Figure 3.4.

3.11. Results and discussions

In this research, we have tried to identify CRs and DRs and its prioritization for integrating SC in an electronic industry. The ICT tools help in effective SCI resulting in cost optimization and effective communication among the SC partners. For the case electronics company, simplification and standardization (DR1 SMS) has the strongest relationship with a relative importance value of 0.2149 compared to other DRs. Hence the company should give prime importance to simplification and standardization while integrating SC using ICT tools. While simplifying and standardizing the processes, role and processes of each SC partner is to be assessed logically and planning should be done accordingly. Imparting simplification and standardization of process in the entire process of SC will bring in revolutionary changes (Sanchez-Rodrıguez et al.,2006; Stajniak and Kolinski, 2016). It helps in constant improvement of SC processes through effective integration that can lead to higher efficiency.

Quality Standards (DR4 QLS) is having a relative importance of 0.1483. Electronics industry is highly competitive and following quality standards is a major order qualifier attribute. Adhering to stringent quality standards could lead to production of better products and services satisfying customer needs and value. Literature reveals that providing quality products which meet the standards is one of the most important DRs to be considered for maintaining proper supplier-customer relationships (Sharma et al., 2012; Gu et al., 2017). Likewise, quality standards in the area of after sales services should also be given due significance by the case company.

IT automation (DR3 ITA) is the next prominent DR with a relative importance of 0.1441. A centralized, distributed or agent based methodology automating the processes should be deployed by the case company on priority basis. The Internet can be used as a medium for automation and collaboration among partners in SC (Kothari et al.,2018). IT automation could result in robustness and efficiency by exchange of information across SC for its effective planning and integration.

Outsourcing (DR2 OTS) of the internal activities of the firm is also of prime importance to the case company with a relative score of 0.1055. In order to concentrate on their core business areas, many companies in recent years have adopted outsourcing practices and the electronics industry is no exception. The case company should take a decision on outsourcing based on the cost involved and available in-house facilities for manufacturing. Outsourcing can be opted to reduce the need for internal flexibility (Tsay et al., 2018; Pankowska et al., 2019).

Process Management (DR5 PRM) has come out with relative significance of 0.1027. It indicates that the case company should ideally streamline the entire processes. Efforts in this direction would enhance customer value in all fronts including cost (Lockamy III, et al., 2004). Effective tools for process management should be used for measuring performance and controlling the activities. IT Integration (DR11 ITI) is another DR with a relative significance of 0.0398 which is to be considered to enhance SC performance. The necessity of access to real time information in an electronics industry is evident and IT integration will enhance the agility and flexibility of the organization and SC partners (Samadi et al., 2016; Pachayappan, 2018). Knowledge Management (DR7 KLM) with a score of 0.0354 includes acquisition of knowledge, integration, protection, innovation and dissemination (Perez-Salazar et al.,2013). The SC can be designed based on the knowledge gathered resulting in better performance. Research and Development (DR6 RAD) is a competitive tool for development of innovative products and services (Jordan 2014), which is having a score of 0.0312. Effective R&D across the SC activities of the electronics industry helps in gaining competitive advantage. E-intermediation (DR9 EIM) is having a relative significance of 0.0306, involves the integration of communication, computing and control in the electronics industry (Mostafa et al., 2019). This strategy could help the case company in connecting to the outer world.

Intelligent Value Chain Networks (DR13 IVN), helps in sharing of information among the partners in the industry and SC (Hanifan et al., 2014), has got a score of 0.0242 in the study. Electronic SC being very robust and dynamic, intelligent value chain networks can support in meeting customer expectations which is one of the top priorities of SC. Design for Manufacturing (DR16 DFM) has a relative significance score of 0.0188. Great significance need to be given for consideration of design aspects while proceeding with digitalization of SC (Roscoe et al.,2019). Smart Contracts (DR8 SMC), 0.0185 helps in communicating among the partners on real time basis (Hu et al., 2019). The smart contracts methodology adopted in the electronics industry helps in assessing the situations on time and executing actions on the basis of the information gathered to plan manufacturing and other related activities in SC process. Gunasekaran et al., (2018) have found that blockchain technologies help in capturing data in real time thereby enhancing SC agility.

Data Driven Innovation (DR12 DDI); 0.0161 can allow the case company to focus on data driven decision making based on the real time data availability (Spanaki et al.,2018). Innovation through effective data management helps in creating better value by providing products and services that match the customer expectation. Data and Business Analytics (DR15 DBA); 0.0122assistsinobtaining real-time information quickly for proper decision making. Data and business analytics has the potential to outperform and transform traditional SCM practices by providing better insights for improving processes, operational efficiency, cost reduction and quick decision making in the electronics SC (Roy, 2018). Proper data and business analytics helps in enhancing the business process by analyzing the information related to various processes obtained from the SC partners.

Gunasekaran et al., (2018) highlighted the role of big data and business analytics in agile manufacturing. They have found out that big data and business analytics plays a crucial role in the agility of an organization. They have also highlighted the relevance of big data and business analytics and its application along with internet of things, industry4.0 and block chain technologies.

ICT Security (DR14 ICS) having a relative significance value of 0.0070 reveals the need for securing information which is transmitted by the company across the SC. ICT security helps in reducing the risk of loss of data, misuse, fraud and tampering of data (Ulhaq et al., 2016). The company has to concentrate more on providing enough security while transmitting and receiving the information to receive the trust of their partners. Auditability (DR10 AUD) has come out with the least relative significant value of 0.0021in this study. It reveals limitations of the company with respect to getting the processes audited. Auditing is helpful in checking whether the set standards and procedures are followed and any deviation is involved (Daghfous et al., 2017). The case company should make efforts for auditing as it would enable them to take corrective actions through well planned and systematic approach in achieving their targeted objectives.

The methodology adopted can be considered by the practicing managers for integration of SC through digitalization. It helps the managers in effective decision making for the integration process. The CRs and DRs specific to the concerned industry can be identified and applied for effective integration. Further, for effective management of the process, the DRs could also be classified into strategic, tactical and operational factors based on the requirements of the company and the industry.

In order to effectively digitalize the supply chain, it is essential to identify the key enablers and its causal and effect relations existing among the enablers. It is noted that the enablers of supply chain digitalization have serious influential relations existing among themselves. The inter-relationships and cause- effect relations among the enablers are studied in detail in Chapter 4.

CHAPTER 4

ANALYSIS OF ENABLERS FOR SUPPLY CHAIN DIGITALIZATION USING INTERPRETIVE STRUCTURAL MODELING AND GREY-DEMATEL APPROACHES

4.1 Enablers for supply chain digitalization

The success of SCI through digitalization depends on the procedure adopted for implementation by giving due significance to the key enablers affecting the process. A new business model can be developed by using advanced technologies. Sestino et al., (2020) have investigated the role of internet of things (IoT) and big data (BD) in managing the digital transformation. They have found that IoT and BD are the reengineering factors for business processes. Lechler et al., (2019) have stressed the need of investigation on the emerging aspects of processing data in real world context. A research framework on enablers in SCD is shown in Figure 4.1.

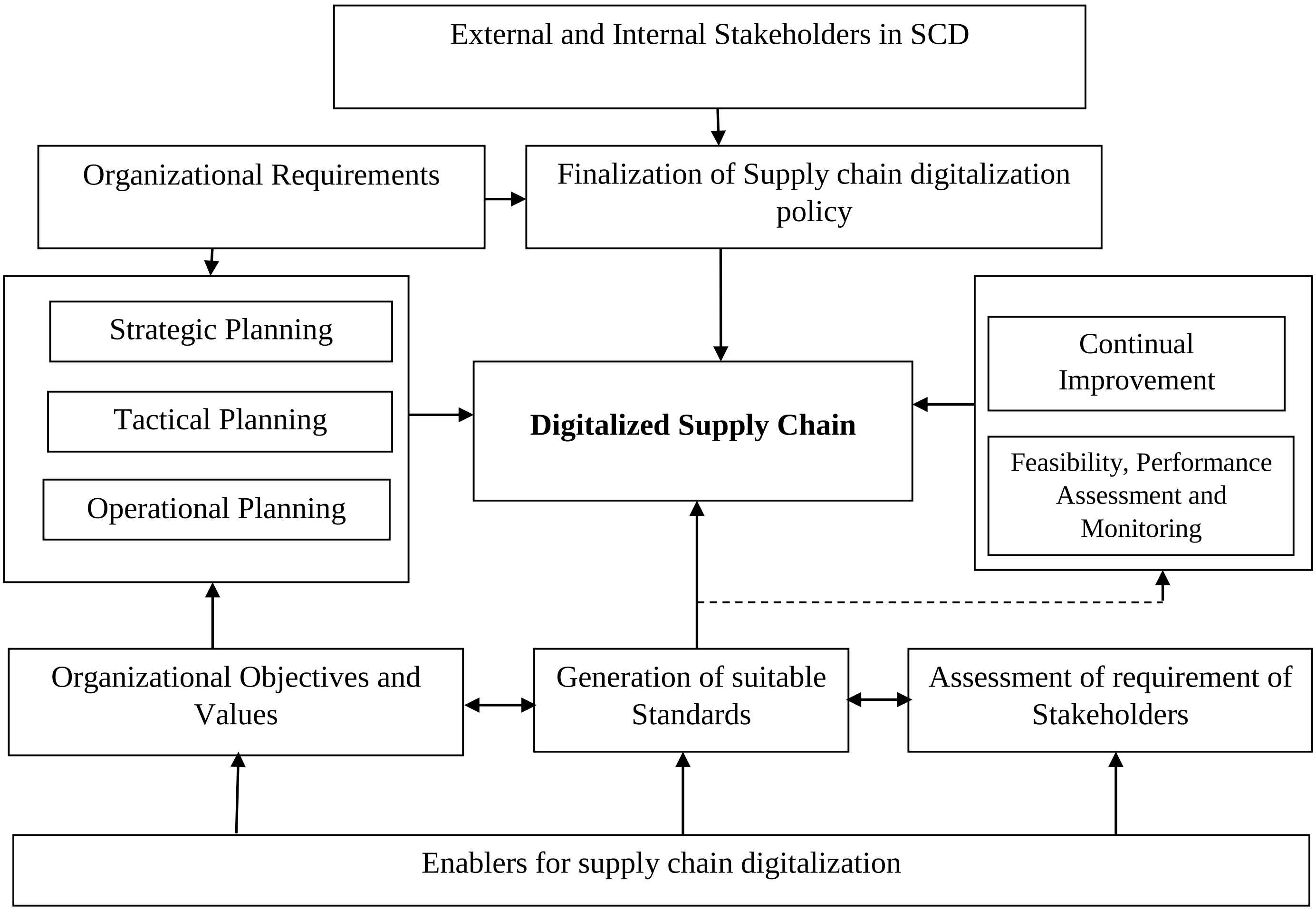


Figure 4.1: A research framework on enablers in SCD

Attaran (2020) has highlighted the role of digital technologies in enabling, enhancing and streamlining transformation of SC.

Table 4.1: Enablers of SCD

Sl.No	Abbr.	Enablers	Relevant Literature	Remarks
E1	TMC	Involvement and Support from top management	Wei et al., 2020; Gawankar et al., 2020.	All activities can be initiated only based on commitment and support from top management.
E2	SAT	State of Art Technologies and Related Infrastructure	Malyavkina et al., 2019; Hofmann et al., 2019	Application and use of most advanced technology enhances SC performance.
E3	DSP	Data Security and Privacy across Networks	Schniederjans et al., 2020; Mosteanu, 2020.	Assurance of proper data security and privacy enhances the digitalization process.
E4	LMS	Long, medium and short term planning	Guo et al.,2020; Kumar et al.,2021	Effective planning will result in proper implementation.
E5	FUNDS	Investments of funds and availability	Xing et al., 2019; Cagle, 2020	Investments for acquiring IT infrastructure and other aspects affects the process.
E6	CULT	Corporate culture among partners	Zangiacomi et al., 2020; Shao et al., 2021	SC partners culture and attitude influence effectiveness of digitalization.
E7	TRUST	Trust among SC partners	Lind and Schupp, 2020; Jabbar et al., 2020	Trust ensures cooperation and communication.
E8	RTD	Data management on real time basis	Kenge and Khan, 2020; Maheshwari et al., 2020.	Analysis of data can be done on real time basis for digitalization.
E9	PRO	Profitable information sharing model with SC partners	Sundram et al., 2020; Li et al., 2020	Increases financial performance through sharing of knowledge, information and skills.
E10	INF	Information Sharing	Ageron et al., 2020; Coronado Mondragon et al., 2020	Facilitates effective integration and decision making.
E11	RMS	Risk management and strategies	Ivanov and Dolgui, 2020a; Yang et al., 2020	Helps in effective SCM by mitigating the risks.
E12	CSP	Cooperation and support from SC partners	Dubey et al., 2020; Ebinger and Omondi, 2020	Increases the responsiveness and efficiency of SC.
E13	EXE	Extended Enterprise	Ivanov and Dolgui, 2020b; Wong et al., 2020	Maximizes the value across the SC.

Marmolejo-Saucedo and Hartmann (2020) in their research have found that companies adopting technological advancements, as Industrial revolution 4.0 will be able to survive in competitive business environments. They also stated that digital transformation of SC requires proper organizing and planning of activities to meet various operational functions. Gupta et al., (2020a) have identified and prioritized key digitization and information technology enablers enhancing SC performance. They have highlighted the relevance of digitization and information technology enablers by organizations to enhance SC performance. Nunez-Merino et al., (2020) have investigated the key aspects and implications of relationships between information and digital technologies of Industry 4.0 and lean SCM. The details of key enablers of SCD identified in this research are shown in Table 4.1 followed by a brief description of each of them.

4.1.1 Involvement and support from top management: The top management plays a crucial role in improving the company's SC performance. Coordination and collaboration can be enhanced with the help of top management support and commitment. Success of any strategic program finalized by the organization depends on the extent of top management support and commitment. The involvement of top management is required at all implementation stages of the project life cycle, i.e. from the initial board level discussions till the go-live of the system. Thus, the involvement and support from the top management is very crucial for initiating and implementing digitalization.

4.1.2 State of Art Technologies and Related Infrastructure: Information technology (IT) is a key driver for enhancing SC efficiency. IT system helps in collaborative planning of SC and enhances SC performance. In order to integrate SC, an efficient IT system is crucial. Information system also plays a vital role in tracking and tracing of products. Advanced digital technologies and well-equipped IT infrastructure is one of the key enablers for the digitalization process.

4.1.3 Data Security and Privacy across Networks: Organizations should evolve strategies and procedures to improve security and privacy of information transmitted across the SC. Data transmitted in SC should be compliant with the regulations and have enough security measures for transmission of information. Data privacy is to be ensured based on compliance with the regulations while interconnecting across the SC. SCI process should consider main aspects like security, privacy, interoperability, regulatory and legal compliance, in which information security should be given due significance as a key enabler.

4.1.4 Long, medium and short term planning: Collaboration among partners in SC is a significant factor in achieving successful SCI. Suitable collaborative planning strategies helps in maximizing the interest of organization, rather than individual interests. The success of long, medium and short term planning in SC depends upon the level of information sharing.IT systems helps in long, medium and short term planning of processes and thus enhances the SC performance.

4.1.5 Investment of funds and availability: The process of IT enablement, adoption of advanced technologies, hiring of technology savvy employees and training of employees requires high investments. Due to the high costs and financial commitment involved, most of the organizations are reluctant to commit key resources. Lack of convincing justifications for high investment also affects the decision-making process for digitalization. Thus, decisions on investments of funds and its availability is another enabler that affects the digitalization process.

4.1.6 Corporate culture among partners: The planning and integration of SC activities should be done by considering the requirements of SC partners towards achieving long term goals. Organizational culture affects the policies on various aspects that assume significance for organizations in the long term. Prevailing culture in the organization is one of the enablers that affect the process of digitalization.

4.1.7 Trust among supply chain partners: SC can be effectively integrated if enough security and trust is established across SC partners. The utilization and sharing of resources like information, knowledge and skills decides the success of SCI. The real strength of SC linkage depends upon the extent of trust, communication, cooperation and adaptation among the SC partners.

4.1.8 Data management on a real time basis: Proper analysis of SC data helps in enhancing the business processes. Data management on a real time basis facilitates rapid access to information for effective decision making. Data analytics has the potential to transform traditional SCM practices by providing insights for improvement of processes and operational efficiencies. Accordingly, based on the benefits that can be reaped from data management, they act as one of the key enablers for the digitalization process.

4.1.9 Profitable information sharing model with SC partners: Effective utilization and sharing of resources like information, knowledge and skills results in better SC performance and leads to higher profit. Success of SCI depends upon the sharing model among SC partners in the dynamic business environment. It results in better financial performance by improving the effectiveness of decision making in business processes. The overall reduction in SC cost results in performance enhancement by way of higher profit margins and enables better integration of SC through digitalization.

4.1.10 Information sharing: Information sharing and integration are correlated with SC performance measures. The two major stages of SCI are degree of information sharing and decision making. Intelligent value chain networks help in sharing of information among SC partners and industry on a real time basis. SC can be integrated effectively by information sharing through advanced digital technologies, which acts as a key enabler for the digitalization process.

4.1.11 Risk management and strategies: The risk mitigation strategies should be reviewed and updated on a regular basis for effective risk management. SC is prone to many risks due to the drastic changes in the business world. Hence, the strategy has now shifted from risk avoidance to risk management. All related activities in the SC should be planned accordingly to mitigate the risk and its effective management.

4.1.12 Commitment among supply chain partners: The commitment and mutual trust among SC partners assists in managing SC relationships effectively.SC partners will try to maximize the individual interests instead of the collaborative interests. Integration among the SC partners within an organization can be achieved through its designed IT strategies. Effective and strong communication among SC partner’s increases responsiveness of employees and efficiency of the SC.

4.1.13 Extended Enterprise: The concept of extended enterprise becomes vital in gaining competitive advantage through collaborative relationships among SC partners. Due to mutual interconnection among the businesses, proper functioning of one business will assist other businesses also to flourish. This results in the collaborative approach of working together, wherein each organization is more than a single entity. The external partners in the extended enterprise plays a major role in the organization's success. Decision makers are shifting away from the traditional form of SC and its infrastructure towards a digitally enabled and fully integrated SC leading to an extended enterprise.

4.2. Research Methodology

In this paper, analysis of the key enablers is done by using Interpretive Structural Modeling (ISM) method. Application of ISM method helps in identifying the prominent influential relations among the key enablers facilitating effective SCD.

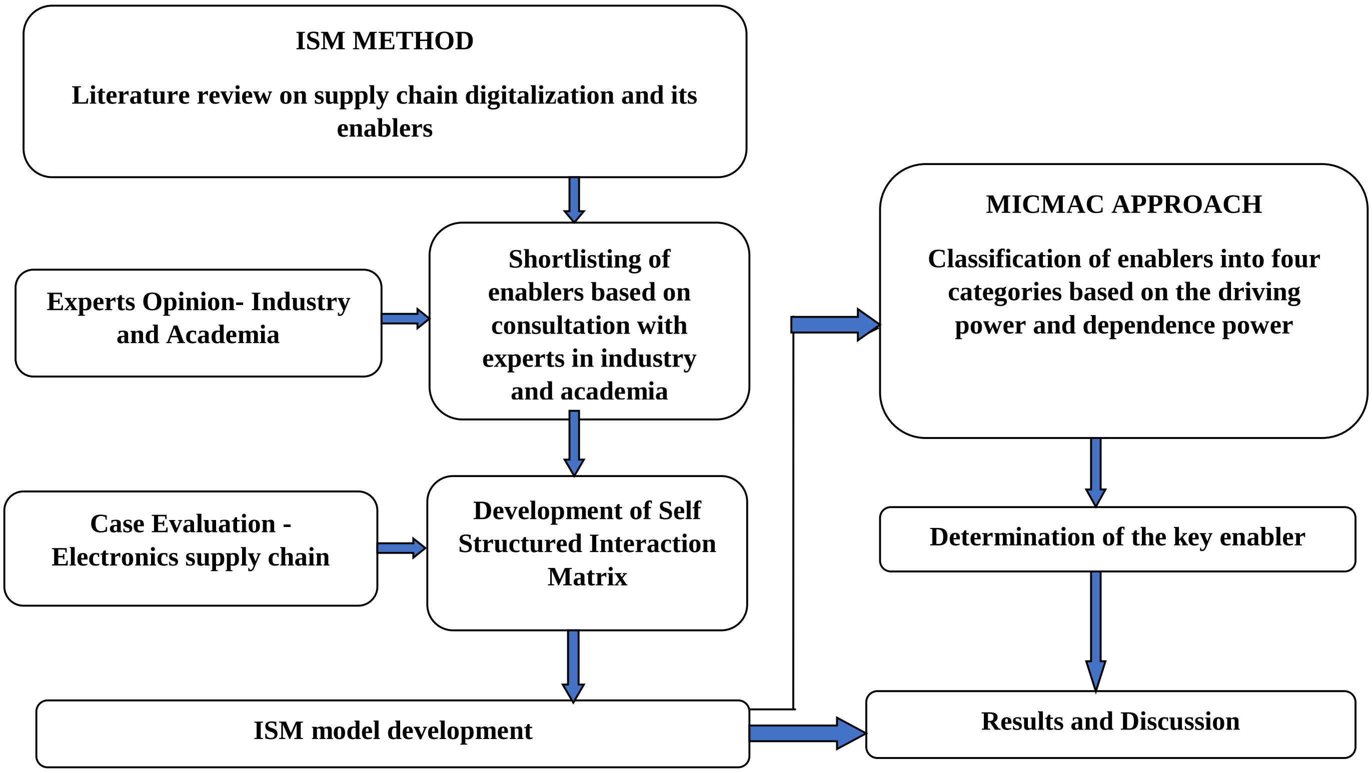


Figure4.2: Flow chart for methodology for ISM and MICMAC approach

The key enablers were identified from literature review and based on consultation with the experts in industry and academia. Accordingly, thirteen major enablers were shortlisted which are to be considered while proceeding with SCI through digitalization so as to gain maximum benefits. ISM method and MICMAC analysis technique is used to categorize the major enablers. A flow chart for the methodology for the ISM and MICMAC approach is given in figure 4.2.

4.2.1 Interpretive Structural Modeling (ISM)

ISM is an interactive learning process in which a set of elements are structured into a comprehensive systematic model wherein both dissimilar and directly related elements are involved. The multilevel structural model developed by using ISM depicts a sub-systems level representation of a complicated system, thereby imposing order and complexity of the relationships among the elements of a system. The basis for development of the ISM method was presented by Warfield (1974) to analyze the complex socioeconomic systems and has been used for policy analysis. Later the method was used for research in analyzing factors influencing building energy performance, assessing retailer responsiveness, supply chain complexity drivers, and supply chain sustainability (Xu et al., 2020; Sharma et al., 2020a; Piya et al., 2020; Chand et al., 2020).

ISM method has the following steps:

Step 1: Shortlisting of the variables that are affecting the system.

Step 2: The contextual relationship among the variables identified in step 1 are found.

Step 3: Pairwise relationship among the variables of the system is developed in the form of a structural self-interaction matrix (SSIM).

Step 4: Transitivity of the matrix is checked based on the reachability matrix developed from SSIM. The basic assumption made in ISM is the transitivity of the contextual relation. Transitivity rule states that if variable A is related to variable B and variable B is related to variable C, then variable A is necessarily related to variable C.

Step 5: Partitioning of the reachability obtained in step 4 into different levels.

Step 6: A diagram is developed based on the reachability matrix and considering the contextual relationships by removing the transitive links.

Step 7: The diagram developed as above in step 6 is converted into an ISM by replacing variable nodes with statements.

Step 8: Conceptual inconsistency is checked by reviewing the ISM model developed in step 7and necessary modifications are made. Finally, a model is drawn representing relationships among the enablers for SCD.

4.3 ISM Model Development - Case Evaluation

The proposed ISM model developed is applied in a case study and is discussed in this section. The case study is performed on an MNC, XYZ Company, which is one of the prominent companies in the electronic industry dealing with electronic consumer products and services in India. This company is considered for the study to take advantage of their expertise and experience in the field, which ensures the credibility of the case study design. The company is rapidly growing in the electronics industry with a very vast range of products and services. It includes home appliances, electrical installation systems and home automations. The organization has a very widely spread SC network in India. However, advancement in digital technologies and its applicability in SCI can bring in much more benefits compared to the existing system is not yet considered by the company. Hence, on a long-term perspective, suitable provisions for effective management of the SCI by means of digitization of the activities across the software platform can be considered. It also enables the procedure to be followed for integration of SC using advanced digital technologies. The experts in the company were consulted and the enablers identified were evaluated. The experts consulted were senior managers who had an industrial experience of over 25 years in the electronics industry responsible for activities of Information Technology and Operations Management in the firm. The academic expert was an Associate Professor in a reputed University engaged in research for over twenty years in various areas of Operations and SCM. He was also associated with many industrial consultancies related to automation of SC projects. All these experts in the study were quite experienced and familiar with digital transformations of SCs happening in electronic industries. The data collected was recorded and categorized to find out the key enabler in integration of SC through digitalization.

Step1: The key enablers affecting the SCD process were finalized by taking into account the opinion from two experts in the electronic firm and one expert from academia. The influence of enablers and its relation to the process of SCD and the relevant literature are detailed in table 4.1.

Step 2: The contextual relationship among the enablers identified in the process of SC studied by two experts from industry and one expert from academia. All the potential influential relations and its interpretations were identified and analyzed through brainstorming sessions.

Step 3: The influential relations among the key enablers are marked in the matrix in binary form. The matrix formed is the direct reachability matrix as shown in Table 4.4. The element in the matrix represents the direct influential relation among the key enablers.

Step 4: The significant transitive relations among the enablers form the interpretive logic is to be identified. All the significant transitive relations shall then be updated in the direct relation matrix by indicating all the transitive relations to form the final reachability matrix. The final reachability matrix thus formed is shown in Table 4.5.

Step 5: Further the level partition is done by following the step 1 to 8 as mentioned in section 4.2 and the enablers are placed level wise indicating the influences among them. The reachability of the elements, its antecedents and the intersection sets were sorted at each level and the procedure is repeated as shown in Tables 4.6 to 4.11.

Step 6: After forming the level partitions, digraphs are drawn by representing the most relevant influence relations. The relations among the enablers can be identified from the final reachability matrix and interpretive logic of the relations. The digraph formed accordingly is shown in figure 4.3.

4.3.1 Structural self-interaction matrix (SSIM)

The contextual relationship among the enablers identified is identified based on expert's opinion. The relationship among the variables (*i* and *j*) are marked by using the symbols V, A, X and O. In case variable, *i* will lead to variable *j*, it is denoted by V; variable *j* leading to variable *I* is denoted by A; variable *i* and *j* leading to each other is represented by X and where variable *i* and *j* are unrelated, it is denoted by O.

An SSIM is developed based on the contextual relationships between the variables and is shown in Table 4.2. In the table, the variable E1 leads to variable E13 so it is marked by V in the cell, likewise variable E2 leads to variable E5 and denoted by A in the cell. Variable E2 and E3 lead to each other, hence represented by X. Variable E4 and E6 do not lead to each other, so it is marked as O.

Table 4.2: Structural self-interaction matrix

Sl. No.	Enabler	Enabler description	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2
1	**E1**	Involvement and Support from top management	V	V	V	V	V	V	V	V	O	O	V	V
2	**E2**	State of Art Technologies and Related Infrastructure	V	V	V	V	V	V	V	O	A	A	X	
3	**E3**	Data Security and Privacy across networks	V	V	V	V	V	V	V	A	A	A		
4	**E4**	Long, medium and short term planning	V	V	V	V	V	V	V	O	X			
5	**E5**	Investments of funds and availability	V	V	V	V	V	V	V	O				
6	**E6**	Corporate culture among partners	V	V	V	V	V	V	V					
7	**E7**	Trust among supply chain partners	A	A	V	V	V	V						
8	**E8**	Data management on real time basis	A	A	V	V	V							
9	**E9**	Profitable information sharing model with SC partners	A	A	V	V								
10	**E10**	Information Sharing	A	A	V									
11	**E11**	Risk management and strategies	A	A										
12	**E12**	Cooperation and support from SC partners	X											
13	**E13**	Extended Enterprise												

4.3.2 Initial Reachability Matrix

The initial reachability matrix is calculated based on the SSIM formulated and converted into a binary matrix by substituting the symbols V, A, X and O by 1 or 0 as the case may be by applying the rules, as in Table 4.3.

Table 4.3: Rule for construction of Initial Reachability Matrix

Sl. No.	Value in SSIM	Value in reachability matrix	
	(i, j)	*(i, j)*	*(j,i)*
1	V	1	0
2	A	0	1
3	X	1	1
4	O	0	0

By applying these rules, an initial reachability matrix for the key enablers for integration of the SC through digitalization is given in table 4.4.

Table 4.4: Initial Reachability Matrix

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**E12**	**E13**
E1	1	1	1	1	1	1	1	1	1	1	1	1	1
E2	0	1	1	0	0	0	1	1	1	1	1	1	1
E3	0	1	1	0	0	0	1	1	1	1	1	1	1
E4	0	1	1	1	1	0	1	1	1	1	1	1	1
E5	0	1	1	1	1	1	1	1	1	1	1	1	1
E6	0	1	0	0	1	1	1	1	1	1	1	1	1
E7	0	0	0	0	0	0	1	1	1	0	0	1	1
E8	0	0	0	0	0	0	1	1	1	0	0	1	1
E9	0	0	0	0	0	0	0	0	1	0	0	0	1
E10	0	1	0	0	0	0	1	1	1	1	1	0	1
E11	0	1	0	0	0	0	1	1	1	1	1	0	1
E12	0	0	0	0	0	0	1	1	1	0	0	1	1
E13	0	0	0	0	0	0	0	0	0	0	0	0	1

4.3.3 Final Reachability Matrix

By taking into account the transitivity rule, the final reachability matrix (Table 4.5) is made from the initial reachability matrix. The transitivity rule states that, if a variable ‘X’ is related to ‘Y’ and ‘Y’ is related to ‘Z’, the ‘X’ is necessarily related to ‘Z’.

Table 4.5: Final Reachability Matrix

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	Driving Power
E1	1	1	1	1	1	1	1	1	1	1	1	1	1	**13**
E2	0	1	1	0	0	0	1	1	1	1	1	1	1	**9**
E3	0	1	1	0	0	0	1	1	1	1	1	1	1	**9**
E4	0	1	1	1	1	1	1	1	1	1	1	1	1	**12**
E5	0	1	1	1	1	1	1	1	1	1	1	1	1	**12**
E6	0	1	1	1	1	1	1	1	1	1	1	1	1	**12**
E7	0	0	0	0	0	0	1	1	1	0	0	1	1	**5**
E8	0	0	0	0	0	0	1	1	1	0	0	1	1	**5**
E9	0	0	0	0	0	0	0	0	1	0	0	0	1	**2**
E10	0	1	1	0	0	0	1	1	1	1	1	1	1	**9**
E11	0	1	1	0	0	0	1	1	1	1	1	1	1	**9**
E12	0	0	0	0	0	0	1	1	1	0	0	1	1	**5**
E13	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Dependence Power	**1**	**8**	**8**	**4**	**4**	**4**	**11**	**11**	**12**	**8**	**8**	**11**	**13**	

The driving power and dependence of each enabler is shown in Table 4.5. The driving power of each enabler is the total number of enablers into which it is having influence. The dependence power means the total number of enablers which is influencing it. In MICMAC analysis, the driving power and dependence powers are used for classification into four groups; autonomous, dependent, linkage and independent variables.

4.3.4 Level Partitions

Table 4.6: Level partitions for enablers: Iteration-I

Sl. No	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10,11,12,13	1	1	
2	2,3,7,8,9,10,11,12,13	1,2,3,4,5,6,10,11	2,3,10,11	
3	2,3,7,8,9,10,11,12,13,	1,2,3,4,5,6,10,11	2, 3,10,11	
4	2,3,4,5,6,7,8,9,10,11,12,13	1,4,5,6	4,5,6	
5	2,3,4,5,6,7,8,9,10,11,12,13	1,4,5,6	4,5,6	
6	2,3,4,5,6,7,8,9,10,11,12,13	1,4,5,6	4,5,6	
7	7,8,9,12,13	1,2,3,4,5,6,7,8,10,11,12	7,8,12	
8	7,8,9,12,13	1,2,3,4,5,6,7,8,10,11,12	7,8,12	
9	9,13	1,2,3,4,5,6,7,8,9,10,11,12	9	
10	2,3,7,8,9,10,11,12,13	1,2,3,4,5,6,10,11	2,3,10,11	
11	2,3,7,8,9,10,11,12,13	1,2,3,4,5,6,10,11	2,3,10,11	
12	7,8,9,12,13	1,2,3,4,5,6,7,8,9,10,11,12	7,8,12	
13	13	1,2,3,4,5,6,7,8,9,10,11,12,13	13	**I**

From the final reachability matrix, the reachability set and antecedent set (Warfield 1974) for each enabler is found. The table 4.6 has come out with the E13 at level I. The level of each enabler is found through a continuous iteration process, which helps in building the diagram and the final ISM model.

Table 4.7: Level partitions for enablers: Iteration-II

Sl. No	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10,11,12	1	1	
2	2,3,7,8,9,10,11,12	1,2,3,4,5,6,10,11	2,3,10,11	
3	2,3,7,8,9,10,11,12	1,2,3,4,5,6,10,11	2, 3,10,11	
4	2,3,4,5,6,7,8,9,10,11,12	1,4,5,6	4,5,6	
5	2,3,4,5,6,7,8,9,10,11,12	1,4,5,6	4,5,6	
6	2,3,4,5,6,7,8,9,10,11,12	1,4,5,6	4,5,6	
7	7,8,9,12	1,2,3,4,5,6,7,8,10,11,12	7,8,12	
8	7,8,9,12	1,2,3,4,5,6,7,8,10,11,12	7,8,12	
9	9	1,2,3,4,5,6,7,8,9,10,11,12	9	**II**
10	2,3,7,8,9,10,11,12	1,2,3,4,5,6,10,11	2,3,10,11	
11	2,3,7,8,9,10,11,12	1,2,3,4,5,6,10,11	2,3,10,11	
12	7,8,9,12	1,2,3,4,5,6,7,8,9,10,11,12	7,8,12	

Table 4.8: Level partitions for enablers: Iteration-III

Sl. No	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,10,11,12	1	1	
2	2,3,7,8,10,11,12	1,2,3,4,5,6,10,11	2,3,10,11	
3	2,3,7,8,10,11,12	1,2,3,4,5,6,10,11	2, 3,10,11	
4	2,3,4,5,6,7,8,10,11,12	1,4,5,6	4,5,6	
5	2,3,4,5,6,7,8,10,11,12	1,4,5,6	4,5,6	
6	2,3,4,5,6,7,8,10,11,12	1,4,5,6	4,5,6	
7	7,8,12	1,2,3,4,5,6,7,8,10,11,12	7,8,12	**III**
8	7,8,12	1,2,3,4,5,6,7,8,10,11,12	7,8,12	**III**
10	2,3,7,8,10,11,12	1,2,3,4,5,6,10,11	2,3,10,11	
11	2,3,7,8,10,11,12	1,2,3,4,5,6,10,11	2,3,10,11	
12	7,8,12	1,2,3,4,5,6,7,8,10,11,12	7,8,12	**III**

Table 4.9: Level partitions for enablers: Iteration-IV

Sl. No	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,10,11	1	1	
2	2,3,10,11	1,2,3,4,5,6,10,11	2,3,10,11	**IV**
3	2,3,10,11	1,2,3,4,5,6,10,11	2, 3,10,11	**IV**
4	2,3,4,5,6,10,11	1,4,5,6	4,5,6	
5	2,3,4,5,6,10,11	1,4,5,6	4,5,6	
6	2,3,4,5,6,10,11	1,4,5,6	4,5,6	
10	2,3,10,11	1,2,3,4,5,6,10,11	2,3,10,11	**IV**
11	2,3,10,11	1,2,3,4,5,6,10,11	2,3,10,11	**IV**

Table 4.10: Level partitions for enablers: Iteration-V

Sl. No	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,4,5,6	1	1	
4	4,5,6	1,4,5,6	4,5,6	**V**
5	4,5,6	1,4,5,6	4,5,6	**V**
6	4,5,6	1,4,5,6	4,5,6	**V**

Table 4.11: Level partitions for enablers: Iteration-VI

Sl. No	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1	1	**VI**

4.3.5 Formation of ISM based Model

The structured ISM model developed from the final reachability matrix is known as diagraph. The transitivity links are removed and the node numbers are replaced by statements and an ISM model is developed, which is shown in figure 4.3. From this figure, it is observed that Involvement and Support from top management (E1) is the most significant enabler for integration of SC through digitalization, as it comes at the base of the ISM hierarchy. Further extended enterprise (E13) is the top-level enabler in the model.

4.3.6 MICMAC Analysis

Matriced'Impacts croises-multiplication applique' and classment is abbreviated as MICMAC. Based on the driving power and dependence power of the variables, MICMAC analysis is done (Attri et al., 2020). In MICMAC analysis, variables will be classified into four clusters, identified as, (i) autonomous variables, (ii) dependent variables, (iii) linkage variables and (iv) independent variables as mentioned in Table 4.12.

Table 4.12: Cluster classification based on MICMAC analysis

Sl. No.	Driving Power	Dependence Power	Cluster
1	Weak	Weak	Autonomous enablers
2	Weak	Strong	Dependent enablers
3	Strong	Strong	Linkage enablers
4	Strong	Weak	Independent enablers

(i) Autonomous variables have weak driving power and weak dependence power. These enablers are relatively disconnected from the system, as they have few links. These enablers are represented in Quadrant-I.

(ii) Dependent variables have weak driving power and strong dependence power. These enablers are represented in Quadrant-II.

(iii) Linkage variables are those variables that have strong driving power and strong dependence power. As these variables are having strong driving and dependence power, they are unstable. Any alterations on these variables will have an effect on other enablers. These variables are shown in Quadrant-III.

(iv) Independent variables have strong driving power, but weak dependence power. These variables are placed in Quadrant--IV.

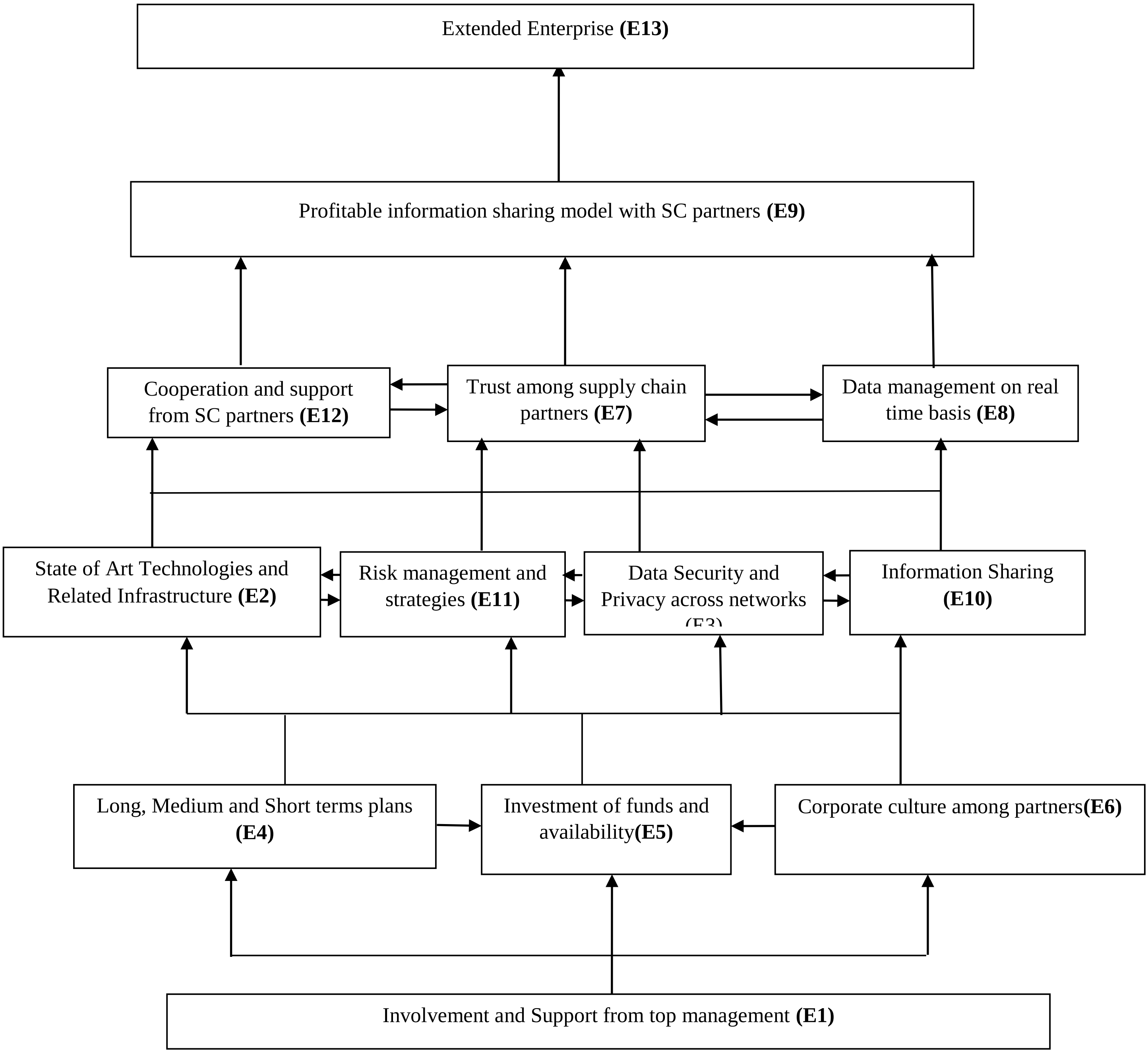


Figure 4.3: An ISM based model for enablers in SCD

The driving power and dependence power diagram of the enablers of SC constructed is shown in figure 4.4. The dependence power is represented in X axis and the Y axis represents the driving power of the respective enablers. Based on the driving power and dependence powers, the enablers identified are classified under the four clusters.

