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RESEARCH ARTICLE

Determining Interconnectedness of Barriers to Interface Management in Large Construction Projects

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Abstract

This study aims to identify the crucial barriers to interface management and understand the interdependencies in Large Infrastructure Construction Projects (LICP). Three-pronged sequential explanatory mixed methods research is adopted comprising a structured survey of experts *(n=102) and* semi-structured interviews *(n=13).* Subsequently, interpretive structural modelling (ISM) integrated with fuzzy protocol is used to analyse pairwise interrelationships among these factors. A 'Multi-layered IM barrier' model is developed with 'Process related issues,' 'Misaligned incentives among project stakeholders' and 'Frequent Change Orders' as the manifested barriers. On the other hand, this study also prioritized the barriers and classified them as driving, linking, and independent. The outcome of this study presents the interdependence of barriers and classification of barriers, focusing on proactive action on driving barriers, which is crucial to the knowledge of interface management. The impact position of LICP with the identified

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project issues can be compared against 'Multi-layered IM barriers' and can help project teams better strategize IM by focusing on essential barriers. In addition, such exercises can improve the coordination among participants in construction projects. Using a structured approach to identifying interdependencies among barriers to IM is a significant original contribution by the study.

Keywords

Interface Management; Interface Issues; Project Management; Interpretive Structural Modelling; Large Infrastructure Construction Projects

Introduction

A sizeable share of large construction projects has been progressively increasing in the modern economic era. Simultaneously, the pandemic-induced economic depression in 2020 vividly revealed that successful project delivery depends on sustainable project lifecycle management and project management principles and approaches. Large infrastructure construction projects (LICP) can be defined as those projects that are multi-stakeholder, long-duration engagement endeavours that are often considered transformative and significantly impact many individuals in a society (Flyvbjerg, 2017). Such projects cause 'displacements' to rapidly transform landscapes and necessitate coordinated capital and sustained governance for their success (Gellert and Lynch, 2003). The project complexity, combined with multi-stakeholder nature, makes it highly probable to have several interfaces to facilitate interactions at boundary points between stakeholders. Coordination-associated problems such as improper communication (Baldwin, et al.,1971; Chen, et al., 2020), mismatch of owner's expectations (Ling and Lau, 2002), rampant bureaucracy (Durdyev and Hosseini, 2020), dishonest practices (Kadry, Osman and Georgy, 2017), and disputes (Chen, et al., 2019) are often observed on projects. Such coordination issues call for synergies through sustained "Interface Management."

Effective and efficient Interface Management (IM) is critical to successful project delivery (Morris, 1983; Pavitt and Gibb, 2003; Shokri, et al., 2012). There is no single agreed definition for interface management (IM); however, it can be described as interaction of entities (for example people, products and organisations) at the level battery limits or boundary.

For instance, a joint study conducted by PMI and KPMG in 2019 on comprehending the Indian construction projects plagued with massive schedule and cost overruns recommended a few measures. One of those recommendations was use of collaborative, agile planning and management of stakeholders. This recommendation is underpinned by the belief that the adoption of 'Interface management' would eliminate the interface-related problems among the contracting players and align and work with a shared understanding, thereby improving productivity. Earlier research studies revealed that control of interface-related issues results in an additional cost to the tune of one-fifth of project costs (Nooteboom, 2004). This shows the importance of interface management in controlling project metrics. Additionally, the recent studies by (Paik, Leviakangas and Choi, 2020 and Sami Ur Rehman, et al., 2020) indicated that project managers deployed BIM for managing large construction projects and attempted to mitigate the interface-related impacts. There are exhaustive studies specific to the identification of interface issues between various stakeholders in the construction supply chain (Al-Hammad, 1995; Alarcon and Mardones, 1998; Al-Hammad, 2000; Fac, et al., 2006; Weshah, et al., 2013; Yeganeh, Azizi and Falsafi, 2019; Chen, et al., 2020). These studies identified interface issues that lacked the information of interdependency among the barriers necessary for project managers to pinpoint the driving issues and embark on proactive measures. Mere identification of barriers is inadequate. However, IM's successful implementation entails the identification of interdependencies and structuring between IM barriers, as well as revealing the most driving and dependent power among these barriers. Understanding interdependence among the barriers provides insights into triggering mechanisms amidst the critical barriers, which forms the motivation for this study.

Nonetheless, little attention is devoted to exploring the interdependencies among the interface management barriers in construction. Thus, to fill this gap, this study attempts to identify the critical barriers to IM implementation and investigate the interdependencies among the identified barriers. This study identifies the driving and dependent IM barriers that enable the construction stakeholders to manage interface-related issues that impact key performance metrics proactively.

