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Prioritization of barriers in industrial symbiosis implementation in automotive industry - Using ISM and MICMAC Analysis

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ABSTRACT

The continuous increase in production, lack of flexibility of organizations, and lack of knowledge on sustainability have led to the depletion of raw materials and increased waste generation. Industrial symbiosis now has become a very effective solution and an essential strategy for responsible consumption and waste utilization. This strategy

helps different organizations to blend their resources, share information, logistics, and waste materials to solve their problems by forming a network to increase profits. This study was directed towards identifying the barriers towards applying Industrial Symbiosis in an organization with probable solutions to them. ISM modeling and MICMAC analysis were used to visualize the impact of different barriers for implementing Industrial symbiosis in an organization and improve efficiency in terms of eco-innovation. The results of this study give experiences and rules to practicing managers in medium and small-scale industries to effectively execute Industrial Symbiosis. The study also adds to the improvement of a basic model for examining the barriers affecting IS with regards to eco-innovation and sustainable frameworks and contributes to ongoing researches on this eco-friendly idea of Industrial Symbiosis.

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KEYWORDS

Industrial Symbiosis,
ISM Modelling,
MICMAC Fuzzy
Analysis, Barriers, Eco-
innovation.

1. Introduction

Sustainable society is achievable through industrial ecological practices, smooth resource circulation through innovative collaborations by industries (Kawanaka *et al.*, 2019). Sustainability is improving living standards not only for current society but also for future generations (Fadhel *et al.*, 2020). Industrial Symbiosis (IS) is a union or partnership among organisations or industries where the waste product of one is used as a raw material for others. It helps to significantly reduce the waste disposal costs as well as raw material costs. This unique idea is one of the keys to reduce wastes and reduce pollution. In IS, the plants are located in such a way that they form a cluster or an eco-innovation park. This strategy helps in reducing transportation costs. In IS, the driving plants cooperate and develop a synergistic thing or an outcome, and organization trade-offs to accomplish a common forceful lead (Chertow, 2000). (Chertow *et al.*, 2008). Apart from the successful IS in Kalundborg, Denmark (Jacobsen, 2006) now this innovative concept is being adopted by many countries like China (Zhang *et al.*, 2010), Australia (Van Beers *et al.*, 2007), Sweden (Martin and Eklund, 2011) and South Korea (Behera *et al.*, 2012) by developing eco-industrial parks. There is a broad scope of research in this field for its practical implementations. This is a relatively new concept and still in its breeding stage, but if companies adopt this approach, they will be at a profit in both their long-term and short-term goals. Other advantages of getting involved in an IS network include exposure to management structure, decision-making methods, and technical knowledge of other industries (Zhu and Ruth, 2014). Because of the lack of knowledge, industries are not aware of the importance of IS and its benefits (Su *et al.*, 2013). As of late, because of the rapid mechanical development and poor asset administration, the utilization of natural assets has been high (Zhe *et al.*, 2016), IS gives a down to earth pathway to address and take care of this issue by shutting the energy and material stream circle (Dong *et al.*, 2013).

IS considers various attributes and forms that can affect the operational practices of a firm (Sakr *et al.*, 2011; Taddeo *et al.*, 2012). The numerous barriers and limitations towards implementing IS network still exists (Tudor *et al.*, 2007; Golev *et al.*, 2014) because of which a few analysts have suggested that the advantages of IS systems can be boosted by enhancement in its plan by utilizing numerical models. Thus, the suitable and effective implementation of IS makes it a debatable subject (Costa and Ferrao, 2010; Posch *et al.*, 2011). Simboli *et al.*, (2014) present that in IS, different firms and governments should try to support each other by compensating each other's losses and sharing profit. (Wu *et al.*, 2017) largely reflect various types of redundancies of IS network and how to establish reliability and stability in IS. (Leigh and Li, 2015) provided helpful insights to develop a cost effective and eco-friendly supply chain that works in such a way that waste from one industry reaches the other within such a time frame that it gets used effectively. Further, Puente *et al.*, (2015) explain the characteristics that improve to the highest chain when the waste from one industry or process becomes an income resource for other industries. Dong *et al.*, (2017) highlight the link among various industries, categorising distinct types of waste and presenting various methods so that they can be utilised efficiently. Bacudio *et al.*, (2016) analysed barriers to the implementation of IS through a quantitative approach. To anchor the upsides of IS, the models have been framed to recognize ideal systems expanding economic advantages (Ng *et al.*, 2014), decrease asset utilization (Aviso *et al.*, 2010a), and lessen carbon outflows (Ubando *et al.*, 2014; Yu *et al.*, 2015). The arrangement at that point recognizes the ideal item stream (Gonela and Zhang, 2014), also picks the most proper waste and asset administration choice (Vadenbo *et al.*, 2014), or then again chooses from the accessible energy to waste frameworks (Taskhiri *et al.*, 2014). In this aspect, the study aims to answer the following research questions (RQ).

RQ1: Which barriers have higher significance during the implementation of IS?

RQ2: What is the relationship between these barriers and how they influence each other?

The primary objective of this examination are -

- To prioritise the barriers towards the implementation of IS.
- To gives industries an overview of the barriers while implementing IS and identify their dependencies.

In this study, interpretive structural modelling (ISM) is utilized to model the barriers affecting the practical implementation of IS in industries. Thirty-three barriers are being distinguished from literature review and opinions of experts from the automotive industry in India. The methodological strides of ISM are being taken after to create a basic model that portrays the dominant barriers that merit consideration. MICMAC investigation has been led to classify the barriers. The result obtained from the study helps decision makers in small-scale industries understand more about the barriers and efficiently implement IS.

2.Literature review

Barriers in implementing industrial symbiosis were also analysed using different other techniques. Barriers in implementing IS in an industrial park are analyzed using Decision Making Trial and Evaluation Laboratory (DEMATEL) in (bacudio *et al.*, 2016). In this paper, a systematic design approach is followed for finding the interrelations of barriers. The final results reveal that the strategies must be directed towards the top management. The most correlated barrier of industrial symbiosis is found out as the lack of awareness about mechanism of Industrial Symbiosis. Drivers and barriers of effective industrial materials were analysed and studied by (Pajunen *et al.*, 2012). This paper focused on drivers and barriers for increasing material efficiency by using industrial by-products instead of raw material. The results suggested that the most important barriers for eco-friendly innovations seem to be the cost of investment and the high risk involved in committing capital to unproven technology. Following this, (Pajunen *et al.*, 2013) assessed the political barriers on industrial symbiosis products. The research perspective was both legal and policy instruments. They also identified numerous possible institutional barriers for using industrial residues. An innovative approach to use inter-industrial residues has been framed. Material and energy efficiency, life-cycle and systems thinking are identified as essential elements of this new approach to inter-industrial residues streams and presented using a by-product assessment procedure. Lu *et al.*, (2020) performed case study in china uncovering the benefits of Industrial symbiosis by targeting resource dependent cities. Mallawaarachchi *et al.*, (2020) discussed about the scientific development of industrial symbiosis and provided a lucid overview by performing bibliometric analysis. Patala *et al.*, (2020) discussed the importance of intermediaries to enhance and promote IS activities. Tao *et al.*, (2019) studied the influence of policies on Industrial symbiosis from the perspective of the implementing firm and suggested framework for efficient policy support.