4.4. Results and discussions

The process of SCD is a challenging task. The key factors influencing transformation from traditional SCM approach to digital one needs due consideration. Thus, an analysis of key enablers affecting the digitalization process is vital. In this study, key enablers influencing SCD in an electronic industry were identified from literature and in consultation with experts from the industry and academia. Further, these key enablers were analyzed using ISM method and MICMAC analysis. Findings of this study provide a roadmap by which organizations can smoothly undertake the process of SCD. The major findings of this study based on the ISM model and MICMAC analysis are as follows.

The hierarchical structural model constructed based on the level partitioning of enablers at six levels is shown in Figure 4.3. The enablers classified at lower level facilitates in achieving effective digitalization by driving through the enablers positioned subsequently at upper levels. Enablers with high driving power occupy at the lower level, while the enablers with high dependence power occupy at the higher level in the ISM model.

Results indicate that the enabler involvement and support from top management (E1) has appeared at the bottom of the ISM model. Thus, it is a key enabler responsible for initiating supply chain digitalization processes in organizations. Literature indicates that top management involvement and support has a major influence on aspects of supply chain connectivity and information sharing (Shibin et al., 2020). For the case electronics company, decision taken by top management and the support initiates the process of digital transformation of SC. This enabler has the highest driving power and thus it signifies that it is driving the remaining enablers in the model. Thus, it becomes evident that top management of organizations need to be proactive in initiating the process of digitalization for achieving success.

The enablers, long, medium and short terms plan (E4), investment of funds and availability (E5) and corporate culture among partners (E6) have appeared at fifth level in the model. The involvement and support from top management will drive for finalization of implementation plans and raising funds for digitalization process. Also, top management has a major role in creating a favourable corporate culture among the partners for achieving the benefits of SCI. Literature indicates that availability of adequate funds (Min et al., 2019), effective planning (Garay-Rondero et al., 2019) and encouraging corporate culture (Ghadge et al., 2020) fosters the process of digitalization.

State of Art Technologies and Related Infrastructure (E2), risk management and strategies (E11), Data Security and Privacy across networks (E3) and information sharing (E10) have appeared at fourth level in the model. Long, medium and short term plans, investment of funds and availability and corporate culture among SC partners would lead to procurement of advanced IT infrastructure and initiating proactive steps related to strategies on risk management and information security. These would strengthen the company's infrastructure for effective information sharing (Tsironis et al., 2019).

Cooperation and support from SC partners (E12), trust among SC partners (E7) and data management on real time basis (E8) have appeared at third level in the model. Cooperation & support and trust among partners (Kamble et al., 2020c) and data management on real time basis (Kara et al., 2020) would lead to achieving profitable information sharing mode with SC partners (E9). Somjai et al., (2019) have highlighted the mediating impact of information sharing and its relation with supply chain capabilities and business performance.

Finally, it is observed that the enabler extended enterprise (E13) is dependent on many of the enablers and has appeared at the top of the ISM model. Akyuz and Gursoy (2019) have addressed importance of information technology in creation of a process oriented, strategically coupled and value creating networked supply chain leading to an extended enterprise. Further the classification of enablers based on MICMAC analysis are as follows.

Autonomous enablers: From Figure 4.4, it is noted that there are no variables found in Quadrant-I. This reveals that all the enablers considered in the study are very significant and plays a crucial role in the process of enabling SCD.

Dependent Enablers: The enablers, trust among supply chain partners (E7), Data management on real time basis (E8), profitable information sharing model with SC partners (E9), cooperation and support from SC partners (E12) and extended enterprise (E13) has come under quadrant-II. The strong dependence power of these enablers reveals that they are interdependent on other enablers. Akyuz and Gursoy (2020) has highlighted the requirement of building trust, collaboration and support from the SC partners for digital transformation of SC activities. This reveals the importance of giving weightage to trust, cooperation and collaboration among the partners facilitating real time sharing of information without any hindrance.

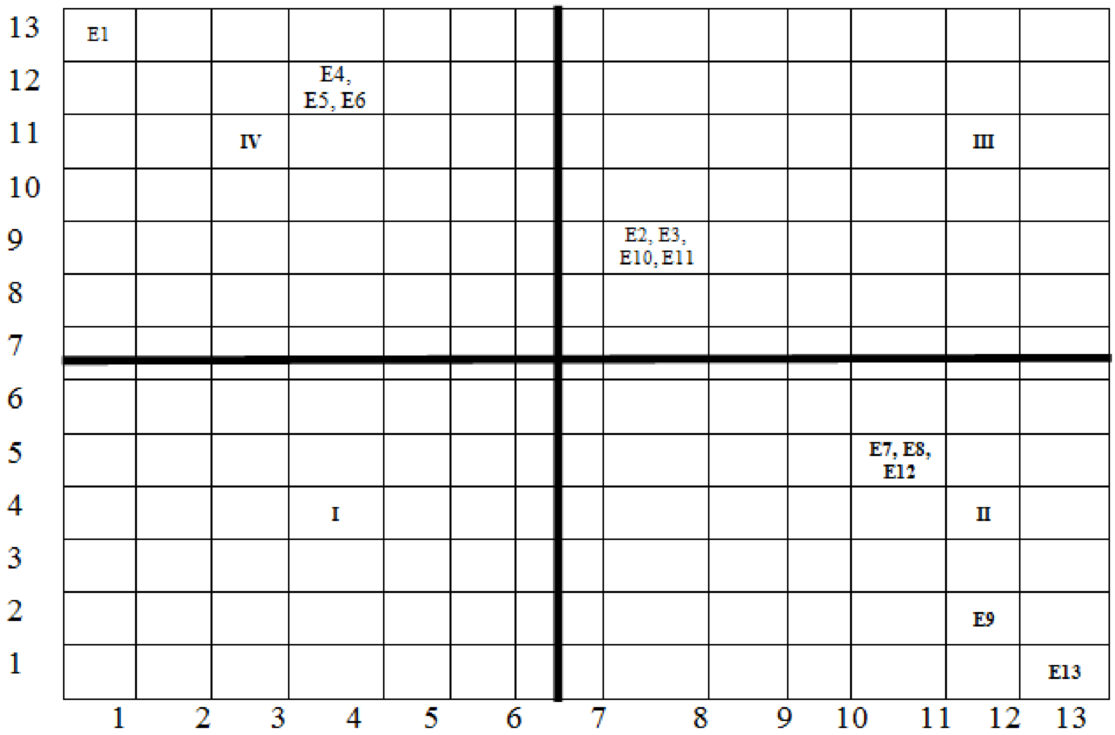


Figure 4.4: Driving and dependence power diagram

Linkage Enablers: State of Art Technologies and Related Infrastructure(E2), Data Security and Privacy across networks (E3), information sharing (E10), risk management and strategies (E11) are four enablers that have appeared under quadrant-III. These enablers possess strong driving and strong dependence powers. Literature reveals that proper IT infrastructure integration and flexibility has a positive impact on organizational performance (Hou, 2020). Munir et al., (2020) investigated the need for having effective SC risk management strategies which affects the operational performance while integrating SC through digitalization.

Independent Enablers: Involvement and support from top management (E1), long, medium and short term planning (E4), Investments of funds and availability (E5) and corporate culture among partners (E6) are four enablers that have appeared in Quadrant–IV. As these enablers possess strong driving powers, they can be classified as key enablers that need to be addressed for SCD. Wong, et al., (2020) have found that the support from top management and financial investments are crucial factors influencing the process of digitalization. Attaran (2020) has highlighted the significance of planning and its impact on the digital technology enablers during the process of SCD.

4.5. Validation of Results

In order to validate the final results and prove the robustness of the final recommendation based on the ISM method, Grey-DEMATEL approach followed by sensitivity analysis is conducted to find out the cause-effect relationship among the enablers and robustness of the results. Further, the results from both the methods were compared and validated through feedback from the industrial and academic experts. The validation done through application of Grey-DEMATEL followed by sensitivity analysis and expert feedback proves that the results are acceptable and thus validated. The diagrammatic representation of the validation methodology used is shown in Figure 4.5.

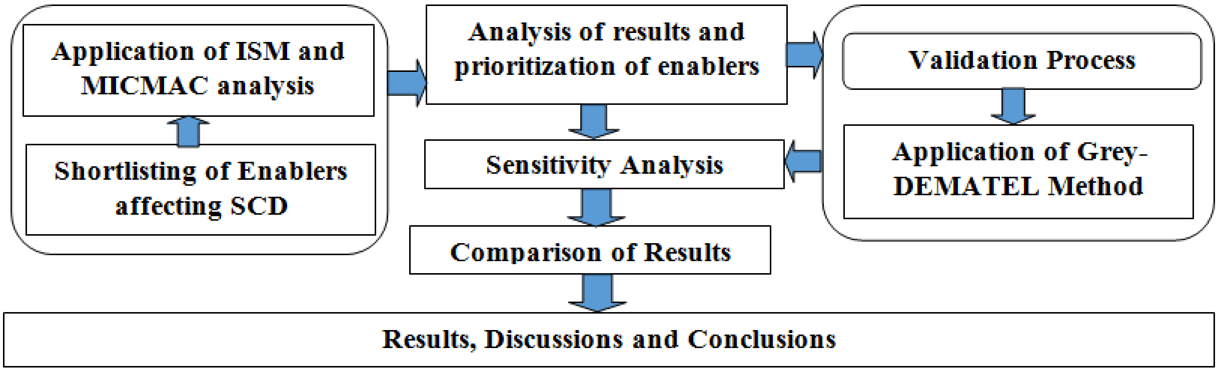


Figure 4.5: Research framework for analysis and validation of enablers of SCD

In a real case analysis, the final results of the study may get affected due to changed circumstances or human judgements and vague information resulting in biased and imprecise results. Hence, in this study a combined approach of Grey Theory with DEMATEL technique is used. The Grey-DEMATEL method doesn't require a large data set while focusing on the enablers affecting a particular firm. Use of any other quantitative models for analyzing the interrelationships and cause–effect parameters among the enablers may not yield better results. Based on the literature review and in discussion with the experts in the industry and academia, major enablers affecting the process of SCD are identified. The relationships of the enablers were analyzed by the three experts from the industry and one expert from academia. An initial direct relationship matrix was formed based on the feedback and discussions from the experts. Further, Grey-DEMATEL method was used to analyze the enablers of the SCD process.

Grey based DEMATEL method is used to analyze the key enablers of SCD. The main aspects of the methodology used and reasons for selection of the methodology are briefly explained. Grey-DEMATEL methodology has been used by researchers for analysis, development and evaluation of industrial systems, for e.g., barriers of automotive industry (Xia et.al, 2015); selection of third party logistics service providers (Govindan et. al., 2016); barrier analysis of shale gas (Wei et.al.2019), etc. Thus grey-based DEMATEL method provides enormous benefits compared to any other methods in dealing with uncertainties caused by lack of proper information and small sample size. By using this method, the prominent influential relations among the enablers facilitating for effective integration of the supply chain can be analyzed. The steps involved in the grey-DEMATEL method are explained in this sub-section.

4.5.1 Grey System theory

Grey system theory is a mathematical theory of grey numbers proposed from a grey set and is very useful for decision making under situations when only a part of the whole information is known (Deng 1982). One of the major advantages of grey theory is that the possible outcomes can be generated with partial information and can be used for decision making process to improve the accuracy of judgments. Also, grey theory can effectively deal with ambiguities resulting from human judgments. Each grey system is defined by grey numbers, grey equations and grey matrices. By integrating a three step procedure, grey numbers can be easily convertible into crisp numbers using modified CFCS method (Fu et al., 2012).

4.5.2 DEMATEL method

DEMATEL method was developed in1970s which is a structural modelling approach used to build and analyze the interdependence relationships and cause-effect relationships between a set of factors (Fontela and Gabus, 1972). It provides solutions to complicated problems by classifying the factors into either as cause or effect group (Wu and Lee, 2007). The interrelationships among the factors can be identified with digraphs or matrices (Wu et al., 2010). Steps in the methodology for grey-DEMATEL are explained below.

Step 1: The first step in the process is to set up a direct relation matrix based on expert's opinion in terms of a five level grey linguistic scale; "No influence", "Very low influence", "Low influence", "High influence" and "Very high influence" are used in this research.

Step 2: In this step, the grey relation matrices are found out. A grey number is converted to an interval with known upper and lower bounds;

$$\otimes x_{ij}^{k} = \left(\underline{\otimes}\, x_{ij}^{k},\ \ \overline{\otimes}\, x_{ij}^{k}\right) \qquad \text{(i)}$$

where respondent *k* rates the influence of success factor *i* over success factor *j*.

Step 3: By combining all grey direct-relation matrices, an average grey relation matrix ($\otimes\, \tilde{x}_{ij}$) is obtained:

$$\otimes\, \tilde{x}_{ij} = \left(\frac{\sum_k \underline{\otimes} x_{ij}^{k}}{q}, \frac{\sum_k \overline{\otimes} x_{ij}^{k}}{q}\right) \qquad \text{(ii)}$$

where q is the number of experts or evaluators.

Step 4: In this step, from the average grey relation matrix the crisp relation matrix is computed. Grey values are converted into crisp values using modified- CFCS method (Arikan et al., 2013) by following the three-step procedure as detailed below:

4.1 Grey values are normalized as:

$$\underline{\otimes}\, \bar{x}_{ij} = \left(\underline{\otimes}\, \tilde{x}_{ij} - {}^{min}_{\ \ j}\underline{\otimes}\, \tilde{x}_{ij}\right)/\Delta_{min}^{max} \qquad \text{(iii)}$$

where $\underline{\otimes}\, \bar{x}_{ij}$ represents the normalized lower limit value of the grey number $\otimes\, \tilde{x}_{ij}$

$$\overline{\otimes}\, \bar{x}_{ij} = \left(\overline{\otimes}\, \tilde{x}_{ij} - {}^{min}_{\ \ j}\overline{\otimes}\, \tilde{x}_{ij}\right)/\Delta_{min}^{max} \qquad \text{(iv)}$$

where $\overline{\otimes}\, \bar{x}_{ij}$ represents the normalized upper limit value of the grey number $\otimes\, \tilde{x}_{ij}$, and

$$\Delta_{min}^{max} = {}^{max}_{\ \ j}\overline{\otimes}\, \tilde{x}_{ij} - {}^{min}_{\ \ j}\underline{\otimes}\, \tilde{x}_{ij} \qquad \text{(v)}$$

4.2 Total normalized crisp values are computed as:

$$Y_{ij} = \left(\frac{\left(\underline{\otimes}\bar{x}_{ij}(1-\underline{\otimes}\bar{x}_{ij})\right)+\left(\overline{\otimes}\bar{x}_{ij}\times\overline{\otimes}\bar{x}_{ij}\right)}{\left(1-\underline{\otimes}\bar{x}_{ij}+\overline{\otimes}\bar{x}_{ij}\right)}\right) \qquad \text{(vi)}$$

4.3 Final crisp values are computed as:

$$z_{ij}^{*} = \left(min\ \underline{\otimes}\, \tilde{x}_{ij} + \left(Y_{ij} \times \Delta_{min}^{max}\right)\right) \qquad \text{(vii)}$$

and, $Z = \left[z_{ij}^{*}\right]$ (viii)

Step 5: Normalized direct crisp relation matrix X is computed by obtaining K and then multiplying average relation matrix *Z* with K.

$$K = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}} \quad \text{(ix)}$$

and $X = Z \times K$ (x)

Step 6: Total relation matrix *M* is obtained as:

$$M = X \times (I - X)^{-1} \quad \text{(xi)}$$

Where *I* is the identity matrix.

Step 7: In this step, the cause and effect parameters among the factors are computed. In total relation matrix M determined above, let represent its elements. Establish R as *n×1* vector, which is the sum of row elements of M. Then, the sum of i^{th} row elements in matrix *M* shows both direct and indirect effects given by success factor *i* towards the other enablers. Establish C as *1×n* vector, which is sum of column elements of M. Also, the sum of j^{th} column in matrix *M,* shows both direct and indirect effects received by success factor *j* from other enablers.

$$R_i = \sum_{j=1}^{n} m_{ij} \forall i \quad \text{(xii)}$$
$$C_j = \sum_{i=1}^{n} m_{ij} \forall j \quad \text{(xiii)}$$

Then dataset $(R_i + C_{j,} R_i - C_j)$ can be formed. $\left(R_i + C_j\right)$ $denotes$ total effect given and received. It shows degree of prominence a success factor has among all enablers. The larger the value of$\left(R_i + C_j\right)$, greater the overall prominence of success factor *i* in terms of overall relationships with other enablers.$\left(R_i - C_j\right)$gives net effect that an success factor has in the entire system. If it is positive, then the success factor *i* is a net cause or foundation, for other enablers. If it is negative, then success factor *i* is net effect of other enablers.

Step 8: By setting up the threshold, figure is plotted. The matrix *M* shows cause and affects among the enablers and a figure is developed. Dataset $(R_i + C_{j,} R_i - C_j)$is then plotted onto a two dimensional axis for each success factor to develop an overall DEMATEL prominence-causal graphs. Weare mapping only those above a threshold value and leave the negligible values as the number of relationships includes many possibilities. This threshold value is calculated by taking the mean of the values m_{ij} from M and then adding one standard deviation to the mean. Digraph showing causal relations above threshold value is plotted from the dataset of $\left(\left(R_i + C_j\right), \left(R_i - C_j\right)\right) \forall i = j$.

The application of proposed model to the case electronics company consists of following three phases:

Phase- I- Data Collection and Identification of enablers of SCD.

Phase- II- Analyzing the shortlisted enablers with Grey-DEMATEL Approach

Phase- III – Results validation

Step 1-2: A direct relationship matrix was formed by using the linguistic assessment scale as shown in Table 4.13.

Table 4.13: Linguistic assessment and associated grey values

Linguistic assessment	Associated grey values	Abbreviation used
No Influence	(0, 0.01)	N
Low Influence	(0.01, 0.25)	L
Medium Influence	(0.25, 0.5)	M
High influence	(0.5, 0.75)	H
Very high influence	(0.75, 1.0)	VH

The direct relationship matrix for enablers of SCD as assessed by experts in grey scales are given from Tables 4.14 - 4.17.

Table 4.14: Linguistic scale direct-relation matrix for enablers of SCD given by Expert 1

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0	0.75	0.75	0.5	0.25	0	0.01	0	0.01	0	0	0.25	0.5
	0.01	1	1	0.75	0.5	0.01	0.25	0.01	0.25	0.01	0.01	0.5	0.75
PRO	0.75	0	0.75	0.5	0.25	0.25	0.25	0.5	0.01	0.25	0.01	0	0.01
	1	0.01	1	0.75	0.5	0.5	0.5	0.75	0.25	0.5	0.25	0.01	0.25
EXE	0.5	0.25	0	0.25	0.01	0	0.01	0.5	0.01	0.01	0	0	0.75
	0.75	0.5	0.01	0.5	0.25	0.01	0.25	0.75	0.25	0.25	0.01	0.01	1
TRUST	0.25	0.01	0.5	0	0.01	0.25	0.5	0.75	0.01	0.01	0.5	0.01	0.75
	0.5	0.25	0.75	0.01	0.25	0.5	0.75	1	0.25	0.25	0.75	0.25	1
CSP	0	0.01	0.25	0.01	0	0.01	0.25	0.01	0.25	0.01	0.01	0.01	0
	0.01	0.25	0.5	0.25	0.01	0.25	0.5	0.25	0.5	0.25	0.25	0.25	0.01
FUNDS	0	0.75	0.01	0.75	0.01	0	0.25	0.25	0.01	0.25	0.01	0	0
	0.01	1	0.25	1	0.25	0.01	0.5	0.5	0.25	0.5	0.25	0.01	0.01
CULT	0.25	0.5	0.25	0.75	0.01	0.5	0	0.25	0	0.25	0	0.01	0.25
	0.5	0.75	0.5	1	0.25	0.75	0.01	0.5	0.01	0.5	0.01	0.25	0.5
SAT	0.01	0.75	0.5	0.5	0.01	0.25	0.5	0	0.01	0.25	0.25	0.01	0.25
	0.25	1	0.75	0.75	0.25	0.5	0.75	0.01	0.25	0.5	0.5	0.25	0.5
RTD	0.01	0.25	0.01	0	0	0.01	0.01	0.01	0	0	0.25	0.01	0
	0.25	0.5	0.25	0.01	0.01	0.25	0.25	0.25	0.01	0.01	0.5	0.25	0.01
TMC	0.01	0.75	0.01	0.5	0.01	0.01	0.25	0.5	0.01	0	0.75	0.01	0.5
	0.25	1	0.25	0.75	0.25	0.25	0.5	0.75	0.25	0.01	1	0.25	0.75
LMS	0.01	0.5	0.5	0.25	0.01	0.25	0.01	0.25	0.01	0.75	0	0.01	0.75
	0.25	0.75	0.75	0.5	0.25	0.5	0.25	0.5	0.25	1	0.01	0.25	1
RMS	0.01	0.01	0	0.25	0.01	0	0	0	0.01	0.25	0.25	0	0.25
	0.25	0.25	0.01	0.5	0.25	0.01	0.01	0.01	0.25	0.5	0.5	0.01	0.5
INF	0.75	0.5	0.75	0.5	0.01	0.01	0.01	0.25	0.01	0.25	0.25	0.01	0
	1	0.75	1	0.75	0.25	0.25	0.25	0.5	0.25	0.5	0.5	0.25	0.01

Table.4.15: Linguistic scale direct-relation matrix for enablers of SCD given by Expert 2

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0	0.5	0.75	0.75	0.01	0.01	0.01	0.01	0.01	0	0.01	0.25	0.5
	0.01	0.75	1	1	0.25	0.25	0.25	0.25	0.25	0.01	0.25	0.5	0.75
PRO	0.5	0	0.5	0.75	0.01	0.01	0.25	0.75	0.25	0.01	0.25	0.01	0.01
	0.75	0.01	0.75	1	0.25	0.25	0.5	1	0.5	0.25	0.5	0.25	0.25
EXE	0.5	0.01	0	0.01	0.25	0.01	0.25	0.25	0.01	0	0	0.01	0.5
	0.75	0.25	0.01	0.25	0.5	0.25	0.5	0.5	0.25	0.01	0.01	0.25	0.75
TRUST	0.01	0.25	0.5	0	0	0.01	0.75	0.5	0.25	0.25	0.5	0.01	0.5
	0.25	0.5	0.75	0.01	0.01	0.25	1	0.75	0.5	0.5	0.75	0.25	0.75
CSP	0.01	0.25	0.01	0.25	0	0.25	0.01	0.25	0.01	0.25	0.25	0.25	0
	0.25	0.5	0.25	0.5	0.01	0.5	0.25	0.5	0.25	0.5	0.5	0.5	0.01
FUNDS	0.01	0.5	0.25	0.5	0.25	0	0.01	0.01	0.25	0.5	0.25	0.01	0
	0.25	0.75	0.5	0.75	0.5	0.01	0.25	0.25	0.5	0.75	0.5	0.25	0.01
CULT	0.01	0.75	0.5	0.5	0.25	0.25	0	0.01	0.01	0.01	0.01	0	0.01
	0.25	1	0.75	0.75	0.5	0.5	0.01	0.25	0.25	0.25	0.25	0.01	0.25
SAT	0.01	0.5	0.75	0.25	0.25	0.01	0.75	0	0.25	0.01	0.01	0	0.01
	0.25	0.75	1	0.5	0.5	0.25	1	0.01	0.5	0.25	0.25	0.01	0.25
RTD	0.25	0.01	0.25	0.01	0.01	0.25	0.25	0.01	0	0.01	0.01	0.01	0
	0.5	0.25	0.5	0.25	0.25	0.5	0.5	0.25	0.01	0.25	0.25	0.25	0.01
TMC	0.25	0.5	0.01	0.25	0.01	0.25	0.01	0.5	0.25	0	0.5	0.25	0.5
	0.5	0.75	0.25	0.5	0.25	0.5	0.25	0.75	0.5	0.01	0.75	0.5	0.75
LMS	0.25	0.75	0.5	0.01	0.01	0.01	0.25	0.01	0.25	0.5	0	0.25	0.5
	0.5	1	0.75	0.25	0.25	0.25	0.5	0.25	0.5	0.75	0.01	0.5	0.75
RMS	0.25	0.25	0.01	0.01	0.25	0.01	0.01	0	0	0.01	0.01	0	0.01
	0.5	0.5	0.25	0.25	0.5	0.25	0.25	0.01	0.01	0.25	0.25	0.01	0.25
INF	0.5	0.75	0.5	0.75	0.25	0.01	0.25	0.01	0.01	0.25	0.01	0.25	0
	0.75	1	0.75	1	0.5	0.25	0.5	0.25	0.25	0.5	0.25	0.5	0.01

Table 4.16: Linguistic scale direct-relation matrix for enablers of SCD given by Expert 3

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0	0.5	0.5	0.75	0.01	0.01	0	0	0.01	0.01	0	0.25	0.5
	0.01	0.75	0.75	1	0.25	0.25	0.01	0.01	0.25	0.25	0.01	0.5	0.75
PRO	0.5	0	0.5	0.75	0.01	0.25	0.01	0.5	0.25	0.01	0.25	0.01	0
	0.75	0.01	0.75	1	0.25	0.5	0.25	0.75	0.5	0.25	0.5	0.25	0.01
EXE	0.75	0.25	0	0.01	0.25	0.01	0.01	0.75	0.25	0.25	0	0.01	0.5
	1	0.5	0.01	0.25	0.5	0.25	0.25	1	0.5	0.5	0.01	0.25	0.75
TRUST	0.01	0.25	0.75	0	0.25	0.01	0.75	0.5	0.25	0.25	0.5	0.25	0.5
	0.25	0.5	1	0.01	0.5	0.25	1	0.75	0.5	0.5	0.75	0.5	0.75
CSP	0.01	0	0.01	0.25	0	0.25	0.01	0.25	0.01	0.25	0.25	0	0
	0.25	0.01	0.25	0.5	0.01	0.5	0.25	0.5	0.25	0.5	0.5	0.01	0.01
FUNDS	0.01	0.5	0.25	0.5	0.25	0	0.01	0.01	0.25	0.01	0.01	0.01	0
	0.25	0.75	0.5	0.75	0.5	0.01	0.25	0.25	0.5	0.25	0.25	0.25	0.01
CULT	0.01	0.75	0.01	0.5	0.25	0.5	0	0.01	0	0.01	0.01	0	0.01
	0.25	1	0.25	0.75	0.5	0.75	0.01	0.25	0.01	0.25	0.25	0.01	0.25
SAT	0.25	0.5	0.75	0.75	0.25	0.01	0.75	0	0.25	0.01	0.01	0.25	0.01
	0.5	0.75	1	1	0.5	0.25	1	0.01	0.5	0.25	0.25	0.5	0.25
RTD	0.25	0.01	0.25	0.01	0.01	0	0.01	0	0	0.01	0.01	0.25	0.01
	0.5	0.25	0.5	0.25	0.25	0.01	0.25	0.01	0.01	0.25	0.25	0.5	0.25
TMC	0.25	0.75	0.01	0.25	0	0.01	0.5	0.25	0.01	0	0.75	0.25	0.25
	0.5	1	0.25	0.5	0.01	0.25	0.75	0.5	0.25	0.01	1	0.5	0.5
LMS	0.25	0.75	0.25	0.5	0.01	0.01	0.01	0.25	0.01	0.01	0	0.25	0.5
	0.5	1	0.5	0.75	0.25	0.25	0.25	0.5	0.25	0.25	0.01	0.5	0.75
RMS	0.25	0.25	0.01	0.01	0.25	0.01	0	0	0.25	0.25	0.01	0	0.01
	0.5	0.5	0.25	0.25	0.5	0.25	0.01	0.01	0.5	0.5	0.25	0.01	0.25
INF	0.75	0.25	0.5	0.25	0.25	0	0.01	0.01	0.25	0.01	0.25	0.01	0
	1	0.5	0.75	0.5	0.5	0.01	0.25	0.25	0.5	0.25	0.5	0.25	0.01

Table 4.17: Linguistic scale direct-relation matrix for enablers of SCD given by Expert 4

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0	0.5	0.5	0.75	0.01	0.01	0.25	0.01	0	0	0.01	0.01	0.75
	0.01	0.75	0.75	1	0.25	0.25	0.5	0.25	0.01	0.01	0.25	0.25	1
PRO	0.5	0	0.5	0.75	0.5	0.01	0.01	0.25	0.01	0.01	0.01	0.01	0
	0.75	0.01	0.75	1	0.75	0.25	0.25	0.5	0.25	0.25	0.25	0.25	0.01
EXE	0.75	0.5	0	0.5	0.01	0.01	0	0.75	0.01	0.25	0.01	0	0.5
	1	0.75	0.01	0.75	0.25	0.25	0.01	1	0.25	0.5	0.25	0.01	0.75
TRUST	0.25	0.25	0.75	0	0.01	0.01	0.25	0.75	0.5	0.25	0	0.5	0.5
	0.5	0.5	1	0.01	0.25	0.25	0.5	1	0.75	0.5	0.01	0.75	0.75
CSP	0.01	0.01	0.5	0.25	0	0.01	0.01	0	0.25	0.01	0.01	0	0.01
	0.25	0.25	0.75	0.5	0.01	0.25	0.25	0.01	0.5	0.25	0.25	0.01	0.25
FUNDS	0.01	0.5	0.25	0.5	0.25	0	0.25	0.01	0.01	0.01	0.25	0	0.01
	0.25	0.75	0.5	0.75	0.5	0.01	0.5	0.25	0.25	0.25	0.5	0.01	0.25
CULT	0.25	0.5	0.25	0.5	0.01	0.5	0	0.25	0.01	0.01	0.01	0	0.25
	0.5	0.75	0.5	0.75	0.25	0.75	0.01	0.5	0.25	0.25	0.25	0.01	0.5
SAT	0.25	0.5	0.75	0.75	0.01	0.01	0.75	0	0.25	0.25	0.01	0.25	0.01
	0.5	0.75	1	1	0.25	0.25	1	0.01	0.5	0.5	0.25	0.5	0.25
RTD	0.25	0.01	0.25	0.01	0.01	0	0	0.01	0	0.01	0.25	0.01	0.01
	0.5	0.25	0.5	0.25	0.25	0.01	0.01	0.25	0.01	0.25	0.5	0.25	0.25
TMC	0.01	0.5	0.01	0.5	0.25	0.25	0.01	0.75	0.25	0	0.75	0.25	0.75
	0.25	0.75	0.25	0.75	0.5	0.5	0.25	1	0.5	0.01	1	0.5	1
LMS	0.25	0.5	0.75	0.25	0.25	0.01	0	0.01	0.01	0.01	0	0.5	0.5
	0.5	0.75	1	0.5	0.5	0.25	0.01	0.25	0.25	0.25	0.01	0.75	0.75
RMS	0.25	0.25	0.01	0.01	0.01	0.01	0.01	0.01	0.25	0.01	0.01	0	0.01
	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.25	0.25	0.01	0.25
INF	0.5	0.5	0.5	0.5	0.25	0.01	0.25	0.25	0.25	0.01	0.01	0	0
	0.75	0.75	0.75	0.75	0.5	0.25	0.5	0.5	0.5	0.25	0.25	0.01	0.01

Step 3- 4: The average grey relation matrix is formed by giving equal weighting to all the supply chain experts in order to have homogeneity. Further, the crisp relation matrix is formed by following the equations (iii) to (viii) are shown in Table 4.18.

Table 4.18: Crisp relation matrix for enablers of SCD

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0	0.736	0.801	0.877	0.175	0.044	0.106	0.019	0.054	0.008	0.018	0.328	0.746
PRO	0.736	0	0.726	0.877	0.343	0.223	0.204	0.659	0.247	0.159	0.204	0.054	0.02
EXE	0.811	0.357	0	0.279	0.258	0.044	0.106	0.736	0.167	0.201	0.007	0.028	0.746
TRUST	0.207	0.282	0.801	0	0.138	0.147	0.726	0.811	0.411	0.317	0.464	0.33	0.746
CSP	0.038	0.109	0.279	0.277	0	0.223	0.13	0.179	0.247	0.238	0.204	0.1	0.007
FUNDS	0.038	0.736	0.277	0.726	0.341	0	0.204	0.134	0.247	0.319	0.204	0.028	0.007
CULT	0.207	0.811	0.352	0.726	0.258	0.613	0	0.207	0.028	0.159	0.037	0.009	0.212
SAT	0.207	0.736	0.877	0.726	0.258	0.147	0.877	0	0.328	0.238	0.13	0.208	0.137
RTD	0.282	0.134	0.277	0.037	0.059	0.092	0.106	0.038	0	0.05	0.204	0.167	0.02
TMC	0.207	0.811	0.057	0.501	0.138	0.223	0.279	0.659	0.247	0	0.877	0.328	0.668
LMS	0.282	0.811	0.651	0.352	0.175	0.147	0.106	0.207	0.167	0.481	0	0.411	0.746
RMS	0.282	0.282	0.037	0.13	0.258	0.044	0.018	0.006	0.208	0.238	0.13	0	0.137
INF	0.811	0.659	0.726	0.651	0.341	0.044	0.204	0.207	0.247	0.238	0.204	0.131	0

Step 5- The normalized direct crisp relation matrix X is computed by using the equations (ix) to (x) and shown in Table 4.19.

Table 4.19: Normalized direct crisp relation matrix for enablers of SCD

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0.000	0.137	0.149	0.163	0.033	0.008	0.020	0.004	0.010	0.001	0.003	0.061	0.139
PRO	0.137	0.000	0.135	0.163	0.064	0.041	0.038	0.122	0.046	0.030	0.038	0.010	0.004
EXE	0.151	0.066	0.000	0.052	0.048	0.008	0.020	0.137	0.031	0.037	0.001	0.005	0.139
TRUST	0.038	0.052	0.149	0.000	0.026	0.027	0.135	0.151	0.076	0.059	0.086	0.061	0.139
CSP	0.007	0.020	0.052	0.051	0.000	0.041	0.024	0.033	0.046	0.044	0.038	0.019	0.001
FUNDS	0.007	0.137	0.051	0.135	0.063	0.000	0.038	0.025	0.046	0.059	0.038	0.005	0.001
CULT	0.038	0.151	0.065	0.135	0.048	0.114	0.000	0.038	0.005	0.030	0.007	0.002	0.039
SAT	0.038	0.137	0.163	0.135	0.048	0.027	0.163	0.000	0.061	0.044	0.024	0.039	0.025
RTD	0.052	0.025	0.051	0.007	0.011	0.017	0.020	0.007	0.000	0.009	0.038	0.031	0.004
TMC	0.038	0.151	0.011	0.093	0.026	0.041	0.052	0.122	0.046	0.000	0.163	0.061	0.124
LMS	0.052	0.151	0.121	0.065	0.033	0.027	0.020	0.038	0.031	0.089	0.000	0.076	0.139
RMS	0.052	0.052	0.007	0.024	0.048	0.008	0.003	0.001	0.039	0.044	0.024	0.000	0.025
INF	0.151	0.122	0.135	0.121	0.063	0.008	0.038	0.038	0.046	0.044	0.038	0.024	0.000

Step 6- The total relation matrix is obtained by using the equation (xi) and shown in Table 4.20.

Table 4.20: Total relation matrix for enablers of SCD

	DSP	PRO	EXE	TRUST	CSP	FUNDS	CULT	SAT	RTD	TMC	LMS	RMS	INF
DSP	0.2196	**0.3695**	**0.4178**	**0.4132**	0.1540	0.0840	0.1678	0.2143	0.1277	0.1100	0.1079	0.1442	**0.3314**
PRO	**0.3466**	0.2842	0.4386	0.4464	0.1920	0.1282	0.2129	**0.3375**	0.1734	0.1493	0.1531	0.1131	0.2367
EXE	**0.3384**	0.3125	0.2785	0.3174	0.1619	0.0825	0.1688	0.3098	0.1401	0.1348	0.1010	0.0933	0.3183
TRUST	0.3048	**0.3914**	**0.4917**	**0.3466**	0.1832	0.1353	0.3196	**0.3898**	0.2187	0.1979	0.2150	0.1715	**0.3816**
CSP	0.1025	0.1464	0.1791	0.1748	0.0579	0.0805	0.0974	0.1298	0.1018	0.0978	0.0932	0.0636	0.0993
FUNDS	0.1712	**0.3316**	0.2750	**0.3431**	0.1579	0.0711	0.1645	0.1993	0.1427	0.1482	0.1332	0.0800	0.1631
CULT	0.2229	**0.3752**	**0.3212**	**0.3817**	0.1605	0.1862	0.1452	0.2313	0.1169	0.1325	0.1110	0.0828	0.2154
SAT	0.2776	**0.4244**	**0.4696**	**0.4392**	0.1881	0.1312	**0.3282**	0.2430	0.1919	0.1690	0.1473	0.1373	0.2564
RTD	0.1212	0.1144	0.1424	0.1001	0.0529	0.0437	0.0657	0.0730	0.0380	0.0466	0.0708	0.0618	0.0768
TMC	0.2926	**0.4688**	**0.3678**	**0.4262**	0.1784	0.1425	0.2397	**0.3573**	0.1909	0.1433	0.2896	0.1752	**0.3587**
LMS	0.2906	**0.4250**	**0.4188**	**0.3621**	0.1693	0.1132	0.1806	0.2628	0.1600	0.2055	0.1239	0.1719	**0.3512**
RMS	0.1321	0.1538	0.1201	0.1335	0.0950	0.0411	0.0608	0.0813	0.0854	0.0866	0.0717	0.0396	0.1058
INF	**0.3685**	**0.3900**	**0.4338**	**0.4079**	0.1908	0.0951	0.1981	0.2593	0.1694	0.1581	0.1518	0.1240	0.2288

Step 7- The Cause/ effect parameters for enablers of SCI were computed from the total relation matrix and is shown in Table 4.21.

Step 8: All the values above the threshold value is depicted in bold in Table 4.21 and their relationships are drawn.

