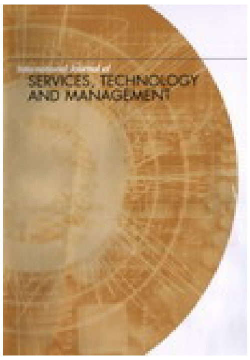

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Unlocking supplier development: a comprehensive analysis of interrelationships and strategies for enhanced performance

Manojkumar V. Dalvi, Vishal A. Bhosale, Anjali S. More

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Unlocking supplier development: a comprehensive analysis of interrelationships and strategies for enhanced performance

Manojkumar V. Dalvi*

Department of Mechanical Engineering,
Navsahyadri Group of Institutes,
Faculty of Engineering,
Naigaon, Pune, India
Email: mddalvi2001@gmail.com
Email: dalvimanojkumar@rediffmail.com
*Corresponding author

Vishal A. Bhosale

School of Mechanical Engineering,
MIT Academy of Engineering,
Alandi, Pune-412105, India
Email: vabhosale@mitaoe.ac.in
Email: vbhosale214@gmail.com

Anjali S. More

AIML Department,
Symbiosis Institute of Technology, Pune,
Symbiosis International (Deemed University),
Pune, India
Email: anjalimore25@gmail.com

Abstract: The primary goal of this study is to identify and analyse the interrelationships among supplier development activities (SDAs) with the aim of step-by-step execution of supplier performance improvement through supplier development (SD). The interrelationships are identified through interpretive structural modelling (ISM), and the driving and dependence power of SDAs are determined using fuzzy matrice d'impacts croisés multiplication appliquée à un classement (MICMAC) analysis. This approach ensures a comprehensive and well-rounded understanding of the dynamics involved in the implementation of SDAs. In total, 25 SDAs are identified through consultation with experts and a literature review. The identified hierarchy of SDAs and their categorisation offer valuable insights for planning and implementing SD in their organisation for managers and decision-making authorities. The objective and its reliability may be enhanced using a well-designed and validated questionnaire to handle the biased opinions by a team of experts.

Keywords: fuzzy MICMAC; supplier development; SD; vendor development.

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Biographical notes: Manojkumar V. Dalvi is a Principal and a Professor in the Mechanical Engineering Department at the Navsahyadri Group of Institutes, Faculty of Engineering, Naigaon, Pune, India. He has done his PhD in the area of Supplier Development and Supply Chain Performance. His area of interest is production management, supplier development and supply chain management. He has about 25 years of experience in industry, teaching and research. He is an Engineering Graduate and MTech in Design Engineering. He has published more than 30 papers in international journals and conferences.

Vishal A. Bhosale is an Assistant Professor at the School of Mechanical Engineering, MIT Academy of Engineering, Alandi, Pune, India. He has done his PhD in the area of knowledge management and supply chain. His area of interest is knowledge flow, operations management and supply chain management. He has about ten years of experience in teaching and research. He is an Engineering Graduate and MTech in Mechanical Engineering. He has published more than 20 papers in international journals and conferences.

Anjali S. More is an Assistant Professor in Department of Computer Engineering, Suman Ramesh Tulsiani Technical Campus Faculty of Engineering Pune and PhD Research Scholar at the National Institute of Technology (SVNIT), Surat, India. She completed her ME (Computer Science Engineering) from Walchand Institute of Technology Solapur. She has several years of experience in teaching and research, also published many papers in reputed international journals and conferences. Her area of research includes big data mining, imbalanced data mining, intrusion detection, etc. She guided many PG students and currently guiding several UG Students at SRTTC FoE.

1 Introduction

The customers are becoming more demanding, expecting higher performance across various dimensions such as quality, reliability, flexibility, innovation, environmental sustainability, and green capability (Li et al, 2022; Patrucco et al., 2022; Sillanpää et al., 2015; Giacchetta and Marchetti, 2013; Loppacher et al., 2011). The product life cycle is shorter, requiring organisations to be more responsive and efficient in their manufacturing processes (Zhang and Li, 2023; Ograh et al., 2023; Zhang et al., 2023). Due to these various aspects buying organisations are dealing with intensified competition and rapid technological advancements. Many manufacturing organisations are responding to these challenges by opting for outsourcing and scaling down their operations (Holma et al., 2021; Irfan et al., 2023; Bravo et al., 2021; Bhattacharyya and Guiffrida, 2015; Dou et al., 2014; Gunasekeran and Kobu, 2007). This strategy allows them to stay competitive and concentrate on their core competencies. There is an increased emphasis on supplier development (SD) to ensure that suppliers meet the evolving expectations and requirements of buying organisations. SD becomes crucial in ensuring that the supply chain (SC) is resilient and aligned with the high standards set by customers (Merminod et al., 2022; Ferrica and Lind, 2023; Gurcaylilar and Erdogan, 2023). Additionally, organisations must invest in innovation, technology, and sustainable practices to meet the evolving demands of the market. Staying ahead in this dynamic environment requires a holistic approach that addresses not only internal operations but also the relationships with suppliers and the fulfilment of customer expectations (Ullah and Narain, 2022; Jia et al., 2022; Ullah et al., 2023; Qi et al., 2015; Sucky and Durst, 2013; Gunasekaran and Kobu, 2007). SD is a collaborative aspect, which fosters stronger partnerships and a shared commitment to achieving common goals. It goes beyond a transactional relationship and emphasises a more strategic and cooperative engagement between the buying organisation and its suppliers.

The observation of this study underscores the strategic importance of SD in optimising SC dynamics and fostering mutually beneficial relationships between buying organisations and suppliers. The success stories in premium organisations like Toyota, Nissan, Sony, Ford, General Motors serve as valuable case studies for others looking to implement effective SD strategies (Kronemeyer et al., 2022; Hoque, 2022; Dos Santos et al., 2023; Barnieri et al, 2023; Talluri et al., 2010; Wagner, 2011). Understanding the sequence of implementation of SDAs is crucial for effective implementation, ensuring that maximum benefits are achieved for both the buying organisation and the suppliers (Jääskeläinen et al., 2022; Patel et al.. 2021; Patrucco et al., 2022; Omurca, 2013; Li et al., 2012). Additionally, studying the interrelationships among these activities, along with their driving and dependence power, helps in creating a strategic and coherent approach. This study of interrelationships amongst SDAs involves recognising which activities drive others and which activities are dependent on preceding actions. For example, joint goal setting is a driver for performance measurement, and the results of performance measurement may drive root cause analysis and subsequent improvement initiatives. Similarly, technology adoption may be dependent on the supplier's readiness, which is influenced by training and development efforts (Prakash et al. 2021; Hong et al., 2023; Emberson et al., 2022; Flankegard et al., 2023). This generalised framework can be adapted based on the specific context and industry requirements, but it provides a structured approach to implementing SDAs and maximising benefits for both parties involved. This study can obtain a nuanced understanding of the dynamics among SDAs, identifying key drivers and elements that are more dependent on others through ISM fuzzy MICMAC approach and the identified interrelationship between SDAs through literature review and industry expert's opinion (Warfield, 1974). This information is invaluable for developing a targeted and effective strategy for enhancing supplier performance and capabilities.