The potential of Industrial Symbiosis and its main and barriers to its implementation is discussed by (neves *et al.*, 2019). This article compiled and analysed literatures according to several factors such as geographic location, type of economic activity, waste/by-products, main benefits, and the methods that focus on potential industrial symbiosis. The results suggested that the there is immense potential for industrial symbiosis throughout the world and especially in Europe. It also listed several key barriers for potential industrial symbiosis and has also given strategies for overcoming the barriers to the realisation of potential Industrial Symbiosis.

Interpretive structural modelling (ISM) is a well-established methodology for identifying relationships among specific items, which define a problem or an issue. This modelling method is used in several barrier analysis literatures. ISM approach is adopted in barrier analysis in implementing sustainable practices by (Raut *et al.*, 2018). In this paper, 14 critical barriers were identified, and the ISM tool was used to establish interrelationship among the identified barriers and to determine the key barriers having high driving power. After analyzing, it was found that six barriers were found to have high influencing power and thus developed model help managers of the organization in understanding importance of the barriers and eliminate them. Likewise, ISM and MICMAC approach combined have always been used in literatures to analyse barriers associated in an application. Barriers in promotion of sustainability through corporate social responsibility in manufacturing industry are discussed by (Bux *et al.*, 2020). The study has been carried out using the ISM-MICMAC approach. The results obtained through the application of ISM and MICMAC signify that the lack of resources, lack of regulations and standards, and lack of policy incentives are the critical barriers for CSR implementation in the manufacturing industry. The usage of ISM MICMAC is not limited to manufacturing sectors. It is widely used in many sectors. Barriers in healthcare services are analysed by (Kumar *et al.*, 2019). This paper focused on identifying the barriers in achieving the quality level in healthcare services. For that purpose, it used ISM and MICMAC for modeling and analysis purpose. The results suggested that most vital barriers are the staff training and the behavioural barriers that needs to be taken into account for an effective healthcare system.

Vinodh and Asokan (2018) discussed about application of ISM and MICMAC for analysis of Lean Six Sigma barriers. The most dominant barriers that affect Lean Six Sigma adoption with environmental considerations have been identified. Three barriers occupied the base segment of the ISM hierarchy and other five occupied the top level of the ISM hierarchy. This approach serve helpful for managers in removing the key dominant barriers and to enable LSS adoption with environmental considerations easily.

Despite a great deal of research starting at now finished on Modern beneficial interaction starting late, its useful plausibility is sketchy because of the prevailing obstructions. Because of the absence of arranging and upgrading modern advantageous interaction buildings, the development of eco-mechanical parks might be impacted by changes in the associations among the included organizations (Zhang *et al.*, 2014). Likewise, because of the absence of help from the larger amount of administration there is an absence of duty from top positions of administration to apply the idea of modern nature (Chiu and Yong 2004). There is an absence of information of mechanical advantageous interaction wordings and ideas because of the absence of devices to show conceivable partners (Gibbs and Deutz. 2005). The absence of physical and institutional grapples prompts the absence of minimum amount, data, political help, and framework to modern beneficial interaction (Sun *et al.*, 2017). The businesses have an absence of assets to put in innovations and encourage modern beneficial interaction (Chiu and Yong 2004). Mechanical plants do not wish to team up plants to frame union and to adjust to auxiliary changes (Stop *et al.*, 2008). Actualizing modern advantageous interaction requires profound established specialized and hierarchical information which is inadequate with regards to (Dividers and Paquin 2015).

Inspiration between social performing artists is a must to empower modern advantageous interaction effectively at basic levels (URSKA FRIC 2015). There is an absence of new inventive thoughts and methodologies for business tasks, which frustrate mechanical advantageous interaction (URSKA FRIC 2015). Absence of adaptability among the businesses, i.e., their powerlessness to react to sudden changes because of inside and outer elements (URSKA FRIC 2015). Weight from various NGO's, open and natural bodies is not overwhelming to apply mechanical advantageous interaction, i.e., more mindfulness is required. (Rangaswami *et al.*, 2013). Geographic closeness expects a noteworthy activity in constraining costs and impacts of transport and upgrading trust and interest among firms and empowering material exchanges (Tseng and Bui, 2016). The absence of an outsider business framework makes it troublesome for enterprises to build up a system for mechanical beneficial interaction (Tseng and Bui, 2016). After dismantling, there can be some division of parts for reusing, this isn't viewed as per (Chertow *et al.*, 2016). The interest for the items fluctuate which make it hard to produce benefit constantly (Dong *et al.*, 2010). Transportation cost to exchange waste and materials from one industry to other is significantly high (Mutha and Pokharel, 2009). Absence of capacity to prepare individuals in regard to modern beneficial interaction and economical store network (Ashton 2011; Li *et al.*, 2015). Higher experts are insensible towards benevolent strategies (Govindan *et al.*, 2014a, 2014b).

3. Methodology

3.1 ISM- based model

ISM is an interactive learning process, consisting of a collection of directly and indirectly organized objects ordered in a systematic way. A myriad of factors might be involved in a complicated problem. The understanding of situation or problem obtained from the direct and indirect connections between these factors is greater than the understanding of situation obtained from a single factor. Therefore, the combined understanding of these relationships and discernments are developed through ISM.

The examination was finished utilizing the Interpretative Basic Displaying (ISM), which is utilized to distinguish and abridge the obstructions and their interrelations, primary destinations of ISM are:

- To recognize and rank the factors.
- To build up an interrelationship among the factors.
- To talk about the administrative ramifications of the examination.

ISM is a famous and a demonstrated system for breaking down connections among factors that characterize an issue. ISM is ground-breaking apparatus to accomplish the target when a substantial number of factors are available which might be specifically identified with one another. In such a sort of circumstance, ISM assumes an exceptionally essential job to understand the structure inside the framework. The ISM demonstrates limits down the complex structure inside an issue into a pattern. ISM has been in successive use in the past by numerous scientists because of

its various advantages. It helps and records the results of social occasion response on complex issues in a capable and considerate way (Attri *et al.*, 2013; Ali and Dubey, 2014; Sushil, 2012, 2009, 2005a, 2005b; Warfield, 1999; Warfield, 1994, 1974). Figure 1 shows the step involved in this study using ISM.