Table 4.21: Cause/ effect parameters for enablers of SCD

Enablers	R_i	C_j	R_i+C_j	R_i-C_j
DSP	2.86142	3.188529	6.050	-0.327
PRO	3.211917	4.187232	7.399	-0.975
EXE	2.757477	4.354399	7.112	-1.597
TRUST	3.74702	4.292467	8.039	-0.545
CSP	1.424198	1.941791	3.366	-0.518
FUNDS	2.380988	1.334705	3.716	1.046
CULT	2.682808	2.349341	5.032	0.333
SAT	3.403331	3.08853	6.492	0.315
RTD	1.007293	1.856847	2.864	-0.850
TMC	3.630907	1.779538	5.410	1.851
LMS	3.234789	1.76958	5.004	1.465
RMS	1.206975	1.45827	2.665	-0.251
INF	3.175608	3.123501	6.299	0.052

A diagrammatic representation of the causal relationship among the enablers for SCD through digitalization is shown in Figure 4.6. A detailed analysis finds out that top management commitment and support (TMC) is the major cause factor for initialization of the SCD process, followed by other cause enablers like long, medium and short term planning, availability of funds and financial investment, cultural alignment among partners, state of art technologies and related infrastructure and information sharing. Accordingly, the cause enablers can be sorted as TMC>LMS>FUNDS>CULT>SAT>INF and effect enablers as RMS>DSP>CSP>TRUST>RTD>PRO>EXE.

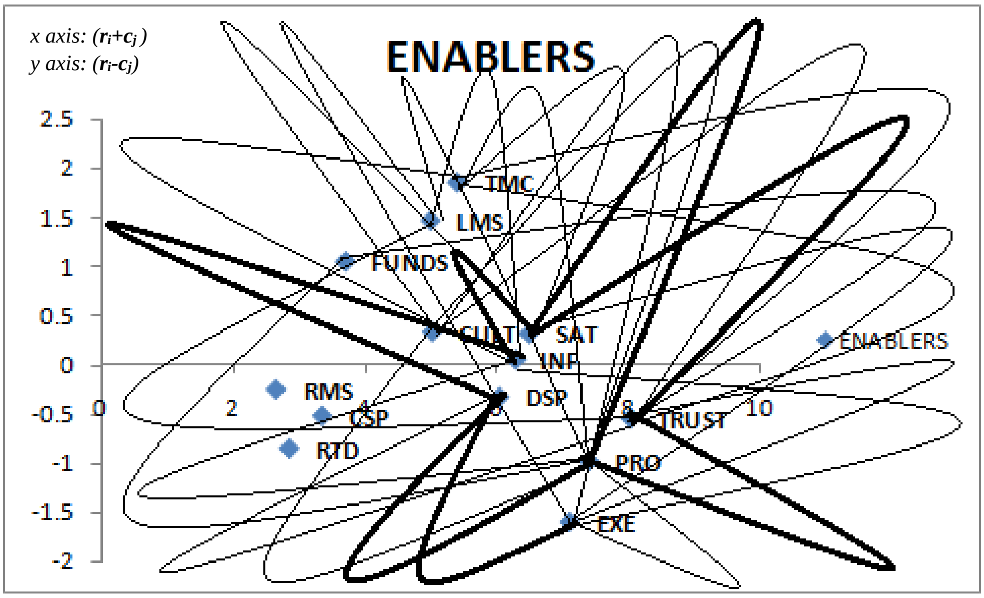


Figure 4.6: Diagram showing causal relationship among the enablers of SCD

4.6. Analysis of findings

Based on the results obtained from the Grey-based-DEMATEL method, the cause-effect relationship among the enablers is identified. Table 4.21 reveals the net cause- effect values and prominence for the enablers for SCI through digitalization. According to the value of net effect (r_i-c_j), the enablers can be divided mainly into two groups (Haleemet al., 2019):

(i) Cause group: where the (r_i-c_j) value greater than zero

(ii) Effect group: where the (r_i-c_j) value is less than zero

4.6.1 Cause group

In this group, the enablers that are having very high influence and affect other enablers very significantly are categorized. According to the (r_i-c_j,) value, it is found that top management commitment and support (TMC) is the most significant driving success factor, followed by long, medium and short term planning (LMS). Further, availability of funds and financial investment (FUNDS), cultural alignment among partners (CUL), state of art technologies and related infrastructure (SAT), and information sharing (INF) are the other major enablers coming in the causal group.

4.6.2 Effects group

It includes those enablers which are mostly affected by other enablers. The enablers where the (r_i-c_j,) value is less than zero is categorized under this group. Effective risk mitigation strategies (RMS), data security and privacy (DSP), commitment among supply chain partners (CSP), trust in supply chain linkages (TRUST), real time data analytics (RTD), profitable sharing model with SC partners (PRO) and Extended Enterprise (EXE) are the enablers categorized in effects group.

4.6.3 Correlation between the enablers

The most critical enablers among the cause and linkage groups can be found out by identifying the (r_i-c_j,) value more than the mean value of(r_i-c_j,). From this the critical enablers that are affecting the process of integration of supply chain through digitalization can be found out. Accordingly, a graph is plotted by highlighting the prominent enablers. The most prominent enablers identified is information sharing (INF), having the highest correlation with other enablers, which reveals that effective integration of the supply chain through the process of digitalization can be achieved through proper sharing of information. The real time sharing of information facilitates quick decision making, which helps the organization in gaining competitive advantage.

4.7 Sensitivity Analysis

In order to verify the robustness of the obtained results, sensitivity analysis is done by assigning the highest weight to each respondent and assigning an equal weight for other respondents. Sensitivity analysis is done by changing the weight given to a particular expert, while keeping the weights of other expert's uniform, which shows its overall effect on the system (Xia et al., 2015). As the experts considered were all Senior Managers in the firm, equal weight is given to each of the experts under four situations, i.e. under situation 1, expert 1 is given a weight of 0.34, and the weights for other three experts are kept uniform as 0.22 and the results are calculated. Likewise, the results under all the four situations are calculated by using the weights as shown in Table 4.22. Separate relationship matrix is formed for all the four situations by computing the (r_i+c_j) and (r_i-c_j) values.

Table 4.22: Weights assigned for analysts during sensitivity analysis

	Expert 1	Expert 2	Expert 3	Expert 4
Situation 1	0.34	0.22	0.22	0.22
Situation 2	0.22	0.34	0.22	0.22
Situation 3	0.22	0.22	0.34	0.22
Situation 4	0.22	0.22	0.22	0.34

Table 4.23: Cause / Effect parameters obtained during sensitivity analysis

	Situation 1		Situation 2		Situation 3		Situation 4	
	r_i+c_j	r_i-c_j	r_i+c_j	r_i-c_j	r_i+c_j	r_i-c_j	r_i+c_j	r_i-c_j
DSP	6.286	-0.328	6.222	-0.308	5.707	-0.346	6.058	-0.362
PRO	7.752	-1.007	7.638	-0.990	6.968	-0.902	7.282	-1.044
EXE	7.404	-1.738	7.230	-1.739	6.682	-1.403	7.205	-1.547
TRUST	8.391	-0.591	8.209	-0.535	7.601	-0.435	8.065	-0.617
CSP	3.352	-0.508	3.542	-0.450	3.229	-0.493	3.294	-0.509
FUNDS	3.949	1.047	3.897	1.097	3.458	0.955	3.643	1.050
CULT	5.304	0.403	5.243	0.251	4.678	0.304	4.941	0.383
SAT	6.833	0.287	6.579	0.262	6.144	0.358	6.530	0.322
RTD	2.841	-0.830	3.005	-0.867	2.756	-0.869	2.851	-0.849
TMC	5.673	1.913	5.551	1.899	5.092	1.701	5.434	1.894
LMS	5.295	1.536	5.198	1.506	4.733	1.331	4.851	1.513
RMS	2.717	-0.175	2.747	-0.271	2.603	-0.259	2.643	-0.265
INF	6.692	-0.008	6.513	0.145	5.811	0.058	6.261	0.031

Table 4.23 shows the cause/effect parameters obtained for sensitivity analysis for all the considered situations. In all the four situations the rankings of most of the enablers were not affected due to change in the weights of the experts, which shows that there is no biasness and proves robustness of the method.

The figure showing the causal relationship among the enablers of SCD in all the four situations are shown from Figures 4.7–4.10. There is similarity in the cause group for all the four situations in which the priority of enablers TMC>LMS>FUNDS>CULT>SAT> INF>RMS>DSP>CSP>TRUST>RTD>PRO>EXE remains unchanged. This shows the robustness of the results obtained. In the figure the two-way relationship among the enablers is represented with bold lines.

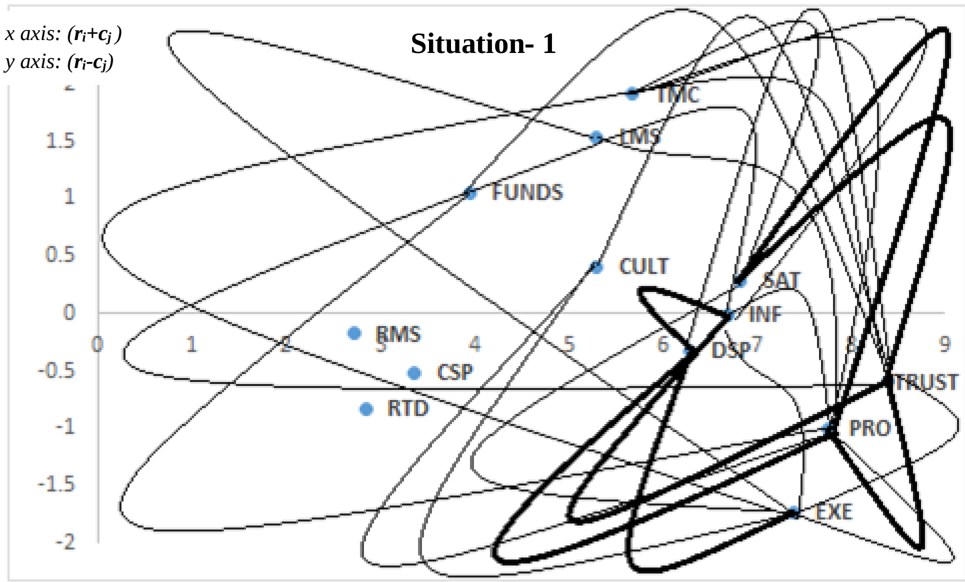


Figure 4.7: Diagram showing causal relationship among the enablers of SCD – Situation 1

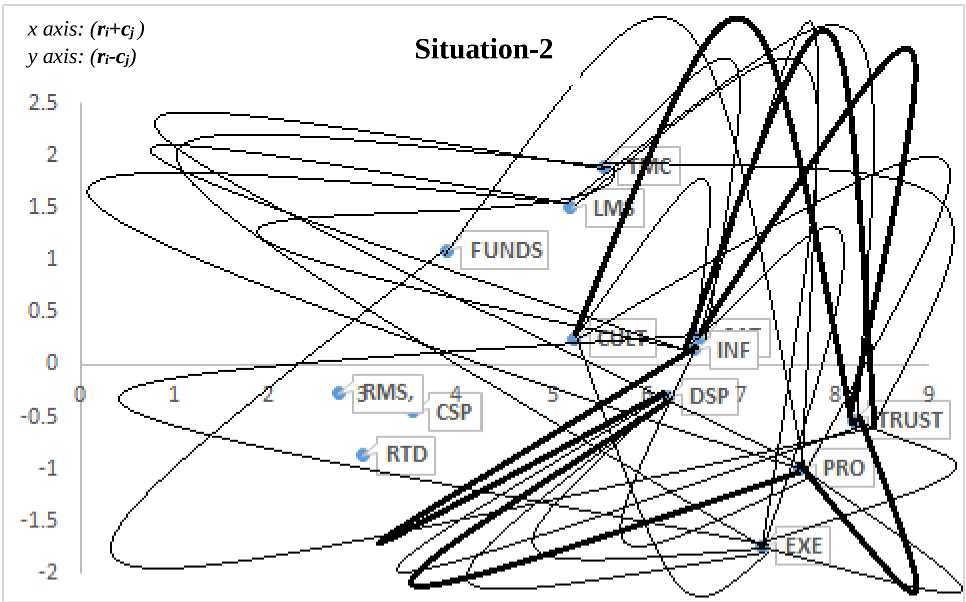


Figure 4.8: Diagram showing causal relationship among the enablers of SCD–Situation 2

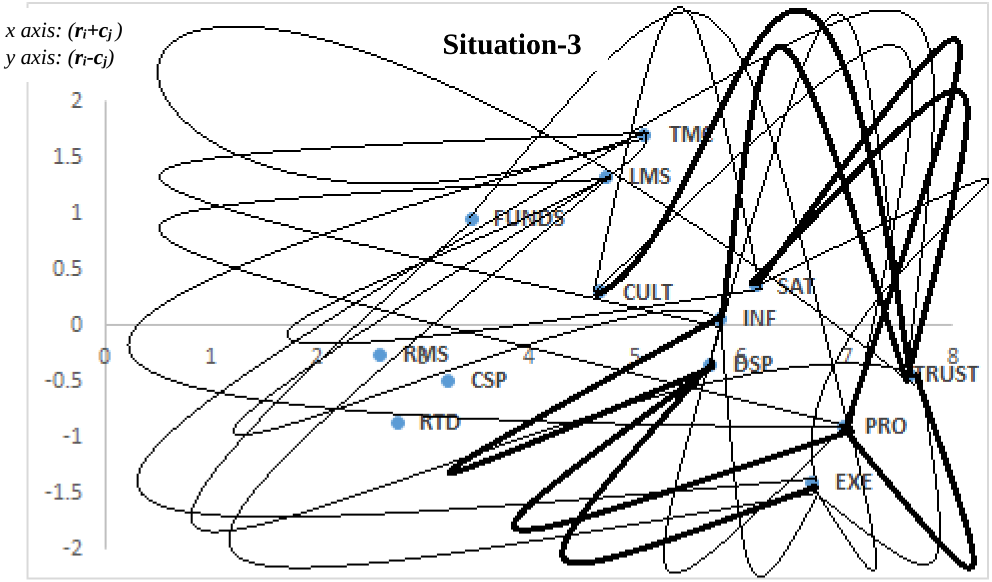


Figure 4.9: Diagram showing causal relationship among the enablers of SCD – Situation 3

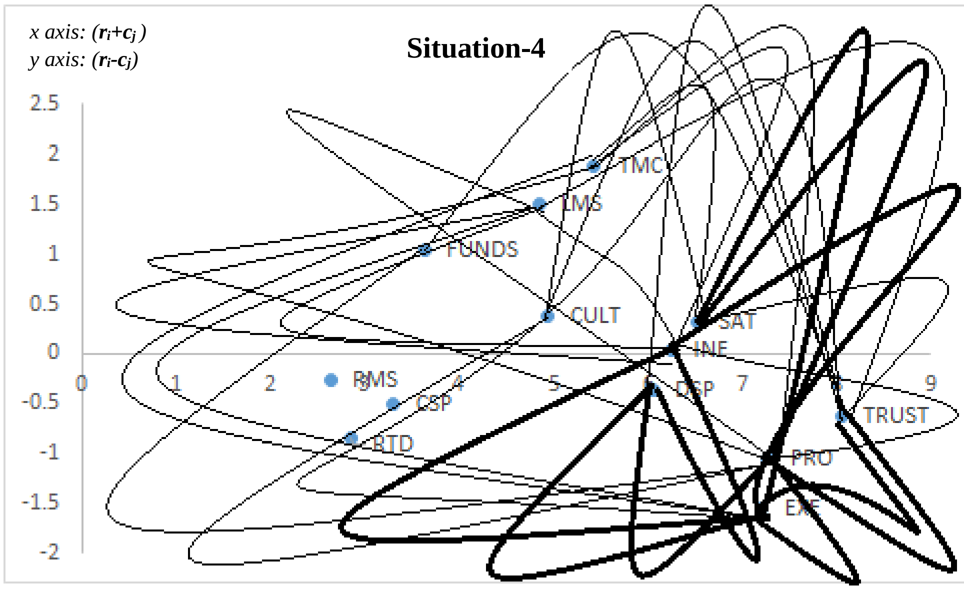


Figure 4.10: Diagram showing causal relationship among the enablers of SCD – Situation 4

The figure showing the results of sensitivity analysis of r_i+c_j *and* r_i-c_j value of enablers for SCD in different situations is shown in Figures 4.11 and 4.12 respectively.

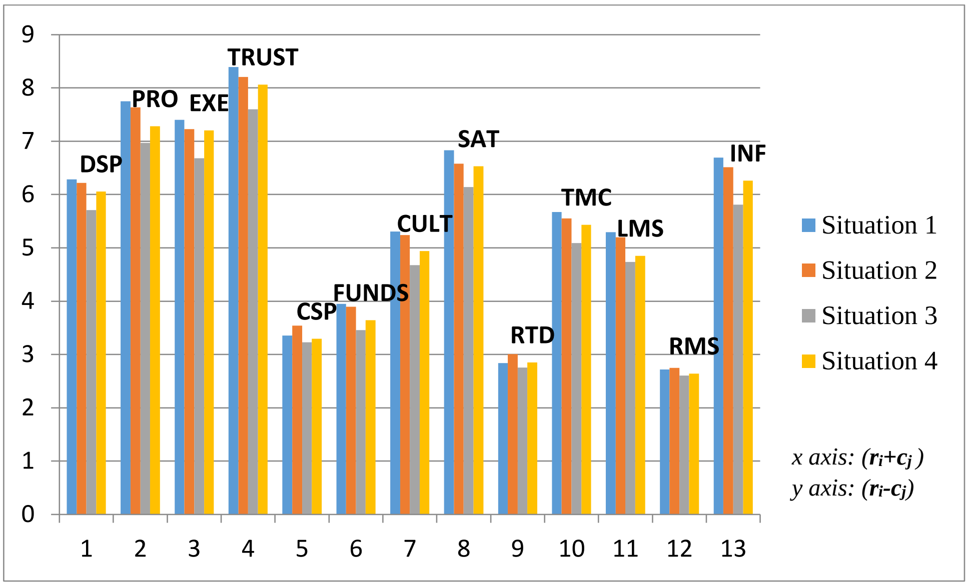


Figure 4.11: Results of sensitivity analysis of r_i+c_j value of enablers for SCD in different situations

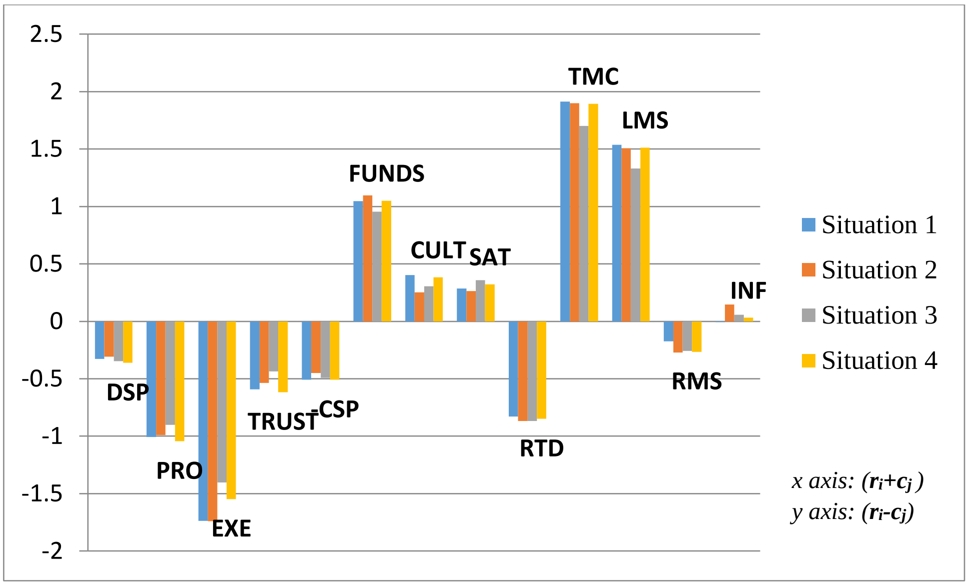


Figure 4.12: Results of sensitivity analysis of r_i-c_j value of enablers for SCD in different situations

Table 4.24. Comparison of results and validation of enablers affecting SCD

Sl.No	Abbr	Enablers	Results		
Code			ISM Model Level/Order	Grey-DEMATEL Cause/Effect	MICMAC Classification Category
E1	TMC	Involvement and Support from top management	1	Cause	Independent
E2	SAT	State of Art Technologies and Related Infrastructure	5	Cause	Linkage
E3	DSP	Data Security and Privacy across networks	7	Effect	Linkage
E4	LMS	Long, medium and short term planning	2	Cause	Independent
E5	FUNDS	Investments of funds and availability	3	Cause	Independent
E6	CULT	Corporate culture among partners	4	Cause	Independent
E7	TRUST	Trust among SC partners	10	Effect	Dependent
E8	RTD	Data management on real time basis	11	Effect	Dependent
E9	PRO	Profitable information sharing model with SC partners	12	Effect	Dependent
E10	INF	Information Sharing	8	Cause	Linkage
E11	RMS	Risk management and strategies	6	Effect	Linkage
E12	CSP	Cooperation and support from SC partners	9	Effect	Dependent
E13	EXE	Extended Enterprise	13	Effect	Dependent

In this chapter the key enablers affecting the process of digitalization are identified and analyzed and validated. Hence, the complementary research problem of identifying and analyzing the causal relations amongst the barriers of supply chain digitalization also needs to be researched. This helps in reducing the gap from the effective supply chain digitalization towards achieving better supply chain performance and gaining competitive advantage. The identification and analysis of key barriers affecting supply chain digitalization process is discussed in Chapter 5.

CHAPTER 5

MODELLING OF INTERRELATIONSHIP AND CAUSE- EFFECT RELATIONS AMONG BARRIERS OF SUPPLY CHAIN DIGITALIZATION USING ISM APPROACH AND GREY-DEMATEL METHODS

5.1 Barriers of supply chain digitalization

The major growth paths in digital transformation includes commercializing digital solutions, utilizing product connectivity and establishing an IoT platform based applications in business (Gebauer et al., 2020). DSC is a productive approach to develop various forms of returns to companies through efficient approaches based on advanced digital solutions and data analytics. Agrawal et al., (2019) has stated that lack of industry specific guidelines, no sense of urgency, lack of digital skills and talent, and high implementation and running costs are the key barriers that affect adoption of DSC.

Ghadge et al., (2020) have analyzed the impact of implementation of I 4.0 on SCs. They developed a systems dynamics model considering the potential drivers and barriers for I 4.0 paradigm. Frederico et al., (2019) presented the conceptualization of I 4.0 in the context of SC by identifying its major constructs and dimensions. Turkes et al., (2019) highlighted lack of information and decision making in Romanian Small and Medium-sized Enterprises (SMEs) while adopting advanced digital technologies.

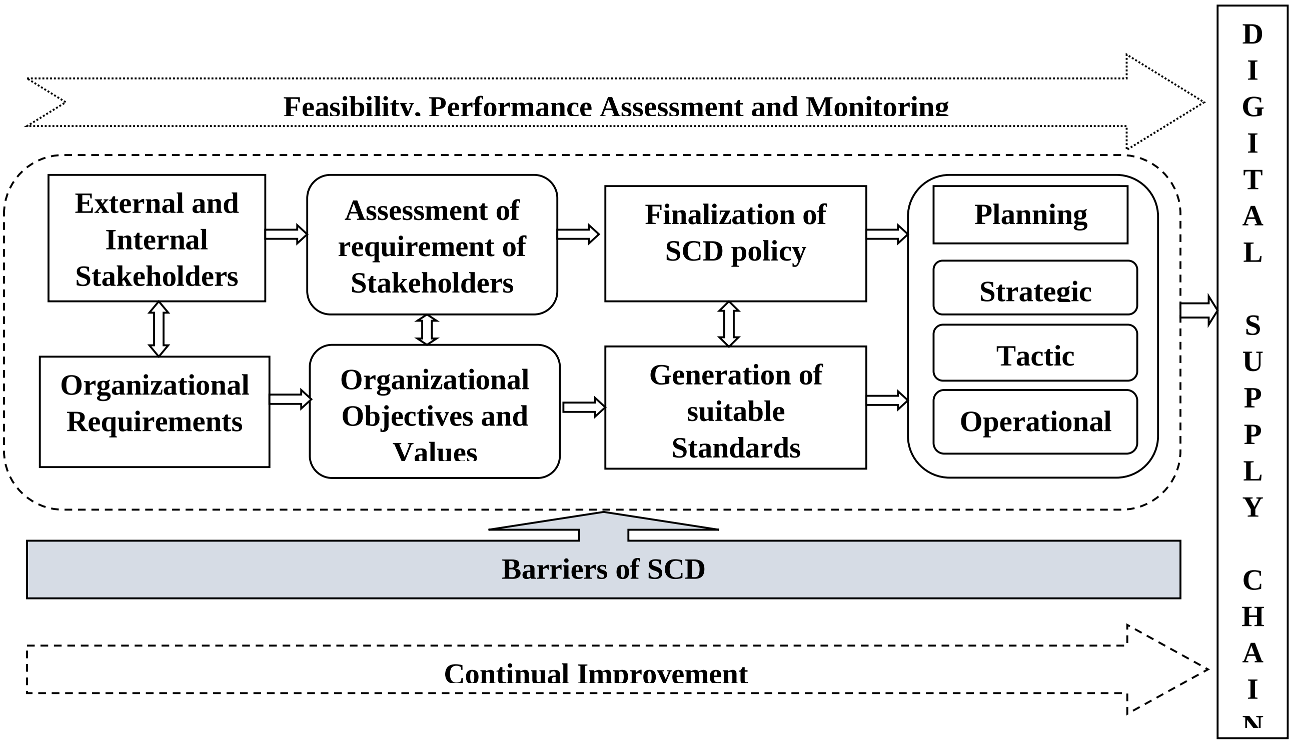


Figure 5.1: Research framework for analyzing barriers of SC digitalization

Table 5.1: Description and reference of the barriers for SCD

Sl.No.	Abbr.	Barriers	Relevance to SCD	References
B1	LSIB	Lack of knowledge on SCD benefits	Benefits reaped from SCD process should be made aware to partners in SC.	Nimmy et al., 2019; Gupta et al., 2020b; Ozkan-Ozen et al., 2020; Montecchi et al., 2019;
B2	NERD	Non-encouragement of R & D	R&D is essential to bring in innovative changes in the SCD process. Lack of R&D becomes a barrier.	Guo et al., 2020; Ghadge et al., 2020; Radanliev et al., 2019; Fu et al., 2019
B3	LFIR	Lack of financial resources	Lack of funds for arranging the resources and meeting organizational expenses	Ghadge et al., 2020; Stentoft et al., 2020; Wang et al., 2019; Xing et al., 2019
B4	MBOI	Misalignment of business objectives with IT	Digitalization process lacks purpose without proper organizational objectives	Hofmann et al., 2019; Garay-Rondero et al., 2019, Zhang et al., 2020; Preindl et al., 2020
B5	POCL	Poor organizational culture inhibiting cross functional interaction	Culture of SC partners affects initiation of SCD process	Dubey et al., 2019; Chunsheng et al., 2019; Gupta et al., 2020b
B6	TMCI	Top management commitment inadequacy	Organizations are unable to proceed with SCD due to Top management commitment inadequacy	Majumdar et al., 2019; Singh et al., 2019; Wei et al., 2020; Gupta et al., 2020b
B7	LIIS	Limited ICT infrastructure and systems	Lack of effective and advanced IT tools affects SCD process	Jamil et al., 2019; Bai et al., 2020; Vosooghidizaji et al., 2020
B8	TINS	Threats related to information security	Lack of enough security measures for information transmission	Bodkhe et al., 2020; Ismagilova et al., 2020; Rejeb et al., 2019; Schniederjans et al., 2020
B9	EMRC	Employee's reluctance to change	Non-cooperation from employees hinders SCD process	Jaaffar et al., 2019; Manville et al., 2019; Hartley et al, 2019; Cichosz et al., 2020
B10	MSCP	Mistrust among SC partners	Security and trust among partners is a significant aspect required in SCD process	Kumar et al., 2020a; Imeri et al., 2019; Wong et al., 2020; Kamble et al, 2020a
B11	LCSI	Lack of commitment from SC partners to share information	Reluctance of the partners of SC to share information across the SC	Anis et al., 2019; Sutduean et al., 2019; Girdwichai et al., 2019; Le et al., 2019
B12	DMSP	Decision making on short term perspective	Decision making perspective done with medium or short term in mind.	Holmstrom et al., 2019; Ivanov et al., 2020b; Barbosa-Povoa et al., 2020; Preindl et al., 2020
B13	LTEM	Lack of training to employees	Lack of training leads to ineffective utilization of resources and affects SCD.	Jajja,et.al., 2018; Gamez-Perez et al., 2020; Jajja et al., 2018; Yadav et al., 2020b.
B14	LEDT	Lack of education and technical know how	Lack of technical/human expertise hinders successful SCD.	Kurpjuweit et al., 2019; Schniederjans et al., 2020; Saberi et al.,2019
B15	LFPM	Lack of framework and performance metrics for SCD	Standards and performance metrics are required to assess the performance of the SC.	Lima-Junior et al., 2020; Bressanelli et al., 2019; Yadav et al., 2020a; Saberi et al., 2019

The SCD process is very challenging and the barriers affecting transformation are to be addressed and eliminated effectively. Previous research dealt with the benefits which can be reaped through effective SCD. Various dimensions and factors to be considered for SCD decision making is equally significant. This study will bring in better insights for SCD on account of advancement in IT and its applications in SC. A research framework for analyzing the barriers affecting SCD process is shown in Figure 5.1.

The major barriers affecting SCD include limited IT infrastructure, reluctance for sharing information, lack of faith among the SC partners, inequity of demand, compatibility issues of the system, limited knowledge and financial implications for digitalization. Lohmer and Lasch (2020) identified major barriers for block chain adoption as legal uncertainties, staff difficulties, unclear governance structures and missing infrastructure. The significant challenges faced by retail sectors due to the impact of COVID-19 acts as operational barriers. Princes (2020) highlighted the disruptive challenges faced by the manufacturing industry and the precautions to be taken to be addressed in Supply Chain 4.0.

Alora et al., (2019) found that financial and information technology barriers are the dominant SC finance adoption barriers. Raj et al., (2020) examined the barriers affecting I 4.0 implementation in the manufacturing sector in the perspective of both developed and developing economies. They found out that lack of digital strategy alongside resource scarcity as the most prominent barrier.

Stentoft et al., (2020) have found that the lack of perceiving I 4.0 drivers obstructs Danish SME's adoption of I 4.0 readiness and application of I 4.0 technologies. Chauhan and Singh (2020) investigated the influence of intrinsic and extrinsic barriers of digitalization on I 4.0 adoption by the firms. They have evaluated the influence of barriers and its linkage between digitalization, SC competency and operational performance of the firm. A detailed description and reference sources with respect to the barriers identified is shown in Table 5.1.

As per empirical classification of resources in a business model (Seppanen, 2007) identified barriers were classified under three major dimensions viz., managerial, knowledge and technological. Accordingly, barriers B1, B3, B4, B5 and B6 falls under managerial category, B2, B12 and B13 under knowledge and B7, B8, B9, B10, B11, B14 and B15 falls under technological category. A lot of research has been done in the area of SCD which are generic in nature and limited to extent of usage of IT in SC. However, in order to digitalize SC effectively, a study on analysis of major barriers affecting SCD is necessitated. This research paper tries to fill this knowledge gap by analyzing the key barriers and developing an ISM model depicting the interrelationships among the barriers affecting SCD process.

Literature reveals that the inability of firms in effective SCD is one of the major concerns that hinders the growth and attaining global presence. The advancement in digital technologies and the intention to gain competitive advantage motivates the firms to devise suitable strategy for effective SCD. Previous studies in the area of SCD neither concentrated on any particular industry nor considered the barriers affecting digitalization aspects. This necessitates the need to identify the key barriers and analyze its interrelationship and influences for better understanding and effective implementation. Hence, the fifteen key barriers identified as in Table 5.1 were based on extensive literature review and discussion with experts in industry and academia. Further, the methodology is applied in a manufacturing firm in the electronics industry.

The revolution in digital technologies is transforming the SC rapidly. The key digital technology enablers which influences the transformation process includes big data cloud computing and the internet of things. Adoption of innovative technologies will lead to generation of new forms of revenue and business value (Buyukozkan and Gocer, 2018). Review of literature reveals that there has been limited research in the SCD process on a much more comprehensive basis considering all aspects affecting the process including various challenges, benefits, dimensions, capabilities and procedure for digitalization.

5.2. Research Methodology

In this paper, analysis of key barriers is done by using Interpretive Structural Modeling (ISM) method and MICMAC analysis. ISM methodology helps in representing an unrelated or complex problem systematically. The ISM method is a well-established and widely implemented approach used by the practitioners and researchers to discover the interrelationships among factors, which otherwise in isolation, are of no due significance. ISM has the capability to provide a better and collective understanding and insights into a problem by generating binary relation to convey the interrelationships. Therefore, ISM method was deemed fit to generate the exhaustive understanding of the barriers that hinders the process of SCD.

ISM-MICMAC integrated approach has been used by researchers in various areas as barriers in implementing lean six sigma in SC (Ali et al., 2020); modelling and examining outcomes of engineering change propagation (Bashr and Ojiako, 2020); logistics barriers faced by foreign firms (Gandhi et al., 2020); humanitarian SCM enablers evaluation (Agarwal et al., 2020), etc.

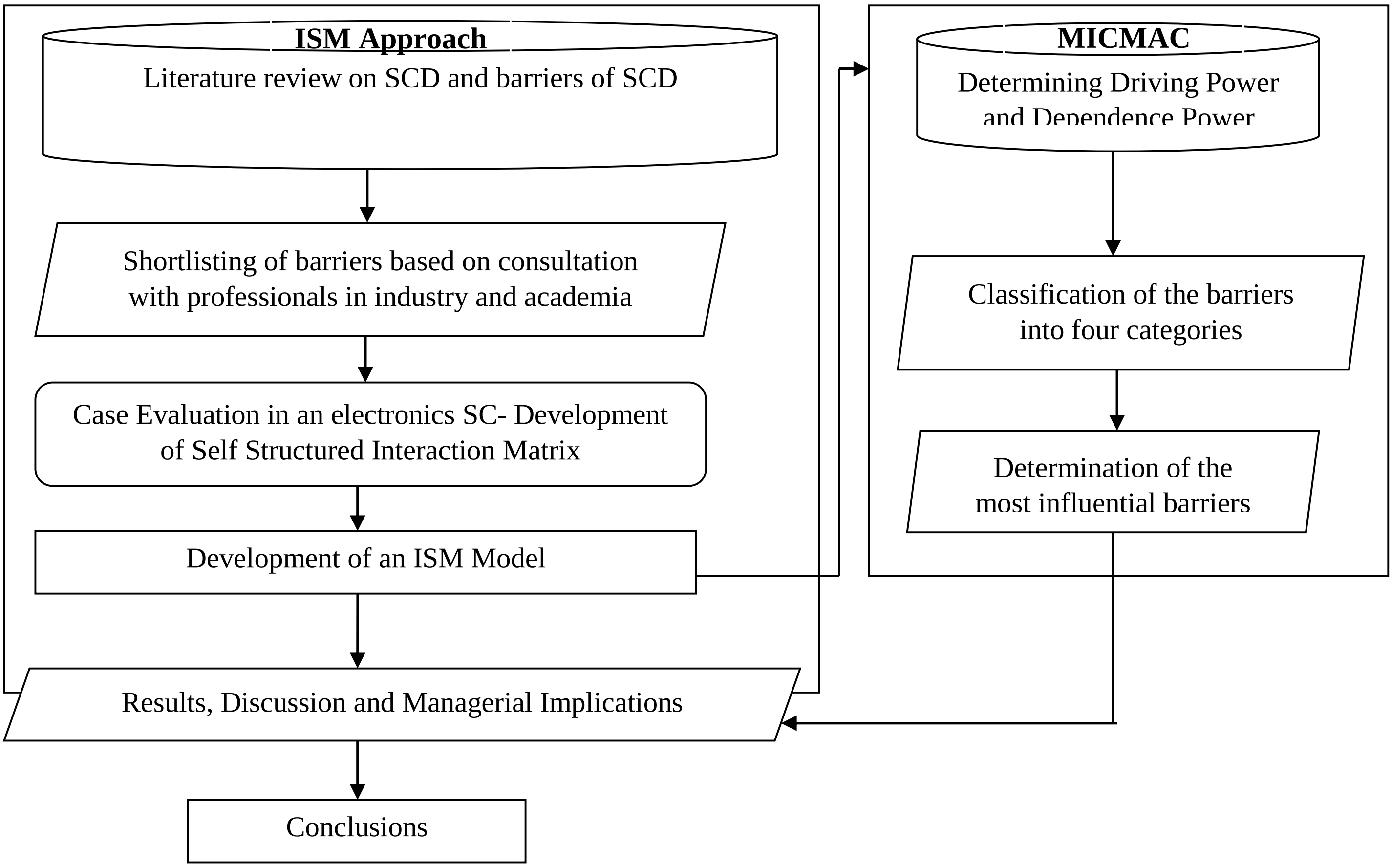


Figure 5.2: ISM and MICMAC methodology used for evaluating barriers of SCD

The key barriers for effective SCD were identified from literature review and also based on opinion from experts in industry and academia. The experts consulted were either controlling or responsible for the business activities concerned within the organizations. Fifteen barriers identified were assessed by the experts group consists of three experts from industry and one expert from academia. ISM method and MICMAC analysis is used to categorize the major barriers. A diagram representing methodology used for this study is illustrated in Figure 5.2.

5.2.1 Interpretive Structural Modeling (ISM)

ISM is an interactive learning process in which a set of elements are structured into a comprehensive systematic model wherein both dissimilar and directly related elements are involved. Based on expert's opinions through brainstorming and consultation, the contextual relationships among the barriers are developed. This study tries to ascertain the most influential barrier in the SCD process by portraying in a multileveled model. Using the ISM method, the prominent influential relations among the key barriers can be identified facilitating effective digitalization of SC.

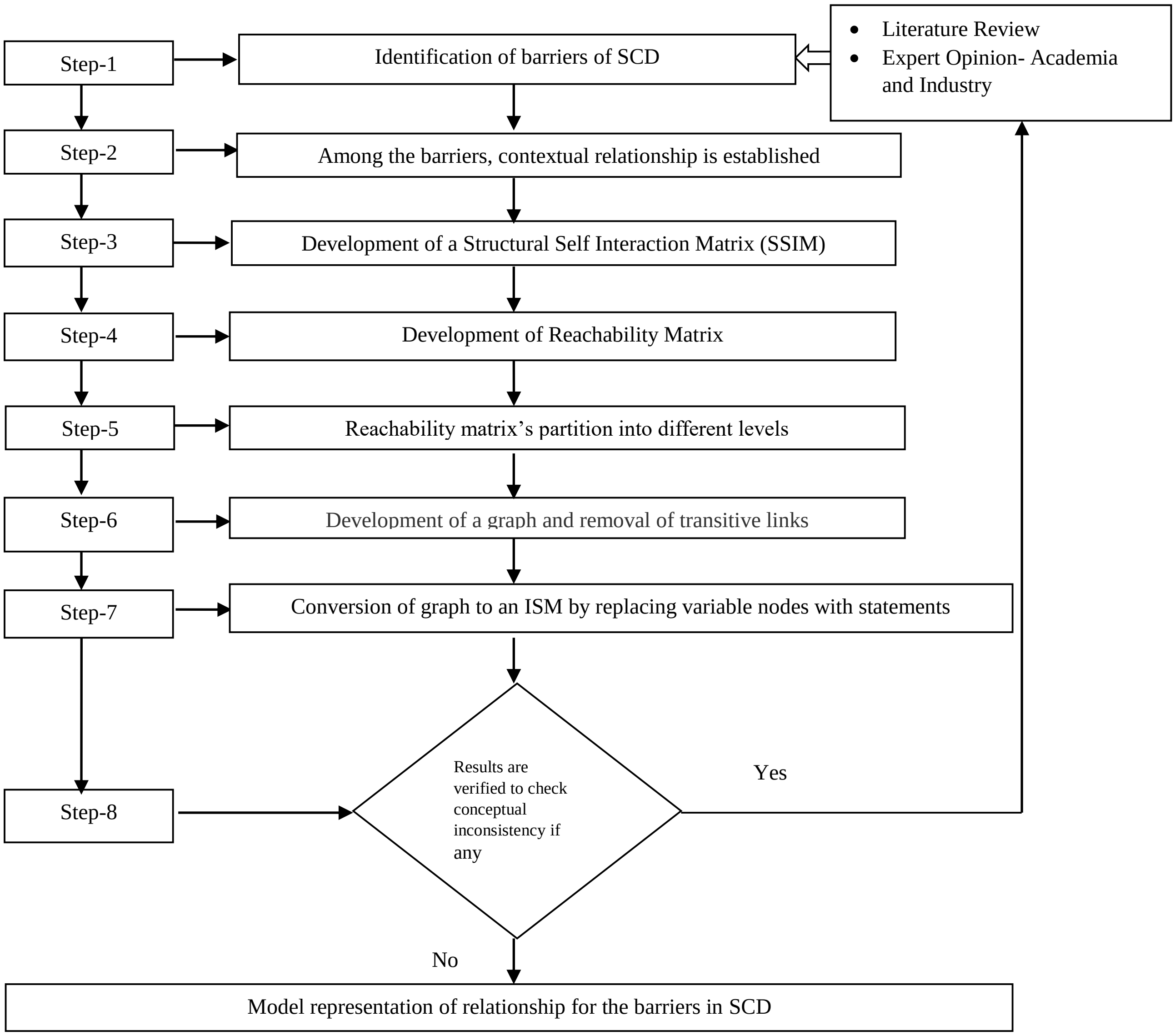


Figure 5.3: Steps involved in ISM model development for barriers in SCD process

The multilevel structural model developed by using ISM depicts a sub-systems level representation of a complicated system, thereby imposing order and relationship complexity among elements of a system. Later, this method has been used for research in management like analyzing success factors of pharmaceutical SC, SC complexity drivers and green textile SC barrier analysis (Majumdar et al., 2019; Piya et al., 2020). The diagrammatic representation of the steps involved in ISM method is presented in Figure 5.3.