The remainder of the paper, Section 2 proposes the literature review methodology and the outcome of literature review. Sections 3 explain integrated ISM and fuzzy MICMAC methodology followed by results and discussion in Section 4. Section 5 concludes with conclusion, limitations and future scope.

2 Literature review

2.1 Research methodology for literature review

The primary objective of the literature review is to exhibit and summarise important SDAs. Only articles specifically published on SD are considered for inclusion in the literature review. The focus is on articles published in academic databases, including

Science Direct, Emerald, and Inderscience Journals. The keywords used for the search are 'SD' and 'vendor development'. The literature review covers articles published from 2002 to the present date. Only international journal articles are selected to serve the related research communities. Conference articles, master and doctoral dissertations, textbooks, unpublished articles, and notes are excluded from the review.

This methodology ensures a focused and comprehensive review of relevant literature on SD activities within the defined parameters (see Figure 1). The exclusion of certain publication types and the emphasis on international journal articles contribute to maintaining the academic rigor and relevance of the literature selected.

Figure 1 Research methodology for literature review (see online version for colours)

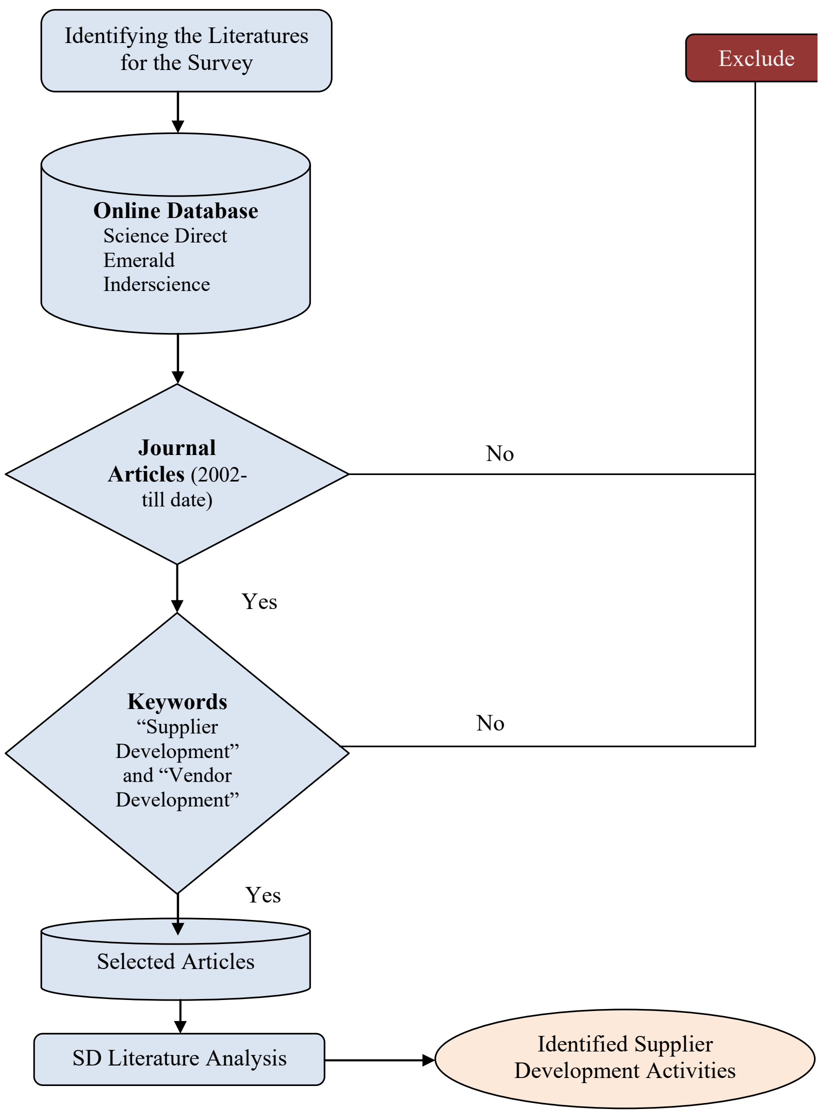


Table 1 SD activities

Supplier development activities (SDAs)	*References*
Top management support and commitment	Li et al. (2022), Patrucco et al. (2022), Zhang and Li (2023), Ograh et al. (2023), Zhang et al. (2023), Dey et al. (2015), Inemek and Matthyssens (2013), Bai and Sarkis (2011), Li et al. (2007)
Long-term relationship	Holma et al. (2021), Irfan et al. (2023), Bravo et al. (2021), Merminod et al. (2022), Ferreira and Lind (2023), Valtakoski (2015), Walker and Brammer (2012), Alireza et al. (2010), Talluri et al. (2010)
Commitment of buyer and supplier	Zhang and Li (2023), Ograh et al. (2023), Sanchez-Rodriguez et al. (2005), Forker and Hershauer (2000)
Long-term contracts	Resende et al. (2023), Dos et al. (2023), Li et al. (2022), Wei et al. (2021), Wynstra et al. (2015)
Continuous increase in volume of outsource work	Bravo et al. (2021), Merminod et al. (2022), Omura (2013), Narasimhan et al. (2001)
Purchasing a large percentage of the suppliers' annual sales	Ograh et al. (2023), Gunasekeran et al. (2008), Wagner (2006), Dyer and Nobeoka (2000)
Supplier recognition and awards of certificates and incentives	Jia et al. (2022), Ullah et al. (2023), Kronemeyer et al. (2022), Hoque (2022),Li et al. (2012), Alireza et al. (2010), Prahinski and Benton (2004)
Relational norms development	Emberson et al. (2022), Johnsen et al. (2022), Flankegard et al. (2023), Bai and Sarkis (2011)
Sharing of operational knowledge	Jääskeläinen et al. (2022), Patel et al. (2021), Patrucco et al. (2022), Pedroso et al. (2021), Prakash et al. (2021), Hong et al. (2023), Bhosale et al. (2018), Zerbini and Borghini (2015), Sanchez-Rodriguez et al. (2005), Forker and Hershauer (2000), Humphreys et al. (2004)
Regular information sharing	Wei et al. (2023), Zhang et al. (2023), Tran et al. (2022), Holma et al. (2021), Irfan et al. (2023), Bhosale et al., (2020), Paparoidamis et al. (2019), Rainy et al. (2012), Krause et al. (2007), Gunasekeran and Ngai (2005)
Providing training related to environmental performance	Lo (2023), Bravo et al. (2021), Merminod et al. (2022), Govindan et al. (2015), Hashemi et al. (2015), Gurel et al. (2015), Sancha et al. (2015)
Providing technical support and technological assistance	Ograh et al. (2023), Zhang et al., (2023), Holma et al. (2021), Irfan et al. (2023), Bravo et al. (2021), Khan and Nicholson (2014), Alireza et al. (2010), Das et al. (2006), Sanchez-Rodriguez et al. (2005)
Investment in training of supplier	Irfan et al. (2023), Das and Senger (2023), Sevinc (2013), Saen (2007), Das et al. (2006), Humphreys et al. (2004)
Investment in temporary transfer of persons	Irfan et al. (2023), Bravo et al. (2021), Routroy and Pradhan (2013), Fu et al. (2012), Li et al. (2007)
Transaction specific investment	Li et al. (2023), Patrucco et al. (2022), Ograh et al. (2023), Humphreys et al.(2004)