Large construction projects use principles and protocols that involve myriad complications in managing with the owners, technical customers, and EPC contractors. This is because the system of LICPs covers many contracts involving varied contractors (Gusakova, 2018). Hence, the same principles and approaches would not work for all the stakeholders (internal and external). To begin with, the management of relational ties with a sole project team among the client, customer, designer and the general contractor, is impracticable (Araújo, Carneiro and Palha, 2020). Moreover, the assumption of a sole project team is based on the distinct focus on all the participants' interests and goals (Pavlov, et al., 2019). In practice, the interests of the participants involved in a LICP vary and are often multipronged. This occurs in situations where the owner intends to lower the construction cost, the general contractor intends to increase the construction cost, and the technical customer intends to transfer the coordination work and tasks to the design firm, necessitating extra payment (Ding, et al., 2019). Also, from the perspective of choosing the most cost-effective alternatives, the management of a sole project team seems impractical for implementation (Hazır and Ulusoy, 2020). From the general contractor's (GC) point of view, the consideration of most profitable construction order is welcomed. However, due to the market conditions and competition from peer industry players, the chances of construction orders to the GCs are few. From the point of view of the customer, the consideration of fulfillment of technical construction order is the priority.

Numerous transformative engineering and construction enterprises are presently functioning to mitigate the extant prominent issues that cause disintegration. One of the critical issues is the antagonistic repercussions for technology-driven advancement. Although, varied forms of contract such as design-build, integrated project delivery (IPD), and public private partnership (PPP) deemed to be modes to foster integration, disintegration nonetheless prevails. Irrespective of the project delivery mechanism adopted for projects, there seems to be several interface issues that originate during execution of projects that hamper integration. (Nam and Tatum, 1992) investigated integration of construction projects and described the non-contractual modes such as client's leadership, autonomous integration champions, and professional ethics of project teams to overcome disintegration. The coordination problems usually manifest as various interfaces cumulatively impacting productivity, coordination and communication issues (Kelly and Berger, 2006; Chen, Reichard and Beliveau, 2007; Allmayer and Winkler, 2014). Construction projects in the recent past are often characterized by technological and organisational complexity. Such projects often involve cross-functional teams working under pressure to comply with condensed schedules and stricter cost objectives. Such interfaces now assume a new character in human-machine interactions and create digitalized asset models for predictive asset maintenance and management (Prieto, 2015; Shokri, et al., 2016; Leviäkangas, Paik and Moon, 2017). Thus, there is an immense need to study increases in IM for complex projects where transdisciplinary teams and construction supply chain (CSC) interactions are numerous (Tah, 2005). Structured protocols, processes and precise documentation are essential components of interactions among interfaces. In order to achieve streamlined interactions across interfaces it is imperative to understand the barriers that affect interface management as the initial step. Often, these barriers are interdependent. The current study achieves this aim by adopting a systematic approach to identify barriers from the extant literature and establishing interdependency among the identified barriers to IM implementation.

Literature Review

DEFINITION, TAXONOMY, AND SIGNIFICANCE OF INTERFACES IN CONSTRUCTION

The term 'interface' can be defined as a liminal or gateway state that demarcates either on the prevalence of a specific type of phenomenon or facilitates non-existent phenomena, territories, conditions, scenarios for use, exploration, exploitation, and participation. Interface Management can be broadly defined as *sharing and managing the boundary limits among the physical constituents, machinery, systems, stages, people, processes, organisations, and others* (Wren, 1967; Wideman, 2002; Godinot, 2003). The interface concept took root from the systems approach, wherein the organisations acted as interdependent systems (Wren, 1967). Thus, the organisations cooperated amongst themselves to achieve both local organisational objectives and global project objectives. Likewise, projects have been decomposed into sub-projects, and their interfaces decide the integration required (Morris, 1983). Interfaces evolved from the disintegration of work into parts accomplished by different stakeholders or organisations (Stuckenbruck, 1983). Their characteristics often classify the interfaces. Firstly, numerous interactions with entities have been classified as 'internal' when the work executed was within one organisation and 'external' when the work was performed on collaborating between different organisations (Healy, 1997).

Further, 'Temporal' interfaces existed when transition occurred from one activity to another (Morris, 1983). For example, a' geographical' interface exists when the boundary occurs between on-site and off-site construction projects. Finally, the interface characteristics often defined the interactions that occur across them. For example, 'Technical' interfaces conditioned the limits of interactions between sub-components of a system. Similarly, 'organisational' interfaces limited the interactions between the groups and individuals.