5.2.2 MICMAC Analysis

MICMAC analysis is done based on the driving power and dependence power of variables. *Matriced'impactscroises-multipication applique´ anclassment* (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. In MICMAC analysis, variables will be classified into four clusters based on its powers (Yang and Lin, 2020).

The four clusters of variables identified are as follows.

5.2.2.1 Autonomous variables: The autonomous variables have weak driving power and weak dependence.

5.2.2.2 Dependent variables: Dependent variables have weak driving power and strong dependence.

5.2.2.3 Linkage variables: The variables which have strong driving power and strong dependence are called linkage variables.

5.2.2.4 Independent variables: The independent variables have strong driving power, but weak dependence.

5.3 Application of ISM model in a case electronics company

In this study, ideas presented above were used to develop an ISM model taking the electronics industry as an example. The case study is performed in XYZ company, which is one of prominent companies in the electronic industry which is in inspection for more than 15 years, dealing with electronic consumer products and services in India. This company is considered for the study to take advantage of their expertise and experience in the field, which ensures credibility of case study design. The company is rapidly growing in the electronics industry with a wide range of products and services and aiming at expanding its business globally. It includes home appliances, electrical installation systems and home automations. The company has a very widely spread SC network in India. However, top management is of the view that there is still scope of improvement in their SC networks and can tap the potential market. The advancement in the digital technologies and its applicability in the SC can bring in much more benefits compared to the existing system, which is not yet considered by the company. In order to fully utilize the available digital technologies and its benefits, the firm is in the process of developing a road map for initiating and implementing the digitalization of the supply process for better performance. However, the barriers that are to be considered and eliminated while proceeding with the digitalization process were not known. Hence, this study provides an insight to the managers to target the key barriers and plan the process accordingly.

SCD being a challenging task, the key barriers that affect the digitalization process needs to be addressed systematically to gain maximum benefits in the long run. The company wanted to systematically analyze and find interrelationship among these barriers and decided to employ integrated ISM-MICMAC methodology to arrive at a solution. The model helps in providing proper guidance for the professionals in effective SCD. Hence, on a long term perspective, suitable provisions for effective management of the SC through digitization is considered. It enables the procedure to be followed for SCD using advanced digital technologies. The experts consulted in the company were senior managers who had more than ten years' experience in the area of Information Technology, Product Life Cycle Management and Operations Management. The academic expert was an Associate Professor in a reputed University dealing in Operations and SCM. He is also associated with industrial projects in automation of SC and related activities.

The data collected was recorded and categorized to find out the key barrier in the SCD process.

Step1: The key barriers affecting the digitalization of the SC process were finalized by taking into account the opinion from the experts in the electronic firm and academia. The influence of barriers and its relation to the process of SCD and the relevant literature are detailed in Table 5.1.

Step 2: The contextual relationship among the barriers identified on the SCD process was analyzed by three experts from the industry and one expert from academia. All the potential influential relations and its interpretations were identified and analyzed through brainstorming sessions.

Step 3: The influential relations among the key barriers are marked in the matrix in binary form. The matrix formed is the direct reachability matrix as shown in Table 5.3. The element in the matrix represents the direct influential relation among the key barriers.

Step 4: The significant transitive relations among the barriers form interpretive logic is to be identified. All the significant transitive relations shall then be updated in the direct relation matrix by indicating all the transitive relations to form the final reachability matrix. The final reachability matrix thus formed is shown in Table 5.4.

Step 5: Further the level partition is done by following the step 1 to 9 as mentioned in section 3.3.4 and the barriers are placed level wise indicating the influences among them. The reachability of the elements, its antecedents and the intersection sets were sorted at each level and the consolidated table showing level partitions by following iterations at nine levels is at Table 5.6.

Step 6: After forming the level partitions, digraphs are drawn by representing the most relevant influence relations. Relations among the barriers can be identified from the final reachability matrix and interpretive logic of the relations. The interpretations of the relations among the barriers are shown in Table 5.4.

5.3.1 Structural self-interaction matrix (SSIM)

The contextual relationships among barriers are identified based on the expert's opinion. The relationship among the variables (m and n) are marked by using the symbols V, A, X and O. In the case of variable "m" will lead to variable "n", it is denoted by V, variable "n", will lead to "m" is denoted by A, variable "m" and "n", will lead to each other is represented by X and where the variable "m", and "n" are unrelated, it is denoted by O. An SSIM is developed based on contextual relationships between the variables and is shown in Table 5.2.

Table 5.2: Structural self-interaction matrix (SSIM)

Barriers	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**	**B15**
B1	V	V	V	V	V	V	V	V	V	V	V	V	V	V
B2		A	A	O	O	V	V	V	V	V	X	X	V	V
B3			A	A	A	V	V	V	V	V	V	V	V	V
B4				X	A	V	V	V	V	V	V	V	V	V
B5					O	V	V	V	V	V	V	V	V	V
B6						V	V	V	V	V	V	V	V	V
B7							V	V	V	V	A	A	A	V
B8								X	V	V	A	A	A	V
B9									V	V	A	A	A	V
B10										V	A	A	A	V
B11											A	A	A	V
B12												X	O	V
B13													O	V
B14														V

In table 5.2, the barrier B1 leads to barrier B2, so it is marked by V in the cell B1 to B2., likewise barrier B4 leads to barrier B2 and denoted by A in the cell (B4 to B2). In the cell (B12 to

B13), barrier B12 and B13 lead to each other, hence represented by X. In the cell (B2 to B6) barrier B2 and B6 do not lead to each other, so it is marked as O.

5.3.2 Initial Reachability Matrix

The initial reachability matrix is calculated based on the SSIM formulated and converted into a binary matrix as shown in Table 5.3, by substituting the symbols V, A, X and O by 1 or 0 as the case may be by applying the following rules.

Table 5.3: Initial Reachability Matrix Formulation

Sl. No.	Value in SSIM *(m,n)*	Reachability matrix value	
		(m,n)	*(n,m)*
1	V	1	0
2	A	0	1
3	X	1	1
4	O	0	0

By applying these rules, an initial reachability matrix for key barriers of SCD is formed and given at Table 5.4.

Table 5.4: Initial reachability matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B2	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1
B3	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1
B4	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1
B5	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1
B6	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
B7	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1
B8	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1
B9	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1
B10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
B11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
B12	0	1	0	0	0	0	1	1	1	1	1	1	1	0	1
B13	0	1	0	0	0	0	1	1	1	1	1	1	1	0	1
B14	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1
B15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 5.5: Final reachability matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Driving Power
B1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
B2	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	**10**
B3	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	**13**
B4	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	**13**
B5	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	**14**
B6	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**14**
B7	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	**7**
B8	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	**5**
B9	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	**5**
B10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	**3**
B11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	**2**
B12	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	**10**
B13	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	**10**
B14	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	**7**
B15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Dependence Power	**1**	**8**	**5**	**5**	**5**	**2**	**10**	**12**	**12**	**13**	**14**	**8**	**8**	**10**	**15**	

5.3.3 Final Reachability Matrix

Final reachability matrix is made from the initial reachability matrix after taking into account the transitivity rule, which shows the driving power and the dependence of each barrier as shown in Table 5.5. Driving power of each barrier means the total number of barriers into which it is having influence and dependence power is the total number of barriers which is influencing it. In MICMAC analysis, driving power and dependence powers are used for classification into four groups, of autonomous, dependent, linkage and independent variables.

5.3.4 Level Partitions

Reachability set and antecedent set for each barrier is found out from the final reachability matrix. The intersection set of these sets for all the barriers are determined by giving top-level variables in the ISM model, wherein reachability and intersection sets are the same. In table 5.6, barrier B15 has come out at level I. The level of each barrier is found out through a continuous iteration process, which helps in generating the figure and final ISM model. The list of barriers at each iteration from iteration I to IX level by removing the corresponding barrier from the previous step and identifying the new barrier by matching the reachability set with antecedent set and in the next iteration is shown in Table5.6.

Table 5.6: Level partitions for barriers: Iteration-I to IX

Iteration	Levels	Barriers
First	I	• Lack of framework and performance metrics for SCD**(B15)**
Second	II	• Lack of commitment from SC partners to share information**(B11)**
Third	III	• Mistrust among SC partners**(B10)**
Fourth	IV	• Threats related to information security**(B8)** • Employee's reluctance to change**(B9)**
Fifth	V	• Limited ICT infrastructure and systems**(B7)** • Lack of education and technical know-how**(B14)**
Sixth	VI	• Non-encouragement of R&D**(B2),** • Decision making on short term perspective**(B12)** • Lack of training to employees**(B13)**
Seventh	VII	• Lack of financial resources**(B3)** • Misalignment of business objectives with IT**(B4)** • Poor organizational culture inhibiting cross functional interaction**(B5)**
Eighth	VIII	• Top management commitment inadequacy**(B6)**
Ninth	IX	• Lack of awareness of benefits of supply chain digitalization(**B1**)

5.3.5 Formation of ISM based Model

The structured ISM model developed from the final reachability matrix is known as diagraph. The transitivity links are removed and node numbers are replaced by statements. Figure 5.4 shows the ISM model and it is observed that Lack of knowledge on SCD benefits (B1) is the most significant barrier affecting the SCD process, as it comes at the base of ISM hierarchy. Further, Lack of framework and performance metrics for SCD (B15) is the most affected barrier that has come out at top in the ISM model. The ISM model portrays the interrelationships among the barriers through diagrammatic representation. Each barrier is placed in the model based on their driving and dependence power and is shown in Figure 5.5 (MICMAC diagram).

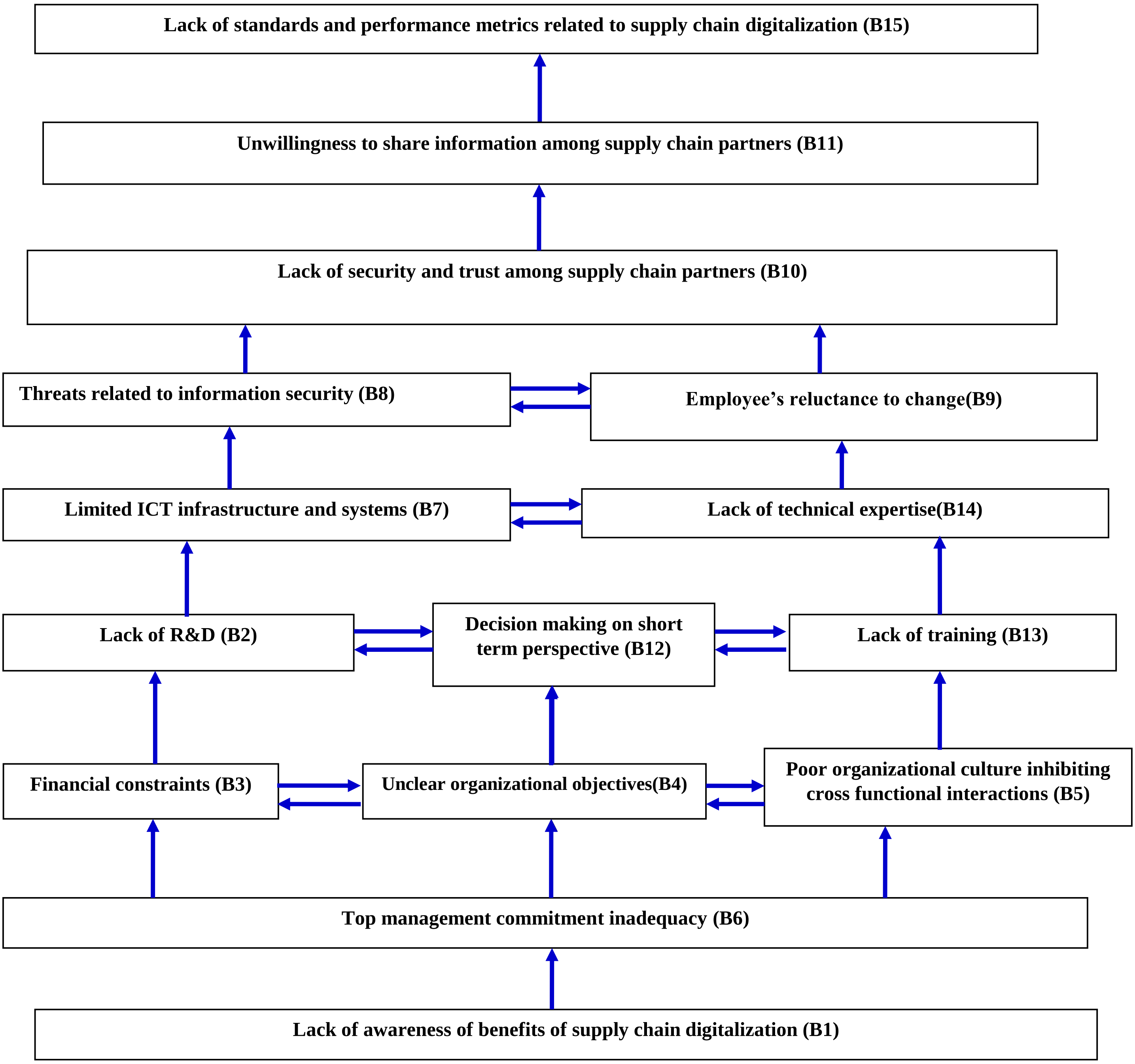


Figure 5.4: An ISM based model for barriers in SCD

In the first level, Lack of framework and performance metrics for SCD (B15) is the lone barrier which is positioned at the top level of the digraph. It reveals that B15 has the maximum dependence power and minimal driving power. Hence, the barrier, B15 depends immensely on the lower level barriers in order to attain any change with respect to its effects on the SCD process. The second and third level down the barrier B15 is occupied by one barrier each, i.e., Lack of commitment from SC partners to share information (B11) and Mistrust among SC partners (B10) which is having slightly more driving power than B15. This reveals that the barrier B11 and B10 are dependent enough to link the other two variables below at fourth and fifth level, i.e. Threats related to information security (B8) and Employee’s reluctance to change (B9), Limited ICT infrastructure and systems (B7) and Lack of technical expertise (B14) which drives the top layer of the ISM model.

The barriers at sixth level, Non-encouragement of R&D (B2), Decision making on short term perspective(B12) and Lack of training to employees (B13) are having robust links among the barriers themselves and other barriers at various levels and positioned in linkage quadrant with similar driving and dependence power. The seventh level consists of Lack of financial resources (B3), Misalignment of business objectives with IT (B4) and Poor organizational culture inhibiting cross functional interactions (B5) with similar driving power and dependence power. These barriers influence other barriers as they have high driving power. The eighth and ninth level of the model consists of, Top management commitment inadequacy (B6) and Lack of knowledge on SCD benefits (B1) which are having high driving power and moderately low dependence power, which forms at the bottom of ISM model. These barriers do not have connections with other barriers, which makes these barriers as dependent but possesses high driving power to influence the barriers in the levels above.

5.3.6 MICMAC Analysis

MICMAC analysis is done based on the driving power and dependence power of variables. In MICMAC analysis, variables will be classified into four clusters based on its powers. The driving power and dependence power are calculated by totaling the number along each column and row for every factor as represented in Table 5.5. Each variable is positioned in the quadrant based on the sum obtained against each row and column which forms the coordinates and shown in Figure 5.5. The X axis in the figure represents dependence power and Y axis represents the driving power of the respective barriers. Based on the driving and dependence powers, the barriers identified are classified under the four clusters.

Majority of the barriers in the MICMAC diagram falls under dependent and independent barriers. This shows that the barriers identified are having high dependence power and high driving power. The clustering reveals that the barriers identified are the key barriers and generally influenced by other barriers. The barriers which fall under Dependent quadrant are those barriers which are having low driving power to influence other barriers. Hence, these barriers are positioned at the top of the ISM model. The autonomous quadrant is vacant which reveals that there are no barriers that have zero interconnections with other barriers in the MICMAC diagram. From the diagrammatic representation, and based on the driving power and dependence power, it is found that all the barriers are connected to other barriers in some way.

From Figure 5.5, it is noted that there are no variables found in Quadrant-I, which represents autonomous barriers having weak driving power and weak dependence. These barriers are having minimal influence or impact and maintain few links with other barriers. Autonomous barriers have the characteristic that they have low influence in the system. Among the fifteen major barriers identified, none of the barriers is coming under Quadrant-I, which reveals that all the barriers considered in this research are having great influence while proceeding with digitalization of SC.

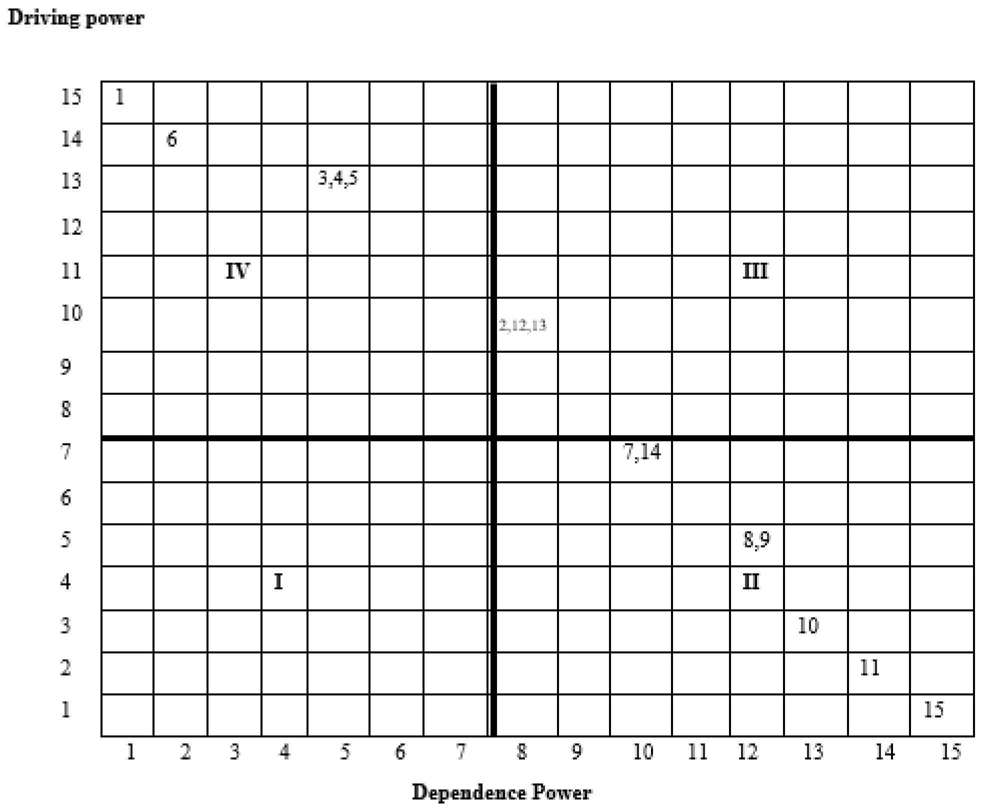


Figure 5.5: Driving power and dependence power diagram for barriers in SCD process

The barriers, Limited ICT infrastructure and systems (B7), Threats related to information security (B8), Employee's reluctance to change (B9), Mistrust among SC partners (B10), Lack of commitment from SC partners to share information (B11), Lack of technical expertise (B14) and Lack of framework and performance metrics for SCD (B15) comes under quadrant-II, dependent barriers that has weak driving power and strong dependence power. The strong dependence power of these barriers indicates that they are greatly influenced by other barriers.

Linkage barriers which are having strong driving power and strong dependence power fall under quadrant-III. These barriers are mostly deemed volatile and any actions involving changes to these barriers will probably cause an equivalent reaction, affecting itself and other barriers. Non-encouragement of R&D (B2), Decision making on short term perspective (B12) and Lack of training to employees (B13) falls under this category. All these barriers are having strong dependence power and driving power. It is obvious that strategic variables like lack of research and development, technical expertise, training and the Decision making on short term perspective hinders the digitalization process of SC.

Quadrant –IV represents the independent barriers having strong driving power, but weak dependence. Lack of knowledge on SCD benefits (B1), Top management commitment inadequacy (B6), Lack of financial resources (B3), Misalignment of business objectives with IT (B4), Poor organizational culture inhibiting cross functional interactions (B5) possesses strong driving power. These are key barriers or root barriers that need to be addressed for proceeding with SCD.

5.4. Results and Discussions

While proceeding with SCD, industry practitioners and researchers should be well aware of the barriers affecting the process as it has an overall impact on the digitalization process. The decision makers need to understand interdependence and relative importance among the barriers. A diagrammatic representation of the classification of the barriers identified based on MICMAC analysis and dimensions are shown in Figure 5.6. MICMAC analysis classifies the barriers into following four clusters for arriving at effective decision making. The interdependence and relative importance among the barriers can also be assessed from this analysis. From Figure 5.5, it is noted none of the barriers is coming under Quadrant-I, which reveals that all the barriers considered are having great influence while proceeding with digitalization of SC.

Among the SCD barriers identified, the majority of the barriers are positioned under dependent, independent and linkage quadrant in MICMAC diagram. Accordingly, these barriers are dependent on each other and show its ability to influence other barriers in the model. In the dependent quadrant there are three variables having comparatively high dependence power which includes Lack of framework and performance metrics for SCD (B15), Lack of commitment from SC partners to share information (B11) and Mistrust among SC partners (B10). These barriers greatly depend on other barriers which are having a high level of volatility, which reveals that any action taken on these barriers will have a corresponding reaction on other barriers.

Barriers, viz., Lack of framework and performance metrics for SCD (B15), Lack of commitment from SC partners to share information (B11) and Mistrust among SC partners (B10) has come at the top of the ISM model. These barriers depend on all other barriers below them in the model. These factors with high dependency power have been established in the research done by Lima-Junior et al., (2020) and Sutduean et al., (2019). Findings from these studies reveal how Lack of framework and performance metrics for SCD, Lack of commitment from SC partners to share information and Mistrust among SC partners acts as the key barriers in the process of SC. In our study also, these barriers have appeared at the top of the ISM model.

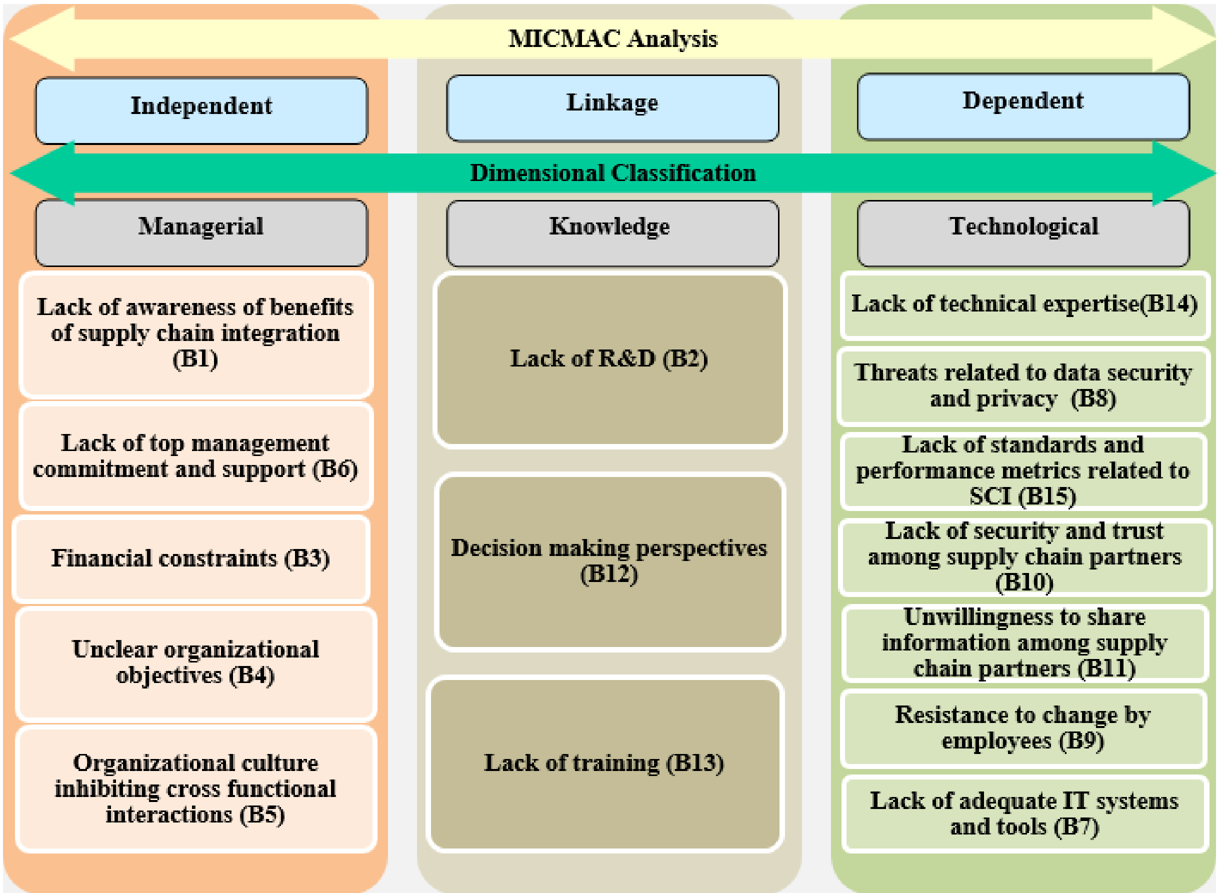


Figure 5.6: Classification of barriers of SCD based on MICMAC analysis and dimension

At level eighth and ninth, more dependent barriers such as Lack of knowledge on SCD benefits (B1) and Top management commitment inadequacy (B6) are positioned. B1 and B6 are identified as the barriers with the highest driving power in MICMAC analysis. In case, a firm suffers from Lack of training to employees (B13), we can infer from the ISM model that the cause can be due to the barriers with a higher driving power, which are Lack of financial resources (B3), Misalignment of business objectives with IT (B4) and Poor organizational culture inhibiting cross functional interactions (B5). Gamez-Perez et al., 2020 has highlighted the requirement of training in SC collaboration and creating SC competence.

Likewise, the barriers; Limited ICT infrastructure and systems (B7) and lack of technical expertise (B14) is having a dominant relationship with threats related to data security(B8) and Employee’s reluctance to change (B9). The interrelationship among these barriers will have a peak impact on the process of SCD. Bodkhe et al., (2020) have highlighted the aspect of Threats related to information security while adopting block chain for I 4.0. Further, the employees past experience and resistance to change also act as barriers for adopting green SC practices (Jaaffar et al., 2019).

The independent barriers having very strong driving power can be classified under managerial category. These barriers are mostly independent of other barriers. Lack of awareness of SCD (B1) has the strongest driving power which appears at the base of ISM hierarchy. B1 comes under managerial category and should be given top most preference from the management of organizations for effective digitalization. The linkage barriers coming under the knowledge category not only possesses high strong driving power but also strong dependent powers. These barriers have linkage with other barriers and influence the digitalization process of SC in the long run. The dependent barriers classified under technological category appear at the top of the ISM model. Impact of dependent barriers depends upon the influence of the barriers under managerial and knowledge based categories.

The digitalization of SC without minimizing the effect of various barriers would lead to lack of proper standards and performance metrics (Stajniak et al.,2016). Results of the ISM model reveals that addressing the barriers under managerial and knowledge based categories would lead to minimizing the effect of technology related barriers. This would help in seamless digitalization of SC. The benefits of SCD need to be addressed among all stakeholders. Lack of knowledge on SCD benefits and commitment from top management on these issues are the initial steps to be addressed while initiating SCD.

The analysis by using MICMAC proves the robustness of the method. The barriers coming under managerial category fall under independent cluster, as these are the most dominant and independent barriers. The knowledge barriers fall under linkage cluster as it acts as a linkage between the managerial and technological barriers. Properly addressing these barriers leads to impart better knowledge and facilitates effective digitalization. The technological barriers fall under dependent cluster wherein the barriers related to technological aspects are identified. The results of the study clearly show linkages between the barriers identified.

5.5. Validation of Results

In order to validate the final results and prove the robustness of the final recommendation based on the ISM method, Grey-DEMATEL approach followed by sensitivity analysis is conducted to find out the cause-effect relationship among the enablers and robustness of the results. Further, the results from both the methods were compared and validated through feedback from the industrial and academic experts. The validation done through application of Grey-DEMATEL followed by sensitivity analysis and expert's feedback proves that the results are acceptable and thus validated. The detailed methodology used to validate the results is shown in Figure 5.7.

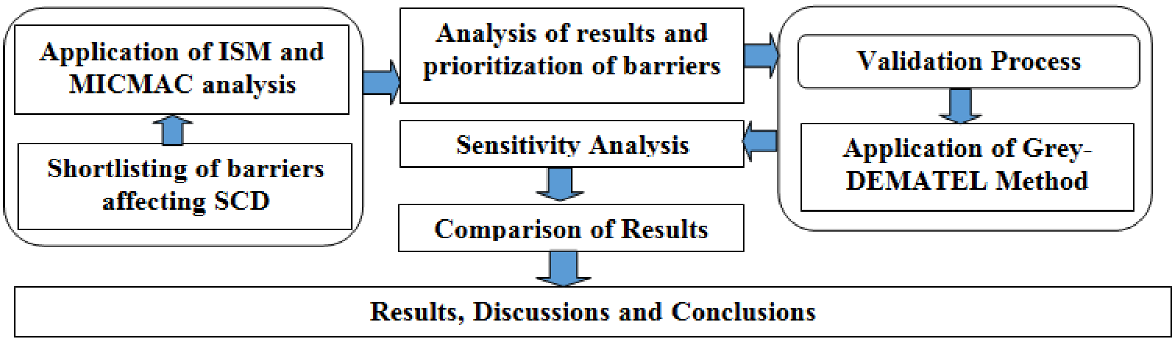


Figure 5.7: Research framework for analysis and validation of barriers of SCD

In order to evaluate the causal relationships, various methodologies were found in the literature such as Total Interpretive Structural modelling, Interpretive Structural Modeling, Analytic Network Process and DEMATEL (Ocampo, 2017). Even though structural relationships among Barriers can be identified by using Total Interpretive Structural modelling and Interpretive Structural Modelling, the strength of relationships among the barriers cannot be identified by these methods (Sufiyan et al., 2019). By using DEMATEL method, strength of relationships among the barriers can be found out (Biswas and Gupta, 2019). However, as the opinions of experts are used, the conventional method has the limitation of subjectivity of the inputs from the experts. Hence, in order to identify the extent of relationships among the Barriers, we have used integrated Grey theory and DEMATEL method in this research. This methodology has been successfully used by various researchers in case of modelling e-waste mitigation strategies (Garg, 2020), and for analysing critical success factors for implementation of drones in logistics sector (Raj and Sah, 2019) etc. Grey-based DEMATEL method provides enormous benefits compared to any other methods in dealing with uncertainties caused by lack of proper information and small sample size. By using this method, prominent influential relations among Barriers facilitating for effective SCD can be analyzed. The procedure and steps involved in the Grey-based DEMATEL method is explained in this section.

5.5.1 Grey System theory

Grey system theory is a mathematical theory of grey numbers proposed from a grey set. The major advantage of grey theory is that possible outcomes can be generated with partial information. Grey theory can be used with any decision making process to improve accuracy of judgments. Each grey system is defined by grey numbers, grey equations and grey matrices. By integrating a three step procedure, grey numbers can be easily convertible into crisp numbers by using modified- converting fuzzy values into crisp scores (CFCS) method.

5.5.2 DEMATEL method

The DEMATEL method was developed in the 1970s in order to solve complex problems in identification of cause-effect relationships. It classifies whole factors into either as cause or effect group by providing solutions to complicated problems. In this method, the inter dependence and influential effect values among variables is found through a causal diagram. It reveals relationships among the factors and also prioritizes them. As DEMATEL method alone cannot address these limitations, the combined application of Grey systems theory developed by Deng and DEMATEL method is found to be a better approach.

Step 1: In order to measure the relationship among the Barriers a direct relation matrix is established based on the feedback from experts, using a five level grey linguistic scale as depicted in Table-5.8.

Step 2: Based on direct relation matrices, grey relation matrices are finalized. A grey no. $\otimes x_{ij}^{k}$ is converted to an interval with known upper and lower bounds;

$$\otimes p_{ij}^{r} = \left(\underline{\otimes}\, p_{ij}^{k},\ \overline{\otimes}\, p_{ij}^{r}\right) \qquad (i)$$

where respondent ‘r’ rates the influence of barrier i over barrier j.

Step 3: An average grey relation matrix $(\otimes\, \tilde{p}_{ij})$ is obtainedby combining the grey direct relation matrices:

$$\otimes\, \tilde{p}_{ij} = \left(\frac{\sum_r \underline{\otimes} p_{ij}^{r}}{n}, \frac{\sum_r \overline{\otimes} p_{ij}^{r}}{n}\right) \qquad (ii)$$

Where ‘n is the number of experts or evaluators.

Step 4: In this step, from the average grey relation matrix, a crisp relation matrix is computed by converting grey values into crisp values using modified- CFCS method (Arikan et al., 2013) by three-step procedure as detailed below:

4.1 Grey values are normalized as:

$$\underline{\otimes}\,\bar{p}_{ij} = \left(\underline{\otimes}\,\tilde{p}_{ij} - {}^{min}{}_{j}\underline{\otimes}\,\tilde{p}_{ij}\right)/\Delta_{min}^{max} \qquad (iii)$$

where $\underline{\otimes}\,\bar{p}_{ij}$ represents the normalized lower limit value of the grey number $\otimes\,\tilde{p}_{ij}$

$$\overline{\otimes}\,\bar{p}_{ij} = \left(\overline{\otimes}\,\tilde{p}_{ij} - {}^{min}{}_{j}\overline{\otimes}\,\tilde{p}_{ij}\right)/\Delta_{min}^{max} \qquad (iv)$$

where $\overline{\otimes}\,\bar{p}_{ij}$ represents the normalized upper limit value of the grey number $\otimes\,\tilde{p}_{ij}$, and

$$\Delta_{min}^{max} = {}^{max}{}_{j}\overline{\otimes}\,\tilde{p}_{ij} - {}^{min}{}_{j}\underline{\otimes}\,\tilde{p}_{ij} \qquad (v)$$

4.4 Total normalized crisp values are computed as:

$$Y_{ij} = \left(\frac{\left(\underline{\otimes}\bar{p}_{ij}\left(1-\underline{\otimes}\bar{p}_{ij}\right)\right)+\left(\overline{\otimes}\bar{p}_{ij}\times\overline{\otimes}\bar{p}_{ij}\right)}{\left(1-\underline{\otimes}\bar{p}_{ij}+\overline{\otimes}\bar{p}_{ij}\right)}\right) \qquad (vi)$$

4.5 Final crisp values are computed as:

$$z_{ij}^{*} = \left(min\,\underline{\otimes}\,\tilde{p}_{ij} + \left(Y_{ij} \times \Delta_{min}^{max}\right)\right) \qquad (vii)$$

and, $Z = \left[z_{ij}^{*}\right]$ *(viii)*

Step 5: By obtaining K and multiplying the average relation matrix Z with K, the normalized direct crisp relation matrix X is computed.

$$K = \frac{1}{\underset{1\le i\le n}{max}\sum_{j=1}^{n} z_{ij}} \qquad (ix)$$

and

$$X = Z \times K \qquad (x)$$

Step 6: The total relation matrix M is obtained as:

$$M = X \times (I - X)^{-1} \qquad (xi)$$

Where *I* is the identity matrix.

Step 7: In total relation matrix M obtained above, let m_{ij} represent its elements. Establish R as *n*×*1* vector, which is sum of row elements of M. Establish C as *1*×*n* vector, which is sum of column elements of M.

$$R_i = \sum_{j=1}^{n} m_{ij} \forall i \qquad (xii)$$

$$C_j = \sum_{i=1}^{n} m_{ij} \forall j \qquad (xiii)$$

$(R_i + C_j)$tells total effect given and received. $(R_i - C_j)$gives net effect that a barrier has on the entire system. If it is positive, then thebarrier *i* is a net cause or foundation, for other barriers. If it is negative, then barrier *i* is net effect of other barriers.

Step 8: The matrix *M* shows how one Barrier affects another and a diagram is developed. Digraph is plotted by setting up the threshold. This threshold value is calculated by taking the mean of the values m_{ij} from M and then adding one standard deviation to the mean. As there are a number of possible relationships we are mapping only those above the threshold value and leave less significant values. Digraph showing causal relations above threshold value is plotted from the dataset of$\left((R_i + C_j), (R_i - C_j)\right) \forall i = j$.

We assume that, considering the vast work experience of the experts consulted, the feedback and inputs are reliable and have been used for this study. The experts were asked to rate the Barriers of SCD on the basis of linguistic scales as given in Table 5.7.

Step 1-2: A direct relationship matrix was formed by using the linguistic assessment scale as shown in Table 5.7.

Table 5.7: Linguistic assessment and associated grey values

Linguistic assessment	Associated grey values	Abbreviation used
No Influence	(0, 0.01)	N
Low Influence	(0.01, 0.25)	L
Medium Influence	(0.25, 0.5)	M
High influence	(0.5, 0.75)	H
Very high influence	(0.75, 1.0)	VH

Further, the data collected was evaluated by following the steps 1 to 8 as mentioned above. The linguistic scale direct relation matrix for the experts' 1, 2, 3 and 4 are shown in Tables5.8- 5.11. Based on the evaluation from the experts, a crisp relationship matrix is shown in Table 5.12, followed by total relationship matrix in Table 5.13.