Table 1 SD activities (continued)

Supplier development activities (SDAs)	*References*
Investment in facility development by providing equipment	Pedroso (2021), Prakash et al. (2021), Flankegard et al. (2023), Javad et al. (2020), Farzad and Kuwan (2011)
Limited investment in number of suppliers	Ullah and Narain (2022), Jia et al. (2022), Ullah et al. (2023), Mohanty et al. (2014)
Frequently visiting supplier site	Zhang et al., (2023), Holma et al. (2021), Talluri et al. (2010), Krause et al. (2000)
Joint problem solving approach	Hong et al. (2023), Emberson et al. (2022), Chang et al. (2011), Cristobal (2005), Sanchez-Rodriguez et al. (2005)
Improvement in suppliers present and future capabilities	Kronemeyer et al. (2022), Hoque (2022), Dos et al. (2023), Barbieri et al (2023), Shao et al. (2014), Li et al. (2012), Talluri et al. (2010)
Supplier evaluation	Patrucco et al. (2022), Zhang and Li (2023), Jafarian et al. (2021), Li et al. (2012, 2007)
Effective feedback and communication system	Kronemeyer et al. (2022), Hoque (2022), Dos et al. (2023), Yan and Dooley (2013), Bai and Sarkis (2011), Wu and Ragatz, (2010)
Providing support to suppliers in materials improvement	Ograh et al. (2023), Zhang et al., (2023), Sanchez-Rodriguez et al. (2005), Forker and Hershauer (2000)
Involvement of buyer in supplier activities	Pedroso (2021), Prakash et al. (2021), Hong et al. (2023), Wu and Ragatz (2010)
Early involvement of supplier or concurrent engineering	Zhang and Li (2023), Yoo et al. (2015), Omura (2013), Li et al. (2007), Sanchez-Rodriguez et al. (2005)
Assisting in work or documentation	Jia et al. (2022), Ullah et al. (2023), Wagner (2006)
Providing support in material improvement	Dos et al. (2023), Li et al. (2007), Wu and Ragatz (2010), Cristobal (2005)
Support in market entry for supplier	Flankegard et al. (2023), Javad et al. (2020), Wagner (2006)

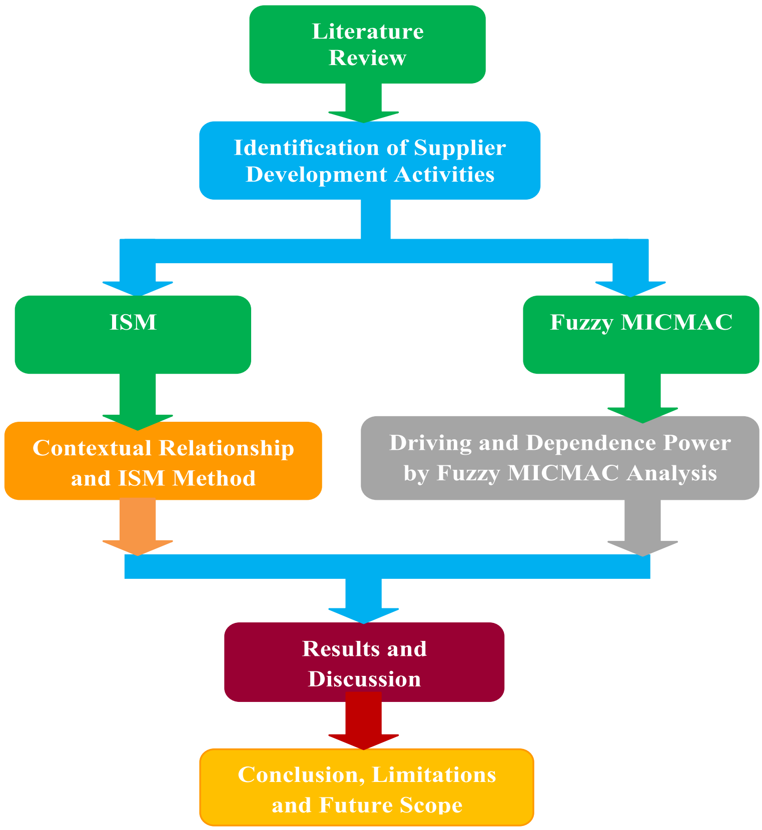
2.2 *Summary of literature review*

An extensive literature review is conducted as per the research methodology, and the summarised literature review is as follows (see Table 1).

3 Integrated ISM and fuzzy MICMAC methodology

This scholarly inquiry delves into the identification of pivotal SDAs via meticulous scrutiny of existing literature and the discerning evaluation of expert perspectives. Leveraging the ISM methodology, this research endeavours to unveil the intricate relationships among SDAs, thereby offering invaluable insights into their interconnectivity and potential synergistic effects. Furthermore, employing the fuzzy MICMAC analysis, the study seeks to meticulously scrutinise these factors based on their respective roles as drivers or dependencies. Through this rigorous examination, the factors are methodically categorised into four distinct clusters: autonomous, dependent, linkage, and independent, thereby providing a nuanced understanding of their hierarchical structure and operational dynamics. The graphical representation delineating the procedural framework of the adopted research methodology is depicted in Figure 2.

Figure 2 Research methodology (see online version for colours)



3.1 ISM methodology and model development

ISM is a methodology designed to study and analyses complex socio-economic systems, which is particularly useful for representing and understanding intricate interrelationships between various elements within a system (Sage, 1977). Complex problems are often decomposed into several subsystems or elements. This decomposition allows for a more focused and manageable analysis of the overall problem. A multilevel ISM model is developed to represent the relationships between the decomposed elements (Warfield, 1974). This multilevel structure enables a hierarchical representation of the system, capturing the interdependencies at different levels.

The decomposition process is typically carried out in consultation with experts from industries and academia. Involving experts ensures a comprehensive understanding of the problem and the identification of relevant elements. The resulting ISM diagram visually represents the relationships between different elements of the system. This visual representation aids in conveying the complex interconnections and relationships in a clear and accessible manner. By breaking down the problem and visually representing its elements and relationships, ISM facilitates a clearer comprehension of the overall system (Kant and Singh, 2009).

ISM serves as a powerful analytical tool for tackling complexity and providing a structured approach to understanding and managing intricate systems. Its ability to visually represent interrelationships helps stakeholders make informed decisions and devise effective strategies (see Table 2)

Table 2 ISM as reported in literature

Representative literature	*Details*
Kant and Singh (2009)	Contextual relationship amongst variables of knowledge management
Sharma and Singh (2013)	Identification of individual/group knowledge sharing barriers in Indian engineering industry
Gorane and Kant (2013)	Relationship amongst SC management enablers with driving and dependence power
Bhosale and Kant (2020)	Developed interrelationship among supply chain knowledge flow barriers
Patel et al. (2021)	Driving and dependence power of circular economy enablers
Ruben et al. (2023)	Identification of interrelationship amongst Barriers of industry 4.0 using ISM Fuzzy MICMAC with driving and dependence power
Das and Sengar (2023)	Modelling barriers of customer engagement of eHealth in India using ISM-Fuzzy MICMAC analysis

The steps to be followed in ISM methodology are as follows:

3.1.1 Identification of factors

The identification of elements related to the problem is recognised as a crucial and foundational step in the ISM method. This step sets the stage for the subsequent analysis by ensuring a comprehensive and relevant list of factors associated with the problem. Gathering input from various sources is emphasised to create a well-rounded and inclusive list of elements. Input may come from experts, stakeholders, literature, or other relevant sources to ensure a comprehensive perspective. The ultimate goal of this step is to generate a complete and sufficient list of factors for analysis.