Figure 1. Methodology adopted in this study using ISM

ISM offers various advantages such as, the process is computerized where the algorithm considers all the relations, efficient process by the use of transitivity principle, minimum knowledge of underlying process is required and provides graphical representation of the problem. However, there are limitations or drawbacks to this methodology. The person who is deciding the factors might have prejudice i.e., they might choose or prefer one factor over the another. Thus, the connection established between these factors will be extremely depended on the person's awareness and understanding. The end model will be affected by this prejudice. Adding to this, factors have no weights associated to them. Thus, the chosen factors have no ranking or relative importance.

3.2 Barriers identified

Barriers identified from the literature are organized in the given Table 1. The barriers are picked from the perspective of the usage of modern advantageous interaction in ventures. Table 1 gives 33 distinct barriers picked through the exhaustive investigation of applicable works of writing, eco-advancement, and modern advantageous interaction are deciding variables of these hindrances. These barriers are identified with the help of industrial experts who are major stakeholders in their respective company with extended period of experience (minimum 10 years). Depiction of every boundary is given in Table 1.

Table 1. Barriers identified through literature review

Sl. No.	Barriers	Description	Relevant literature
B1	Lack of planning and redesigning industrial symbiosis complexes.	The growth of eco-industrial parks may be influenced by changes in the connections among the involved companies. This makes the IS complexes susceptible to change requiring flexible IS complexes	Zhang et al (2014)
B2	Lack of support from the higher level of management	There is an absence of duty from best positions of administration to apply the idea of mechanical environment. Appropriate steps from higher level of management to implement IS increases it chances of getting adopted.	Chiu and Yong (2004)
B3	Absence of knowledge	There is an absence of information of mechanical advantageous interaction wordings and ideas because of the absence of instruments to show conceivable partners. Absence of numerous pre-existing IS complexes for others to rely on if uncertainty arises	Gibbs and Deutz (2005)
B4	Absence of will for collaboration	Absence of eagerness and reaction by mechanical plants to frame partnership and to adjust to auxiliary changes. Coopetition involve investing significant amount of time and capital, which makes it inconvenient	Park et al (2008)
B5	Lack of technology	Lack of latest technologies in the industries prevents sustainable by-product exchange and construction of far reaching mechanical advantageous interactions.	Jacqueline et al (2015)
B6	Lack of funds	There is a lack of funds for industries to install new technologies and facilitate industrial symbiosis and also investment from an individual company will not lead to sustainable Industrial Symbiosis	Anthony and Yong. (2004)
B7	Lack of physical and institutional anchors	Physical anchors provide critical mass while institutional anchors provide information, political support, and infrastructure to industrial symbiosis. Instituting these anchors involves a large amount of coordinated efforts between conceivable partners and time.	Sun et al (2017)
B8	Lack of incentive from the government	Lack of efforts from the government to promote industrial symbiosis by regulating the taxes and introducing policies to encourage industrial symbiosis.	Boons et al (2011)

Sl. No.	Barriers	Description	Relevant literature
		There are no prevailing efforts from government to promote IS.	
B9	Lack of training	Implementing industrial symbiosis requires deep rooted technical and organizational knowledge which is lacking and since IS is relatively new method, least importance is given to provide proper training.	Judith and Paquin (2015)
B10	Lack of motivation between social actors	Motivation between social actors is must to enable industrial symbiosis successfully at primary levels. Lack of effort from these individuals who exercise agency as opposed to constraining social structures offsets the plausible situation.	URŠKA FRIC (2015)
B11	Lack of inter-organizational flexibility	Lack of flexibility among the industries, i.e. their inability to respond to sudden changes due to internal and external factors. Setting up an separate unit for IS is also seeming unfeasible without the involvement of government	URŠKA FRIC (2015)
B12	Lack of new ideas	There is a lack of new innovative ideas and approaches for business operations which hinders industrial symbiosis. Wanting of pressure from social influencers prevents the industries from pushing innovation for better business operations.	URŠKA FRIC (2015)
B13	Lack of eco industrial parks	Due to the high cost of setting up an eco-industrial park, industrial unit of different categories are scattered. Absence of cooperation between industries also acts an important factor that prevents the establishment of parks	Antonina et al (2016)
B14	Absence of pressure from the masses	Pressure from different NGO's, public and environmental bodies are not heavy to apply industrial symbiosis more awareness is needed. Focus of NGO's on issues that directly influence the environment rather than indirect and chain factors reduces the reach of these niche concepts	Ram et al (2013)
B15	Lack of reverse logistics practices.	Lack of reverse logistics practices which means the reuse of waste materials. High capital, lack of comprehension on rationale of returns and insufficient labour pose a challenge to implement reverse logistic practices.	Joseph et al (2010)

Sl. No.	Barriers	Description	Relevant literature
B16	Different short- and long-term goals	Misalignment of the short-term goals for the instant gains shatters the very idea of the long-term goals. Absence of attention to adjust short and long-haul objectives.	Jack et al (2010)
B17	Unpredictable return flow of materials	Lack of steady return flow of materials to keep the production rate constant. This uncertainty makes it difficult for the other industries that are in symbiosis with the raw-material proving company to establish a proper supply chain.	Rizos et al (2016)
B18	Lack of support from the supplier	Constant supply of fixed quantity of material is challenging for the supplier. Industrial symbiosis relies on suppliers (other industries) for raw materials but due to lack of support it is very inconsistent.	Rizos et al (2016)
B19	Lack of involvement of industries	Due to risks and competitions, industries are reluctant to involve in innovative ideas and a circular economy.	Rizos et al (2016)
B20	Lack of research	Lack of research and innovation to produce green products at relatively cheaper price. Absence of coercion from government and impetus prevents the industries from researching new boundaries for the greater good.	Teh et al (2014)
B21	Lesser demand of green products	Because of the absence of mindfulness, the interest for green items is low; a higher interest will urge ventures to rehearse squander reusing and gain benefits.	Teh et al (2014)
B22	Distance between collaborating industries	Due to lack of clustering of industries, IS is less viable due to higher transportation costs. Presence Eco industrial parks will help offset this barrier but construction of one requires overcoming several inter-related barriers which makes it even difficult	Teh et al (2014)
B23	Lack of unified policies	Higher authorities are ignorant towards friendly policies.	Moktadir et al (2018)
B24	Lack of institutions to train personnel	Lack of ability to train people in respect to industrial symbiosis and sustainable supply chain. Since, IS is relatively nascent there is no established institution to bring forth experts in IS	Govindan et al (2015)
B25	Improper management	Absence of an institutional help for reconciliation, coordination and correspondence.	Rizos et al (2015)