Table 5.8: Linguistic scale direct-relation matrix for Barriers of SCD given by expert 1

	LCSI	MBOI	NERD	EMRC	LSIB	LFPM	DMSP	TMCI	LEDT	MSCP	LFIR	LIIS	TINS	POCL	LTEM
LCSI	N	L	H	L	M	L	N	L	H	VH	M	N	N	L	N
MBOI	H	N	L	H	H	VH	L	M	VH	H	L	M	M	H	M
NERD	VH	L	N	H	L	H	M	M	L	H	N	L	H	H	M
EMRC	M	H	M	N	L	H	M	H	H	L	N	M	H	M	M
LSIB	H	VH	M	H	N	VH	L	M	VH	VH	L	H	L	H	L
LFPM	N	H	L	H	N	N	N	H	H	M	N	M	L	N	L
DMSP	L	L	M	H	M	L	N	L	M	N	N	L	H	N	H
TMCI	M	H	M	H	H	H	H	N	VH	M	M	H	M	M	H
LEDT	VH	VH	L	H	M	H	L	H	N	M	L	H	L	H	L
MSCP	H	M	VH	L	L	L	M	N	H	N	N	N	M	N	N
LFIR	H	L	L	M	M	H	N	L	L	N	N	L	N	L	M
LIIS	N	L	H	M	H	M	L	L	H	M	N	N	L	H	L
TINS	N	L	H	H	L	M	H	N	L	M	N	L	M	L	H
POCL	N	M	L	L	H	M	L	H	H	L	N	H	H	N	L
LTEM	N	L	M	H	H	N	L	M	M	M	H	L	M	M	N

Table 5.9: Linguistic scale direct-relation matrix for Barriers of SCD given by expert 2

	LCSI	MBOI	NERD	EMRC	LSIB	LFPM	DMSP	TMCI	LEDT	MSCP	LFIR	LIIS	TINS	POCL	LTEM
LCSI	N	L	H	L	M	L	N	L	M	VH	M	N	N	L	N
MBOI	H	N	L	H	H	VH	L	M	VH	H	L	M	M	VH	M
NERD	H	M	N	H	M	M	H	M	L	H	L	L	VH	VH	M
EMRC	M	H	H	N	L	H	L	H	H	L	N	H	H	L	L
LSIB	H	VH	H	H	N	VH	M	M	VH	H	M	H	M	H	L
LFPM	L	H	M	H	N	N	N	H	H	M	N	M	N	N	M
DMSP	L	L	L	M	L	M	N	M	M	N	L	L	H	N	H
TMCI	L	H	H	VH	H	H	H	N	VH	H	M	H	M	L	M
LEDT	H	VH	L	H	M	H	L	H	N	M	L	H	M	H	L
MSCP	H	M	VH	L	L	M	L	L	H	N	M	L	M	N	N
LFIR	H	L	L	M	M	H	L	M	M	L	N	L	L	M	L
LIIS	N	M	H	L	H	M	L	L	H	H	L	N	L	H	L
TINS	L	L	H	H	L	VH	H	N	L	M	N	M	N	M	H
POCL	N	H	M	M	VH	VH	M	H	H	M	L	H	VH	N	M
LTEM	L	M	M	H	H	N	L	M	L	L	H	L	M	L	N

Table 5.10: Linguistic scale direct-relation matrix for Barriers of SCD given by expert 3

	LCSI	MBOI	NERD	EMRC	LSIB	LFPM	DMSP	TMCI	LEDT	MSCP	LFIR	LIIS	TINS	POCL	LTEM
LCSI	N	M	H	L	M	M	N	L	L	VH	M	L	N	L	N
MBOI	H	N	L	VH	H	VH	L	L	VH	H	L	M	L	VH	M
NERD	VH	L	N	H	M	H	M	M	L	H	N	N	H	H	M
EMRC	H	H	M	N	L	H	M	H	H	M	N	M	H	L	M
LSIB	H	VH	M	H	N	VH	M	M	VH	H	M	H	M	H	L
LFPM	N	H	L	H	N	N	N	H	H	M	N	M	M	L	M
DMSP	L	M	L	H	M	M	N	M	L	N	N	M	H	N	H
TMCI	L	H	M	VH	H	H	H	N	VH	M	L	H	M	L	H
LEDT	M	VH	L	H	M	H	M	H	N	M	M	H	M	H	M
MSCP	H	M	VH	L	L	M	M	L	H	L	N	M	M	N	L
LFIR	H	M	M	M	L	H	L	L	M	N	N	L	L	M	L
LIIS	L	L	H	L	VH	L	L	M	H	H	N	N	L	H	L
TINS	N	M	H	H	L	H	H	N	M	M	L	M	N	L	H
POCL	L	M	M	M	H	L	M	M	H	L	N	H	H	N	M
LTEM	N	L	L	H	M	L	L	M	L	L	H	M	M	M	N

Table 5.11: Linguistic scale direct-relation matrix for Barriers of SCD given by expert 4

	LCSI	MBOI	NERD	EMRC	LSIB	LFPM	DMSP	TMCI	LEDT	MSCP	LFIR	LIIS	TINS	POCL	LTEM
LCSI	N	M	H	N	M	L	L	L	M	H	M	L	N	L	N
MBOI	H	N	M	H	M	VH	L	H	VH	H	M	H	M	H	L
NERD	VH	M	N	H	M	H	L	M	M	H	L	M	H	H	M
EMRC	L	H	M	N	M	H	L	VH	H	M	L	M	H	L	M
LSIB	M	H	H	H	N	VH	M	M	VH	VH	M	H	M	H	L
LFPM	N	H	L	H	L	N	N	H	H	M	N	M	M	L	M
DMSP	L	H	L	H	M	L	N	L	M	L	L	L	H	N	H
TMCI	M	H	M	N	H	VH	H	N	VH	H	L	H	M	M	H
LEDT	VH	VH	L	H	M	H	H	H	N	M	M	H	M	H	M
MSCP	H	L	VH	N	M	M	L	L	H	N	N	L	L	L	L
LFIR	H	L	M	M	M	H	N	M	M	L	N	L	N	M	M
LIIS	N	N	H	H	H	H	L	L	H	M	L	N	L	H	M
TINS	L	L	H	H	M	M	H	N	L	M	N	L	N	L	H
POCL	L	M	L	L	H	L	M	H	H	L	L	H	H	N	L
LTEM	L	L	M	H	M	N	M	L	M	L	H	L	M	M	N

Table 5.12: Crisp relation matrix for Barriers of SCD

	LCSI	MBOI	NERD	EMRC	LSIB	LFPM	DMSP	TMCI	LEDT	MSCP	LFIR	LIIS	TINS	POCL	LTEM
LCSI	0	0.199	0.643	0.04	0.362	0.127	0.008	0.063	0.347	0.83	0.368	0.021	0	0.06	0
MBOI	0.651	0	0.127	0.746	0.593	0.942	0.066	0.363	0.942	0.612	0.142	0.447	0.287	0.811	0.293
NERD	0.877	0.199	0	0.668	0.287	0.569	0.371	0.362	0.127	0.612	0.021	0.114	0.746	0.736	0.368
EMRC	0.352	0.643	0.42	0	0.137	0.643	0.217	0.746	0.643	0.179	0.008	0.447	0.668	0.134	0.293
LSIB	0.576	0.868	0.494	0.668	0	0.942	0.293	0.362	0.942	0.757	0.293	0.68	0.287	0.659	0.066
LFPM	0.007	0.643	0.127	0.668	0.007	0	0	0.668	0.643	0.32	0	0.368	0.182	0.019	0.293
DMSP	0.057	0.274	0.127	0.593	0.287	0.199	0	0.212	0.272	0.003	0.021	0.142	0.668	0	0.68
TMCI	0.204	0.643	0.42	0.623	0.668	0.718	0.68	0	0.942	0.466	0.217	0.68	0.362	0.207	0.602
LEDT	0.726	0.942	0.055	0.668	0.362	0.643	0.295	0.668	0	0.32	0.217	0.68	0.287	0.659	0.217
MSCP	0.651	0.272	0.942	0.04	0.137	0.272	0.217	0.04	0.643	0.003	0.072	0.114	0.287	0.006	0.021
LFIR	0.651	0.127	0.199	0.362	0.287	0.643	0.021	0.212	0.272	0.009	0	0.066	0.02	0.282	0.217
LIIS	0.007	0.104	0.643	0.289	0.746	0.347	0.066	0.137	0.643	0.466	0.021	0	0.063	0.659	0.142
TINS	0.018	0.127	0.643	0.668	0.137	0.569	0.68	0	0.127	0.32	0.008	0.217	0.071	0.134	0.68
POCL	0.018	0.42	0.199	0.212	0.746	0.348	0.293	0.593	0.643	0.109	0.021	0.68	0.746	0	0.217
LTEM	0.018	0.127	0.272	0.668	0.515	0.006	0.142	0.287	0.199	0.109	0.68	0.142	0.362	0.282	0

The matrix generated was processed further based on the step by step procedure for the Grey –DEMATEL integrated methodology. The prominence and net effect were calculated for each of the Barriers identified and is shown in Table 5.14. As the number of relationships among the barriers includes all possibilities and large numbers, we have mapped those relationships which are above a threshold value. The threshold value helps in finding out the significant relationships of the number of elements in the total relation matrix. The threshold value was calculated and fixed at 0.1879 by considering the mean and standard deviation of the values m_{ij} from the matrix M (Table 5.13). The mean value of M is derived as 0.1284 and the standard deviation as 0.0595. From these values, the threshold value is derived as 0.1879 (0.1284 + 0.0595). All the values which are equal and above the threshold values are highlighted (in bold) in the overall matrix M, as shown in Table 5.13. Further the relationships among Barriers are plotted in the figure considering these values. The two way relationships among the Barriers, which are significant, are shown with bold lines in the figures. One way relationships among the Barriers are shown using a normal single line.

Table 5.13: Total relation matrix for Barriers of SCD

	LCSI	**MBOI**	**NERD**	**EMRC**	**LSIB**	**LFPM**	**DMSP**	**TMCI**	**LEDT**	**MSCP**	**LFIR**	**LIIS**	**TINS**	**POCL**	**LTEM**
LCSI	0.0635	0.0847	0.1356	0.0721	0.0918	0.0887	0.0351	0.0573	0.1171	0.1577	0.0653	0.0516	0.0513	0.0593	0.0361
MBOI	**0.1899**	0.1478	0.1367	**0.2441**	0.1876	**0.2728**	0.0846	0.1682	**0.2901**	**0.1981**	0.0638	0.1791	0.1487	**0.2061**	0.1219
NERD	**0.1896**	0.1340	0.1038	**0.2044**	0.1264	**0.1931**	0.1114	0.1369	0.1538	0.1737	0.0410	0.1068	0.1877	0.1671	0.1213
EMRC	0.1318	**0.1914**	0.1465	0.1346	0.1131	**0.2106**	0.0943	0.1851	**0.2185**	0.1249	0.0390	0.1524	0.1735	0.1082	0.1151
LSIB	**0.1985**	**0.2619**	**0.1927**	**0.2541**	0.1307	**0.2932**	0.1191	0.1794	**0.3093**	**0.2298**	0.0835	**0.2159**	0.1624	**0.2050**	0.1072
LFPM	0.0732	0.1681	0.0885	0.1811	0.0767	0.1045	0.0508	0.1570	**0.1901**	0.1151	0.0294	0.1232	0.0938	0.0744	0.0937
DMSP	0.0597	0.1039	0.0766	0.1583	0.0924	0.1072	0.0433	0.0868	0.1173	0.0603	0.0299	0.0778	0.1428	0.0560	0.1339
TMCI	0.1451	**0.2285**	0.1742	**0.2476**	**0.2033**	**0.2579**	0.1624	0.1276	**0.2955**	0.1847	0.0771	**0.2084**	0.1671	0.1463	0.1698
LEDT	**0.1912**	**0.2470**	0.1239	**0.2308**	0.1624	**0.2354**	0.1085	**0.1952**	0.1767	0.1613	0.0714	**0.1995**	0.1440	0.1865	0.1143
MSCP	0.1469	0.1036	0.1761	0.0895	0.0750	0.1165	0.0683	0.0654	0.1603	0.0715	0.0332	0.0708	0.0965	0.0631	0.0512
LFIR	0.1320	0.0855	0.0801	0.1185	0.0892	0.1536	0.0375	0.0859	0.1166	0.0635	0.0241	0.0653	0.0564	0.0850	0.0680
LIIS	0.0829	0.1131	0.1575	0.1420	0.1686	0.1535	0.0623	0.1005	**0.1961**	0.1406	0.0329	0.0852	0.0910	0.1597	0.0755
TINS	0.0652	0.0945	0.1472	0.1786	0.0811	0.1578	0.1287	0.0725	0.1112	0.1059	0.0286	0.0917	0.0857	0.0777	0.1415
POCL	0.0890	0.1661	0.1203	0.1598	0.1862	0.1772	0.1035	0.1647	**0.2195**	0.1143	0.0397	0.1828	0.1821	0.0942	0.1044
LTEM	0.0680	0.0940	0.0991	0.1696	0.1259	0.0975	0.0633	0.1014	0.1200	0.0788	0.1083	0.0845	0.1108	0.0967	0.0526

5.6 Analysis of findings

Based on the results obtained from the grey-DEMATEL method, the cause-effect relationships among the barriers are identified. The effect among barriers is shown by r_i+c_j values and r_i-c_j shows the causal relations among barriers.

Table 5.14: Cause/ effect parameters for barriers of SCD

Barriers	r_i	c_j	r_i+c_j	r_i-c_j
LCSI	1.16728	1.82648	2.994	-0.659
MBOI	2.63941	2.22409	4.863	0.415
NERD	2.15095	1.95875	4.110	0.192
EMRC	2.13901	2.58511	4.724	-0.446
LSIB	2.94254	1.91031	4.853	1.032
LFPM	1.61969	2.61946	4.239	-1.000
DMSP	1.34613	1.27302	2.619	0.073
TMCI	2.7955	1.88379	4.679	0.912
LEDT	2.54798	2.79213	5.340	-0.244
MSCP	1.38794	1.98022	3.368	-0.592
LFIR	1.26127	0.76708	2.028	0.494
LIIS	1.76143	1.89501	3.656	-0.134
TINS	1.56775	1.89397	3.462	-0.326
POCL	2.10377	1.78523	3.889	0.319
LTEM	1.47042	1.50643	2.977	-0.036

The significance of a barrier is revealed by ***ri+cj*** value. A positive value of r_i-c_j reveals that the barrier has a cause effect on other Barriers and a negative value of r_i-c_j implies the influence of Barriers by other Barriers. Table 5.14 reveals net cause-effect values and prominence for Barriers. The cause and effect figure is shown in Figure 5.8.

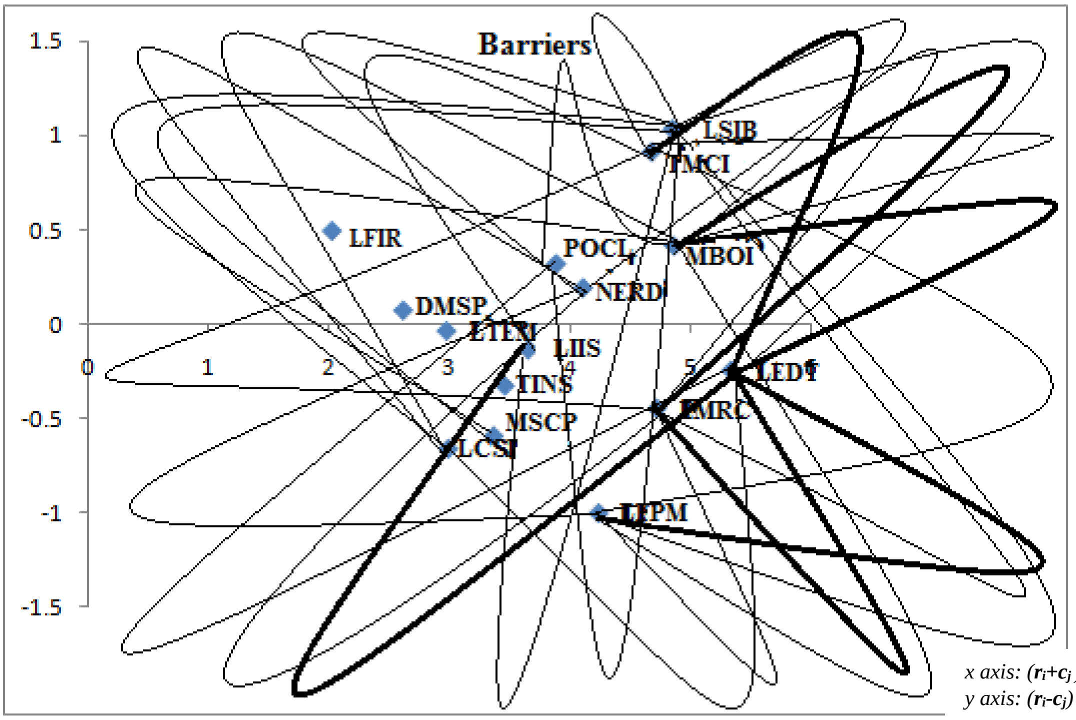


Figure 5.8: Diagram showing causal relationship among barriers of SCD

According to the value of net effect (r_i-c_j,), the barriers can be divided mainly into two groups: (i) Cause group: where the (r_i-c_j) value greater than zero (ii) Effect group: where the

(r_i-c_j) value is less than zero. Table 5.14 and Figure 5.6 reveals that all the five prominent Barriers with the highest value fall under managerial dimensions. These barriers include lack of knowledge on SCD benefits (LSIB), Top management commitment inadequacy (TMCI), Lack of financial resources (LFIR), Misalignment of business objectives with IT (MBOI) and poor organizational culture (POCL).

5.6.1 Analysis of cause group

In this group, the Barriers that are having very high influence and affect other barriers very significantly are categorized. Based on the (r_i-c_j,) value, it is found that lack of knowledge on SCD benefits (LSIB) is the most influential Barrier, followed by Top management commitment inadequacy (TMCI). The findings about identification of LSIB and TMCI are major cause barriers and were discussed with the experts, and they have accepted it as the major barriers.

Further Barriers, lack of financial resources (LFIR), Misalignment of business objectives with IT (MBOI), poor organizational culture (POCL), Non-encouragement of R&D (NERD), Lack of training to employees (LTEM) are the other major Barriers categorized in cause group. Considerable amount of financial investment is required for digitalization of SC. Hence, the constraint of fund availability is another major Barrier. In order to effectively digitalize SC, the organizational objective should be clear and supported by culture in the organization. Lack of a properly defined objective and culture inhibiting the growth and changes in the organization acts as barriers. Further, non-encouragement of R&D in the firm and Lack of training to employees also hinders the process of digitalization. Considering the business activities, R&D should be made effective to bring in innovative ideas that facilitate growth of the organization. The business transactions and dealings among the SC partners shall be designed in such a way as to facilitate effective and competitive management of SC. All these can be achieved by providing proper training. Hence, Non-encouragement of R&D and Lack of training to employees has also come out subsequently as major cause barriers.

5.6.2 Analysis of effects group

It includes those Barriers which are mostly affected by other Barriers. The Barriers where (ri-c_j) value is less than zero is categorized in this group. Lack of education and technical know-how (LEDT) and Threats related to information security (TINS) are the major effects group Barriers. The benefits of digitalization process can be gained fully through effective transactions on a real time basis using advanced digital technologies. Hence, Lack of education and technical know-how and Threats related to information security hinders the process. These major effects barriers should be addressed effectively to gain maximum benefits. Further, Employee's reluctance to change (EMRC), Mistrust among SC partners (MSCP), Lack of commitment from SC partners to share information (LCSI), Lack of framework and performance metrics for SCI(LFPM), Decision making on short term perspective (DMSP) and Limited ICT infrastructure and systems (LIIS) are the other Barriers categorized in effects group.

5.7 Sensitivity Analysis

In order to verify the robustness of the obtained results, sensitivity analysis is done by assigning the highest weight to each respondent and assigning an equal weight for other respondents. The weights assigned for the analysis is shown in Table 5.15.

Table 5.15: Weights assigned for analysts during sensitivity analysis

	Expert 1	**Expert 2**	**Expert 3**	**Expert 4**
Situation 1	0.34	0.22	0.22	0.22
Situation 2	0.22	0.34	0.22	0.22
Situation 3	0.22	0.22	0.34	0.22
Situation 4	0.22	0.22	0.22	0.34

Four situations were considered. The cause effect parameters obtained in the four situations are shown in Table 5.16. In all the four situations the rankings of most of the barriers were not affected due to change in the weights of the analysts. This is graphically shown in Figures 5.9 and 5.10.

Table 5.16: Cause/ Effect parameters obtained during sensitivity analysis

	Situation 1		Situation 2		Situation 3		Situation 4	
	r_i+c_j	r_i-c_j	r_i+c_j	r_i-c_j	r_i+c_j	r_i-c_j	r_i+c_j	r_i-c_j
LCSI	3.037	-0.683	2.937	-0.655	2.948	-0.637	2.974	-0.654
MBOI	4.867	0.435	4.823	0.395	4.813	0.393	4.835	0.443
NERD	4.092	0.189	4.115	0.173	4.032	0.202	4.108	0.202
EMRC	4.751	-0.454	4.638	-0.449	4.673	-0.452	4.674	-0.422
LSIB	4.856	1.032	4.803	1.047	4.791	1.036	4.855	1.006
LFPM	4.225	-0.989	4.209	-1.030	4.190	-0.979	4.222	-0.990
DMSP	2.622	0.099	2.554	0.056	2.637	0.066	2.625	0.085
TMCI	4.717	0.944	4.636	0.903	4.611	0.902	4.649	0.902
LEDT	5.361	-0.274	5.247	-0.257	5.259	-0.221	5.353	-0.223
MSCP	3.380	-0.616	3.346	-0.596	3.368	-0.571	3.359	-0.614
LFIR	1.973	0.494	2.009	0.485	1.990	0.497	2.055	0.504
LIIS	3.629	-0.134	3.613	-0.146	3.625	-0.157	3.650	-0.132
TINS	3.453	-0.335	3.442	-0.313	3.447	-0.307	3.436	-0.333
POCL	3.873	0.276	3.927	0.394	3.824	0.304	3.838	0.273
LTEM	3.008	0.015	2.920	-0.006	2.953	-0.076	2.978	-0.048

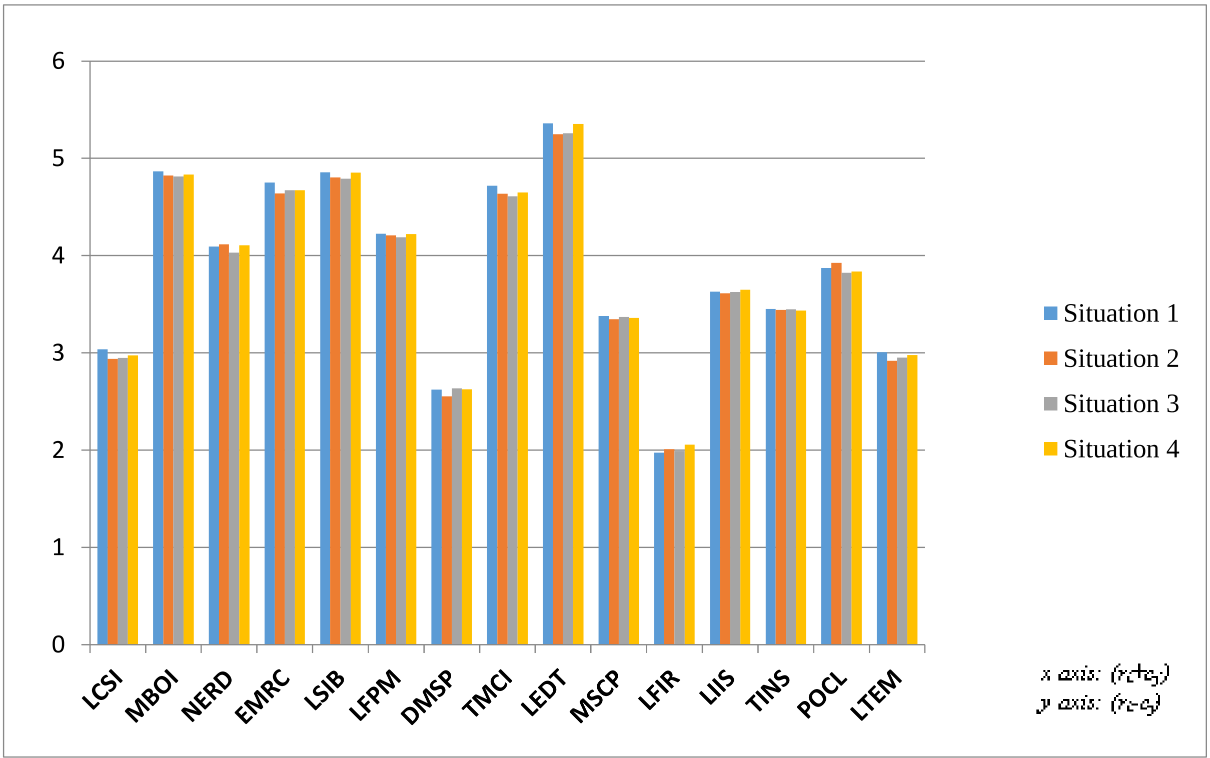


Figure 5.9: Results of sensitivity analysis of r_i+c_j value of barriers for SCD in different situations

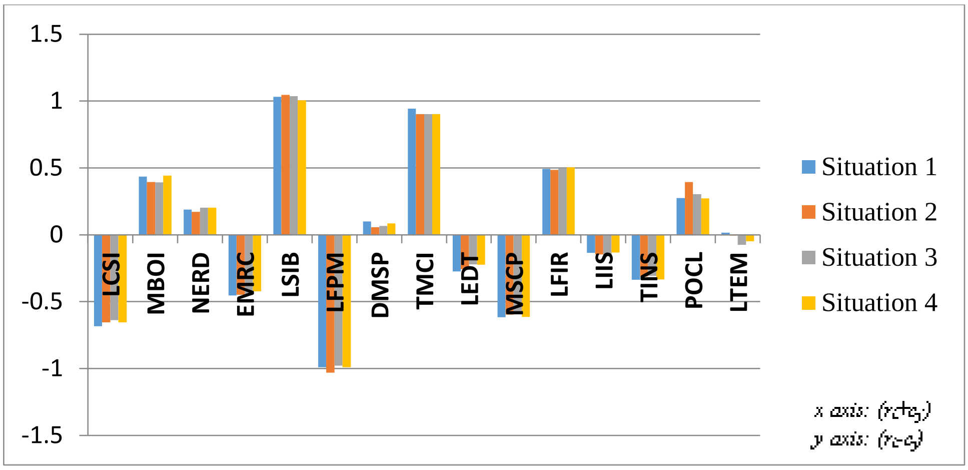


Figure 5.10: Results of sensitivity analysis of r_i-c_j value of barriers for SCD in different situations

The cause and effect figure of all the four situations with different weights is shown in figures 5.11- 5.14. It can be seen from this figure that there are negligible changes in the results. The same ranking obtained from the results of sensitivity analysis for all the major barriers identified proves the robustness of the results obtained.

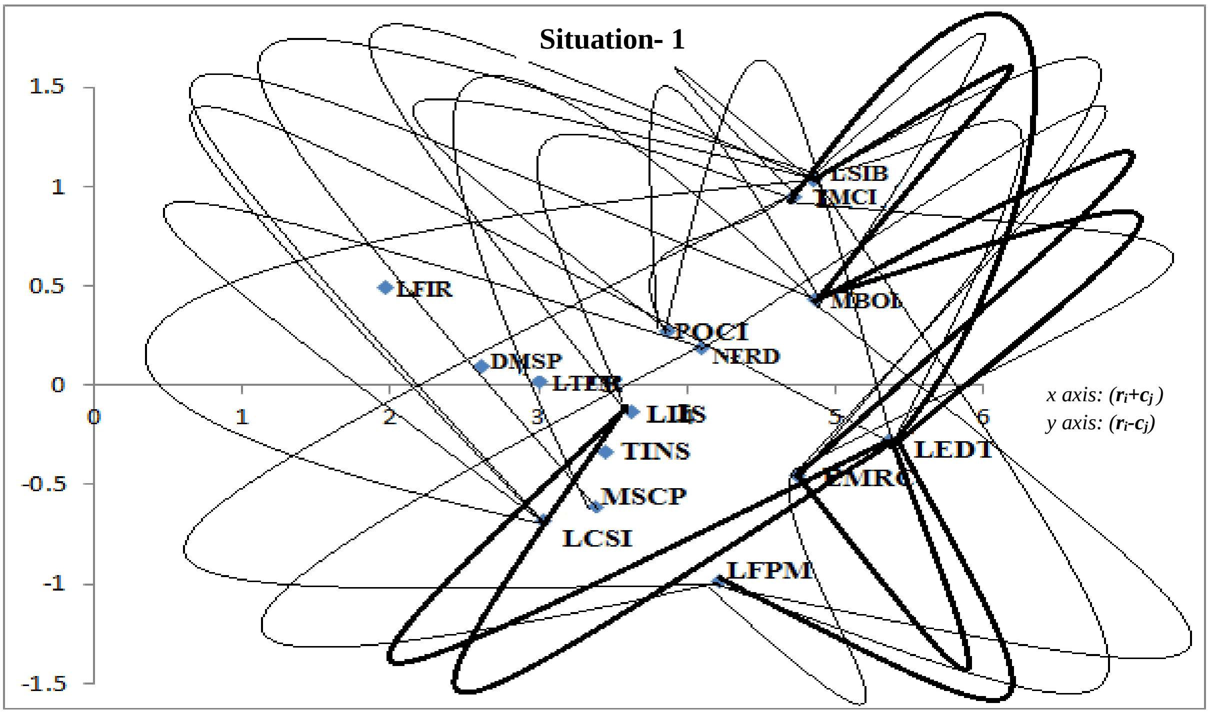


Figure 5.11: Diagram showing causal relationship among barriers of SCD– Expert 1

It also proves that there is no serious bias on the ratings given by various experts. The two-way relationship among the barriers is represented with bold lines.

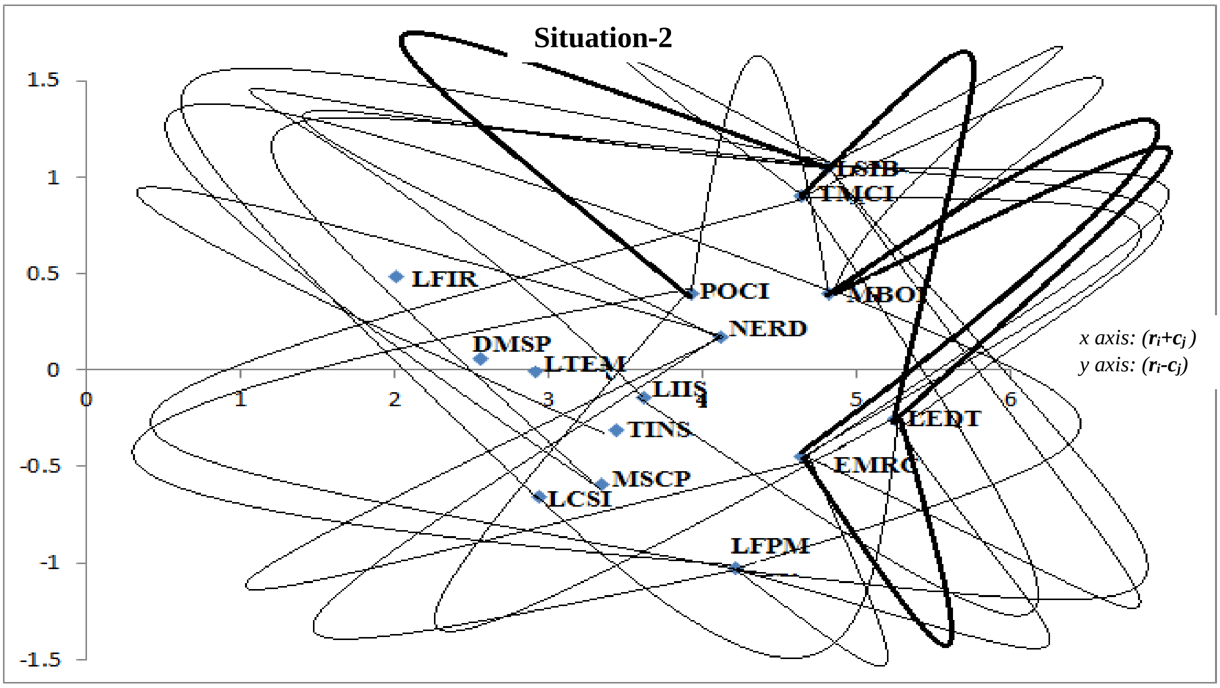


Figure 5.12: Diagram showing causal relationship among barriers of SCD– Expert 2

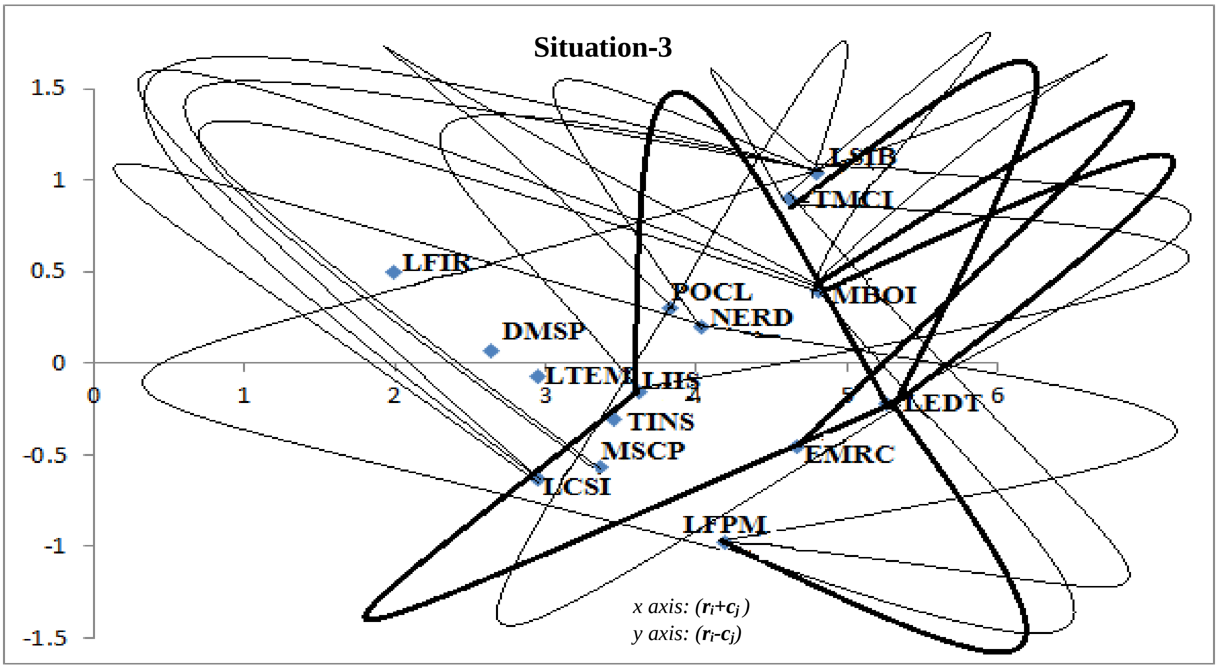


Figure 5.13: Diagram showing causal relationship among barriers of SCD– Expert 3

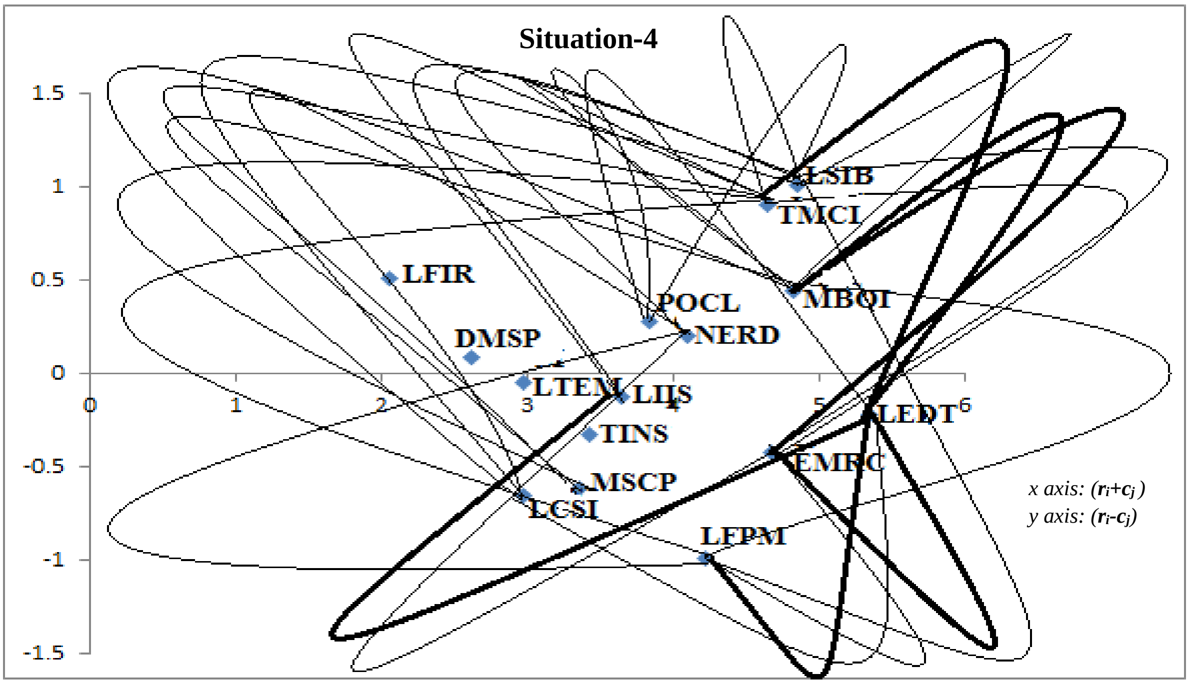


Figure 5.14: Diagram showing causal relationship among barriers of SCD– Expert 4

Table5.17. Comparison of results and validation of barriers affecting SCD

Sl.No Code	**Abbr**	**Barriers**	**Results** ISM Model Level/Order	Grey-DEMATEL Cause/Effect	MICMAC Classification Category
B1	LSIB	Lack of knowledge on SCD benefits	1	Cause	Independent
B2	NERD	Non-encouragement of R&D	6	Cause	Linkage
B3	LFIR	Lack of financial resources	3	Cause	Independent
B4	MBOI	Misalignment of business objectives with IT	4	Cause	Independent
B5	POCL	Poor organizational culture inhibiting cross functional interaction	5	Cause	Independent
B6	TMCI	Top management commitment inadequacy	2	Cause	Independent
B7	LIIS	Limited ICT infrastructure and systems	9	Effect	Dependent
B8	TINS	Threats related to information security	11	Effect	Dependent
B9	EMRC	Employee’s reluctance to change	12	Effect	Dependent
B10	MSCP	Mistrust among SC partners	13	Effect	Dependent
B11	LCSI	Lack of commitment from SC partners to share information	14	Effect	Dependent
B12	DMSP	Decision making on short term perspective	7	Effect	Linkage
B13	LTEM	Lack of training to employees	8	Cause	Linkage
B14	LEDT	Lack of education and technical know how	10	Effect	Dependent
B15	LFPM	Lack of framework and performance metrics for SCD	15	Effect	Dependent

The gaps in literature towards effective supply chain digitalization by addressing the key enablers and barriers affecting the process have been discussed in Chapters 4 and 5. The literature reveals that there is a lack of proper framework for digitalization of supply chain by identifying the key decision making factors affecting the process. Hence, it is essentially significant to develop a framework for effective supply chain digitalization. In order to address this gap in the literature, a framework is proposed and discussed in the next chapter.

CHAPTER 6

DEVELOPMENT OF A CONCEPTUAL FRAMEWORK FOR SUPPLY CHAIN DIGITALIZATION USING INTEGRATED SYSTEMS MODEL APPROACH AND DIKW HIERARCHY

6.1 Decision Making Factors (DMF) for SCD

Successful SCD is a challenging task. The major challenges faced are budget, low outcome and time overrun during the implementation process. Other factors include lack of IT, information sharing, demand distortion-bullwhip, system incompatibility, lack of knowledge and cost of integration. The purpose of SCD cannot be fulfilled just by adopting modern equipment and technologies. Lechler et al., (2019) have stressed the relevance of investigating and further study on the emerging aspects of processing data in real world contexts.

Table 6.1: Description and reference of critical DMF for SCD

Sl.No	Decision making factors	References	Relevance to SCD
DMF1	Top Management Commitment and Support	Wei et al., 2020; Gupta et al., 2020b	Organizations are unable to proceed with SCD due to lack of top management commitment and support
DMF 2	Financial Investments	Wang et al., 2019; Xing et al., 2019	Financial investments are required for arranging the resources and meeting expenses
DMF3	Organizational Objectives	Zhang et al.,2020; Preindl et al., 2020	Digitalization process lacks purpose without proper organizational objectives
DMF4	Technical Expertise	Kurpjuweit et al., 2019; Saberi et al., 2019	Availability of Technical expertise adds to the SCD process
DMF5	Preparedness for data management	Mandal, 2019; Botchie et al., 2019	Readiness of data management for digitalization process is significant
DMF6	Research and Development	Cukier, 2018; Radanliev et al., 2019; Fu et al., 2019	R&D is mandated to bring in innovative changes in SCD process
DMF7	Adequate IT systems and tools	Ulhaq.et.al, 2016; Malyavkina et al., 2019	Effective and advanced IT tools are required for SCD
DMF8	Data security and privacy	Rejeb et al., 2019; Schniederjans et al., 2020	Security and privacy is crucial for information transmission
DMF9	Trust among SC partners	Salam, 2017; Wong et al., 2020	Security and trust among the partners is a significant aspect required for SCD
DMF10	Information sharing among SC partners	De Giovanni et al., 2019; Girdwichai et al., 2019	SC partners shall be willing to share information across the SC
DMF11	Standards and performance metrics related to SCD	Yadav et al., 2020; Lima-Junior et al, 2020	Standards and performance metrics are required to measure the performance of the SC
DMF12	Decision making perspectives	Barbosa-Povoa et al., 2020; Preindl et al., 2020	Decision making perspective shall be done on a long term basis

SCI process has three levels of facilitators like information integration, coordination and information sharing and organizational relationship linkage (Alfalla-Luque et al., 2012). Information integration is the major component of SCI process, which is applicable to all business organizations. There is a positive relationship between SCI and performance of the firm by involving information, operational and relational integration (Leuschner et al., 2013).