This step also comprises collaborative input and a systematic approach to identifying relevant factors, is crucial for the success of the ISM analysis. It ensures that the subsequent modelling and interpretation are built on a robust foundation of elements relevant to the problem under investigation. The techniques such as brainstorming sessions or the Delphi method are suggested for finalising the list of factors.

The finalised 25 SDAs for this study are as follows (see Table 3).

3.1.2 Contextual relationship

The primary objective is to understand how the elements are related to each other within the context of the problem. The focus is on identifying the nature of relationships among the elements and determining how each element influences the others. To achieve this objective, a structural self-interaction matrix (SSIM) is developed. The SSIM captures the relationships among the elements and provides a structured representation of their interactions. The development of the SSIM involves a pairwise comparison of elements. This comparison is conducted to assess the strength and nature of the relationships between each pair of elements. The SSIM is presented in matrix form, where each element is compared with every other element. The matrix helps visualise the interconnections and influences among the identified elements. The SSIM allows for the identification of the nature of relationships, indicating whether the influence between elements is positive, negative, or neutral (see Table 4). Positive influences suggest a promoting relationship, while negative influences suggest inhibiting factors.

Table 3 SD activities (SDAs)

Sr. no.	*Supplier development activities (SDAs)*
SDA 1	Support in market entry for supplier
SDA 2	Long-term contracts
SDA 3	Providing technical support and technological assistance
SDA 4	Assisting in work or documentation
SDA 5	Top management support and commitment
SDA 6	Effective feedback and communication system
SDA 7	Supplier evaluation
SDA 8	Providing training related to environmental performance
SDA 9	Sharing of operational knowledge
SDA 10	Investment in facility development by providing equipment
SDA 11	Regular information sharing
SDA 12	Limited investment in number of suppliers
SDA 13	Continuous increase in volume of outsource work
SDA 14	Joint problem solving approach
SDA 15	Transaction specific investment
SDA 16	Providing support to suppliers in materials improvement
SDA 17	Involvement of buyer in supplier activities
SDA 18	Improvement in suppliers present and future capabilities
SDA 19	Long-term relationship
SDA 20	Commitment of buyer and supplier
SDA 21	Frequently visiting supplier site
SDA 22	Supplier recognition and awards of certificates and incentives
SDA 23	Investment in training of supplier
SDA 24	Purchasing a large percentage of the suppliers' annual sale
SDA 25	Early involvement of supplier or concurrent engineering

This step is crucial in establishing the structural relationships among the elements, providing a foundation for subsequent analyses. The SSIM offers a systematic way to represent and quantify the interactions, helping to uncover patterns and dependencies within the system

Table 4 Structural self-interaction matrix

SDE code	*25*	*24*	*23*	...	...	*5*	*4*	*3*	*2*
SDE1	A	A	V	…	…	A	A	A	A
SDE2	V	A	V	…	…	A	V	V	
SDE3	A	A	V	…	…	A	X		
SDE4	A	A	V	…	…	…			
…	…	…	…	…	…				
…	…	…	…	…					
SDE21	A	A	V						
SDE22	A	A	X						
SDE23	A	A							
SDE24	V								
SDE25									

3.1.3 Rechability matrix

The fundamental principle guiding ISM is the transitivity of contextual relations. This principle ensures that if there is a relationship between element A and element B, and another relationship between element B and element C, then it is mandatory that there is also a relationship between element A and element C. The transitivity property is a key characteristic of contextual relationships in ISM. It reflects the logical consistency in the influence or relationship between elements within the system. The reachability matrix derived from the SSIM follows this fundamental principle of ISM. The transitive property is adhered to during the derivation process, maintaining the logical flow of relationships between elements (see Table 5).

Table 5 Initial reachability matrix

SDE code	*1*	*2*	*3*	...	...	...	*23*	*24*	*25*
SDE1	1	0	0	…	…	…	1	0	0
SDE2	1	1	1	…	…	…	1	0	1
SDE3	1	0	1	…	…	…	1	0	0
…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…
SDE23	0	0	0	…	…	…	1	0	0
SDE24	1	1	1	…	…	…	1	1	1
SDE25	1	0	1	…	…	…	1	0	1

By ensuring transitivity, the derived matrix maintains logical consistency in representing the relationships among the identified elements. This consistency is crucial for the validity and reliability of the ISM model. The transitivity principle contributes to a systematic analysis of the relationships between elements, allowing for a clear and coherent representation (see Table 6).

Table 6 Final reachability matrix

SDE code	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*
SDE1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0
SDE2	1	1	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1
SDE3	1	0	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE4	1	0	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE5	1	1	1	1	1	1	0	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1
SDE6	1	0	1	1	0	1	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE7	1	1	1	1	0	1	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SDE8	1	0	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0
SDE9	1	0	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE10	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
SDE11	1	0	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE12	1	0	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0
SDE13	1	0	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0
SDE14	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0
SDE15	1	0	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE16	1	0	1	1	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0
SDE17	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	1	1	0	0
SDE18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0
SDE19	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	0
SDE20	1	1	1	1	0	1	0	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SDE21	1	0	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0
SDE22	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0
SDE23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0
SDE24	1	1	1	1	0	1	0	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	1	1	1	1
SDE25	1	0	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1

Note: *indicates transitivity.

The transitivity principle reinforces the reliability and integrity of the ISM model, ensuring that the relationships identified are logically sound and adhere to a consistent pattern. This adherence to the transitive property contributes to the robustness of the ISM analysis, making it a valuable tool for understanding the interconnections among elements within the system.

Figure 3 ISM-based model of SDAs (see online version for colours)