Sl. No.	Barriers	Description	Relevant literature
B26	Long legal procedures	Entangled frameworks and long methods that ventures face to get accreditations, and additionally to meet norms and legitimate commitments.	Ashton. (2011)
B27	High transportation cost	Transportation cost to transfer waste and materials from one industry to other is relatively high compared to the nominal transportation cost. Adding the uncertainty of input materials further increases the transportation costs.	Baina et al (2010)
B28	Varying demands for products	Supplier can't predict or adjust to the demands as the return material itself is highly unstable. The demand for the products varies which make it difficult to generate profit all the time.	Mutha et al (2009)
B29	Different product recovery options are not considered	The lack of sustainable recovery options to recover the waste generated. Lack of pressure from masses do encourage companies to overlook sustainability.	Lee et al (2010)
B30	Recycling is not considered	After disassembly there can be some fraction of parts for recycling, this is not considered.	Paksoy et al (2012)
B31	Lack of transparency to develop industrial symbiosis	Lack of a third-party brokerage system or government agency makes it difficult for industries to develop a network for industrial symbiosis.	Boons et al (2016)
B32	Geographical barriers	Geographic vicinity assumes a key job in limiting expenses and effects of transport.	Tseng et al (2016)
B33	Lack of sharing waste treatment installations	The enterprises and types of waste products that are processed or reused in their own facilities.	Tseng et al (2016)

3.3 Building up the Structural Self-Interaction Matrix (SSIM)

After the obstructions are distinguished through the writing survey, a logical relationship is formed between the boundaries as for the sets of the hindrances. The connections among the boundaries were analysed through the reactions recorded through a poll, the poll was sent to the business specialists and later tried for the legitimacy of substance. The reactions were recorded and broke down for the development of a basic structural self-interaction matrix (SSIM). For creating structural self-interaction matrix (SSIM) in Table 2, the given symbols have been used to imply the course of associations between elements (i and j):

- V: i prompt j however j does not prompt i.
- A: i don't prompt j yet j prompt i.
- X: j prompt i and i prompt j.
- O: j and i are irrelevant to one another.

3.4 Building the reachability matrix

The SSIM has been changed over into a twofold system, i.e., the reachability network (Table 3) by substituting V, A, X and O by 1 and 0. The substitutions of '1' and '0' is done as given below:

- In the event that the (i, j) passage in the SSIM is V, at that point the (i,j) section in the reachability grid moves toward becoming '1' and (j,i) passage progresses toward becoming '0'.
- In the event that the (i, j) passage in the SSIM is A, at that point the (i,j) section in the reachability grid moves toward becoming '0' and (j,i) passage progresses toward becoming '1'.
- In the event that the (i, j) passage in the SSIM is X, at that point the (i,j) section in the reachability grid moves toward becoming '1' and (j,i) passage likewise moves toward becoming '1'.
- In the event that the (i, j) passage in the SSIM is O, at that point the (i,j) section in the reachability lattice moves toward becoming '0' and (j,i) passage likewise progresses toward becoming '0'.

3.5 Transitivity principle

After the underlying reachability framework is inferred, the idea of transitivity is presented with the goal that a portion of the cells of the underlying reachability lattice are filled by surmising. Transitivity can be clarified with the accompanying precedent if component 'i' identifies with component 'j' and component 'j' identifies with component 'k', at that point transitivity infers component 'i' identifies with component 'k'. It helps in keeping up the theoretical consistency. The last reachability grid will then comprise of a few sections from the match insightful examinations and some deduced passages. The transitivity idea is utilized to fill the hole assuming any.

Transitivity is the essential suspicion in ISM and is constantly utilized in this demonstrating approach (Watson, 1978; Sharma *et al.*, 1995; Sushil, 2005a, 2005b). Following the above guidelines, the underlying reachability grid is readied. In the wake of consolidating the transitivity idea as depicted over, the last reachability grid is gotten in Table 4.

3.6 Level Partitioning

From the last reachability matrix in Table 4, the reachability set and the antecedent set for each barrier chosen is found. The reachability set includes the barrier itself and others which the barrier might help to achieve (barrier B1 helps in the overcoming barriers B1, B4, B10, B11, B14, B17, B19, B25, B27, B33) The antecedent set comprises of the barrier itself and other barriers which help in achieving it (barriers B1, B5, B7, B10, B11, B16, B18, B19, B23, B24, B25, B26, B27, B29, B30, B32 helps in overcoming barrier B1). After this, the intersection set is obtained for all the barriers. The last reachability framework acquired in Table 4 is divided into various levels. After the main emphasis, the variable ordered to level 1 are disposed of and the parcelling method is rehashed on the staying variable to decide the level 2. These cycles are proceeded until the point that the level of every factor has been resolved. The outcomes for cycles 1 to 8 are outlined in Table 5.

3.7 Digraph

From the final reachability matrix and levelling of barriers, the fundamental model is made by techniques for centres and lines of edges. In case there is an association between the barriers j and i, this is showed up by an arrow which demonstrates from i to j. The derived ISM model is represented in Figure 2 also known as digraph or directed graph.

Table 2. Structural self-interaction matrix

	B 32	B 31	B 30	B 29	B 28	B 27	B 26	B 25	B 24	B 23	B 22	B 21	B 20	B 19	B 18	B 17	B 16	B 15	B 14	B 13	B 12	B 11	B 10	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1
B1	V	A	O	A	A	O	V	A	V	A	A	O	O	O	V	A	V	A	O	V	O	O	V	V	O	O	A	O	A	V	O	O
B2	O	O	A	A	V	V	A	A	A	O	A	O	O	O	A	O	O	V	A	V	V	V	A	A	O	A	O	V	V	V	A	
B3	A	V	A	A	A	O	O	V	A	A	V	O	O	V	V	V	V	O	O	V	O	O	A	A	A	A	V	A	A	O		
B4	O	O	A	A	A	A	O	A	O	O	V	O	V	A	A	V	V	V	V	O	O	O	A	O	A	V	O	A	V			
B5	V	V	A	V	V	O	V	V	A	O	A	V	V	V	A	A	V	O	A	V	V	O	V	O	V	A	A	V				
B6	V	A	V	V	V	V	A	V	V	O	V	A	V	A	O	O	A	V	O	A	V	A	A	V	A	A	O					
B7	V	O	O	A	V	O	O	A	V	O	O	O	A	A	A	O	V	V	V	A	O	V	A	O	V	V						
B8	A	A	O	V	O	A	V	A	A	A	A	V	V	A	V	A	O	O	A	V	V	V	V	V	V	V						
B9	O	V	A	O	O	O	O	A	O	V	O	O	A	O	O	V	V	O	A	A	O	V	A	O								
B10	A	A	O	A	V	A	V	V	A	V	A	V	O	O	V	O	V	A	A	A	V	O	O									
B11	V	O	A	V	O	V	A	V	O	O	A	O	O	O	O	A	O	A	A	O	O	O										
B12	A	V	O	A	A	O	A	O	A	V	A	A	O	V	V	A	A	O	A	O	V											
B13	A	A	O	V	V	V	O	A	O	V	A	O	O	O	O	A	A	O	A	O												
B14	A	O	O	O	A	V	A	V	V	A	V	O	A	A	O	A	V	V	A													
B15	A	A	V	V	A	O	V	A	A	O	A	O	O	O	O	V	O	A														
B16	V	V	V	V	V	A	O	O	O	O	O	O	O	O	V	V	V															
B17	V	A	A	A	A	O	A	A	A	V	V	V	A	O	O																	
B18	V	O	V	O	O	V	O	V	V	A	V	A	V	A	A																	
B19	O	O	V	O	V	O	O	A	A	O	V	V	V	A																		
B20	A	V	V	O	A	A	O	O	A	O	O	V	A																			
B21	V	O	O	O	A	V	O	O	O	O	A	V																				
B22	O	A	O	V	V	O	A	V	O	V	A																					
B23	V	V	V	A	A	V	A	O	A	V																						
B24	V	V	A	O	O	A	V	V	A																							
B25	O	A	V	V	V	A	A	A																								
B26	O	A	A	A	V	V	A																									
B27	O	O	O	A	A	A																										
B28	O	V	V	O	A																											
B29	O	V	A	V																												
B30	A	O	V																													
B31	A	A																														
B32	V																															
B33																																