Flexibility in operations and reduced cycle time are the core components of SCD (Stank et.al.,2019). Meanwhile, the availability of more data may create new uncertainties termed as 'uncertainty dilemma' (Lechler et.al., 2019). SCD involves the process of creating computer powered processes to handle value chain activities in a SC. It transforms the entire SC from end-to-end by facilitating availability of required inputs for executing the role of each SC partner.

SCD while compared with the conventional SC management differs drastically on account of management of knowledge, information and emerging technologies. This study tries to identify the key DMF that affect the process of SCD. A detailed description and reference sources with respect to key DMF identified in this study is shown in Table 6.1.

The innovative application of information systems in SC has raised various research questions on the intersection of data, technology, business and society in leveraging the thoughts being the core concept of business, policy and education (Agarwal and Dhar, 2014). The advanced digital solutions are transforming the business process from physical to data-driven services. This study is an attempt to bring in better insights for the decision making process on account of the advancement in IT and its use in SC. Information integration is the major component of the SCD process, which is applicable to all business organizations. Thus, organizations need to ensure proper collaboration both internally and externally among the SC partners for better performance of SC.

A conceptual approach for development of DIKW framework for SCD is shown in figure 6.1. The framework for SCD consists of various dimensions in which all the internal and external DMF affecting integration process is considered. Functional dimensions of each of the SC partners, its interrelationships and SCD policy needs to be framed accordingly. Improvements or betterment of any of the processes in the network and changes required is to be done based on monitoring and assessment.

Big data analytics in SC represents further scope for research being a developing technology (Hofmann and Rutschmann, 2018). From the literature it is found that the area of SCD in the era of digital transformation is a less explored area. The developments and advancement in IT forces the organizations to restructure the business models and functional roles in the SC. The

SC strategy and its relationship with the adoption of most advanced novel technologies are to be studied in detail. The digitally integrated SC and the effects of data driven services and management activities in the SC also need to be explored.

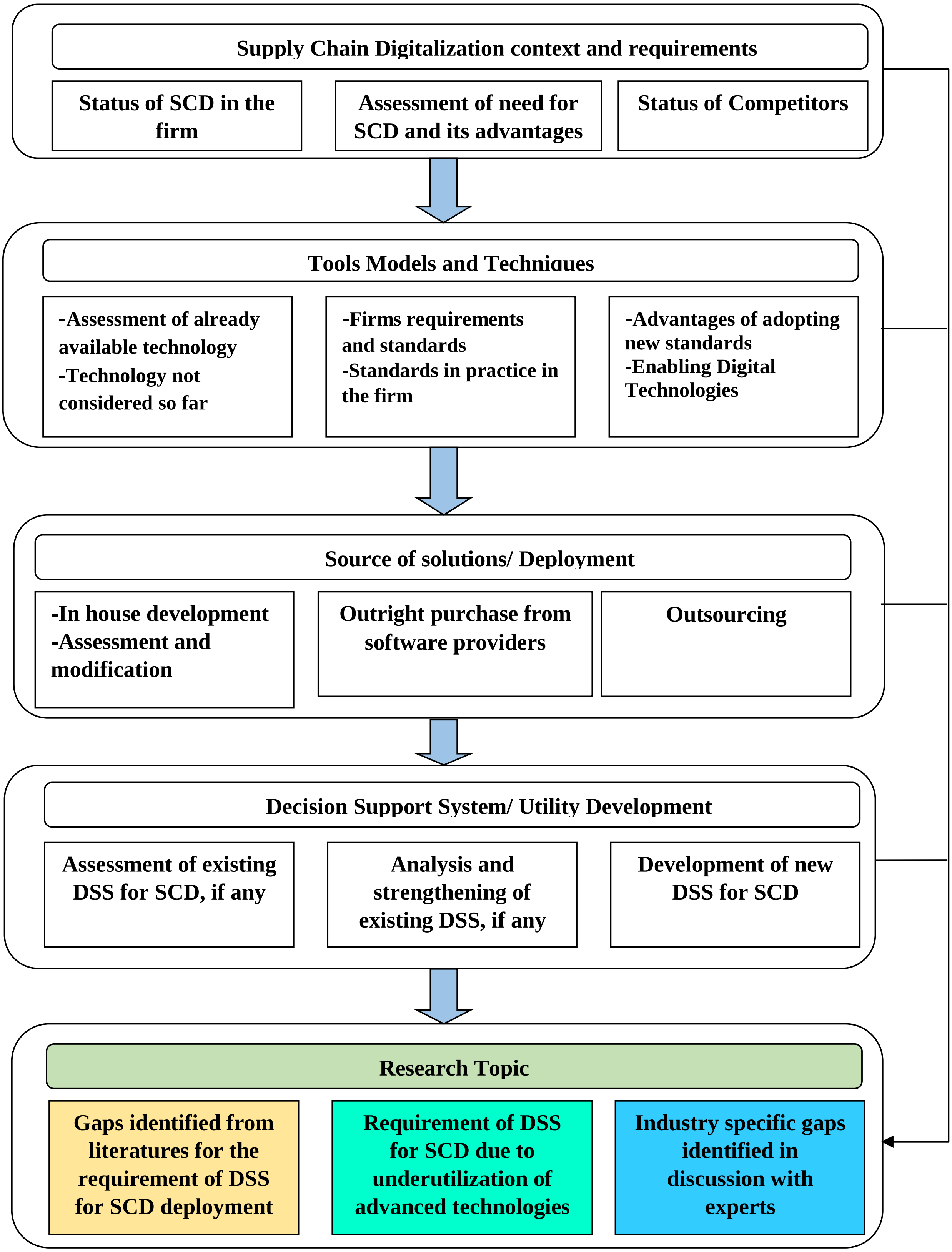


Figure 6.1: Conceptual approach for development of DIKW framework for SCD

6.2 Research Design and Methods

In this research we adopt DIKW (Data, Information, Knowledge and Wisdom) hierarchy to classify the DMF by linking the factors to each of the elements in the DIKW hierarchy.

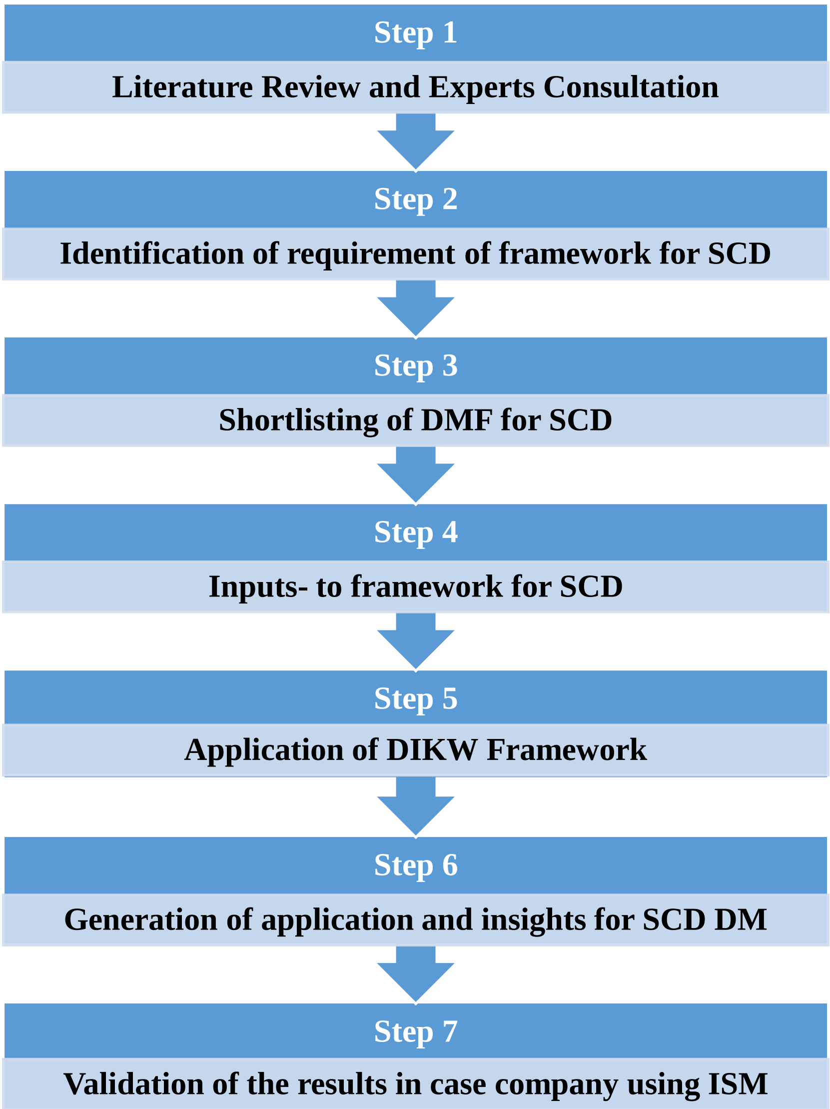


Figure 6.2: Diagrammatic representation of the research methodology

The DIKW model can represent the interrelationships among the components with control relationships in a flow diagram format with feedback loops. Further, the DIKW model developed is verified by applying to a case company in the electronics industry. The result of the case study is validated using the ISM method. A diagrammatic representation of the research methodology is shown in figure 6.2.

6.2.1 The DIKW Model

DIKW hierarchy can be used for better decision making (Ribeiro, 2020). Improved decision and policy making can be done by professionals based on integrated use of available data, information, knowledge and wisdom. Improvement in decision making is the main driver in any model developed for dimensional situation analysis (Ming et.al,2015). This study has used the DIKW hierarchy for arriving at better decision making for effective SCD.

The DIKW model is represented in a hierarchical pyramid form in which the bottom of the pyramid represents the data, followed by information, knowledge and wisdom. It explicitly mentions that the higher elements in the pyramid can be achieved after transformation of lower elements. Processing of available data leads to information, and transformation of information leads to knowledge and finally knowledge leads to wisdom. As the elements in the hierarchy go up, the value also increases, explaining it as a value chain (Chaffey and Wood,2005), as quoted in Rowley (2007). The DIKW model can also be represented in a flow diagram format showing the interrelationships among the components with control relationships and feedback loops. In the present study, a graphical representation in such a format is used to mention the value chain in Figure 4. The definition for each level in the DIKW model is given based on the DMF identified and transformation process occurring at each stage and a framework is developed accordingly.

In a DIKW hierarchy, the data can be considered as raw measurements, and information generates links between these measurements. Data is also considered as initial and recorded descriptions of any activity, event or things and transactions. The data collected are processed and inferred with a meaning can be termed as information, which is essential for creating knowledge. Information is made of well-formed data which are meaningful for further analysis or inference. With expert opinion, experience and skills are added to the combination of data and information, it can be termed as knowledge, which is a valuable asset in the decision making process (Chaffey and Wood, 2005). The knowledge accumulated leads to wisdom which helps to understand and apply concepts to new situations or problems. Wisdom helps to proceed practically in a given situation based on ethical judgment made by an individual's belief system.

6.2.2 Interpretive Structural Modeling (ISM)

ISM is an interactive learning process in which a set of elements are structured into a comprehensive systematic model wherein both dissimilar and directly related elements are involved. The multilevel structural model developed by using ISM depicts a sub-systems level representation of a complication system, thereby imposing order and complexity of the relationships among the elements of a system. Later the method was used for research in management like sustainable SC management, and buyer supplier partnership (Mohseni et.al., 2019). Twelve major DMF were shortlisted from literature review and based on opinion from experts in the industry and academia which are significant to gain maximum benefits, while proceeding with SCD. The ISM method is used to validate the results based on the case study.

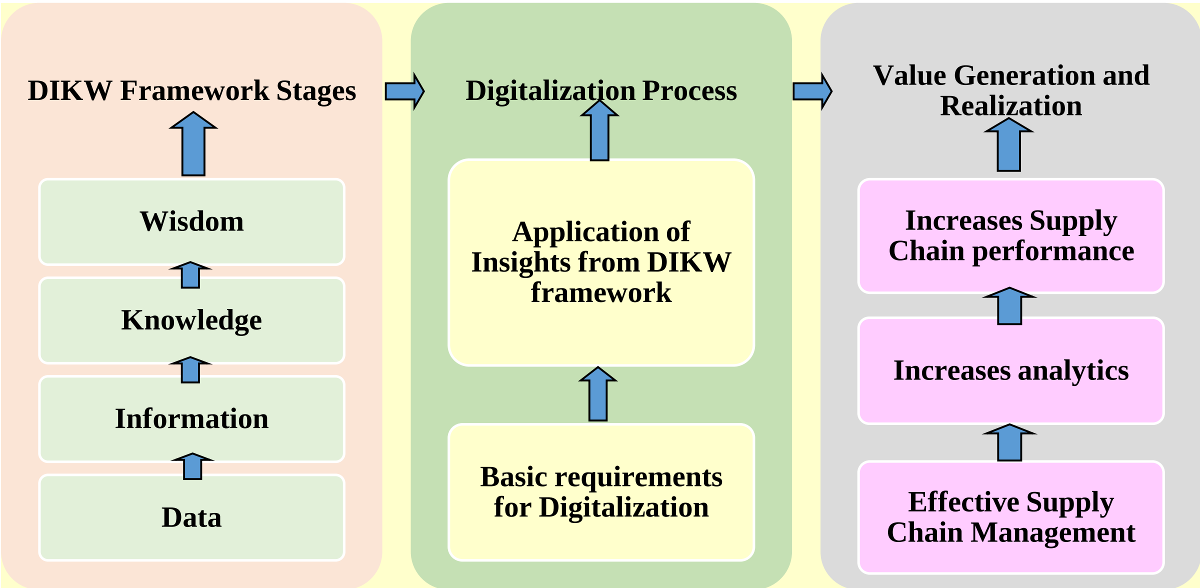


Figure 6.3 Work flow of application of DIKW framework for SCD Process

6.2.3. Systems approach in Decision Making

The system approach in decision making helps the decision maker to analyze the impact of decision taken in the system as a whole. System can be defined as an assemblage or combination of elements or parts forming a complex or unitary whole (Blanchard, et al., 2006). The system approach of decision making needs to consider various elements that interact with each other and their relationships to achieve a common goal. It also aids the decision maker in identifying where the decision impacts the system.

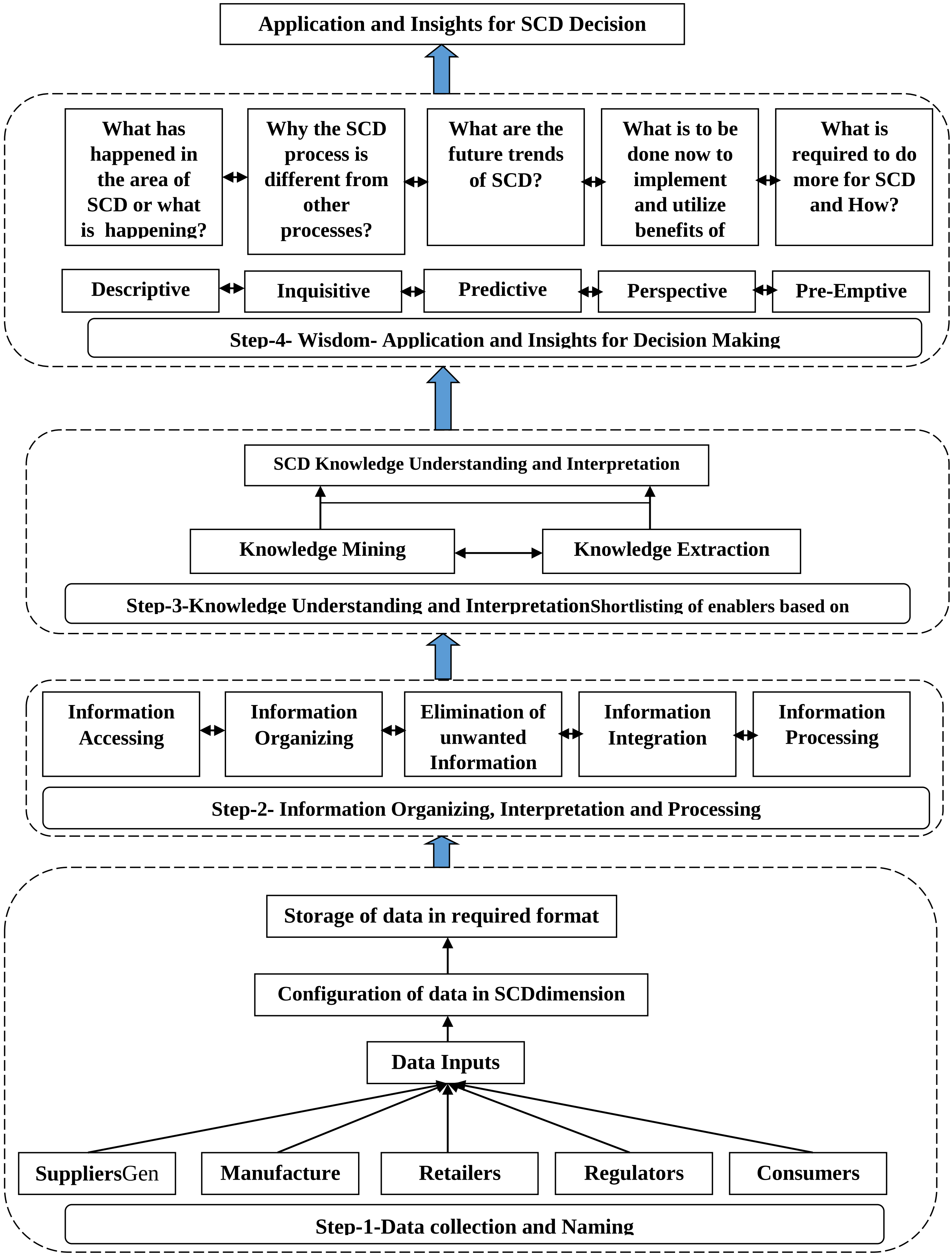


Figure 6.4: Framework for Supply Chain Digitalization based on DIKW Hierarchy

6.2.4 DIKW framework and work flow of SCD process

The framework is developed based on the concept of DIKW pyramid in which the aspects with respect to various SC partners are gathered and processed. It includes requirements from suppliers, manufacturers, retailers, regulators and consumers which are having an impact on SC processes.

The major DMF are also to be considered and analyzed at each level of the DIKW pyramid and processed along with the inputs collected from the partners for consideration in the next level for the decision making process. The three main dimensions of SCD framework are organizational, technological and innovative dimensions.

SCD can be materialized effectively by taking into account DMF affecting the process at each level of DIKW hierarchy from data to wisdom. By proceeding with the sequence in the DIKW hierarchy, a suitable decision for SCD can be arrived at. Accordingly, based on the DMF and applying DIKW pyramid practically, all the twelve major DMF identified are to be processed and analyzed through each stage of the DIKW framework from data to wisdom. A diagrammatic representation of the work flow of the SCD process is shown in Figure 6.3.

The sequence of proceeding with the DIKW hierarchy, and finally the framework developed helps in arriving at a suitable decision for SCD without getting caught in any of the traditional or established framework and tools available for SCD. The sequential procedure presented by considering all the key DMF will allow the decision maker to consider all influential elements of each of the factors, by removing the hindrances so as to digitalize SC effectively. A DIKW based framework for SCD is shown in Figure 6.4.

6.2.5. Integration of DIKW framework with Decision Support System (DSS)

The relevance of the development and application of Decision Support Systems (DSS) for supply chain management will continue to evolve due to advancements in digital technologies. DSS assists a business in decision-making by producing detailed information reports based on effective data analysis through human- powered, automated, or both mechanisms. Contrary to a traditional system, a DSS can be tailored to suit the firm or individual involved in decision-making. A DSS mainly consists of three components, namely, input database, decision-making framework, and output. The decision support systems (DSS) developed in the field of the supply chain are mainly based on a numerical simulation approach (Gromov et al., 2019), followed by MCDM based techniques (Karthik, 2015). The DSS developed in supply chain has been used widely for supplier relationships (Sahu et al., 2018); production (Gardas et al., 2019); transportation (Essien et al., 2018); construction (Guerlain et al., 2019); transactions (Brauner et al., 2019) and e-commerce. Hence an integrated approach of DIKW Hierarchy and systems model into a DSS for effective decision-making on SCD will be a novel contribution to the literature also for practical applications.

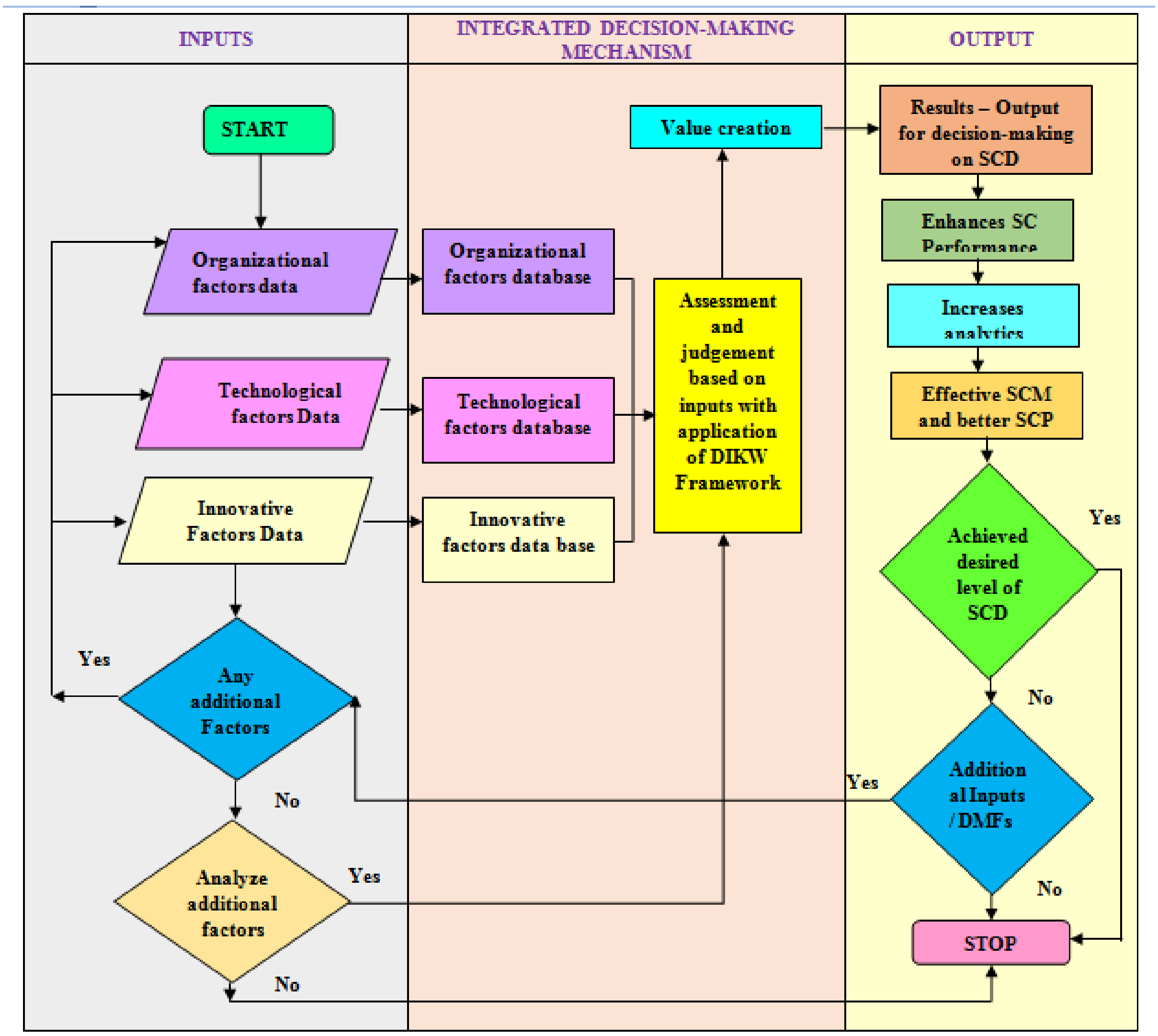


Figure-6.5 Diagrammatic representation of integrated Decision Support System

The model-driven DSS relies on data, and the parameters are found out based on information provided by the users. Further, the situations are analyzed based on the information generated and processed in the decision-making model. Hence, the integrated DSS will assist business organizations in effective decision-making by processing raw data into useful information. The output from the DSS aids the decision-making at strategic, tactical, and operational levels of the organization. The model-driven DSS assists in com- piling useful data and information to make effective decisions and solving problems through a human interface. A diagrammatic representation of the integrated DSS developed is shown in Fig.6.5. The inputs considered in the system are the data about DMFs under various categories like organizational, technological, and innovative data; the process part includes analysis and value creation by the DIKW framework, followed by output as the results and insights for effective decision-making.

6.3 Case Evaluation

In this paper, analysis of key DMF and the development of a framework are validated by using Interpretive Structural Modeling (ISM) method. ISM has been used in various studies to analyze and identify the interrelationships among the factors. Thus, the ISM method is used in this study to identify the interrelationships and analyze the DMF with respect to SCD. The application of the model on a case company in the electronics industry for validating the proposed model is explained in detail in this section.

The case study is performed in an MNC, XYZ Company, which is one of the prominent companies in the electronic industry dealing with manufacturing of electronic consumer products and services. This company is considered for the study to take advantage of their expertise and experience in the field, which ensures the credibility of the case study design. The company is rapidly growing in the electronics industry with a very vast range of products and services. The advancement in digital technologies and its applicability in integration can bring in much more benefits compared to the existing system. The experts in the company were consulted and the key DMF identified were evaluated. The DMF identified from the literature were further shortlisted based on brainstorming sessions with the experts. The expert's panel consists of four members; three from industry and one from academia. The experts selected are having an overall experience of more than 15 years. The experts from the company are Senior Managers in the area of IT, Product Life Cycle Management and Operations Management. The academic expert is an Associate Professor in a reputed University researching in the area of Operations and Supply Chain Management and associated with industrial projects related to automation of SC activities. We assume that, considering the vast work experience of the experts consulted, the feedback and inputs are reliable and have been used for this study.

The sequential procedure presented by considering all the key DMF would allow the decision maker to consider all influential elements of each of the factors for SCD effectively.

6.4 Validation using ISM model

An SSIM is developed based on the contextual relationships between the DMF and is shown in Table 6.2.

Table 6.2: Structural self-interaction matrix (SSIM)

Factors	DMF 12	DMF 11	DMF 10	DMF 9	DMF 8	DMF 7	DMF 6	DMF 5	DMF 4	DMF 3	DMF 2
DMF1. Top management Commitment and Support	V	O	V	V	V	V	V	A	V	V	V
DMF 2. Organizational Objectives	V	O	V	V	V	V	V	A	V	X	
DMF 3. Financial investments	V	V	V	V	V	V	V	A	V		
DMF 4. Technical expertise	V	V	V	V	V	X	X	A			
DMF 5. Preparedness for Data Management/BPR	V	V	V	V	V	V	V				
DMF 6. Adequate IT Systems and tools	V	O	V	V	V	X					
DMF 7. Research and Development	V	V	V	O	V						
DMF8. Information security and privacy across networks	V	O	V	X							
DMF9. Trust among SC partners	V	O	V								
DMF 10. Information sharing among SC partners	V	V									
DMF 11. Standards and performance metrics for SCD	V										
DMF 12. Decision making perspectives											

Subsequent to this the initial reachability matrix and final reachability matrix were worked out and iteration process was done to build the ISM model. The tables showing the iterations from I to VIII is shown from Table 6.5 to 6.12. The ISM model developed based on the process is shown in Figure 6.6.

Table 6.3: Initial reachability matrix of DMFs

Factors	1	2	3	4	5	6	7	8	9	10	11	12
1. Commitment from top management	1	1	1	1	0	1	1	1	1	1	0	1
2. Organizational Objectives	0	1	1	1	0	1	1	1	1	1	0	1
3. Financial investments	0	1	1	1	0	1	1	1	1	1	1	1
4. Technical expertise	0	0	0	1	0	1	1	1	1	1	1	1
5. Preparedness for Data Management/BPR	1	1	1	1	1	1	1	1	1	1	1	1
6. Adequate IT Systems and tools	0	0	0	1	0	1	1	1	1	1	0	1
7. Research and Development	0	0	0	1	0	1	1	1	0	1	1	1
8. Information security and privacy across networks	0	0	0	0	0	0	0	1	1	1	0	1
9. Trust among supply chain partners	0	0	0	0	0	0	0	1	1	1	0	1
10. Information sharing among supply chain partners	0	0	0	0	0	0	0	0	0	1	1	1
11. Standards and performance metrics for integration	0	0	0	0	0	0	0	0	0	0	1	1
12. Decision making perspectives	0	0	0	0	0	0	0	0	0	0	0	1

Table 6.4: Final reachability matrix of DMFs

Factors	1	2	3	4	5	6	7	8	9	10	11	12	Driver Power
1. Commitment from top management	1	1	1	1	0	1	1	1	1	1	1	1	**11**
2. Organizational Objectives	0	1	1	1	0	1	1	1	1	1	1	1	**10**
3. Financial investments	0	1	1	1	0	1	1	1	1	1	1	1	**10**
4. Technical expertise	0	0	0	1	0	1	1	1	1	1	1	1	**8**
5. Preparedness for Data Management/BPR	1	1	1	1	1	1	1	1	1	1	1	1	**12**
6. Adequate IT Systems and tools	0	0	0	1	0	1	1	1	1	1	1	1	**8**
7. Research and Development	0	0	0	1	0	1	1	1	1	1	1	1	**8**
8. Information security and privacy across networks	0	0	0	0	0	0	0	1	1	1	1	1	**5**
9. Trust among supply chain partners	0	0	0	0	0	0	0	1	1	1	1	1	**5**
10. Information sharing among supply chain partners	0	0	0	0	0	0	0	0	0	1	1	1	**3**
11. Standards and performance metrics for integration	0	0	0	0	0	0	0	0	0	0	1	1	**2**
12. Decision making perspectives	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence power	**2**	**4**	**4**	**7**	**1**	**7**	**7**	**9**	**9**	**10**	**11**	**12**	

Table 6.5: Level partition for DMFs: Iteration 1

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 7, 8, 9, 10, 11,12	1, 5	1	
2	2, 3, 4, 6, 7, 8, 9, 10, 11,12	1, 2, 3, 5	2, 3	
3	2, 3, 4, 6, 7, 8, 9, 10, 11,12	1, 2, 3, 5	2, 3	
4	4, 6, 7, 8, 9, 10, 11,12	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12	5	5	
6	4, 6, 7, 8, 9, 10, 11,12	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
7	4, 6, 7, 8, 9, 10, 11,12	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
8	8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 8, 9	8, 9	
9	8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 8, 9	8, 9	
10	10, 11, 12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	10	
11	11,12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	11	
12	12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	12	**I**

Table 6.6: Level partition for DMFs: Iteration 2

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 7, 8, 9, 10, 11	1, 5	1	
2	2, 3, 4, 6, 7, 8, 9, 10, 11	1, 2, 3, 5	2, 3	
3	2, 3, 4, 6, 7, 8, 9, 10, 11	1, 2, 3, 5	2, 3	
4	4, 6, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	5	5	
6	4, 6, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
7	4, 6, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
8	8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 8, 9	8, 9	
9	8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 8, 9	8,9	
10	10, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	10	
11	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	11	**II**

Table 6.7: Level partition for DMFs: Iteration 3

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 7, 8, 9, 10	1, 5	1	
2	2, 3, 4, 6, 7, 8, 9, 10	1, 2, 3, 5	2, 3	
3	2, 3, 4, 6, 7, 8, 9, 10	1, 2, 3, 5	2, 3	
4	4, 6, 7, 8, 9, 10	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	5	5	
6	4, 6, 7, 8, 9, 10	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
7	4, 6, 7, 8, 9, 10	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
8	8, 9, 10	1, 2, 3, 4, 5, 6, 7, 8, 9	8,9	
9	8, 9, 10	1, 2, 3, 4, 5, 6, 7, 8, 9	8,9	
10	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	10	**III**

Table 6.8: Level partition for DMFs: Iteration 4

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 7, 8, 9	1, 5	1	
2	2, 3, 4, 6, 7, 8, 9	1, 2, 3, 5	2, 3	
3	2, 3, 4, 6, 7, 8, 9	1, 2, 3, 5	2, 3	
4	4, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
5	1, 2, 3, 4, 5, 6, 7, 8, 9	5	5	
6	4, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
7	4, 6, 7, 8, 9	1, 2, 3, 4, 5, 6, 7	4, 6, 7	
8	8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9	8,9	**IV**
9	8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9	8,9	**IV**

Table 6.9: Level partition for DMFs: Iteration 5

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 7	1, 5	1	
2	2, 3, 4, 6, 7	1, 2, 3, 5	2, 3	
3	2, 3, 4, 6, 7,	1, 2, 3, 5	2, 3	
4	4, 6, 7	1, 2, 3, 4, 5, 6, 7	4, 6, 7	**V**
5	1, 2, 3, 4, 5, 6, 7	5	5	
6	4, 6, 7	1, 2, 3, 4, 5, 6, 7	4, 6, 7	**V**
7	4, 6, 7	1, 2, 3, 4, 5, 6, 7	4, 6, 7	**V**

Table 6.10: Level partition for DMFs: Iteration 6

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3	1, 5	1	
2	2, 3	1, 2, 3, 5	2, 3	**VI**
3	2, 3	1, 2, 3, 5	2, 3	**VI**
5	1, 2, 3, 5	5	5	

Table 6.11: Level partition for DMFs: Iteration 7

Factor	Reachability set	Antecedent set	Intersection set	Level
1	1	1, 5	1	**VII**
5	1, 5	5	5	

Table 6.12: Level partition for DMFs: Iteration 8

Factor	Reachability set	Antecedent set	Intersection set	Level
5	5	5	5	**VIII**

6.5. Results and discussion

The key DMF identified were categorized based on the DIKW hierarchy into data, information, knowledge and wisdom. Data is the initial phase of communication or any process where the facts are obtained and processed further for obtaining a valuable output. These are objective facts or observations which are discrete in nature in an unorganized and unprocessed form without conveying any specific meaning. Preparedness for data management (DMF5), top management commitment (DMF1), financial Investments (DMF2) and organizational objectives (DMF3) comes under data in the DIKW hierarchy. The willingness for managing data and changing the business process along with commitment in top management are the dominant DMF, followed by financial investments required for adopting changes in data management and finalizing of clear organizational objectives are the initial steps.

When the data adds value to convey meaning it is known as information (Chaffey and Wood,2005).Research and development (DMF6), adequate IT systems and tools (DMF7), technical expertise (DMF4), information security and privacy across networks (DMF8)are the factors that come under the information level of DIKW hierarchy. Information emerges from the data based on cognitive processing. Meaning emerges from data processing which will result in creation of information which can be made useful for arriving at a decision based on the value addition occurring at the next levels.

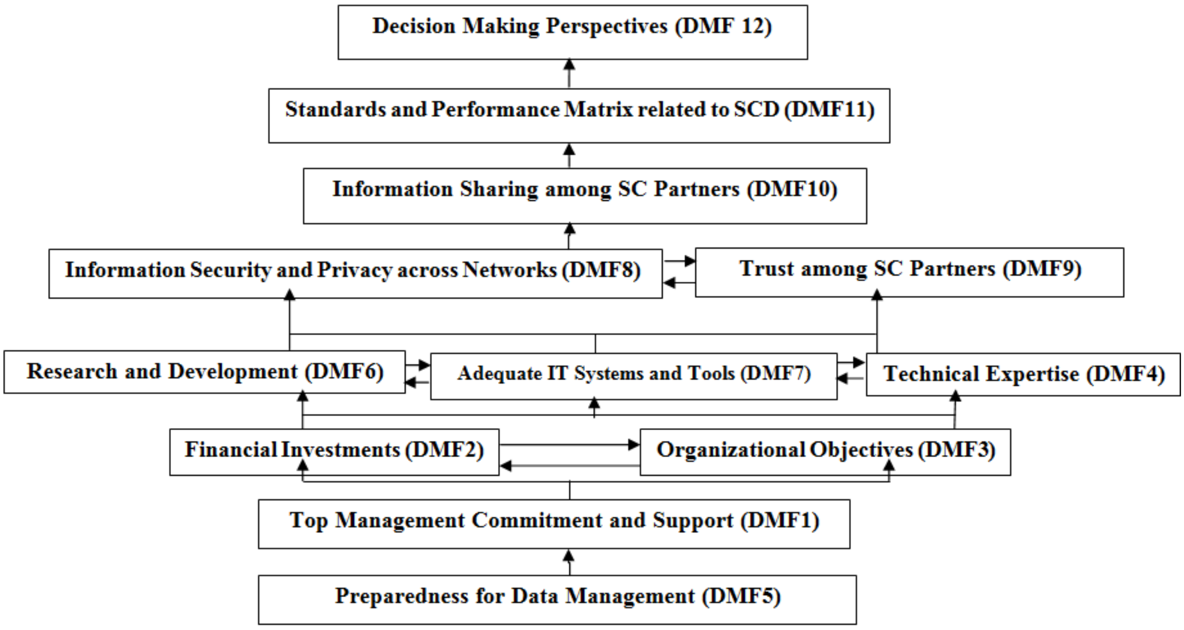


Figure 6.6: ISM Model of key Decision Making Factors

The third level in the DIKW hierarchy is knowledge which constitutes the beliefs of a person which is judged to be true. The data or information which is processed and organized to infer understanding, learning, experience and expertise while applying to an activity or problem, can be termed as knowledge. The three components of knowledge include information, meaning and the context. The meaning inferred shall depend on the context in which the information is processed. Trust among SC partners (DMF9), information sharing among SC partners(DMF10), standards and performance matrix related to SCD (DMF11) are the key DMFs falling under knowledge level. The existence of trust, information sharing and standards are the beliefs in the mind of SC partners that adds value to information. Such value addition helps in proper SCD by proceeding with each phase as per the framework developed.

Wisdom is the process of utilizing the knowledge to the best of ability to learn and achieve the desired goals. Wisdom can be in the form of individual wisdom and organizational wisdom.

Finally, at the wisdom level of the hierarchy, data, information and knowledge leads to decision making perspectives (DMF12), in which decision on SCD can be taken based on wisdom. It constitutes the normative judgment of a person on the process to be adopted for SCD by giving due importance to the DMF. The DMF identified were classified under three major categories like managerial, technological and innovative dimensions (Seppanen, 2007). The classification of DMF identified based on the dimensions are shown in Figure 6.7.