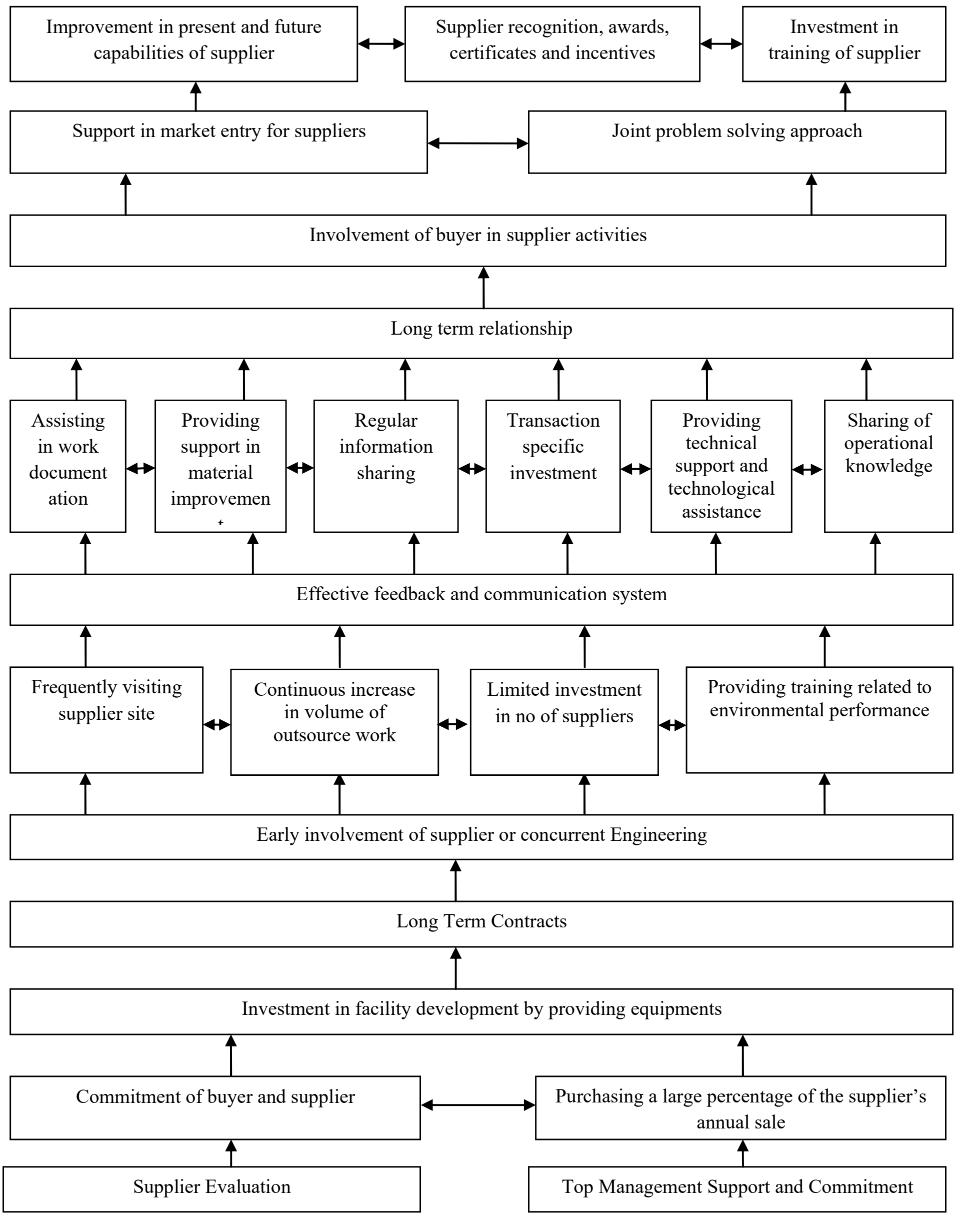


Table 7 Level of SDEs

SDE code	*Reachability set*	*Antecedent set*	*Intersection set*	*Level*
SDE1	1, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, 21, 24, 25	1, 14	II
SDE2	2	2, 5, 7, 10, 20, 24	2	IX
SDE3	3, 4, 9, 11, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 20, 21, 24, 25	3, 4, 9, 11, 15, 16	V
SDE4	3, 4, 9, 11, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 20, 21, 24, 25	3, 4, 9, 11, 15, 16	V
SDE 5	5, 7	5	5, 7	XII
SDE 6	6	2, 5, 6, 7, 8, 10, 12, 13, 20, 21, 24, 25	6	VI
SDE 7	5, 7	7	5, 7	XII
SDE 8	8, 12, 13, 21	2, 5, 7, 8, 10, 12, 13, 20, 21, 24, 25	8, 12, 13, 21	VII
SDE 9	3, 4, 9, 11, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 20, 21, 24, 25	3, 4, 9, 11, 15, 16	V
SDE 10	10	5, 7, 10, 20, 24	10	X
SDE 11	3, 4, 9, 11, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 20, 21, 24, 25	3, 4, 9, 11, 15, 16	V
SDE 12	8, 12, 13, 21	2, 5, 7, 8, 10, 12, 13, 20, 21, 24.25	8, 12, 13, 21	VII
SDE 13	8, 12, 13, 21	2, 5, 7, 8, 10, 12, 13, 20, 21, 24, 25	8, 12, 13, 21	VII
SDE 14	1, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, 21, 24, 25	1, 14	II
SDE 15	3, 4, 9, 11, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 20, 21, 24, 25	3, 4, 9, 11, 15, 16	V
SDE 16	3, 4, 9, 11, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 20, 21, 24, 25	3, 4, 9, 11, 15, 16	V
SDE 17	17	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 19, 20, 21, 24, 25	17	III
SDE 18	18, 22, 23	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25	18, 22, 23	I
SDE 19	19	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 19, 20, 21, 24, 25	19	IV
SDE 20	20, 24	5, 7, 20, 24	20, 24	XI
SDE 21	8, 12, 13, 21	2, 5, 7, 8, 10, 12, 13, 20, 21, 24, 25	8, 12, 13, 21	VII
SDE 22	18, 22, 23	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25	18, 22, 23	I
SDE 23	18, 22, 23	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25	18, 22, 23	I
SDE 24	20, 24	5, 7, 20, 24	20, 24	XI
SDE 25	25	2, 5, 7, 10, 20, 24, 25	25	VIII

3.1.4 Canonical matrix

Elements identified in the earlier steps are arranged based on their assigned levels. Levels indicate the hierarchical position of each element within the system (see Table 7). The arrangement of elements based on levels contributes to the creation of the canonical matrix. In the canonical matrix, diagonal elements represent the levels of the elements, providing a structured representation. Diagonal elements of the matrix signify the levels of the elements. Off-diagonal elements represent the direct influences or relationships between elements. Converting the reachability matrix into a canonical matrix helps visualise the hierarchical structure of the system. The placement of elements in the matrix reflects their relative positions in terms of influence and hierarchy.

The canonical matrix provides a clear representation of both the levels of influence and the relationships between elements. This format enhances the interpretability of the hierarchical structure of the system. The canonical matrix serves as a foundational component for creating the final ISM diagram. It encapsulates the key information about levels, influences, and relationships, which will be translated into the visual representation. The information from the canonical matrix is used to construct the final ISM diagram. The ISM diagram visually represents the complex relationships and hierarchy within the system (see Figure 3).

This step is critical for transforming the analytical data into a visual representation that stakeholders can interpret easily. The ISM diagram becomes a powerful communication tool, providing a comprehensive view of the system's structure and interdependencies.

3.1.5 Digraph and final structural model

The canonical matrix serves as the basis for drawing a directed graph or digraph. In this representation, vertices or nodes correspond to the identified elements, and lines or edges depict the direct influences between these elements. The directed graph provides a visual representation that makes it easier to interpret the relationships between elements. Elements and their connections are visually organised, reflecting the hierarchical levels identified in the canonical matrix. The hierarchical levels of the elements are visually displayed in the digraph. This visual representation enhances the understanding of the hierarchical structure within the system.

Through the examination of relationships in the reachability matrix, transitive links are identified. Transitive links represent indirect influences that need to be scrutinised for a more accurate depiction of direct influences. Transitive links are then removed to create a more accurate representation of direct influences. This step ensures that the ISM diagram focuses on the most direct and significant relationships between elements. The removal of transitive links contributes to creating a more accurate and streamlined representation of the system's structure. The resulting ISM diagram provides a clearer view of the essential direct influences between elements.