Table 3. Initial Reachability Matrix

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 2 0	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)	
B 1	1	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1 0
B 2	0	1	0	1	1	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1 0
B 3	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1 1
B 4	0	0	1	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1 0
B 5	1	0	0	0	1	1	0	0	1	0	1	0	1	1	0	0	1	0	0	1	1	1	0	0	0	1	1	0	1	1	0	1	1	1	6
B 6	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	1	1	1	0	1	1	1	1	0	1	1 4
B 7	1	0	0	0	1	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0	1	0	1	0	1	1	1	0	1	1	1	1	0	1	1 6
B 8	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	1 7
B 9	0	0	1	1	0	1	1	0	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1 0
B 10	0	1	1	0	0	0	0	0	0	1	0	1	0	1	1	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1 1
B 11	0	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1 2	
B 12	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	8
B 13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	5	

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 2 0	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)			
B 1 4 B 1 5 B 1 6 B 1 7 B 1 8 B 1 9 B 2 0 B 2 1 B 2 2 B 2 3 B 2 4 B 2 5	0	0	0	0	0	1	1	0	1	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	
	0	1	0	0	1	0	0	1	1	0	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	3	
	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	3	
	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	7	
	1	0	0	0	1	0	0	1	0	0	1	1	1	1	0	0	0	1	0	0	1	0	1	0	1	0	1	1	0	1	0	0	1	0	1	1	5
	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0	1	0	1	0	0	1	0	
	0	0	0	1	0	1	1	1	0	0	0	0	0	1	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2
	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	7	
	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	1	0	0	1	1	0	0	0	0	0	1	0
	1	1	0	0	1	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	1	6
	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1	1	1
	0	1	1	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	1	1	0	0	1	1	1	0	0	0	1	1	1	1	0	0	1	5	

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 2 0	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)	
B 2 6 B 2 7 B 2 8 B 2 9 B 3 0 B 3 1 B 3 2 B 3 3 (B)	1	1	0	1	0	0	0	1	1	1	0	0	1	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	1 4
	0	1	0	0	0	1	1	0	0	0	1	1	0	1	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	1 2
	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	1	1	0	0	1	1	0	0	1 0
	1	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	1	1	0	1	0	0	0	0	1	1	1	1	0	1	0	1 5
	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0	1	1	0	0	0	1 1
	0	1	1	1	1	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1 2
	1	0	0	0	0	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1 3
	0	0	1	0	0	0	0	1	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1 0
	1 1	1 3	1 2	1 2	1 1	1 3	1 1	1 2	9	8	1 0	1 5	1 4	1 5	1 1	7	1 9	1 1	9	1 0	1 1	1 0	1 3	1 0	1 0	1 4	9	1 2	1 2	1 3	1 4	1 2	1 3	1 3	

Table 4. Final Reachability Matrix

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 2 0	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)	
B 1	1	0	0	1	1 *	0	1 *	0	0	1	1	0	0	1	0	1 *	1	1 *	1	0	0	0	1 *	1 *	1	1 *	1	0	1 *	1 *	0	1 *	0	0	2 0

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 2 0	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)	
B 2	0	1	0	1	1	1	0	0	0	1*	0	1	1	1	1*	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1*	0	0	1 3
B 3	0	1	1	1*	1*	0	1	1*	1*	1*	1*	0	0	1	0	0	1	1	1	1	0	0	1	1*	1*	1	0	0	1*	1*	1*	1	1*	2 3	
B 4	0	1*	1	1	1	0	1*	1	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1*	0	0	1 3
B 5	1	1*	1*	1*	1	1	1*	1*	1	0	1	0	1	1	1*	1*	1	1*	0	1	1	1	1*	0	0	1	1	0	1	1	1*	1	1	2 7	
B 6	0	1*	0	1	0	1	1*	0	0	1	0	0	1	0	0	1	0	0	0	0	1	1*	1	1*	1	1	0	1	1	1	1	1*	1	1	1 9
B 7	1	0	0	1*	1	1*	1	0	1*	1	1*	0	1	0	0	1	1	0	0	1*	1	1*	1	1*	1	1	1*	1	1	1	1	1*	1	1	2 5
B 8	0	1	1	1*	1	1	1	1	1	1	1	1	1	1	1*	1*	0	1*	1	0	1	1	0	0	1*	0	0	1	1*	0	1	0	1*	1*	2 5
B 9	0	0	1	1	0	1	1	0	1	0	0	1	0	0	1*	0	1	1	0	0	1*	0	0	0	1	0	0	0	0	0	0	1*	1	0	1 3
B 10	0	1	1	0	0	1*	1*	1*	0	1	1*	1	0	1	1	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1*	1	0	1 7
B 11	0	1	1	1	1*	1	1	1*	1	1	1	0	0	0	1*	0	0	1*	0	0	0	0	0	1*	1*	0	1	1*	1	0	1	1*	1*	1	2 3
B 12	0	1*	0	0	0	1	1	0	0	1*	0	1	1	0	1*	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1 1
B 13	0	0	0	0	0	0	1*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	6
B 14	0	1*	0	0	0	1	1	0	1	1*	0	0	0	1	1*	1	1	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	1 3
B 15	0	1	0	1*	1	0	0	1	1	1*	1	1	1	1	1	1*	0	1	0	0	0	0	1*	1*	1*	1*	0	1	0	1*	1	1	1*	1*	2 3
B 16	1	1*	0	0	1*	1*	1*	1*	1*	0	1	1*	1*	1*	1	1	1	1	1	1	0	0	0	0	0	0	0	1*	0	1	1	1	1	1	2 3