The interfaces have also been classified as 'complete' and 'partial' matches based on compatibility in project interactions. Seamless matching between physical, operational, and data exchange in interactions was achieved in the complete match. However, this was often challenging to attain. A partial match was a frequent scenario where few common characteristics prevailed amongst the work practices or operations in practical scenarios. Such partial incompatibility leads to issues at interfaces in several ways. However, the interactions across interfaces were crucial for project progress. For instance, in an organisational interface, the contact between the design team and related parties has been paramount to exchanging precise design data (Gibb, 1995). Thus, when issues exist across such interfaces, they impact stakeholders involved.

SIGNIFICANCE OF INTERFACES IN CONSTRUCTION

The interface agreements should be established on critical issues, i.e., who warrants the interfaces. The absence of clear expectations in the agreement or roles delineated at such interface leads to insufficient design data exchange and organisation problems. Similarly, in a physical interface, the connections or the boundaries between two or more building elements or components like civil work and mechanical, electrical and plumbing (MEP) elements interact (Pavitt and Gibb, 2003). For example, the information regarding the as-built duct openings from civil execution teams has been a mandatory prerequisite for MEP work execution (Pavitt and Gibb, 2003). Again at this interface, improper information exchange leads to redundant processes and reworks (Lin, 2013).

It is essential to understand IM in construction, as ineffective communications management across interfaces of construction project players were the primary reasons for cost and schedule overruns in capital projects (Han, Kim and Kim, 2007). Therefore, the key to successful construction project execution has been dependent on actively managing respective stakeholders, interfaces, and the risks imbued in improper communications. Such IM processes were imperative throughout the project life cycle. In consequence of this case and improving project key performance indices (KPIs), IM practices were poised to serve as an effective tool to oversee the project and its performance (Al-Hammad, 2000; Pavitt and Gibb, 2003; Yun, Mulva, and O'Brien, 2012).

IMPACT OF INTERFACE-RELATED BARRIERS AND THE NEED FOR INTERDEPENDENCY STUDY AMONG BARRIERS

Though a matured and well-established concept in the manufacturing industry, IM has been comparatively a new development in the construction industry (Chen, 2007). The impact of interface problems lead to the deterrence of collaboration between stakeholders (Töpfer, 1995). Furthermore, inadequate management of technical interfaces resulted in rework, excess delays, and costs (Sundgren, 1999). Managing internal and external interfaces necessitates different skill sets (Stuckenbruck, 1983; Healy, 1997). Also, careful management has been essential while manoeuvring from the conceptual phase to the commissioning stage (Morris, 1983; Stuckenbruck, 1983; Caron, Marchet and Perego, 1998). The mentioned interface-related problems were detrimental to the project's performance. Therefore, it is essential to identify and explore the interdependencies among the barriers to interface management adoption in the early stage of a project life cycle. Hence, the process of investigation of interdependencies aid construction practitioners and the research community in understanding their nature and prioritizing based on ranking.

Barriers imply the hurdles to the implementation of Interface Management implementation in construction. Therefore, IM execution requires the identification of these barriers. Literature on identifying interface issues has been explored in the dimensions of people, processes, resources, documentation, project management, and environmental aspects, which are considered as control elements for IM strategy (Chen, Reichard and Beliveau, 2008). Additionally, the interrelation between two stakeholders such as owners and general contractors (Al-Hammad, 1990), design engineers and general contractor professionals (Al-Mansouri, 1988; Al-Hammad and Assaf, 1992), general contractors and sub-contractors (Al-Hammad, 1993; Hinze and Andres, 1994), owner and facility management stakeholders (Al-Hammad, 1995), as well as owners and engineering design professionals (Al-Hammad and Al-Hammad, 1996) have been investigated.

Extant research investigations ranked the barriers; however, the importance of identification and interdependency of critical barriers remains to be understood. Also, as IM implementation has been new to the construction domain, studies related to large infrastructure projects necessitate understanding the relevance of interdependencies amongst the barriers. The presence of a varied number of IM barriers poses difficulty in the successful implementation of IM. Thus, it necessitates examining the influence of the identified barriers and determining the interrelationship between these barriers while implementing IM. Merely identifying and uprooting these driving barriers is arduous and requires additional examination. Also, it is impossible to eliminate all types of barriers concurrently. Therefore, industries need to ascertain the most potent barrier. The current study's key objectives include identifying the critical barriers, determining the interdependencies among the selected IM barriers, and examining the driving and dependency powers of IMBs for the effective implementation of IM in an organisation. To fulfill the objectives mentioned above, a consolidated ISM-fuzzy MICMAC analysis has been established to comprehensively understand the interactions among varied IMBs to address those barriers that are needed for effective IM implementation.