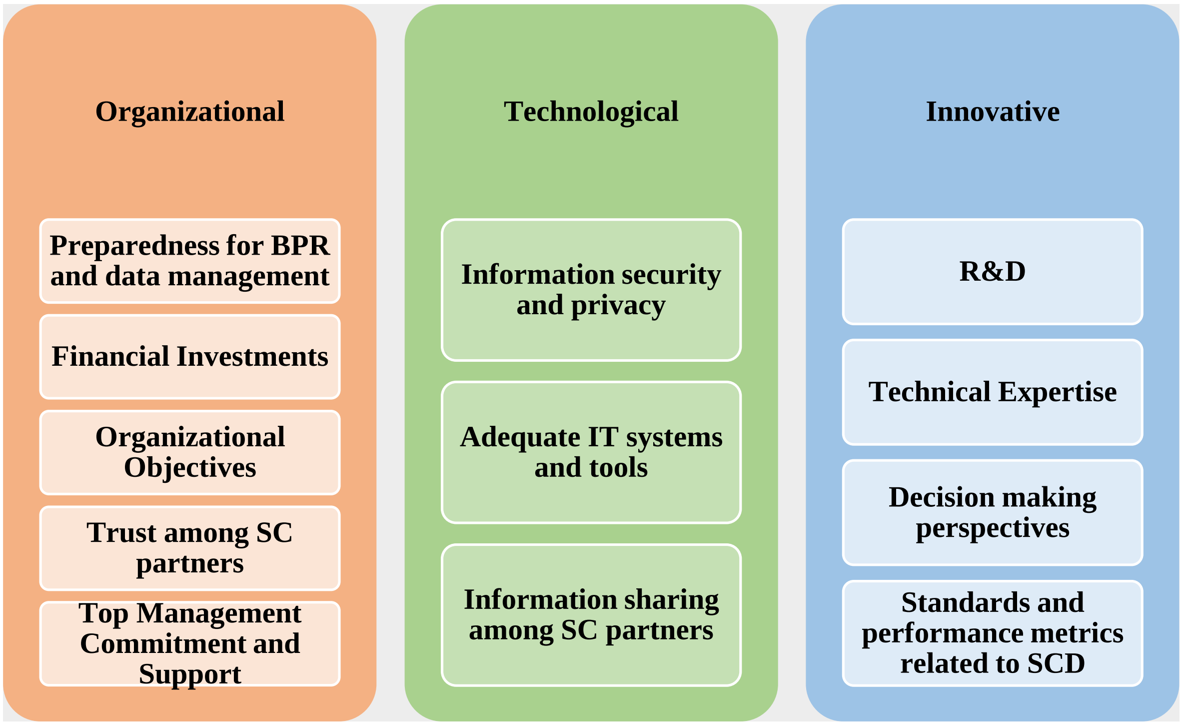


Figure 6.7: DMF classification

Some of the major findings of this study are detailed below:

Firstly, the SCD is to be done by considering the key DMF and its interrelationships. In this study, the major DMF affecting the process of SCD were shortlisted based on literature review and in consultation with the experts in industry and academia. Secondly, a sequential method for SCD process and a framework is developed. It includes identification of key DMF followed by application of DIKW hierarchy and systems approach.

Thirdly, the results arrived from the study is applied in a case electronics company and robustness of the framework developed is validated using ISM method. The interrelationships among the DMF were identified and an ISM model is developed by prioritizing the DMF so that the most dominant DMF can be identified. While proceeding with SCD and taking a decision on the implementation process, the key DMF identified has to be given due consideration for arriving at a decision for effective SCD.

The sequential methodology along with the framework and ISM model developed can support the decision making process and development of appropriate design for SCD. The results of the study act as a guideline for the professionals and the practicing managers for the decision making process in the concerned field.

The twelve key DMF identified were classified based on three dimensions, i.e. Organizational dimensions, technological dimensions and innovative dimensions. The study contributes to the theoretical and practical knowledge on the process of SCD by introducing a novel method and approach to be followed while proceeding with SCD.

This study has significant implications for researchers and practitioners in supply chain digitalization. The first major implication is the identification of DMFs influencing the digitalization pro- cess. Considering the recent publications in supply chain digitalization (Holmstrom et al., 2019, Seyedghorban et al., 2020, Buyukozkan and Gocer, 2018) this study provides a significant contribution to supply chain digitalization. Further, based on the previous studies highlighting the influence of environmental factors affecting the adoption of digital technologies (Simoes et al., 2019), conducting further research by mobilizing various theoretical frameworks (Ageron et al., 2020), we have identified the key DMFs to be considered during the digitalization process. Thus, in this research, an integrated framework for supply chain digitalization is developed using DIKW Hierarchy and System model approach.

The literature review on digital supply chain (DSC) denotes a gap between theoretical studies and its practical applications. Researches pertaining to implementation and decision making process with respect to DSC are very limited. A study on this aspect will contribute to theoretical knowledge and its practical applications in the supply chain. Hence, there is a need to develop a model for IOIS adoption in the supply chain, which is discussed in detail in Chapter 7.

CHAPTER 7

SUPPLY CHAIN DIGITALIZATION: AN INTEGRATED MCDM APPROACH FOR INTER-ORGANIZATIONAL INFORMATION SYSTEMS SELECTION IN AN ELECTRONIC SUPPLY CHAIN

7.1 Digitalization of supply chain

A digital supply chain network is an interconnected network wherein supply chain partners are interconnected through advanced information and communication technology tools facilitating continuous flow of information and automation (Xue et al., 2013). The digitalization process will result in value creation and capturing opportunities in a firm through real time data access and sharing of data and analytics (Grubic and Jennions, 2018; Hakanen and Rajala, 2018).

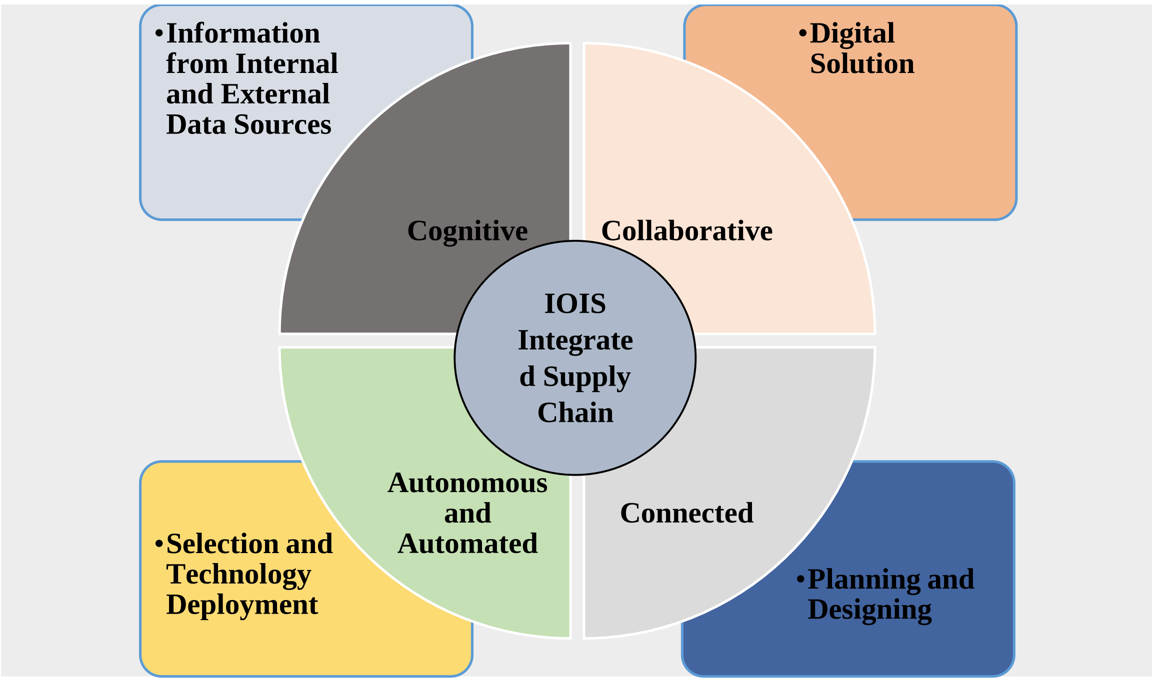


Figure 7.1: Research framework for IOIS integrated supply chain

The strategic adoption of digital technologies by firms is gaining relevance, whereas research on implementation of digital technologies in the supply chain to gain operational feasibility is rarely found in literature (Patrick et al., 2020). Literature reveals that the digitalization process results in gaining competitive advantage and opportunities for a company, whereas its implementation is equally challenging. Marwedel and Engel (2016) have found that a company's inability to alter its business is one of the challenges associated with the digitalization process. The five common mistakes that companies face while adopting to digital technologies, include (i) additional cost for the customer, (ii) privacy and security risks, (iii) threat from competitors with digitally advanced products and services, (iv)delay in switching over to digitisation resulting in losing customers and (v) over estimation of the internal capabilities to proceed with digitalization (Porter and Heppelmann, 2015). An integrated research framework for digitalization of supply chain using IOIS is shown in Figure 7.1.

A framework for digital technologies must consider various hardware and software solutions that facilitates development of an integrated model for supply chain digitalization. This framework would be helpful for organizations in identifying and planning activities for digitalization of supply chains. It involves various activities viz. (i) decision dimensions (ii) selection process and (iii) its implementation. The use of advanced digital platforms helps in gaining significant opportunities (Lenka et al., 2017). Intelligence capability, connect capability and analytic capabilities are the three components of digitalization capabilities which are identified from the literature.

The digitalization process creates collaborative value across supply chain networks and among the supply chain partners (Muller et al., 2018). Supply chains will become more productive by gaining the ability to collect, share and process the information for effective decision making. Knowledge management helps in driving the firm by taking more risk thus by gaining operational and strategic competence (Xue, 2014). Cloud computing and block chain are advanced digital technologies that provide data sharing on a real time basis across the supply chain (Tapscott and Tapscott, 2016). 3D printing and reconfigurable manufacturing technologies reduces lead time and supply chain costs (Cao et al., 2017).

7.2 Inter-organizational information systems in supply chain

Literature reveals that IOIS is one of the key factors that helps in maintaining inter-organizational relationships (Rahman, 2017). Firms involved in the integration of supply chain using IOIS can share technologies and exchange information on a real time basis to facilitate in making decisions (Haseeb et al, 2019). Dynamism of supply chain can be measured based on introduction of new products and its revenue share, frequency of innovation for new products and rate of operating processes for innovation (Lee et al., 2016). Information sharing, trust and collaboration are some of the key forms of inter-organisational competencies in relationship based supply chain (Mirkovski et al., 2016; Abdallah et al., 2017). In a digitized SC, companies use various software platforms to collaborate and drive SC activities. Major software platforms available in the market include Oracle, E2open, Man-hattan, Epicor Dassault Systems, Logility, Descartes, etc. The selection of software platforms and their associated digital solutions varies among firms as it depends mainly on the nature of business activities. The relevant literature on IOIS in the supply chain is given in Table 7.1. A diagrammatic representation of various types of IOIS and core supply chain management technologies are shown in Figure 7.2.

Table 7.1: Literature on Inter-Organizational Information Systems in Supply Chain

Sl. No	Area of Study	References	Relevance of Study
1	IT and organizational performance	Sutduean et al., 2019	Importance of material and information flow in supply chain integration and its correlation with supply chain performance.
2	IT infrastructure and trade digitalization	Saengchai et al., 2019	Relationship between IT standardization, integration and supply chain performance.
3	Digital supply chain business models	Nurk, 2019	Capabilities of information systems in supply chain.
4	Smart supply chain management.	Wu et al., 2016	Guidance for developing smart supply chains.
5	Using integrated information systems in management	Gonzalvez-Gallego et al., 2015	Effects of integrated information systems in firm's performance.
6	Decision model for content management systems	Oztaysi, 2014	Development of decision model.
7	Reconfiguration of the supply chain networks.	Kristianto et. al., 2012	Stresses integration of manufacturing and product design for supply chain reconfiguration using decision support system.
8	Impact of business analytics in supply chain performance	Trkman et al., 2010	Business analytics using information systems

It is found that a high level of dynamism in supply chain results in sharing of information through integrated systems within and among the organizations (Lee et al.,2016). The major concept of inter-organizational relationship refers to trust, commitment and shared vision among supply chain partners (Varoutsa and Scapens, 2015). Enhancing the performance of supply chain for sustaining competitive advantage is one of the critical issues (Trkman et al., 2015). The speed of information flows can be increased using advanced digital technologies having linkage between enterprise resource planning solutions (Moeuf et al., 2018). Accurate and real time sharing of information among the supply chain partners helps in effective supply chain management. Information sharing among supply chain partners is one of the key components of supply chain while adopting IOIS (Yilmaz et al., 2016). It leads to better inter-organisational relationships and interfacing among organizations sharing common vision (Ramanathan, 2014).

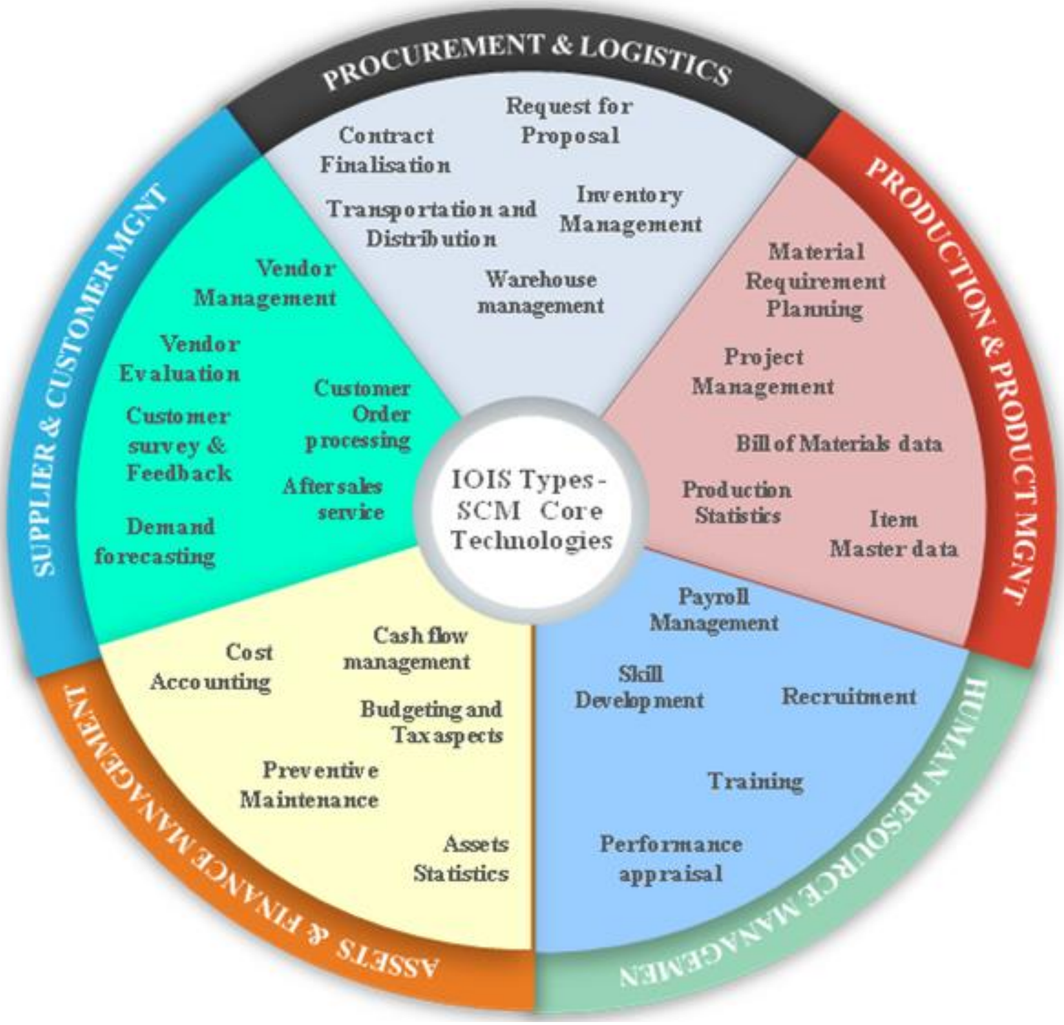


Figure 7.2: Inter-organizational information system types and supply chain management core technologies

Supply chains are rapidly transforming based on digital technologies (Ferdows, 2018; Ivanov et al., 2019). Digital technologies can be classified under three major areas. The first one is digital technology enabler (Gurria, 2017) which is the backbone of the digitisation process and consists of big data (Cao et al., 2017; Nguyen et al., 2017), internet of things (Moeuf, 2018) and cloud computing. The second one is digital system integrator which consists of cyber-physical systems, simulations and artificial intelligence (Khaitan and McCalley, 2015; Wang et al., 2015). The third area is application technologies that include additive manufacturing, 3D printing (Mellor, 2014; Durach et al., 2015) human-machine integration and autonomous machines and systems (Gurria, 2017). Digital technologies help in integrating data collected from various sources and facilitates on time production and distribution of goods and services. Further, the application of these advanced technologies creates business value and higher revenue for firms (Buyukozkan and Gocer, 2018).

Literature with respect to investigating the relationship between supplier, integration of IT, logistic integration and organizational performance is found. Sutduean et al., (2019) have found that material and information flow has significant correlation with supply chain performance. Kakhki and Gargeya (2019) have classified literature review on IOIS in supply chain management into six clusters. Studies with respect to the relationship between IT standardization and supply chain performance and IT integration are also found in literature. Saengchai et al., (2019) have addressed the mediating role of IT infrastructure between standardization, integration and supply chain performance.

7.3. Research methodology

This section deals with the research methodology used in the study. The decision model for supply chain digitalization using IOIS is developed by initiating a thorough literature review of existing studies on IOIS, digitalization of supply chain and followed by its validation with a case study in electronics industry. Theoretical knowledge and literature available is used as a methodological approach to construct the decision making framework (Luz Martin-Pena et al., 2018). The model developed comprises application of a quantitative approach using Analytic Hierarchy Process integrated TOPSIS methodology. Validation of the model developed is done through case evaluation by applying in an electronics firm, as the consumer electronics industry is facing drastic challenges due to technological, environmental and social developments. The major challenges include business risks (Migalska et al., 2020), social responsibility (Leclerc et al., 2020), regulatory norms (Oteng-Ababio et al., 2020), competition (Jena, et al., 2019), shorter product life cycles (Huang et al., 2019) and changing customer demands (Li et al., 2019c). All these challenges can be addressed through development of dynamic and efficient supply chains.

Further, constructivist theory and decision making framework methodology are supported with a case study (Hakanen and Rajala, 2018). In order to build and verify the decision making framework, a case study is designed with an approach to technology and development of technology as valuable for formation of scientific theory (Schallmo et al., 2017). Diagrammatic representation of the research methodology is given in Figure 7.3.

Business strategies focus on the integration of supply chain (Vickery et al., 2003). Supply chain integration process is a multi-structural decentralized system with independent elements (Ivanov, 2010). However, there remain complexities in prioritizing these strategies. In order to proceed with integration, the decision framework should consider new concepts and advanced methodologies. Further categories of integration can be related by applying qualitative methodologies along with engineering design techniques. The opportunities that firms will get from the process of digital supply chain networks are enormous as smart manufacturing enables savings and economies of scale (Brettel et al., 2016).

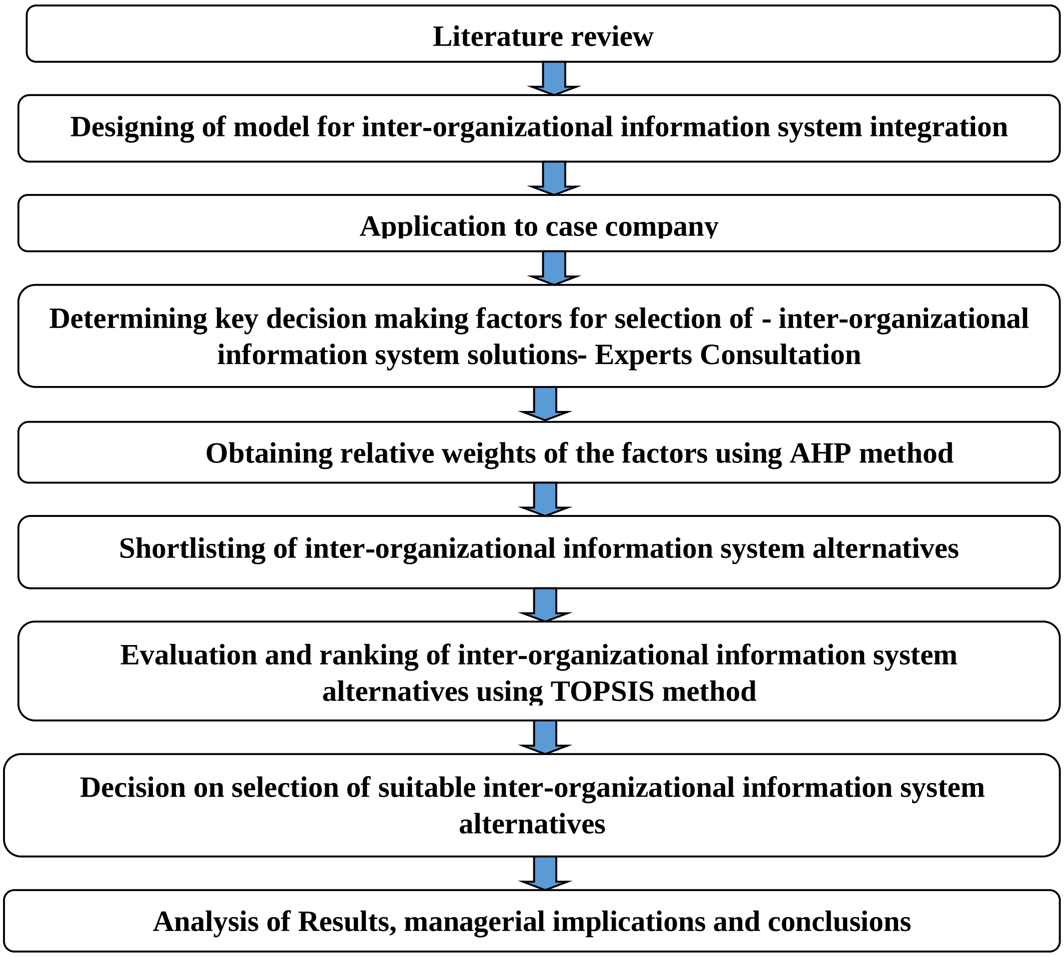


Figure 7.3: IOIS Selection- Research methodology

7.3.1 AHP

Analytic Hierarchy Process (AHP) is an effective mathematical tool as it prioritizes the criteria and aids in effective decision making (Saaty, 1980). One of the advantages of AHP is that it can consider both qualitative and quantitative criteria. AHP methodology has judiciously been used in a number of recent researches for effective decision making. Mastrocinque et al., (2020) have used the AHP based model for sustainable supply chain in case of the renewable energy sector. AyuNariswari et al., (2019) have used AHP in case of aircraft spare part inventory management. Consistency of results can also be checked in AHP, thus reducing the bias of the evaluator, if any, in the process. AHP consists of the following steps: (i) defining alternatives, (ii) defining problems and criteria, (iii) establishing priority among the criteria using pairwise comparison, (iv) consistency check and (vi) finding out relative weights. A nine point Saaty's scale is used in this research (Saaty, 1980).

7.3.2 TOPSIS

Yoon and Hwang (1995) developed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which can be used for performance evaluation of alternatives through similarity with the ideal solution. Li et al., (2019b) have also used the extended TOPSIS method for developing a sustainable supplier selection model based on sustainable practices employed.

In the TOPSIS method, the alternative which is close to the positive ideal solution and far from the negative ideal solution is considered as the best alternative. The criteria which maximizes the benefits and minimizes the cost criteria is considered as the positive ideal solution, whereas the negative ideal solution maximizes cost and minimizes benefit criteria. Hence, a positive ideal solution comprises all the best values and worst values attainable against each criterion.

7.3.3Analytic Hierarchy Process integrated TOPSIS method

In general, the problems involving decision making calls for consideration of both qualitative and quantitative criteria. One of the challenges that the decision makers are facing is the lack of precise knowledge about factors affecting the system. The proposed method helps in utilizing the advantages of integrated approach against the individual MCDM methods. Thus, in this research we have used hybrid MCDM methodologies integrating AHP-TOPSIS theory that can handle problems with uncertainties.

AHP method is used to solve problems through pairwise comparisons. It can consider both quantitative and qualitative criteria which has made it a preferred MCDM technique for decision making in many operations management models. However, one of the limitations of AHP is the inconsistency of decision makers in judging the criteria, which can be overcome by checking the consistency ratio to reduce the bias of decision makers, if any.

The ideal solution selected by applying TOPSIS method will have the best value for all the criteria considered. Both tangible and intangible factors affecting the decision making process can be considered in this approach. Considering the merits of the methodologies a combination of AHP integrated TOPSIS method is used for selection of best IOIS alternative in this research.

Kumar et al., (2020) have used an integrated AHP-TOPSIS method for prioritization of attributes in case of agile manufacturing in Indian context. Bhattacharya et al., (2020) have also used the above combination of methodologies for selection of efficient sustainable partners. The selection of appropriate IOIS solutions for digitalization of the supply chain can be done based on the ranking of the alternatives derived from the AHP-TOPSIS method.

7.4. Decision model for Inter-organizational information systems integration of supply chain

Supply Chain Operations Reference (SCOR) model has been developed by Supply Chain Council, a diagnostic tool and a framework that features business process reengineering and supply chain management practices (Wang et al., 2010; Zhou et al., 2011). SCOR model provides a methodology for management of processes and activities management of supply chain, by following a set of guidelines. Literature reveals that digital supply chain capabilities consist of various dimensions like planning, customer involvement, coordination, supplier involvement and IT exploration. Further, opportunity to achieve organizational benefit is possible with the help of technology enablers like digitizing, integrating, automating, intelligence and analytics.

In order to proceed with digital transformation, firms should understand and analyze their internal and external capabilities (Uhl et al., 2014). The digitization of supply chain will improve performance of firm (i) by retaining customers, (ii)reducing operating costs and (iii) increasing overall capability (Gurria, 2017). Gaining supply chain capability will enhance competitive advantage through effective integration from suppliers through manufacturing processes (Laaper et al., 2017) and finally to end customers (Kristal et al., 2010). This research is novel as it addresses the steps to be followed for digitalization of supply chain. Figure 7.4 shows a general schematic diagram of model for digitalization of supply chain which can be considered for IOIS integration process in any industry. The application of integrated AHP-TOPIS method for decision making in the process of supply chain digitalization should follow various steps as illustrated in Figure 7.4.

Figure 7.4: An integrated model for Inter-organizational information systems integration of supply chain

7.4.1 Steps for Inter-organizational information systems integration

7.4.1.1 *Step1: Organizational vision in Inter-organizational information systems integration*: The vision of a firm in the process of digitization should be clearly assessed prior to initiating steps in the process of digitization of supply chain. Firm's objectives and long term vision also need to be assessed. The nature of business activities should also be taken into consideration while determining the vision in digitization of supply chain.

7.4.1.2. *Step 2: Analysis of current situation and risks involved:* The current situation of business and supply chain is very important and needs to be properly studied. Potential risks of digitalization along with its feasibility need attention. Risk mitigation strategies could be helpful in offsetting potential risks.

7.4.1.3. *Step3: Finalization of implementation strategy:* Implementation of digital technologies in the supply chain should be finalized by taking into account firms' internal and external capabilities. Strategic, tactical and operational objectives of the firm should be given due consideration at the time of implementation. This will help in properly planning and implementing the required solutions in a sequential manner that suits the organization.

7.4.1.4. *Step4: Assessment of requirement of Inter-organizational information systems*: The extent of requirement of technological and digital solutions to bridge the gap needs to be assessed. All supply chain partners need to be connected properly through effective digital technology tools. This would facilitate effective decision making.

7.4.1.5. *Step 5: Research and Analysis on Inter-organizational information systems effects*: A thorough research and analysis of the effects of implementation of digital technologies is needed to find out the changes and occurrence of disruptions, if any. Proper security and maintenance measures are to be adopted to set off the disruptions. Properly analyzed and implemented supply chain would be resilient and competitive.

7.4.1.6. ***Step 6: Evaluation of effect of Inter-organizational information systems Implementation*****:** The effect of implementation of digital technology on both internal and external accounts needs to be assessed. The impact on adoption of digital technology in the supply chain should be evaluated thoroughly. Necessary corrective measures or modifications can be planned in advance if impact on the business activity is properly assessed.

7.4.1.7. Step 7: Finalisation of factors for Inter-organizational information systems decision making: Various criteria need to be considered while choosing or developing required solutions for digitization. Major criteria that need consideration are: digital technology enablers, project completion time, financial resources required, capabilities, ease of operations, post sales product support, brand name reputation, functional fit and future scalability, control linkages among supply chain partners, information sharing across supply chain partners, business and data analytic and quality and risk control for decision making.

7.4.1.8. ***Step 8: Assessment of Inter-organizational information systems options and shortlisting*****:** The options of end to end software solutions should be considered by giving due weightage to major criteria identified under step 7 above. The nature of the solutions available and its suitability to business and adaptability to existing systems is to be assessed.

7.4.1.9. ***Step 9: Finalization of road map for implementation*****:** After the completion of steps 1-8, based on results and decisions taken, a roadmap for implementation of the project could be finalized. The schedule of implementation along with the arrangements is to be made for effective implementation.

7.4.1.10. ***Step10: Inter-organizational information systems Implementation and Upgradation*****:** The final step in the process of digital transformation of supply chain is its implementation and upgradation. The solution should be deployed based on findings and if possible, based on a pilot project mode for reviewing the results. Further, it should be properly upgraded or modified based on the requirement, as it is expected to run in a dynamic business environment. Thus, end-to-end reengineered digitized supply chain connecting all supply chain partners can be implemented by following the sequence of steps as detailed above.

AHP-TOPSIS integrated method for IOIS integration of supply chain is integrated into a three phase activity as shown in Figure 7.5 and explained below in detail.

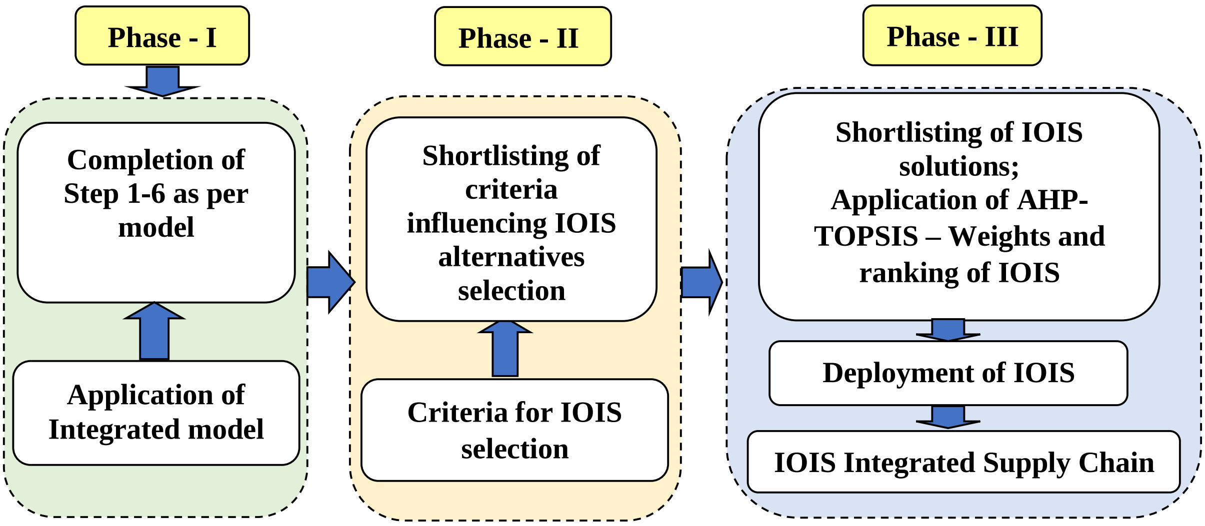


Figure 7.5: Digitalization of supply chain- Integrated decision making process

(i) *Phase I*- Application of integrated model for digitalization of supply chain: This phase consists of considering the current assessment of the organizational conditions and capabilities. The process should be initiated with finalization of organization vision, followed by assessment of the prevailing situations in the market and associated risks. Based on the assessment, strategies for addressing the challenges and meeting the requirements for proceeding with the process of digitalization needs to be finalized. Identification of gaps in technology and areas where digital applications can be used needs to be done followed by research and analysis of overall impact and effects on the business activities.

(ii)*Phase II*- Shortlisting of key criteria influencing IOIS selection: Various criteria affecting implementation of IOIS is shortlisted in this phase. The requirements pertaining to each of supply chain partners and functional areas affecting the digitalization process is also given due attention.

(iii) *Phase III* - Application of integrated AHP-TOPSIS for ranking and selection of IOIS alternatives: After completion of Phase I and II, final phase deals with shortlisting of IOIS alternatives and application of integrated AHP-TOPSIS methodologies. AHP method is applied to find out the weights of DMF and TOPSIS method is used to rank shortlisted IOIS alternatives. Subsequent to the selection of best IOIS alternative, effective strategies is to be adopted for deployment of the same.

7.5. Application of model to case Electronics Company

7.5.1 Case study

The model developed is applied in a case study and is discussed in this section. Supply chain of the electronics manufacturing industry is very complex in nature. Electronics industry is facing many challenges due to increased global competition, frequent changes in consumer requirements and rapid advancement in technologies. Digitalization has the potential to revolutionize the supply chain processes initiating from planning, sourcing, manufacturing, delivery, return and after-sales service. IOIS adoption in the electronics industry assumes great significance as it enables electronic manufacturers to be more agile and innovative. The case study is performed on M/s.XYZ Company, which is one of the prominent consumer electronics companies in the electronics industry. This company is considered for the study to take advantage of their expertise and experience in the field that ensures credibility of the case study design. The company is rapidly growing with a very vast range of products and services and planning to expand the supply chain network further across the globe in line with the expansion strategy. Due to the recent advancements and developments in digital technology solutions, top management of the company is of the view that application of innovative technologies in their supply chain during expansion could bring more benefits against the existing system. Hence, from a long term perspective, suitable provisions for effective management of the supply chain by means of digitization of the activities across the functional levels needs to be considered by the company. Due to the challenges involved in the selection of IOIS, digitalization process and decision making, the application of the proposed decision model will assist the managers in effective decision making.

Accordingly, the model developed as explained in the previous section is evaluated in a case company. Experts in the company were consulted and discussion was held regarding the shortlisting of IOIS decision making factors and solution alternatives. A series of interviews were held with industry experts representing various functional levels. The experts identified from the case company were having experience of more than 10 years. Discussions were held with a group consisting of four experts, three from the case company and one from academia. The three industrial experts consulted were all senior managers in the area of Product Life Cycle Management. Fourth expert was an academician doing research in the area of Operations and Supply Chain Management.

In the methodology adopted, twelve decision making factors and four alternatives of IOIS solutions required for the XYZ Company in the electronics industry were shortlisted. As the company is planning for further expansion of the supply chain network on a global level, end-to-end solutions covering all aspects of supply chain and the decision making factors as applicable were considered. The criteria used for selection of IOIS consists of attributes pertaining to cost and benefit with various characteristics for assessment. An integrated model for IOIS adoption for the case electronics firm is shown in Figure 7.6.

Based on the discussion and feedback from the experts in the company the most relevant twelve decision making factors for digitization of supply chain through IOIS in the case company were shortlisted. The decision making factors identified were classified under four major dimensions like technological, operational, application and innovative as shown in Figure. 7.7.

7.5.2. Decision making factors considered for the case company

7.5.2.1 Digital Technology Enablers (DTE): Digital technologies used in the process of supply chain integration can capture the required data for use and further processing. The Internet has brought in new digital technology enablers like sensors and geo location, social media, robotics, user interface, 3D printing, nanotech, etc. Digital supply chains with the help of enablers can process enormous amounts of information. DTE also helps in creating a digitally enabled business model to bring supply chain partners on a common platform facilitating seamless communication.

7.5.2.2 Project Completion Time (PCT): The time required to complete the project undertaken is of great significance while integrating supply chain using IOIS. In this context, specific milestones are to be achieved taking into consideration available resources, which assumes great significance. Project completion should include a detailed plan of all processes and steps to be followed for on time completion.

7.5.2.3 Financial Resources Required (FRR): Financial Resources required refers to all budgets required for digitalization of supply chain. Proper financial investment for digitalization will result in effective cost savings in the long run. Smart connectivity among supply chain partners will result in process improvement and efficient use of resources

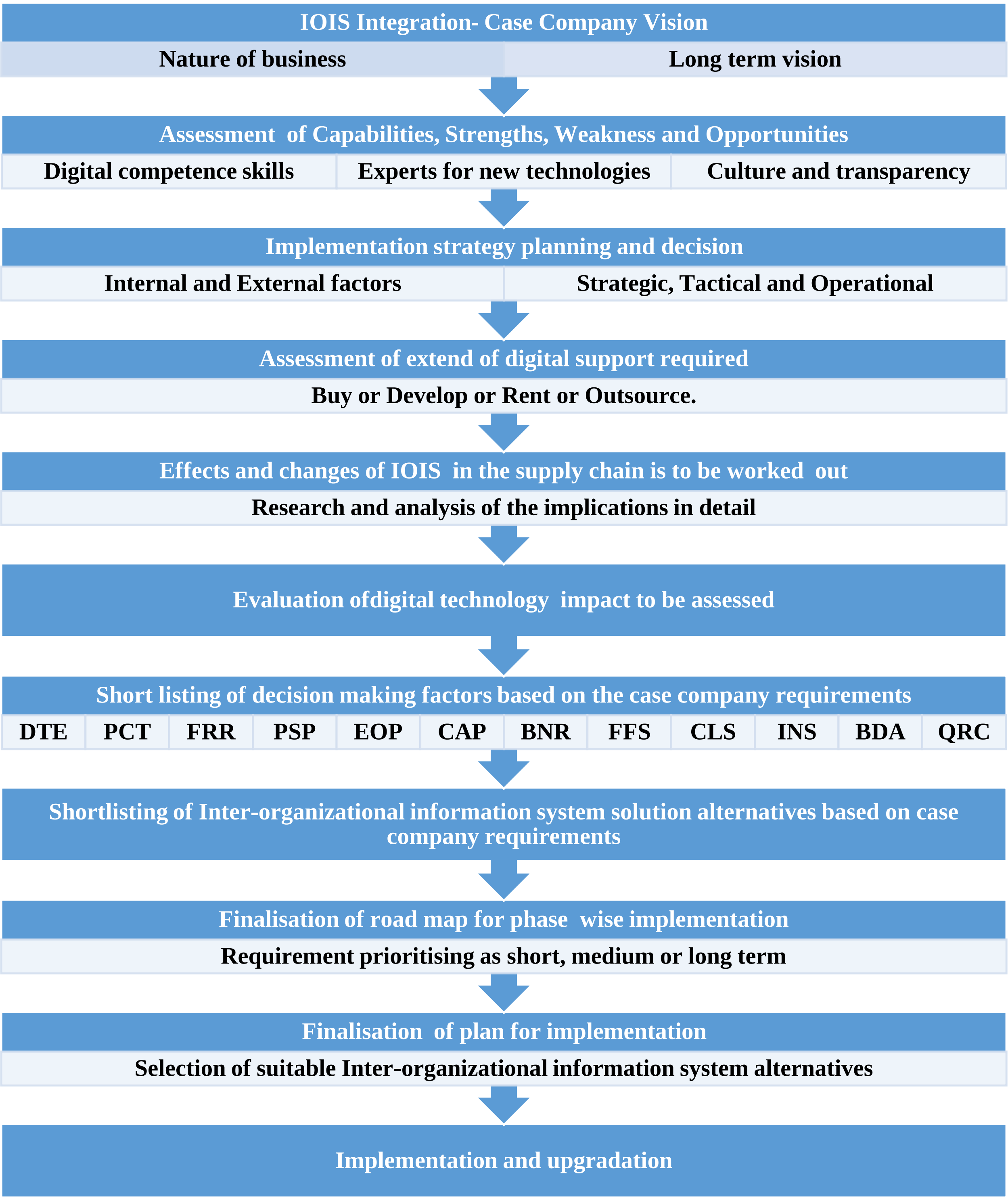


Figure 7.6: An integrated model for Inter-organizational information system adoption in case electronics firm

Legend: DTE: Digital Technology Enablers, PCT: Project Completion Time, FRR: Financial Resources Required, CAP: Capabilities, EOP: Ease of Operations, PSP: Post Sales Product Support, BNR: Brand Name Reputation, FFS: Functional fit and future scalability, CLS: Control linkages among SC partners, INS: Information sharing across SC partners, BDA: Business and data analytics, QRC: Quality and Risk control

7.5.2.4 Capabilities (CAP): A digitalised supply chain network should be capable of providing access to real time information, resulting in supply chain visibility and collaboration among partners. Web enabled capabilities can be utilised to maximum possible extent while digitising the supply chain. The digital network established in the company should be optimised to fit into the business goals and plans.