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)	
B 1 7	0	0	0	0	0	1	1*	0	1*	1*	0	1	1	0	0	1	0	0	0	0	1	1	1	0	0	1*	0	0	0	1*	0	1	1	2
B 1 8	1	0	1*	1*	1	1*	0	1	1*	1*	1	1	1	1	1*	1*	1*	1	1*	0	1	1*	1	1*	1	1	0	1	0	0	1	0	1	2 6
B 1 9	1*	1	0	1	1	0	0	0	0	0	0	0	0	0	1*	0	1	1	1*	1	1	1	1	0	1*	0	0	0	1	0	1	0	0	1 4
B 2 0	0	0	0	1	0	1	1	1	0	0	0	0	0	1	0	0	1	1	1	1	1*	1	0	0	0	0	0	0	0	0	1	1	1*	1 4
B 2 1	0	0	0	0	0	1*	1*	0	1	1*	0	0	0	1	0	0	0	1*	1	1	1	0	0	0	0	0	0	1	0	0	0	0	1	1
B 2 2	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	1*	0	1*	1	0	1	0	1	1*	0	1	1	0	0	0	0	1 3
B 2 3	1	1	0	0	1	1*	1*	1	0	0	1	1	1	0	1	0	0	1*	1*	0	1	1	1	1	0	1*	1*	1	1*	1*	1	1	1	2 4
B 2 4	1	1*	1	0	1*	1*	0	1	0	0	1*	1*	1*	1	1*	0	1	1	0	0	1*	1*	1*	1	0	1	1	0	1*	1*	1*	1	1	2 5
B 2 5	1*	1	1	0	1	1*	0	1	0	0	0	1	0	0	1	0	1	0	1	1	0	0	1	1	1	0	1*	1*	1	1	1	0	0	1 9
B 2 6	1	1	1*	1	1*	1*	0	1	1	1	1*	1*	1	1	0	1	1*	1	1*	0	1*	1*	1	1	0	1	1	1*	1*	1*	1*	0	2 8	
B 2 7	1*	1	0	0	0	1	1	0	0	0	1	1	0	1	1*	0	1	0	0	0	0	1	1	0	1	1	1*	0	0	0	0	0	0	1 5
B 2 8	0	0	0	1	0	0	0	1	0	0	0	0	1*	0	1*	1	0	0	0	1	0	0	0	1	1	0	1	1	0	0	1	1	0	1 2

	B 3 1	B 3 0	B 2 9	B 2 8	B 2 7	B 2 6	B 2 5	B 2 4	B 2 3	B 2 2	B 2 1	B 2 0	B 1 9	B 1 8	B 1 7	B 1 6	B 1 5	B 1 4	B 1 3	B 1 2	B 1 1	B 1 0	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1	B 0	B 1	(A)	
B 2 9	1	0	1	1	0	0	0	1 *	0	0	0	1	1 *	1	1	1 *	1	0	0	1	1	0	1	1 *	1 *	0	1	1	1	1	0	1	0	2 0	
B 3 0	1	1	1	1	0	0	0	1 *	0	0	0	1	1 *	1 *	1 *	1 *	1	0	0	1 *	1 *	0	1	1 *	1 *	1	1	1 *	1 *	1	1	0	0	2 2	
B 3 1	0	1	1	1	1	1 *	0	0	1	1	1	0	0	0	1 *	1 *	1	1 *	1 *	0	0	0	0	1	1 *	1	0	1 *	1	0	1	0	1 *	2 0	
B 3 2	1	1 *	1 *	1 *	1 *	1	1	1	1 *	1 *	1 *	0	1	0	1	0	1	0	0	0	0	1	0	1 *	1	1	0	1 *	1 *	1 *	1	1	1	2 4	
B 3 3	0	0	1	0	0	1 *	0	1	0	0	0	1	1	1	1	0	0	0	0	1	1 *	0	0	0	0	0	0	0	0	0	1	1	0	1	1 2
(B)	1 6	2 1	1 6	2 0	1 8	2 4	2 2	1 9	1 5	1 7	1 6	1 9	1 9	1 8	2 4	1 7	2 0	1 4	1 4	1 5	1 7	1 6	1 9	2 1	1 7	1 6	1 7	1 9	1 9	1 9	2 4	1 8	1 8		

Table 5. Ranking of barriers

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
B1	1,4,10,11,14,17,19,25,27,33	1,5,7,10,11,16,18,19,23,24,25,26,27,29,30,32	1,10,11,19,25,27	V
B2	2,4,5,6,12,13,14,16,28,29	2,3,4,5,6,8,10,11,12,14,15,16,19,23,24,25,26,27,30,31,32	2,4,5,6,12,14,16	II
B3	2,3,7,14,17,18,19,20,23,26,32	3,4,5,8,9,10,11,18,24,25,26,29,30,31,32,33	3,18,24,26,32	VII
B4	3,4,5,8,15,16,17,18,21,23	1,2,3,4,5,6,7,8,9,11,15,18,19,20,26,28,29,30,31,32	3,4,5,8,15,18	V