The ISM diagram, with its nodes, edges, and hierarchical levels, becomes a powerful tool for stakeholders to understand the interconnections and influences within the system. It aids in decision-making, strategic planning, and problem-solving by offering a visually intuitive representation of complex relationships.

This conversion process adds a layer of descriptive clarity to the ISM diagram as SDA nodes are replaced with statements making it more accessible and meaningful to a wider audience (see Figure 3).

3.2 ISM Fuzzy MICMAC Analysis

This binary nature of the reachability matrix is a fundamental characteristic of the traditional ISM approach. It indicates whether there is a direct relationship (1) or no direct relationship (0) between two SDAs. Convert the binary reachability matrix obtained from the ISM analysis into a fuzzy reachability matrix. Instead of using binary values (0 or 1).

In Fuzzy MICMAC analysis, relationships are assigned fuzzy membership values, indicating degrees of strength or intensity. This fuzzy logic approach enables a more nuanced understanding of the influence and dependence powers among the elements, allowing for distinctions between very strong, strong, and less strong relationships. By incorporating fuzzy logic, the Fuzzy MICMAC analysis addresses the limitation of the traditional ISM model, providing a more realistic and granular representation of complex interrelationships. This nuanced view is particularly valuable in systems where relationships between elements exhibit varying degrees of influence and importance. Fuzzy MICMAC analysis is a valuable extension that enhances the capabilities of the ISM model by allowing for a more sophisticated representation of the strengths of relationships. It provides decision-makers with a richer understanding of the dynamics within a system, considering the varied intensities of connections among elements. The fuzzy MICMAC analysis can be elaborated through following steps

3.2.1 Binary direct reachability matrix

The binary direct reachability matrix (BDRM) is a binary matrix that captures the direct reachability relationships between different components or elements represented by SDAs in a system. By excluding self-referential relationships, i.e., setting diagonal entries to zero, the focus is on the direct connections between different elements, providing a simplified representation of the system's structure or interconnections. The BDRM is as follows (see Table 8).

Table 8 Binary direct reachability matrix

SDE code	*1*	*2*	*3*	*...*	*...*	*...*	*23*	*24*	*25*
SDE1	0	0	0	…	…	…	1	0	0
SDE2	1	0	1	…	…	…	1	0	1
SDE3	1	0	0	…	…	…	1	0	0
…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…
SDE23	0	0	0	…	…	…	0	0	0
SDE24	1	1	1	…	…	…	1	0	1
SDE25	1	0	1	…	…	…	1	0	0

3.2.2 Development of fuzzy direct reachability matrix

The extension of MICMAC analysis using fuzzy set theory involves incorporating degrees of membership to account for uncertainty and imprecision in the relationships between system elements. The introduction of a qualitative scale further enhances the analysis by capturing the intensity or strength of interactions between SDAs in a more nuanced way (see Table 9).

Table 9 The fuzzy linguistic scale

Linguistic variable	*Triangular fuzzy number*
No influence (no)	(0, 0, 0)
Very low influence (VL)	(0, 0.1, 0.3)
Low influence (L)	(0.1, 0.3, 0.5)
Medium influence (M)	(0.3, 0.5, 0.7)
High influence (H)	(0.5, 0.7, 0.9)
Very high influence (VH)	(0.7, 0.9, 1)
Complete influence (C)	(1, 1, 1)

The fuzzy direct reachability matrix (FDRM) is an enhanced matrix that incorporates both BDRM and qualitative considerations from experts. This approach allows for a more refined analysis that considers not only the presence or absence of relationships but also the qualitative nuances provided by domain experts (see Table 10).

Table 10 Fuzzy direct rechability matrix

SDE code	*1*	*2*	*3*	...	...	...	*23*	*24*	*25*
SDE1	0	0	0	…	…	…	0.3	0	0
SDE2	0.3	0	0.5	…	…	…	0.1	0	0.9
SDE3	0.5	0	0	…	…	…	0.3	0	0
…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…
SDE23	0	0	0	…	…	…	0	0	0
SDE24	0.3	0.7	0.5	…	…	…	0.1	0	0.7
SDE25	0.3	0	0.5	…	…	…	0.1	0	0

3.2.3 Fuzzy MICMAC stabilised matrix

This process involves starting with the FDRM, performing fuzzy matrix multiplications iteratively, and monitoring the driving and dependence powers until they stabilise. This iterative approach allows for a more refined analysis of the interactions between system elements, considering both binary and fuzzy information, and incorporating qualitative considerations from experts. The goal is to capture the nuances and uncertainties in the relationships between system elements, providing a more accurate representation of the complex interactions in the system.

Table 11 Fuzzy MICMAC stabilised matrix

SDE code	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*SUM*
SDE1	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0.9	0.9	0	0	*3*
SDE2	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0	*16.2*
SDE3	0.9	0	0	0.9	0	0	0	0	0.9	0	0.9	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*10.8*
SDE4	0.9	0	0.9	0	0	0	0	0	0.9	0	0.9	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*10.8*
SDE5	0.9	0.9	0.9	0.9	0	0.9	0	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	*20.7*
SDE6	0.9	6	0.9	0.9	0	0	0	0	0.9	0	0.9	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*17.7*
SDE7	0.9	0.9	0.9	0.9	0	0.9	0	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	*20.7*
SDE8	0.9	0	0.9	0.9	0	0.9	0	0	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0	*15.3*
SDE9	0.9	0	0.9	0.9	0	0	0	0	0	0	0.9	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*10.8*
SDE10	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0.9	*17.1*
SDE11	0.9	0	0.9	0.9	0	0	0	0	0.9	0	0	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*10.8*
SDE12	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0	*15.3*
SDE13	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0	*15.3*
SDE14	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0.9	0.9	0	0	*3.4*
SDE15	0.9	0	0.9	0.9	0	0	0	0	0.9	0	0.9	0	0	0.9	0	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*10.8*
SDE16	0.9	0	0.9	0.9	0	0	0	0	0.9	0	0.9	0	0	0.9	0.9	0	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*10.8*
SDE17	0.7	0	0	0.5	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0.7	0	0	0	0.7	0.7	0	0	*4*
SDE18	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0.9	0	0	*2.7*
SDE19	0.7	0	0	0.3	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0.7	0	0	0	0.7	0.7	0	0	*3.8*
SDE20	0.9	0.9	0.9	0.9	0	0.9	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0.7	0.9	*19.6*
SDE21	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0	0.9	0.9	0	0	*15.3*
SDE22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0.9	0	0	*1.8*
SDE23	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0.9	0	0	0	*2.7*
SDE24	0.9	0.9	0.9	0.9	0	0.9	0	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0.9	*18.9*
SDE25	0.9	0	0.9	0.9	0	0.9	0	0.9	0.9	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9	0	0	*16.2*
SUM	*17.6*	*9.6*	*15.3*	*18.9*	*0*	*9.9*	*0*	*9*	*15.3*	*3.6*	*15.3*	*9*	*9*	*17.6*	*15.3*	*15.3*	*16.2*	*21.2*	*16.2*	*1.8*	*9*	*21.2*	*21.2*	*2.5*	*4.5*	

In the context of obtaining a fuzzy MICMAC stabilised matrix by repeatedly multiplying the FDRM, these principles ensure that the fuzzy nature of the relationships is appropriately considered and refined in each iteration, which also follows the fuzzy matrix multiplication principle. The rule is given below.

$$C = A, B = \text{Max } k\left[\left(\min a_{ik},\ b_{kj}\right)\right]$$

where A= [a_{ik}] and B = [bk_j].