7.5.2.5 Ease of Operations (EOP): Supply chain partners should have the ease and accessibility of using advanced digital technologies. Introduction of a digital supply chain network which is compatible with the existing system and user-friendly makes the transformation process easier. The return from digitization investments can be maximized based on the cooperation from all supply chain partners. Hence, the ease of operations of the solution to be deployed should be considered prior to proceeding with the process of digitalization.

7.5.2.6 Post Sales Product Support (PSP): The process of digitalization and maintenance requires support from service providers or development teams. Post-sales support service includes providing training, upgrades of the software solution, providing on call breakdown maintenance and support, fixing bugs, if any. Provision of availability of post sales product support is of due significance as any malfunction in the system has to be resolved within the shortest possible time to avoid any unfavourable outcomes. The aggressive methods of 24/7 availability of the support service through online knowledge bases will be an added advantage.

7.5.2.7 Brand Name Reputation (BNR): The reputation of the company which develops the software is another criterion to be considered. The projects that the company has implemented in the past can be verified, based on the references, if required. The success of the project depends upon the vendor who is undertaking the job. The competency of the brand and its success rate should be examined.

7.5.2.8 Functional fit and future scalability (FFS: IOIS selected should suit the functional requirements of organisations. All the functional requirements in supply chain activities are to be considered and addressed. Further scalability of the IOIS to cope with the growing needs of the organisations should also be considered. It includes the capability of the IOIS solution to grow and handle high business volume and data. Scalability can be done through advanced digital solutions like cloud service or software as a service solution.

7.5.2.9 Control linkages among SC partners (CLS): The control linkage among the supply chain partners is one of the core aspects to be considered while adopting IOIS integration to gain competitive advantage. A higher level of control linkages can be established based on trust and commitment among supply chain partners. It facilitates better performance in short term and long term based on proper control linkages established through proper analysis of market and business activities.

7.5.2.10 Information sharing across SC partners (INS): Sharing of information among supply chain partners has a great impact on supply chain performance. It helps in establishing proper linkage among the supply chain partners for effective transmission of information. It also facilitates in establishing long term cooperation and coordination among the partners in the supply chain by bringing in better visibility and effective planning of supply chain activities.

7.5.2.11 Business and data analytics (BDA): Analysis of business and data based on the access to integrated information helps in making effective decisions on supply chain activities. It also helps in forecasting and planning of demand and production activities which helps in scaling of business by gaining deeper insights from the data. Business and data analytics capability will bring data-driven intelligence to the organization by cost reduction and gaining competitive advantage.

7.5.2.12 Quality and Risk control (QRC): Quality and risk control is another major factor which is to be considered while selecting IOIS. The quality of information depends upon the trust among the supply chain partners. This factor has an important effect on responsiveness of the supply chain. Risk control includes protecting the data from degradation or loss during transmission.

Table 7.2: Scores of alternatives

Criteria	Alternative -1	Alternative -2	Alternative -3	Alternative -4
DTE	7	6.5	5.5	8
PCT	14	19	16	12
FRR	17000	19500	18000	13250
CAP	6.5	4.5	5.5	7.5
EOP	7	7	6	8
PSP	6.5	4.5	3.5	6
BNR	6	6.5	5.5	7.5
FFS	8	5	5	8.5
CLS	6.5	5.5	7	7
INS	7	7	6.5	8
BDA	6	6.5	8	8.5
QRC	8	7	7.5	7

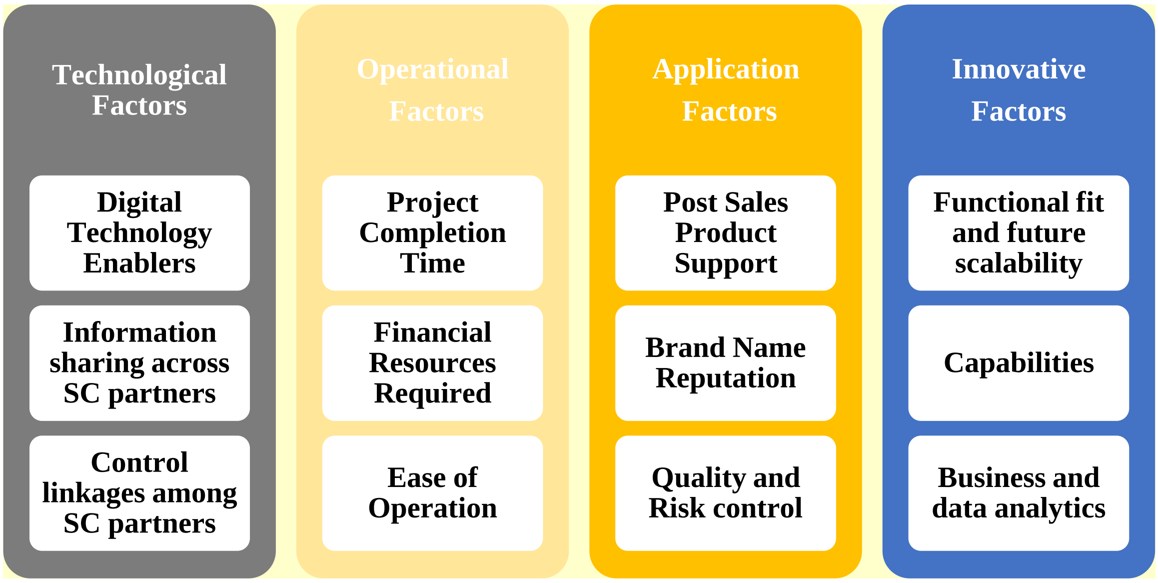


Figure 7.7: Classification of decision making factors for Inter-organizational information systems adoption in case electronics firm

In this study, the two tangible values that are considered are Financial Resources Required (FRR) which is mentioned in USD and Project Completion Time (PCT) is mentioned in weeks. FRR is mentioned as the total funds required for implementation of IOIS solution for digitalization. Likewise, PCT is the time required to complete total implementation of the solution. For other decision making factors, the expert evaluations are represented in a 1–10 scale. Various IOIS alternative solutions for the integration process by using IOIS are shortlisted and shown in Table 7.2.

A decision matrix is finalized based on decision making factors for evaluation and IOIS alternatives that are under consideration. The selection of alternatives depends on the influence of decision making factors shortlisted. Hence, the significance of each of the decision making factors are to be found out as for which decision making factor, more weightage is to be given. AHP is used to find out the weights of twelve decision making factors that are shortlisted. Accordingly, a pairwise comparison matrix for decision making factors are done and is shown in Table 7.3. An example for decision making factors mentioned in Table 7.3 is explained for better understanding. The value for Capabilities(CAP) in the fourth row and first column is 0.5, which means Capabilities is 0.5 times as important as Digital Technology Enablers (DTE). The values mentioned in the table 7.3 diagonally are given as 1, as it shows value for comparison with the same criteria. The pairwise comparison done is verified by finding out the consistency ratio. Based on the acceptable consistency ratio (under 0.10) obtained, weights of decision making factors are found out by using the AHP method, which is shown in Table 7.3.

Table 7.3: The pairwise comparison matrix

	DTE	PCT	FRR	CAP	EOP	PSP	BNR	FFS	CLS	INS	BDA	QRC	Weight
DTE	1	1	1	2	2	4	7	7	9	9	2	2	0.178
PCT	1	1	2	3	2	4	3	7	9	8	3	3	0.193
FRR	1	0.5	1	2	1	5	2	6	8	9	2	2	0.142
CAP	0.5	0.333	0.5	1	1	3	3	4	8	8	2	1	0.104
EOP	0.5	0.5	1	1	1	2	3	4	8	8	2	2	0.116
PSP	0.25	0.25	0.2	0.333	0.5	1	1	2	3	8	2	2	0.058
BNR	0.142	0.333	0.5	0.333	0.333	1	1	1	2	6	1	1	0.047
FFS	0.142	0.142	0.166	0.25	0.25	0.5	1	1	2	4	2	1	0.037
CLS	0.111	0.111	0.125	0.125	0.125	0.333	0.5	0.5	1	2	1	1	0.022
INS	0.111	0.125	0.111	0.125	0.125	0.125	0.166	0.25	0.5	1	1	1	0.015
BDA	0.5	0.333	0.5	0.5	0.5	0.5	1	0.5	1	1	1	5	0.047
QRC	0.5	0.333	0.5	1	0.5	0.5	1	1	1	1	0.2	1	0.040

7.5.3 Results of TOPSIS method

In this study four different IOIS alternative solutions were evaluated by the TOPSIS method to select the most suitable solution needed by the case electronics company. The weights of the criteria were determined based on the expert consultation and the distances of the IOIS alternatives to the ideal solution were calculated. The weighted normalized decision matrix is computed, followed by calculation of positive ideal solution and negative ideal solution. Further, the relative closeness of the IOIS alternatives to the ideal solution is computed and the alternatives are ranked accordingly. The results obtained for case study using TOPSIS method is given Table 7.4. In this table, values of separation distances of positive and negative ideal alternatives (d_i^+ and d_i^-) and relative closeness (C_i^+) to the positive ideal alternative for all alternatives are also shown. It is seen that Alternative 4 has come out as the best one, followed by Alternative 1. The ranking of Alternatives 2 and 3 remains in fourth and third position respectively.

Table 7.4: Results of TOPSIS method

Alternatives	d^-	d^+	C^+	Rank
Alternative 1	0.0466	0.02840	0.62146	2
Alternative 2	0.0169	0.06289	0.21195	4
Alternative 3	0.0225	0.05537	0.2893	3
Alternative 4	0.0705	0.00388	0.94787	1

7.6 Results and Discussions

In view of the advancement in technologies, digitalization of supply chain adopting IOIS is one of the prominent topics in recent times. In order to survive in the competitive business world, it has become a necessity to proceed with digitalization of the supply chain (Schrauf et al., 2016). The study by MIT and Capgemini mentions the importance of competitive advantage that the companies gain due to digitalization. Hence the companies that decide on the digital transformation vision will perform better (Bradach et al., 2014). By digitalization, the capability of the supply chain would enhance drastically which can result in high operational performance.

The effectiveness of the proposed model is demonstrated by applying in an electronics firm. Twelve major decision making factors were identified and four IOIS alternatives were shortlisted. The factors identified were categorised under four major dimensions. Based on the results of AHP, project completion time (0.193) is identified as the most significant criteria, followed by digital technology enablers (0.178) and financial resources required (0.142) which falls as the top three decision making factors. Based on the case study conducted in an electronic firm, it can be concluded that the Alternative 4 is found to be the most suitable IOIS alternative which is from a well-known and established vendor. The company concerns project completion time and digital technology enablers as the most prominent decision making factors among all other criteria identified. Accordingly, the alternatives are ranked and alternative 4 is found to be the best among all IOIS alternatives shortlisted and considered.

Electronics industry is dynamic in nature. Adoption of concepts like contract manufacturing, regulatory compliance and sustainability has a drastic impact in the electronics industry. The industry is also going through rapid product innovations resulting in a lower product life cycle. In order to be competitive, electronics industries should manage supply chains effectively. This demands for accurate forecasting methods. Digitalization of supply chain becomes important and assists in effective collaboration of supply chain, risk management, supply chain planning (Allaoui et al., 2019), sustainability and reverse logistics (Agrawal and Singh, 2019). Supply chain digitalization also provides manufacturers the capability to assess disruptions and to plan for adjustments on a real time basis. Electronics manufacturers should invest in integration of data, business intelligence capabilities and event tracking capabilities so as to respond proactively to the dynamic changes in the business environment. Thus, it becomes evident that IOIS adoption in electronics industries assumes importance and helps in building cost effective and responsive supply chains (Naway and Rahmat, 2019).

Among the DMFs identified, Project Completion Time (0.193), Digital Technology Enablers (0.178), Financial Resources Required (0.142), Ease of Operation (0.116) and Capabilities (0.104) has come out as top five DMFs for selection of IOIS. One of the significant findings is that the top three DMFs have come under operational dimensions. Thus, it can be inferred that DMFs under operational dimensions are to be given due significance while proceeding with adoption of IOIS. The project completion time should be given the highest weightage, as entire activities related to the process of IOIS adoption should be completed within the minimum time period. Consumption of more time for the process of integration will lead to disruption and lack of effective coordination in supply chain activities.

Further to the consideration of time period, digital technology enablers should be given due significance. Advanced state of art digital technologies is to be considered for effective supply chain digitalization process. The latest developments in technological arena needs to be given adequate weightage for selection and adoption of IOIS resulting in transformation of business models and better supply chain performance. The financial investments required for adoption of IOIS is another factor which is to be given due weightage. The entire process needs to be done at a reasonable cost by developing a roadmap for integration through effective assessment of the existing supply chain. Further, the financial resources required are to be assessed considering the return on investment.

Ease of operation of the IOIS system facilitates effective implementation and usage of the system. An IOIS having greater ease of operation integrates and manages all activities in the supply chain effectively. It also allows supply chain partners to access data in a comprehensive manner anywhere and at any time. The capabilities of IOIS system is to be assessed properly prior to shortlisting of IOIS alternatives. IOIS integrates between supply chain capabilities and technical capabilities. Global advancements and increasing uncertainties have led to increased supply chain challenges. Adoption of an IOIS alternative having sound capabilities makes the supply chain robust and dynamic and thereby enhances competitive advantage.

The integrated model developed for digitalization of the supply chain using IOIS as illustrated in Figure 7.5 describes dimensions, strategies and overall contents of the integration process. This will enhance the scope for supply chain integration. Managers can make effective decisions based on the model for enhancing the efficiency of organizations. The model developed can be applied in any industry by identifying the factors as applicable and shortlisting alternatives.

This study provides valuable insights for the practitioners and academicians regarding the process of supply chain digitalization by adopting IOIS. The process of digitalization of requires a robust change which involves the commitment from the top management, innovative thinking and support from the supply chain partners like suppliers, customers and employees. The successful implementation can reap benefits in the form of higher profits, better performance, flexibility and higher efficiency of the supply chain. Further, the proposed model can help supply chain managers and practitioners to integrate the supply chain and also in standardizing the processes.

The details of the *five* problems addressed are elaborated in Chapters 3, 4, 5, 6 and 7. The present research has certain limitations and practical constraints. The conclusions, managerial and practical implications and limitations derived out of the research and scope of future works are discussed in the next chapter.

CHAPTER 8

CONCLUSIONS, LIMITATIONS AND FUTURE SCOPE OF THE STUDY

8.1. Problem 1

Digitalization of SC has gained immense relevance due to the advancement in digital technologies. This study has proposed an integrated ANP-QFD model for prioritization CRs and DRs for integration of SC through digitalization. The finding of this study provides insights on various attributes that contribute to the process of SCD. The firms should give due significance to the CRs and DRs as per the prioritization in order to enhance SCP. It is also expected that the model will serve as an important tool in digitalization of SC enabling the organization to become more dynamic and competitive. The model developed can also be adjusted suitably to add more requirements specific to the industry for effective decision making.

In order to prioritize CRs and DRs for SCD, a case evaluation in an electronic manufacturing firm has been conducted. The CRs and DRs relevant to the digitalization process were identified and shortlisted based on literature review and in consultation with experts from industry and academia. The interdependencies among CRs and DRs were also analyzed. The overall prioritization of the CRs and DRs were identified in a phased manner using ANP-QFD methodology. The proposed model has aimed at bridging the existing gap in literature in digitalization process by identifying the major CRs and DRs which are to be considered in the process of SCD. The study also analyzed and prioritized the extent of interrelationship among the requirements. A HOQ is also constructed for effective decision making in the process of digitalization.

The study has shown how a systematic analysis can be done for identifying the interdependencies among various CRs and DRs. The model developed in the study provides a rational and reliable solution which can be applied in any organization which is proceeding with the process of digitalization, by suitably modifying the CRs and DRs specific to the industry.

In order to gain competitive advantage and to survive in the market, digitalization of SC has become a necessity. The adoption of advanced digital technologies will revolutionize the SC process and its management. The companies should consider the changed scenarios and have a strong vision to adopt digitalization for better performance. This study attempts to bring better insights to the process of SCI through digitalization that has both managerial and theoretical implications. It provides insight to theoretical relationships among CRs and DRs that are to be considered for SCD.

The CRs and DRs identified in the study helps in proper planning of the digitalization process and identifying solutions for successful integration. The managers can infer which design requirement is to be given due importance and how the process of SCD can be achieved effectively. The model helps to understand the relationship among CRs and DRs. It also helps managers to understand the extent of dependence and influence among each CRs and DRs. By using the framework given in this study, SC managers can finalize policies and procedures to be adopted for the SCD process. The digitalization policy and procedure to be followed can be initiated by giving due significance for the CRs and DRs identified. The attributes identified in this research are quite generic and with suitable modifications could be applied to other industries as well.

The study involving pair-wise comparison among the attributes is a time-consuming task. The results obtained in this study are based on the opinion of experts for the case company and thus depends upon the expert's familiarity with the company and its industry. Also, the bias of experts to some of the criteria might have influenced the results. We have tried to minimize this limitation by verifying the consistency ratio as suggested by Saaty (1996). The attributes identified in this research are quite generic and with suitable modifications could be applied to other industries as well.

Future research could be done by conducting a similar study in a different industry using the same CRs and DRs or with suitable modifications and results could be compared. Combinations of MCDM methodologies can also be used and results could be verified. A different ranking method such as TOPSIS can be used to prioritize the CRs and DRs. The priority weights obtained from different methods can also be compared. The tool can also be used by researchers for conducting a broader level of analysis of the CRs and DRs in another firm or industry.

8.2 Problem 2

SCI through digitalization allows an organization to become smart enough to cope up with the dynamic changes in the digital era. Digitalization allows the firms to gain transparency, competitive advantage and better SCM decision making. This research has developed a framework for enablers of SCD. We have also analyzed influences and interrelations along the enablers that can assist decision makers while proceeding with the process of SCD.

This research has made some unique contributions. Firstly, it has explicitly analyzed the key enablers affecting the process of SCD seen in the electronics industry. Secondly, we have used the methodologies of ISM followed by MICMAC analysis. Application of ISM method helps in identifying the contextual relationship among the enablers. MICMAC analysis has been used to investigate the driving power and dependence power of the enablers that facilitates us in identifying key enablers affecting the process of SCD.

The ISM model developed in this research can support decision making process and development of a design for SC through digitalization. It also provides directions for managers and professionals in the field for decision making processes for SCD. Even though a diversity of integration practices is available, the approach of integration through the digitalization process adopted in this study helps the companies to focus on the key enablers effectively. It is found that the process of SCI through digitalization is multi-dimensional and has several rooted theoretical perspectives. In this research, we have addressed one of these dimensions by systematically bringing out the major enablers that are to be considered for decision making while integrating SC. This exercise leads to effective digitalization of SC that enhances the efficiency and competitiveness of a firm.

The prioritization and identification of interrelations among the enablers helps in determining the most significant enabler and due weightage can be given to those enablers in the digitalization process. The establishment of interrelationship among the enablers facilitates the managers to decide on which enablers of digitalization are to be given more attention at any point of time. This can increase the competitiveness of a firm. The enablers identified in this research are quite generic and with marginal changes can be adopted for other industries as well.

This study has been conducted specifically in the electronics industry and hence, one of the limitations of the study is the industry specific nature. Also, enablers of SCD were identified from the literature and also in consultation with the experts in the firm and academia. Future studies could add more variables at the cost of complexity.   Future scope of this study could attempt validation of this model by using structural equation modeling approaches.

8.3. Problem 3

This research has investigated diverse barriers that affect the SCD process in an electronics industry. ISM modelling has been used to categorize each of the barriers identified and interrelationships among them have been portrayed. This model can assist the practitioners and academicians in understanding the interrelationship among the key barriers of SCD. The application of the ISM model in the study provides further insights to the managers to identify the interrelationships among the barriers.

The study found the volatile nature of the barriers in the perspective of the impact among the barriers itself and its interrelationships. It is prudent to analyze the barriers identified and its impact as a joint entity rather than viewing in isolation. The MICMAC diagram of barriers shows a high level of dependence and driving powers among the barriers. The high level of driving powers of the barriers refers to dominant influence over other barriers. Likewise, the barriers with high dependence powers are positioned at the top of the ISM model.

This research has attempted to contribute both practically and theoretically. First, this study has compiled relevant literature on SCD and identified the key barriers affecting the process of digitalization. Second, this research has explored the key barriers that affect the process of SCD and derived a framework for the digitalization process in an electronics SC. Third, the dependence and driving powers of the key barriers affecting the digitalization process is found out and represented in a MICMAC diagram. The portraying of barriers in four quadrants of the MICMAC diagram enables the researchers to evidently identify the barriers as dependent, independent, linkage or autonomous barriers. Fifth, the linkage between the classification of barriers based on the dimensions and MICMAC analysis was brought out defining the requirement for an integrative approach for addressing the barriers effectively. Finally, the ISM model developed facilitates the researchers and practitioners in choosing the identified barriers for empirically evaluating the proposed research mode.

The findings of this study help to address the issues on account of the barriers of SCD and its associated challenges. This research has identified a list of prominent barriers that need to be considered while proceeding with SCD. Results of the study provide a road map that the companies can adopt to mitigate the barriers affecting SCD process. The study also supports that performance of organization depends upon the efficiency of SC attained through digitalization. The competitiveness and global advancement is forcing the firms to digitalize the SC. The digitalization process can be done effectively by suitably addressing and minimizing the barriers identified.

Findings of this study have implications at both theoretical and practical levels. Adoption of advanced technology and its applications in SCs is a major challenge faced by managers for achieving competitive advantage. Organizations can proceed with digitalization by adopting the proposed model to gain competitive advantage as it would help them in analyzing and interpreting interrelationship among barriers of SCD. The proposed model provides valuable insights for managing challenges that may arise at various levels during the process of SCD. Cooperation and trust from partners in the SC can also be gained by effectively identifying, addressing and eliminating these barriers. This study reveals that practitioners and researchers should not only focus on the drivers and other dimensions while making decision on SCD, but also focus on minimizing the barriers affecting the digitalization process.

The barriers in this research were finalized mainly from literature and shortlisted in consultation with the experts from industry and academia. Thus, the bias of experts to some of the variables might have influenced final results. As the study conducted is specific with respect to an electronics firm, characteristics specific to the electronic industry might also have influenced the results. Future research could also consider more barriers affecting the digitalization process at the cost of complexity. Multi criteria decision making techniques like TOPSIS and decision making trial and evaluation laboratory could be used to analyze barriers of SCD. The model can be applied in different organizations to find out the generality and its acceptance, thus improving the knowledge base.

8.4 Problem 4

This study sets out a detailed framework that can be used in SCD by considering the DMF by defining the data, information, knowledge, and wisdom. We have analysed major DMF, and a framework for SCD is developed by linking it with the DIKW pyramid. The structure is drawn by considering the idea of inputs or actions to be initiated for SCD as data, followed by information for the decision-maker as the description of factors, tools, and techniques required. The value addition in data and information results in a better understanding of the SCD process, classified under the knowledge category. The knowledge inferred will be helpful for the decision-maker in understanding the decision-making process effectively. Finally, the decision-maker initiated the process of SCD by using the results of the analysis in the right manner, termed as wisdom for the decision-maker. This study aims to contribute to the literature on a better understanding of the relationship between the major DMF affecting SCD and linking it with DIKW elements. This method also facilitates in identifying and categorising the key DMF based on their level of influence in digitalisation under various dimensions. The integrated approach of DIKW hierarchy and the system process is effective and successful as it helps in effective decision-making.

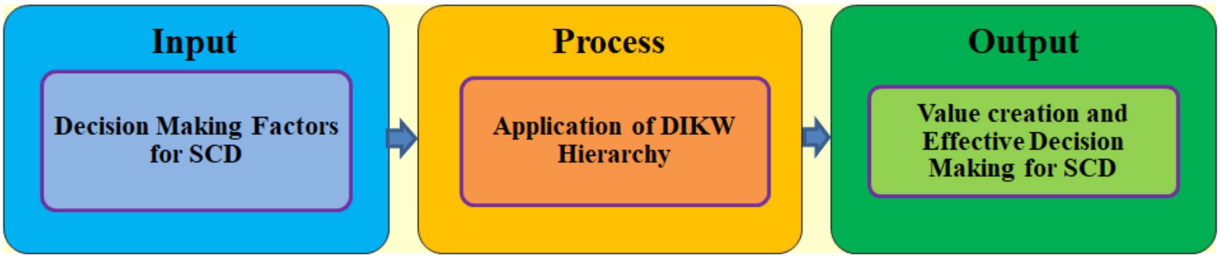


Figure 8.1: Systems model of SCD Process

A diagrammatic representation of proposed systems model of SCD is illustrated in Figure 8.1. As SCD can gain a competitive advantage, organisations can proceed with SCD by adopting the model developed. The systems model of the SCD process developed includes subsystems that consist of interacting and independent components. The subsystems interact with each other to attain their purpose and the purpose of the system in the whole for which they are embedded. The human activity concepts like preparedness for data processing and top management commitment is also considered in the model, which ensures the totality of the systems model in addition to other aspects. Inputs considered for the model are the major DMF affecting the process of SCD. Further, the process part consists of the method adopted for processing inputs through the DIKW framework and systems model approach. The results of the study were validated based on feedback from experts in the electronics industry and a comparison with existing literature. Finally, the output provides insights for effective decision-making for SCD.

The findings from this study provide theoretical and managerial implications on SCD decision-making. It offers support to understand the DMF that affects the process of SCD. The managers can infer which DMF shall be given due importance and to be given priority for effective SCD. The procedure of identifying the key DMF is crucial in the effective digitalisation process. Managers can identify the key DMF, which results in proper categorisation and prioritisation of the DMF for an effective integration process. The contextual relationships identified among the DMF assists the policymakers and managers in formulating an action plan for the digitalisation of SC. It helps the policy and decision-makers to design and frame a suitable strategy for the SCD process.

This research was conducted in an electronics firm in Indian context. The practices followed by the firm can be considered as the global practice, due to the similarities in electronics supply chain, even though bias may exist due to country specific reasons. The industrial and governance structure followed in various countries shall also be considered, which will influence the process of supply chain digitalization. Hence, the generalizability of the supply chain digitalization framework developed should be tested and augmented through research in industries in other countries.

For better understanding and practical application of the model, the framework is integrated with decision support system. Accordingly, to our best of knowledge, this is the first attempt in identifying the key DMFs to be considered for supply chain digitalization and developing a framework using integrated DIKW Hierarchy and systems model approach. Hence, this research represents a significant contribution to the theory of supply chain digitalization. Secondly, this research argues that in order to have thorough understanding of the process of supply chain digitalization, better insights on the key DMFs and its interrelationships affecting the process of supply chain digitalization is required. The existing literature has mentioned only about a framework for food supply chain digitalization in Thailand (Kittipanya-Ngam and Tan, 2020); an enterprise architecture rail- way supply chain framework in the context of the Malaysian Transportation industry (Jayakrishnan et al., 2020); a framework for digital supply chain capabilities using narrative literature approach considering industry 4.0 elements (Queiroz et al., 2019) and a conceptual framework on the application of advanced digital technologies in supply chain management processes (Ehie and Ferreira, 2019). Hence, our research significantly contributes to the process of supply chain digitalization.

Thirdly, this research introduces a robust framework for SCD which integrates two methodologies and integration with DSS model which facilitates in better understanding of the process of SCD, its dimensions, key factors to be considered resulting in enhancement of knowledge in the area of SCD and aids in developing better digitalized supply chains. Accordingly, framework developed in this study assists in initiating the process of supply chain digitalization for the practioneers and enhances the literature base and provides better insights for researchers and academicians.

Finally, the implication is with respect to the key DMFs identified which are considered as inputs for the framework. Considering the advancement in digital technologies and development of innovative supply chain network designs, the framework developed offers opportunities for the practitioners and researchers to test the framework empirically under various changed scenarios in different countries and industries.

The study's outcome also helps the practitioners identify and categorise the key DMF that are to be considered during the SCD process. It will improve the SC effectiveness through proper integration and digitalisation. The model helps to understand the relationship among the DMF. This study provides a framework for supply chain digitalisation and also in finalising policies and procedures to be adopted for the digitalisation process. The researchers can also use the tool for conducting a broader level of analysis of the DMF in another firm or industry.

One of the limitations of this study is the number of DMF identified, which is twelve. Further research can be done by considering more DMF, and the results can be tested. The DMF finalised are identified mainly from the literature and shortlisted in consultation with the experts in the firm and academia. The final results were based on the feedback from the experts in an electronics firm. Hence the characteristics specific to the electronic industry might have influenced the results. There can be relationships among other elements affecting the process of SCD apart from the influence of key DMF under three major dimensions. Hence, the future scope could be including those factors for further studies. A detailed guideline in order to enhance the performance and effectiveness of the framework can be explored and developed. Future research on the influence of other DMFs and finalization of guideline will provide a much comprehensive understanding of the framework. Considering the complexity in other industry specific supply chains, future research can be done on validation of the universality of the framework developed, by applying with more similar and different supply chains. Multi-criteria decision-making techniques like decision-making trial and evaluation laboratory could be used in future studies to gain more insights on the topic.

8.5. Problem 5

In this research, the integrated model developed for digitalization of the SC using IOIS, describes dimensions, strategies, and overall contents of the integration process that could enhance the scope for SCD. Digitalization requires a robust change that involves the commitment from top management, innovative thinking, and support from the SC partners like suppliers, customers, and employees. The successful implementation can reap benefits in higher profits, better performance, flexibility, and higher SC efficiency. The main focus of the study is on selecting suitable IOIS solutions for effective supply chain digitization and its management. The existing SC models available in the literature are insufficient to decide upon the digitalization process using IOIS.

In this study, the model's capability to integrate activities in the SC using digital technologies is addressed and tested with a case study. This study tries to address the knowledge gap in the procedure by developing a suitable model for digitalizing the SC by adopting IOIS. Accordingly, the key decision-making factors for selecting IOIS solutions were identified from the literature and shortlisted in consultation with the experts. Further, a model for SCD by adopting IOIS was developed and validated through case evaluation using a hybrid AHP-TOPSIS method. The model was developed by considering the nature of the business activities and SC requirements. The proposed model helps to identify the main DMFs for the prioritization and selection of suitable IOIS alternatives. Overall, the proposed method is effective and less time-consuming.

The model presented in this study would enable the researchers, practitioners, and academicians to understand better the SC processes in case of factors affecting selecting suitable IOIS alternatives. The proposed method can also identify and select suitable IOIS required by an organization to digitalize its business activities. Functional areas that are to be digitized in the organization need to be found, and the model can be applied for effective digitalization. This research also helps provide insights into the process of shortlisting criteria and selecting suitable IOIS alternatives. The proposed model shows that integration of SC results in better visibility and enhances SC capabilities. The practitioners can also use the model on a much broader basis in various industries for effective SC integration using IOIS. Hence, as a preliminary stage, the integrated MCDM approach developed in selecting appropriate IOIS provides better insights in achieving the desired results.

The findings from this research provide managerial and theoretical implications for selecting suitable IOIS solutions considering the influence of key DMFs. This research contributes to the theory of SCD by assisting in understanding the key DMFs influencing the selection of appropriate IOIS solutions. It also provides better insights into the significant DMFs and their inter-relationships that influence IOIS alternatives. The IOIS integrated SC research framework developed assists in enhancing the literature base and knowledge on SCD by providing better insights for researchers and academicians. The model developed will also assist the managers and policymakers in devising suitable strategies for selecting appropriate IOIS selection leading to SCD. The decision model developed can be used by scholars and practicing managers for conducting a more comprehensive level of examination of the key DMFs and selection of IOIS in another industry or firm. The research outcome can also be used in identifying and categorizing the key DMFs for effective digitalization. The relationship among the key DMFs can be understood effectively using the outcomes of this research. Further, the requirement of an innovative SC network and its design can be materialized based on applying the decision-making model developed in this research.

The model developed in this research can be used by the managers and decision-makers dealing with uncertainties of selecting appropriate IOIS solutions. As a result, managers can make effective decisions based on the model for improving the efficiency of organizations. Further, the model developed can be applied in any industry by identifying the applicable and shortlisting alternatives. It also assists the companies in establishing a systematic approach for selecting IOIS considering a set of key DMFs. The advancement in digital technologies and this research concentrating on the consumer electronics industry allow firms to create better opportunities for revenue generation through innovation using IOIS. Due to similarities in the SC functions followed by various companies, its practices can be considered a global practice in SCs, even though country-specific bias can influence it.

This study has a few limitations as well. One of the limitations of the AHP method is the subjective nature, wherein the weights are assigned by decision-makers based upon the individual opinion. Pairwise comparison among variables using AHP is a laborious and time-consuming task. The complexity of calculations would increase with the number of criteria. Even though the experts consulted for pairwise comparisons were renowned people in their field, the bias of experts towards the criteria might have influenced the final results. We have tried to address it by use of consistency index (Saaty,1980). The proposed model has been applied to a company in the electronics Industry. Hence, the model needs to be studied and examined further by the researchers working in other sectors. Future research could also attempt to test the findings of this study using different multi-criteria decision-making methodologies. The decision model developed in this paper is generic and can quickly be adopted by other companies with marginal changes by adding more criteria and sub-criteria specific to the industry concerned.

In this research, we have identified and considered twelve DMFs only, which is one of the limitations of this research. Hence, future research can be done by considering more DMFs, and the findings can be verified. Further, the key DMFs were shortlisted based on literature review and discussion with experts from the electronics industry and academia. Validation of the model developed was done in an electronics SC. Hence, the model needs to be validated in the SCs in other industries considering the DMFs specific to the industry. Further, a different multi-criteria decision-making method could gain better insights regarding the adoption of IOIS in SCs.

To summarize, it is found that all these features and application of digital technologies are interlinked with various emerging areas like resilient supply chain, sustainable supply chain, intertwined supply chain and reconfigurable supply chain which forms a principally new research area. Based on the new areas evolved in the domain of supply chain, an appropriate conclusive conceptual guidance considering the new areas can also be explored.

8.6 Conclusion

SCD can benefit companies irrespective of its size, sector or stage. Digitalization process is not always smooth sailing, as it encounters serious challenges and setbacks during the process. A comprehensive digital strategy is to be developed for digitalization, considering cultural and organizational shifts. A successful digital strategy enhances business performance. Effective long-term strategy, planning and utilization of the resources should be done to integrate digital innovation into an enterprise. The approach of ‘to make’ or ‘to buy’ can be adopted with necessary changes to the firm’s business operations, processes, structure and people.

Legacy systems are interlinked within an enterprise and require cooperation from all departments and functional areas, as it addresses the transformation of culture, process and technology. An organization while moving on from legacy systems to the process of digitalization, needs to take a strategic decision on the financial investment needed. While proceeding with such transformation, many companies lack experience or history in dealing with advanced technology to make business goals a reality. Appropriate strategies are required to convert from legacy systems to advanced digital platforms for organizations to perform better in line with their business objectives. Integration of legacy software with the new systems, its maintenance, and support are challenging tasks. Hence, most organizations consider reengineering the existing solution in contingencies, like a complete system outage. However, to survive in a competitive business environment, companies need to rethink their current business models and make them digital-ready. The modernization of legacy systems leads to attaining competitive advantage, creating happier clients/ employees, future-ready business, unlocking big data opportunities and better performance and reliability.

The evolutionary method follows a systematic step-by-step modernization of software without disrupting the major business processes, thus reducing the risks. On the other hand, digitalization process can also follow a revolutionary method, that involves replacement of legacy system with advanced digital platform after shutting down the old system. This approach helps in reducing damages, security breaches, data loss and system downtime. Irrespective of the approach followed, digitalization is a complex, risky and labour intensive process. Yet, the results are worth the risks and challenges involved.

Companies deciding to proceed with digitalization have to make a critical decision regarding whether to make or buy before investing in technologies. Large enterprises can afford to invest in developing custom-built platforms for specific requirements. Even though the cost of third party solution seems affordable, the customization and integration cost as per the organization's requirement requires more investments. We have to assess whether the existing systems and assets are modern and scalable, and already digitalized. After this, the requirements have to be prioritized, and digitalization need not happen all at once. The approach of relying on third party expertise in the process of digitalization process can also be explored. The process can be initiated by analyzing the current solution, developing a suitable business strategy, application of latest technologies, prioritizing the features and rebuilding the product from scratch and using architecture solutions.

Even though the digital transformation of the supply chain has been underway in many firms, the Covid-19 pandemic and disruptions in supply chain have necessitated the requirement of a digital supply chain requirement for swifter and focused action. Software providers are providing applications in various functional areas for end-to-end connectivity.

The findings of this thesis provide theoretical aspects, frameworks, and interconnected models that can help the process of digitalization in organizations:

- Specifically, it provides insights into how companies can proceed with digitalization considering the customer and design requirements.

- One of the important finding of this research is that an organization should consider mitigating the barriers of SCD. This can lead to better implementation of SCD in organizations.
- Similarly, enablers of SCD particularly, the causal enablers should be given due consideration for achieving the real potential / benefits.
- Integrated DIKW-DSS model assist the decision makers in identifying and prioritizing the critical decision making factors (DMFs) leading to effective digitalization.
- IOIS selection model provides insights on how the advanced digital technologies can be selected and implemented within the organization and across organizational boundaries resulting in value creation.

Overall our research has studied select issues on SCD. This can assist organizations in drawing conclusions on how digitalization results in value creation and better SC performance.

The manufacturing industry can create new business models and enhanced process improvements using advanced digital technologies. Digitalization allows creating an interconnected and collaborated network, wherein the previously unconnected sources were brought into the supply chain network. Better efficiency, opportunities for growth, reduction in cost etc., can be attained, resulting in an overall net positive balance of value creation through digitalization.

The thesis recommends that each organization need to follow a unique path considering their requirements and level of the digitalization needed. The unique resource combinations available across the network also have to be considered during the transformation process. Considering this, the managers can develop an appropriate strategy and road map for value creation goals through digitalization, by analyzing the consequences of changes across the supply chain network.

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LIST OF PUBLICATIONS BASED ON THE THESIS

Refereed International Journals:

1. Deepu, T. S., & Ravi, V. (2020) An integrated ANP–QFD approach for prioritization of customer and design requirements for digitalization in an electronic supply chain. ***Benchmarking: An International Journal***. 28(4), pp.1213–1246. doi:10.1108/ bij-06-2020-0298

2. Deepu, T. S., & Ravi, V. (2020) Analysis of enablers of supply chain digitalization of electronics industry: An Interpretive Structural Modeling Approach, ***International Journal of Logistics and System Management***. 1(1), 1. doi:10.1504/ijlsm.2021. 10038493

3. Deepu, T. S., & Ravi, V. (2021). Exploring critical success factors influencing adoption of digital twin and physical internet in electronics industry using grey-DEMATEL approach. ***Digital Business***, 100009. 1(2), 100009. doi: 10.1016/j.digbus. 2021.100009

4. Deepu, T. S., & Ravi, V. (2021). A conceptual framework for supply chain digitalization using integrated systems model approach and DIKW hierarchy. ***Intelligent Systems with Applications***, 10, 200048. doi: 10.1016/j.iswa. 2021.200048

5. Deepu, T. S., & Ravi, V. (2021). Supply chain digitalization: Integrated MCDM approach for Inter-Organizational Information Systems selection in an electronic supply chain. ***International Journal of Information Management Data Insights***. 1(2), 100038. doi: 10.1016/j.jjimei.2021.100038

6. Deepu, T. S., & Ravi, V., (2019) Integration and Efficiency Enhancement of Supply Chain by using Information and Communication Technology Tools. ***International Journal of Innovative Science and Research Technology***. Vol.No.4(12), pp-752-760.

7. Deepu, T. S., & Ravi, V. (2021) Modelling of interrelationships among enterprise and inter-enterprise information system barriers affecting digitalization in electronic supply chain. ***Business Process Management Journal*** **(Accepted for publication).**

Conference Proceedings

1. Deepu T S & Ravi V., (2020), Prioritization of Customer and Design requirements for an Information Technology enabled Electronics Supply Chain, ***IEEE 2020 Research, Innovation, Knowledge Management and Technology Application for Business Sustainability (INBUSH 2020)***.
2. Deepu T S., Ravi V & Rakesh R Menon., (2016). An investigation on the Role of Information Technology Tools in Supply Chain Integration. ***International Conference organized by Indian Institution of Industrial Engineering (IIIE), jointly organized by CET, GEC-W and POMS-USA***.