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
B5	1,3,4,5,6,8,9,11,13,14,15,16,17,18,20,21,22,23,26,27,29,30,32,33	1,2,3,4,5,7,8,11,15,16,18,19,23,24,25,26,31,32	1,3,4,5,8,11,15,16,18,23,26,32	VI
B6	6,10,13,16,21,23,25,26,28,29,30,31,33	2,5,6,7,8,9,10,11,12,14,16,17,18,20,21,22,23,24,25,26,27,31,32,33	6,10,16,21,23,25,26,31,33	II
B7	3,7,8,9,11,12,14,20,22,23,24,27,32	1,3,4,5,6,7,8,9,10,11,12,13,14,16,17,20,21,22,23,26,27,32	3,7,8,11,23,27,32	V
B8	2,3,5,6,7,8,9,10,11,12,13,14,19,21,22,17,30	3,4,5,8,10,11,15,16,18,20,23,24,25,26,28,29,30,32,33	3,5,8,10,11,30	VII
B9	3,4,6,7,9,12,17,18,24,32	3,5,7,8,9,11,14,15,16,17,18,21,26,31,32	3,7,9,17,18,32	IV
B10	2,3,10,12,14,15,17,18,21,24,32	1,2,3,6,7,8,10,11,12,14,15,17,18,21,26,31,32	2,3,10,12,14,15,17,18,21,32	II
B11	2,3,4,6,7,9,10,11,26,28,30,33	1,3,5,7,8,10,11,15,16,18,23,24,26,27,31,32	3,7,10,11,26	IV
B12	6,7,12,13,19,20,24,32	2,7,8,9,10,12,15,16,17,18,19,22,23,24,25,26,27,29,30,33	7,12,19,24	VI
B13	13,24,28,29,30	2,5,6,7,8,12,13,15,16,17,18,23,24,26,28,29,30,32,33	13,24,28,29,30	I
B14	6,7,9,14,16,17,23,25,26,28	1,2,3,5,8,10,14,15,16,18,20,21,24,26,27,29,30,33	14,16,26	VII
B15	2,5,8,9,11,12,13,14,15,18,27,30,31	2,4,5,8,9,10,11,12,14,15,16,18,22,23,24,25,26,27,28,29,30,31,32,33	2,5,8,9,11,12,24,14,15,18,27,29,30,31	II
B16	1,2,5,8,9,11,12,13,14,15,16,17,18,19,20,27,29,30,31,32,33	1,2,4,5,6,7,8,11,14,15,16,18,19,28,29,30,31	1,2,5,8,11,14,15,16,18,19,29,30,31	VI
B17	6,12,13,17,22,23,33	1,3,4,5,7,9,10,14,16,17,18,20,24,25,26,27,29,30,31,32	17	IV
B18	1,5,6,8,11,12,13,14,17,18,21,22,23,25,26,28,31,33	1,3,4,5,8,9,10,11,15,16,18,19,20,22,23,24,25,26,31	1,5,8,11,18,20,22,23,25,26,31	V
B19	2,4,5,18,19,21,22,23,29,31	1,3,8,12,16,18,19,20,21,22,23,25,26,31	18,19,21,22,23,31	III
B20	4,6,7,8,14,17,18,19,20,22,31,32	3,5,7,12,16,18,19,20,21,25,26,28,29,30,33	7,18,19,20	VI
B21	9,14,20,21,22,28,33	4,5,6,7,8,9,10,18,19,20,21,22,23,24,29,30,33	9,20,21,22,33	III
B22	6,7,12,15,18,22,24,26,29,30	5,6,7,8,15,17,18,19,20,21,22,23,24,26,27,32	6,7,15,18,22,24,26	IV
B23	1,2,5,6,7,8,11,12,13,15,18,21,22,23,24,26,28,29,30,31,32,33	1,3,4,5,6,7,11,14,15,17,18,19,23,24,25,26,27,29,30	1,5,6,7,11,15,18,23,24,26,29,30	VI

Barrier no.	Reachability set	Antecedent set	Intersection set	Level
B24	1,2,3,5,6,7,8,11,12,13,14,15,17,18,21,22,23,24,26,27,28,29,30,31,32,33	1,3,6,7,9,10,11,12,13,15,18,22,23,24,25,26,28,29,30,31,32	1,3,6,7,11,12,13,15,18,22,23,24,26,28,29,30,31,32	VI
B25	2,3,5,8,12,15,17,19,20,23,24,25,29,30,31	1,3,6,7,8,14,15,18,19,25,26,27,28,29,30,31,32	3,8,15,19,25,29,30,31	V
B26	1,2,3,4,5,8,9,10,12,13,15,17,19,20,23,24,25,26,28,29,30,31	1,3,5,6,7,11,14,18,22,23,24,26,27,30,31,32	1,3,5,23,24,26,30,31	VIII
B27	2,6,7,11,12,14,17,22,23,25,26,27	1,5,7,8,11,15,16,17,22,23,24,25,26,27,28,29,30	7,11,17,22,23,25,26,27	III
B28	4,8,16,20,24,25,27,28,31,32	2,6,7,8,11,13,14,18,21,23,24,25,26,27,28,29,30,31,32	8,24,25,27,28,31,32	V
B29	1,3,4,8,12,14,15,16,17,20,21,23,24,25,27,28,29,30,32	1,2,3,5,6,7,13,15,16,19,22,23,24,25,26,29,30,31,32	1,3,15,16,23,24,25,29,30,32	VI
B30	1,2,3,4,8,12,14,15,16,17,20,21,23,24,25,26,27,28,29,30,31,32	1,3,5,6,7,8,11,13,15,16,22,23,24,25,26,29,30,32,33	1,3,8,15,16,23,24,25,26,29,30	VII
B31	2,3,4,5,9,10,11,17,24,26,29,31	2,3,4,5,6,7,9,10,11,15,16,17,18,19,20,23,24,25,26,28,30,31,32,33	2,3,4,5,9,10,11,17,24,26,31	II
B32	1,2,3,4,5,6,7,8,9,10,11,13,15,17,22,24,25,28,29,31,32,33	1,3,5,6,7,8,9,10,11,12,15,16,20,23,24,28,29,32	1,3,5,6,7,8,9,10,11,15,24,26,29,32	VI
B33	3,8,12,13,14,15,20,30,31,33	1,3,5,6,7,8,11,15,16,17,18,20,21,23,24,31,32,33	3,8,15,20,31,33	III

Figure 2. Digraph

4.6. MICMAC Analysis

Matriced'Impacts croises-multiplication appliqué and clasment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. The motive of employing MICMAC is to gauge the dependence and driving power(s) of the identified barrier. This examination is utilized to segregate the chosen barriers and aggregate them into four categories, namely: driving factors, dependence factors, autonomous factors and linkage factors. Table 6 shows final reachability matrix obtained. In MICMAC, factors are classified in four quadrants as given below in Figure 3.

Table 6. Position coordinates of distinguished factors

Variables	Dependence Power (A)	Driving Power (B)
1	16	20
2	21	13
3	16	23
4	20	13
5	18	27
6	24	19
7	22	25
8	19	25
9	15	13
10	17	17
11	16	23
12	19	11
13	19	6
14	18	13
15	24	23
16	17	23
17	20	12
18	14	26
19	14	14
20	15	14
21	17	11
22	16	13
23	19	24
24	21	25
25	17	19
26	16	28
27	17	15
28	19	12
29	19	20
30	19	22
31	24	20
32	18	24
33	18	12

Figure 3. Dependence and driving power diagram

5 Results and discussions

The main objective of this research is to prioritise the barriers towards the implementation of IS by establishing interdependencies among the barriers and to give industries an overview of the barriers while implementing IS by analysing the driving and dependencies of these barriers. In order to achieve these objectives, ISM – based model and MICMAC analysis is utilized. The established dependencies between these barriers helps the management to make better decisions. All the below mentioned observations are obtained from Dependence and driving power diagram, Figure 3.

The barrier in the quadrant I is called autonomous barriers and these factors have a feeble drive control and frail reliance control. In this quadrant, we have three factors like lack of training (B9), lack of involvement of industries (B19), and lack of research (B20). These barriers are less important since they do not have high driving and reliance control. Lack of training leads to unfamiliarity with industrial symbiosis concepts in several aspects such as technical and organizational expertise. Bacudioa et al (2016) categorized The results of this study differs with the findings for Bacudioa et al (2016) as lack of training was categorized as an effect barrier in a study conducted in industrial park in the Philippines. Similarly, the lack of innovation is regarded as an effect of lack of commitment from top management.