CLASSIFICATION OF INTERFACE MANAGEMENT BARRIERS FROM THE LITERATURE

The grouping of barriers is arranged below, and the references for the same are mentioned in Table 1.

1. Contractual: The barriers such as nonexistence of contract standards, specifications, penalty clauses, ambiguity in interpretation and sub-standard drafting of the contract clauses, delays in design

engineering, and respective approvals from owner's end, engineering, procurement, and construction schedule delays and recurring change orders.

2. Economic: Barriers such as ad-hoc detailing of schedule of payment, absence of cost indices of construction materials for estimation, poor cost estimation for maintenance works, meagre allocation of budget for design engineering work relative to requirements, exorbitant engineering design fees, and misaligned incentives among the stakeholders
3. Use of Technology: Technology-based barriers such as change management issues in technology adoption and poor forecasting of project-specific problems concerning materials and technology (which includes the incompetency of the professionals in using technology).
4. Planning: Statutes based barriers such as region-specific legislation and regulatory compliance problems, naïve in working with the government auditing protocols and procedures
5. Statutory: Planning related barriers such as inadequate work packaging, design and subcontracting, engineering design, unawareness in construction material availability, and building fast-tracking phenomenon in construction activities
6. Coordination: Coordination issues such as the presence of numerous project interface conflicts with project players, engineering and process-based issues, a lacuna of information exchange, and inadequate coordination and association amongst the construction supply chain
7. Communication: Communication-based problems such as lacuna of site-specific knowledge, local climatic and environmental factors, inadequate communication and reporting skills among the stakeholders, and design-communication tools between the designer and owner representatives.
8. Acts of God: Acts of God-related barriers such as poor knowledge of environmental hazards consideration at the design phase at the local level.

Therefore, the current study conducts a holistic investigation of the interrelations among the contemporary barrier elements to Interface Management in large infrastructure projects to address this gap. Consequently, the planned objectives are:

a. To identify critical barriers associated with IM implementation in the large infrastructure projects
b. To determine the interdependence between the identified critical barriers to IM implementation and their classification
c. To develop a structured model of identified top IM barriers

Research Method

Sequential explanatory mixed methods research comprising three phases is used to understand the structure and interactions among the IM barriers, as depicted in Figure 1. The first phase includes exploring relevant peer-reviewed construction interface management literature from databases like Scopus, Web of Science and articles from publishers like Emerald, Science Direct, Taylor & Francis, and Wiley to identify an initial set of IM barriers. The second phase encompasses the downsizing of identified barriers through a structured questionnaire survey. Lastly, interpretive structural modelling (ISM) is directed to aid pairwise interdependency inputs from experts in the third phase on the final set of IM barriers. The detailed steps of the research are presented in the subsequent sections.

Sequential mixed methods research has been used. As the first objective entails identifying critical barriers, the quantitative method was considered the most suitable. Therefore, a questionnaire survey has been used to realize the first objective. The second objective deals with the expert opinions through a semi-structured interview approach to evaluate the pairwise relations for the final IM barriers; hence, the qualitative method was deployed.