By summing the rows and columns of the fuzzy stabilised matrix, which will provide the insights into the driving and dependence powers of the SDAs in the system. This step is crucial for identifying the key elements that play influential roles and those that are more dependent within the analysed system (see Table 11).

4 Findings and discussions

A thorough identification of 25 SDAs through literature review, academic expert opinions, and insights from industry practitioners is completed in this study. The interrelations among these SDAs are then analysed using the ISM methodology, a structured approach that integrates expert judgment to understand the hierarchy with driving and dependence power using fuzzy MICAMC approach. The hierarchical structure of the model likely reveals not only the relationships among SDAs but also their relative importance and dependencies. This structured approach aids in understanding the systemic nature of the various identified SDAs influencing the system.

Top management support and commitment along with supplier evaluation is identified as fundamental and basic SDAs. These SDAs are positioned at the top level of the structural model, indicating their high influence and importance. This suggests that the success of other SDAs may be contingent on strong support and commitment from top management and the supplier evaluation indicates the significance of assessing supplier capabilities as a foundational aspect of the system. At the top of this structural model, improvement in present and future capabilities of the Supplier suggests a focus on enhancing and evolving the capabilities of suppliers over a period of time. Investment in training of supplier emphasises the importance of investing in the training and development of suppliers. Supplier recognition, awards, certificates, and incentives reflects the recognition and reward mechanisms for suppliers, reinforcing positive behaviour and relationship. The model incorporates a depth of 12 hierarchy levels, indicating a detailed and granular understanding of the relationships and dependencies among the identified SDAs. Each level likely represents a more detailed aspect or subcategory of the higher-level SDAs. The top-level placement of fundamental SDAs suggests that these elements play a foundational role in shaping the success of the overall system. The outcomes at the first level indicate the desired results or achievements expected from the implementation of the identified SDAs.

The detailed hierarchy of SDAs, with top management support, commitment, and supplier evaluation at the highest levels, provides valuable insights into the fundamental aspects of the system. The expected outcomes at the first level highlight the goals and anticipated benefits of implementing these SDAs in the context of supplier relationships and capabilities.

The commitment of both buyer and supplier, coupled with the practice of purchasing a significant portion of the supplier's annual sales, is positioned strategically in the hierarchy of SDAs. The emphasis on building supplier confidence and faith indicates recognition of the importance of trust in the step-by-step implementation and success of SD.

The level three in the hierarchy involves an investment in facility development, specifically by providing equipment to suppliers. The intended outcome is the improvement of supplier facilities, and this action is strategically positioned to align with the expected performance outcomes desired by the buying organisation. The mutual benefit is highlighted, where the improvement in supplier facilities aligns with the expected performance outcomes desired by the buying organisation. This emphasises a win-win scenario for both parties involved. It suggests that the investment and improvement in supplier facilities are directly related to the performance outcomes expected by the buying organisation. Performance outcomes may include increased efficiency, quality, or other key performance indicators that align with the goals of the buying organisation.

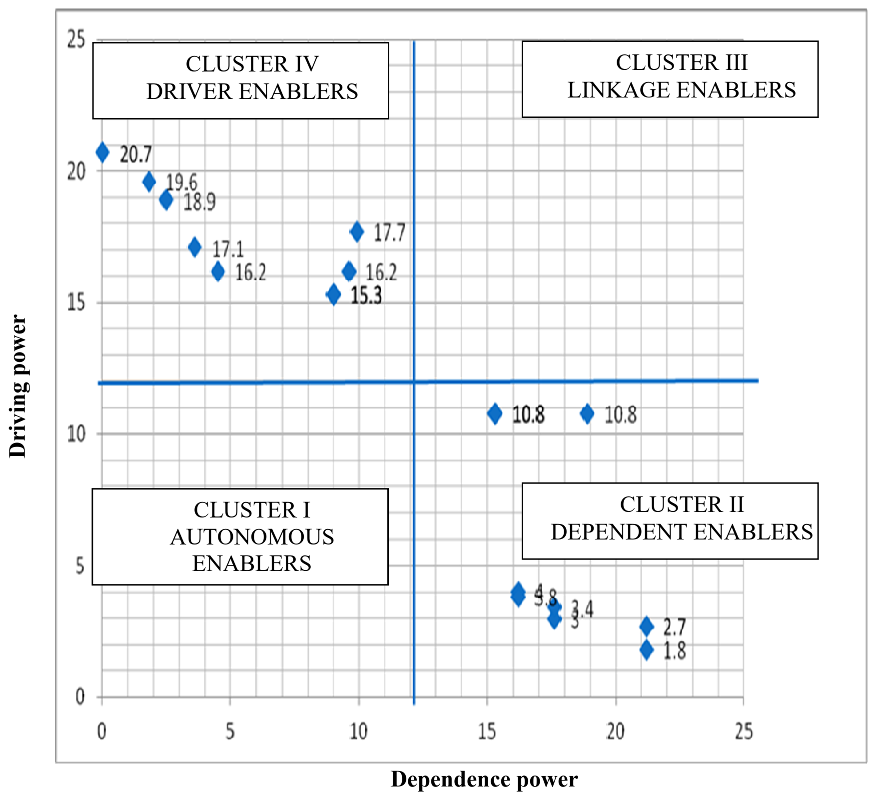
Long-term contracts are placed at level four, suggesting its importance in the sequence of actions or considerations within the system design. Long-term contracts have strategic significance as it implies a commitment between the buyer and supplier over an extended period. This can provide stability, foster a strong relationship, and support ongoing collaboration. The fifth level in the structural model is indicating that early supplier involvement is a subsequent consideration following long-term contracts. Early supplier involvement, also known as concurrent engineering, suggests engaging suppliers in the design and development phases of a product or project. This can lead to improved collaboration, reduced lead times, and enhanced product quality. The SDAs at these two levels reflects a focus on building strong and collaborative relationships with suppliers, with implications for stability, innovation, and overall system performance.

The SDAs at this fifth level in the hierarchy, including frequent visits to supplier sites, continuous increase in the volume of outsourced work, limited investment in the number of suppliers, and training related to environmental performance, collectively reflect a strategic approach to supplier management. These actions contribute to relationship-building, efficiency gains, and sustainability considerations within the broader system design.

An effective communication system is not only internal but may also involve engaging suppliers in meaningful communication. This engagement can lead to a more collaborative and mutually beneficial relationship. A very crucial and important SDA, i.e., effective feedback and communication system is at next level of the hierarchy of the structural model. Placing effective feedback and communication systems at the next level in the hierarchy underscores its critical role in the success of the system. This SDA is likely considered a foundational element for ensuring that the various components of the system operate cohesively and efficiently.