Quadrant 2: Dependence factors - These factors have a frail drive control, however solid reliance control. In this quadrant, we have 11 factors which are, lack of sharing waste treatment installations (B33), varying demands for products (B28), high transportation cost (B27), distance between collaborating industries (B22), lesser demand of green products (B21), unpredictable return flow of materials (B17), absence of pressure from the masses (B14), lack of eco-industrial parks (B13), lack of new ideas (B12), absence of will for collaboration (B4) and lack of support from the higher level of management (B2). In earlier studies, the absence of will for collaboration is seen as an effect barrier as similar to the finding of this study. The higher distance between collaborating industries highly influences higher transportation cost. On the other hand, the Kosmol and Otto (2020) identified lack of demand for green products as an important market

related barrier. These solid reliance control indicates that, these barriers need all the other barriers to come together in order to increase their effect on successful implementation of IS i.e., their success is highly dependent on the success of the other barriers.

Quadrant 3: Linkage factors - These factors have a solid drive control and additionally solid reliance control. In this quadrant, we have 18 factors which are geographical barriers (B32), lack of transparency to develop IS (B31), recycling is not considered (B30), different product recovery options are not considered (B29), long legal procedures (B26), improper management (B25), lack of institutions to train personnel (B24), lack of unified policies (B23), different short and long term goals (B16), lack of reverse logistics practices (B15), lack of inter-organizational flexibility (B11), lack of motivation between social actors (B10), lack of incentive from the government (B8), lack of physical and institutional anchors (B7), lack of funds (B6), lack of technology (B5), absence of knowledge (B3) and lack of planning and redesigning IS complexes (B1). A large portion of the barriers fall under these categories. Since they have both solid driving and reliance control any change occurring to these barriers will hinder the process to overcome other barriers and also have a feedback on themselves. These are highly volatile barriers that might affect the successful implementation of IS. It can also be observed from Figure 2 that most these have barriers occupy higher position. Thus, more importance must be given to these barriers while implementing IS to have a successful endeavour.

Quadrant 4: Driving factors -These factors have a solid drive control, however frail reliance control. In this quadrant we only have one factor, i.e., lack of support from the supplier (B18). Since this barrier has solid drive control, it can have extreme effects on other barriers. In earlier studies, the barriers like lack of trust, lack of funding and lack of policy were categorised as cause barriers. However, the lack of support from supplier will have the similar effect on implementation of industrial symbiosis. They must be addressed more carefully and may be treated as principal cause of all other barriers.

6. Implication of the research

The drivers engaged with the execution of IS for the firm under examination present extensive difficulties for the administration of firm. This examination has been created to dissect the relationship among the barriers towards practical implementation of IS in industries. It can likewise go about as a manual for the top administration to choose the strategy in the effective execution of IS to reduce the waste as well as raw material cost and increase the profit as well as productivity, this study will help in the development of eco-industrial parks which can act as an IS model. In this study, the barriers are distinguished from literature review and automotive experts in India. The model developed can be applied to other developing countries for better decision making, since the scenarios are same.

The implications that can be interpreted from this study are as follows:

1. This study will aid the management in deciding which barrier to prioritise based on their level and also offer a better understanding of the chosen barriers
2. ISM model establishes the order in which the steps must be taken by the decision makers for successful deployment of IS. MICMAC analysis indicates the set of barriers that needs to be addressed by the decision-makers based on their driving and reliance control.
3. It can be interpreted from MICMAC analysis that majority of the factors/barriers chosen for this study fall under the linkage factors, thus it can be inferred that all the factors have strong dependence and strong driving power. Thus, all the barriers are heavily related to each other as well as have a strong individual driving power and are volatile in nature. This calls for a careful implementation of IS from management by properly addressing these barriers.
4. Long legal procedure (B26) is most dominant barrier towards the successful implementation of IS and seeks utmost attention
5. Classification of the barriers based on their significance will help the decision maker to strategize decisions at various levels of an organisation.
6. The government should take steps to reduce the legal procedure required. This in turn will encourage industries to adopt IS. Furthermore, providing incentives such as tax cuts to the industries who adopt IS might lead to improved adoption of IS among their competitors or neighbouring industries.
7. NGO's and other non-profit organisations should increase their demands for effective waste management i.e., IS and actively conduct awareness campaign to masses so as to increase their knowledge about IS.
8. Industries can try to adopt the concept of Corporate Social Responsibility for better implementation of Industrial Symbiosis for the benefit of environment
9. Industries should try to shed their differences and coordinated effort between these industries must be made to consider recycling as significant option and their employees must be trained effectively.

10. Enhancing the use of technology for activities such as, monitoring return flow of materials, gauging the optimal distance for improved and efficient transportation can make the implementation of IS easier and cost-effective.

The financial evaluation delineated that the IS system can make a generous commitment following 10 years to the two employments and potential incomes. Also, positive commitments are foreseen to local people abilities base, research and advancement and provincial personality. In the semi-quantitative scoring appraisal, the advancement scored vary for all markers. The far-reaching nature of this evaluation will be vital to represent the capability of modern advantageous interaction to districts, broadly furthermore, globally, with the end goal to propel neighbourhood endeavours with encouraging mechanical advantageous interaction and to see how these systems can be evaluated both quantitatively and subjectively.

7. Conclusions and Further research

The present extraction rate of raw materials is alarming and is not sustainable, this is because of constrained assets as well as because of the production of waste involved in the production processes, there is a need to for more awareness and reuse of waste and the concept of IS provided that model of reusing the waste as a raw material for some other industry. Thirty-three compelling factors go about as the powerful boundaries towards the usage of IS in an association. These factors have been distinguished from literature review and automotive expert's assessment. The specialist's inputs have been gathered and used to make SSIM matrix speaking to the interrelationships of those recognized factors. At that point these thirty-three elements were separated into eight levels based on their driving power from the final reachability matrix portraying their significance. The created ISM demonstrate has been utilized to empower re-manufacturing associations to take choices on vital components.

Though the ISM model helps in establishing the relationship and dependencies between the barriers, the barriers chosen might have a prejudice based on the person who decides it. This study identified 33 distinct barriers for the implementation of IS. In case, if the study requires modification suitable barriers can be included or employed barriers can be excluded befittingly. Fuzzy set theory (FST) can be used in accordance with MICMAC analysis to have better results. This model can be tested statistically using suitable tool. Case studies can also be used to hypothetically test the model. The study is expected to support with model to understand the relationship among barriers for effectively implementing IS in industries. However, the current study used ISM method to develop the model which has certain shortcomings like the strength of relationship is unclear. This can be improved utilizing the DEMATEL method in future.

Conflict of interest

The authors declare that they have no conflict of interest.

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