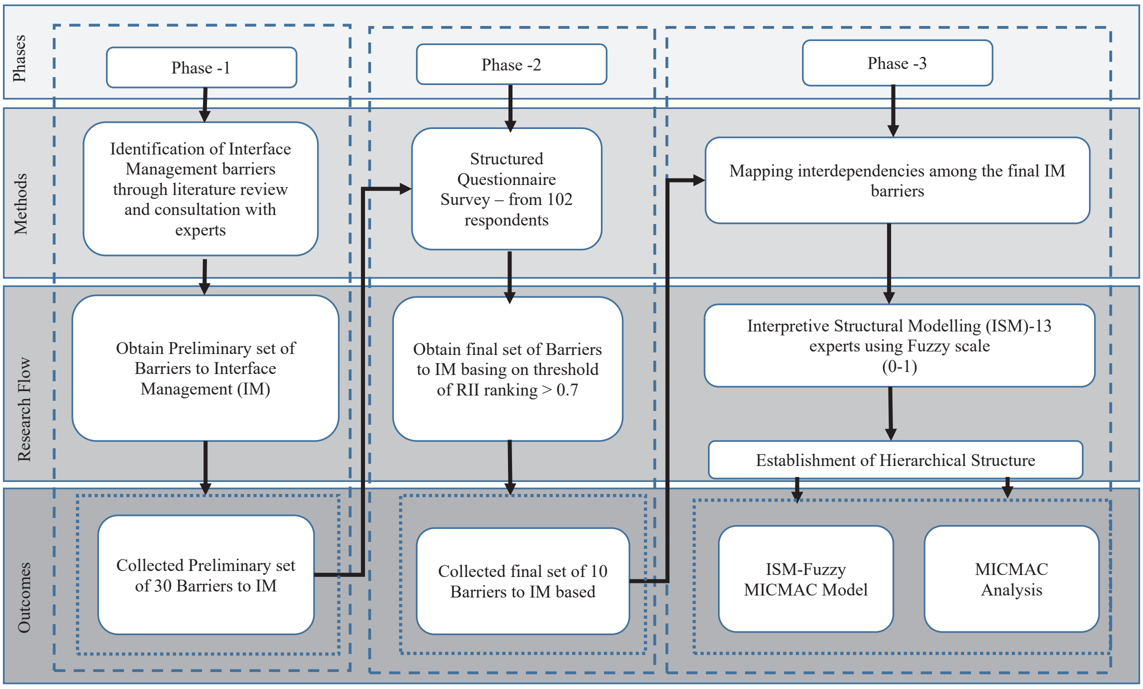

Figure 1. Analytical Research methodology

PHASE I: SYSTEMATIC REVIEW FOR IDENTIFICATION OF PRELIMINARY BARRIERS TO IM

In the first phase, interface related issues are sourced from extant literature using keywords such as 'interfaces in construction,' 'interface problems,' 'interface issues' and 'interface management in the construction industry' from databases such as Scopus, Web of Science, and articles of related conferences. Then a qualitative review of extracted research articles was performed, and upon validation of identified barriers with industry practitioners, a set of thirty (30) preliminary barriers to interface management were confirmed. Then, the preliminary barriers to IM were categorized as contractual, economic, use of technology, statutory and legislative compliance, planning, coordination, communication, and acts of God, as depicted in Table 1.

Table 1. List of Preliminary 30 barriers to IM.

Barriers to Interface Management (IM) from Literature Review			
Code	Category	Description	Reference
1	Contractual	Lack of contractual standards and specifications	(Al-Hammad, 1995; Al-Hammad and Al-Hammad, 1996; Al-Hammad, 2000; Ayudhya, 2011; Eray, et al., 2017; Sha'ar, et al., 2017; Abu-Reishah and Hiyassat, 2021)
2	Contractual	Contractual performance delays and client's delay in design approvals	(Al-Hammad, 1995; Weshah, et al., 2013; Pauwels, Zhang and Lee, 2017; Sha'ar, et al., 2017; Sweis, et al., 2019; Elhusseiny, Nosair and Ezeldin, 2021)

Table 1. continued

Barriers to Interface Management (IM) from Literature Review			
Code	Category	Description	Reference
3	Contractual	Engineering, procurement, and construction Schedule delays	(Al-Hammad, 1995; Weshah, et al., 2013; Kim, Lee and Choi, 2019; Lee, et al., 2019; Yang, et al., 2019)
4	Contractual	Ambiguous contract language and poor drafting of contractual agreement	(Al-Hammad and Al-Hammad, 1996; Al-Hammad, 2000; Huang, et al., 2008; Ayudhya, 2011; Assaf, et al., 2019; Nguyen and Phu Nguyen, 2020)
5	Contractual	Contract deficient of Penalty Clauses	(Al-Hammad, 1995; Assaf, et al., 2019; Nguyen and Phu Nguyen, 2020)
6	Contractual	Frequent Change Orders	(Al-Hammad and Al-Hammad, 1996; Zidane and Andersen, 2018; Durdyev and Hosseini, 2020)
7	Contractual	Delays in Design Services completion	(Al-Hammad and Al-Hammad, 1996; Johnson and Babu, 2020; Shoar and Payan, 2021)
8	Economic	Poor detailing of Schedule of Payments	(Al-Hammad, 1995; Weshah, et al., 2013; Rachid, Toufik and Mohammed, 2019; Durdyev and Hosseini, 2020)
9	Economic	Lack of Construction cost Indices for estimation	Al-Hammad, 1995; Hussain, et al., 2018)
10	Economic	Incorrect Maintenance Cost estimation	(Al-Hammad, 1995; Song, Hu and Feng, 2018)
11	Economic	Misaligned incentives among project stakeholders	(Al-Hammad, 1995; Zhang, et al., 2020)
12	Economic	Low Budget for Design Services Relative to Requirements	(Al-Hammad and Al-Hammad, 1996; Sha'ar, et al., 2017)
13	Economic	High engineering Design fees	(Al-Hammad and Al-Hammad, 1996; Assaf, Hassanain and Abdallah, 2017; Assaf, et al., 2019)
14	Use of Technology	Improper forecast of project-specific issues related to technology and material	(Al-Hammad, 1995; Ahn, et al., 2017; Sepasgozar, et al., 2019)
15	Use of Technology	Resistance to technology adoption	(Al-Hammad, 1995; Ahn, et al., 2017; Sha'ar, et al., 2017; Arefazar, et al., 2019)