The various SDAs at the next level include collaboration in creating, organising, or improving documentation related to work processes. It may involve sharing best practices, procedures, or other relevant documentation. Providing support in material improvement indicates a collaborative effort to enhance the quality or characteristics of materials used in the processes. This could involve joint research, development, or implementation of improvements in materials. Regular information sharing highlights the importance of consistent and frequent sharing of information between the buyer and the supplier. This can contribute to transparency, alignment of goals, and improved decision-making. Transaction specific investment implies that investments are made in a targeted and specific manner, likely to support or optimise particular transactions or aspects of the business relationship. Providing technical support and technological assistance Indicates a commitment to providing expertise and assistance in technical matters. This may involve sharing technical knowledge, providing support for technology implementation, or collaborating on technological advancements. Sharing of operational knowledge emphasises the importance of exchanging operational knowledge between the buyer and supplier. This could involve insights into operational processes, efficiencies, or improvements. This level in the hierarchy represents a set of sophisticated and strategic SDAs that go beyond basic collaboration. These activities involve in-depth cooperation, knowledge exchange, and joint efforts to improve various aspects of the business relationship between the buyer and supplier.

Figure 4 Clusters of SDAs (see online version for colours)



The next two levels includes long-term relationship and involvement of buyer in supplier activities at nine and tenth level. These two levels in the hierarchy of structural model emphasise the strategic aspects of the buyer-supplier relationship. Long-term relationships and active involvement in supplier activities signify a commitment to enduring partnerships, mutual collaboration, and potentially deeper integration in the operational aspects of the supplier.

The eleventh level in the hierarchy represents advanced strategic initiatives involving market support for suppliers and a joint problem-solving approach. These elements are anticipated to have a profound impact on the final outcomes, emphasising a high level of collaboration, strategic partnership, and proactive problem resolution within the buyer-supplier relationship.

Another objective of this study is to determine the driving and dependence power of finalised SDAs through fuzzy MICMAC analysis, which is a comprehensive approach for the understanding of dynamics and relationships among SDAs (see Figure 4).

The results of the fuzzy MICMAC analysis have revealed four distinct clusters SDAs i. e. Autonomous SDAs, dependent SDAs. linkages SDAs and independent SDAs, each characterised by different levels of driver power and dependence.

4.1 Autonomous SDAs

In this study, there are no SDAs, which come under this category of weak drivers and weak dependence. The absence of SDAs with weak drivers and weak dependence in the study's findings suggests a positive evaluation of all 25 identified SDAs. This implies that each identified SDA is perceived as important and relevant, contributing to the overall success and dynamics of the system being studied (see Figure 4).

4.2 Dependent SDAs

Figure 4 also depicts that SDAs namely improvement in supplier's present and future capabilities (SDE18), Supplier recognition, awards, certificates and incentives (SDE 22), investment in training of supplier (SDE23), support in market entry for supplier (SDE1), joint problem solving approach (SDE14), involvement of buyer in supplier activities (SDE17), long-term relationship (SDE19), assisting in work documentation (SDE4), providing support to suppliers in material improvement (SDE16), transaction specific investment (SDE15), and sharing of operational knowledge (SDE9) these SDAs are strongly dependent on the others but weak drivers (see Figure 4). SDAs at the top level of the ISM hierarchy are portrayed as pivotal and indispensable components in the successful implementation of System Design activities. The strong dependence underscores their interconnected nature and emphasises the critical role they play in shaping the overall outcomes of the system design process.

4.3 Linkages SDAs

In our study, there is no SDA comes under this category, this absence of SDAs in this category has implications for decision-making, indicating that attention may need to be focused on other aspects of the SDAs to maintain stability and balance within the system. The absence of SDAs with strong driving power and strong dependence in the study suggests a balanced and relatively stable set of System Design Artefacts. This observation has implications for understanding the system's dynamics, feedback loops, and the potential impacts of individual SDAs on the overall system stability

4.4 Independent SDAs

The Figure 4 also shows that SDAs namely supplier evaluation (SDA 7), top management support and commitment (SDA 5), commitment of buyer and supplier (SDA 20), purchasing a large percentage of the supplier's annual sale (SDA 24), investment in facility development by providing equipment (SDA 10), long-term contracts (SDA 2), early involvement of supplier or concurrent engineering (SDA 25), continuous increase in volume of outsource work (SDA 13), limited investment in no of suppliers (SDA 12), providing training related to environmental performance (SDA 8), effective feedback and communication system (SDA 6) comes under the another a very important cluster, i.e., independent cluster having strong driving power but weak dependence.

This emphasises the strategic role of top management and decision-making authorities in formulating a strategy to address SDAs, with a specific focus on those with strong driving power. The prioritisation of these influential SDAs reflects an understanding of their potential impact on the overall success of System Design Activities and the need for a proactive and targeted approach in managing them.

5 Conclusions

This study underscores the strategic role of outsourcing in response to a changing business landscape and the critical importance of supplier relationships and development for a competitive SC. The emphasis on focusing on core competencies and efficient resource allocation aligns with contemporary business strategies to stay competitive in a dynamic market

This study recognises the inherent risks and challenges in implementing SDAs and takes a proactive approach to identify and understand factors that may hinder success. The combination of literature review, expert opinions, ISM, and fuzzy MICMAC analysis provides a comprehensive and structured methodology for assessing and addressing the interrelationships among the identified SDAs.

The study is positioned as a valuable and innovative contribution that goes beyond theoretical insights. It is expected to have practical implications for industry practitioners while enhancing the academic understanding of system design. The combination of ISM fuzzy MICMAC analysis and actionable guidance through the ISM model adds depth and applicability to the study's findings.

The fuzzy MICMAC analysis, particularly the categorisation of SDAs by their driving power, informs a strategic approach for decision-making. The recommendation to focus efforts on higher driving power SDAs aligns with the goal of maximising impact on the overall success of SDAs. The combination of ISM and fuzzy MICMAC is positioned as a powerful framework, offering insights for top management in formulating strategies and making informed decisions in the context of system design activities.

5.1 Unique contributions of the research

1. Strategic role of outsourcing and supplier relationship management: By aligning with contemporary business strategies that emphasise core competencies and efficient resource allocation, the study provides insights into staying competitive in dynamic markets through strategic outsourcing decisions.

2 Comprehensive methodology for assessing system design activities (SDAs): The study offers a proactive approach to identifying and understanding factors that hinder the success of SDAs, integrating literature review, expert opinions, ISM, and fuzzy MICMAC analysis to provide a comprehensive and structured methodology.

3 Practical tool for decision-making in system design: Positioned as a valuable resource for decision-making and classification based on specific needs, this tool enhances practical implications while providing actionable guidance through the ISM model, adding depth and applicability to the study's findings.

5.2 Limitations of the research

1 Despite using structured instruments and questionnaires, the study's reliance on a diverse group of industry experts and academicians may still be limited by the sample size and representation. A larger and more diverse sample could provide a broader range of perspectives and insights into the topic.

2 While the use of structured instruments enhances objectivity, reliability, and validity, the generalisability of findings may be constrained by the specific context or industry focus of the study. Future research could explore different industries or contexts to assess the transferability of the proposed methodologies.

5.3 Future research directions

1 Comparing the effectiveness of different methodologies for data collection and analysis, such as structured instruments versus qualitative interviews, could offer valuable insights into their respective strengths and limitations. This comparative analysis could inform researchers and practitioners about the most suitable approaches for similar studies in the future.

2 Extending the research to different geographic regions, industries, or organisational sizes could help validate the applicability and effectiveness of the proposed methodologies in diverse contexts. This would enhance the robustness and generalisability of the findings, providing valuable insights for a broader range of stakeholders.

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