Table 1. continued

Barriers to Interface Management (IM) from Literature Review			
Code	Category	Description	Reference
16	Statutory	Local and legislation and regulation related issues	Al-Hammad, 2000; Huang et al., 2008; Ku, et al., 2010; Bekdik et al., 2018)
17		Inexperience with government auditing protocols and procedures	(Huang et al., 2008; Ku, et al., 2010; Kivilä, Martinsuo and Vuorinen, 2017; Biesenthal et al., 2018)
18	Planning	Improper work packaging design and subcontracting	(Chen, 2007; Zidane and Andersen, 2018)
19	Planning	Inappropriate engineering design	(Al-Hammad and Al-Hammad, 1996; Zidane and Andersen, 2018)
20	Planning	Unawareness about Construction Materials availability	(Al-Hammad and Al-Hammad, 1996; Sinesilassie, Tabish and Jha, 2018; Hamerski, et al., 2020)
21	Planning	Implementation of fast-track engineering and construction techniques	(Al-Hammad and Assaf, 1992)
22	Coordination	Increased project interfaces conflicts with stakeholders	(Ku, et al., 2010; Shokri et al., 2016; Shen et al., 2017)
23	Coordination	Process related issues	(Al-Hammad and Assaf, 1992; Al-Hammad, 1993; Al-Hammad, 2000; Chen, 2007; Mortaheb and Rahimi, 2010; Ayudhya, 2011; Oraee, et al., 2017)
24	Coordination	Lack of Proper Information exchange between stakeholders	(Al-Hammad and Al-Hammad, 1996; Li, et al., 2015; Li, et al., 2016; Mok, Shen and Yang, 2017)
25	Coordination	Insufficient communication and coordination among project stakeholders	(Al-Hammad, 1993; Al-Hammad and Al-Hammad, 1996; Al-Hammad, 2000; Fac, et al., 2006; Arain and Assaf, 2007; Chen, 2007; Ku, et al., 2010; Yeh et al., 2020)
26	Communication	Unawareness of Environmental Factors consideration during the design phase	(Al-Hammad and Al-Hammad, 1996; Tian, 2013)
27	Communication	Lack of site-related knowledge	(Al-Hammad and Assaf, 1992; Yap, Abdul-Rahman and Wang, 2018; Yap, et al., 2021)

Table 1. continued

Barriers to Interface Management (IM) from Literature Review			
Code	Category	Description	Reference
28	Communication	Insufficient communication and reporting skills among the stakeholders	(Al-Hammad, 1995; Chen, et al., 2019)
29	Communication	Insufficient Design Communication tools between Designer and Owner	(Al-Hammad and Al-Hammad, 1996; Chen, et al., 2019)
30	Acts of God	Lack of Knowledge of Local Climatic and Environmental Factors	(Al-Hammad, 2000; Chen, Reichard and Beliveau, 2008; Huang, et al., 2008; Ayudhya, 2011; Famiyeh, et al., 2017)

PHASE II: STRUCTURED QUESTIONNAIRE SURVEY

A structured questionnaire survey for primary data collection comprising identified preliminary barriers to IM derived from phase-I is developed on a rating of IM barriers importance over a five-point Likert scale (with '1' being the least importance and '5' high importance). The questionnaire was sent to 354 identified industry practitioners and the research community through online modes such as e-mail, WhatsApp, and social media. Purposive sampling was chosen due to the lower availability of a population of construction professionals who possess expertise in the IM-related domain. The purposive sampling technique was used, and the structured survey data collection was administered for two months with fortnight reminders to the survey responders. The participants chosen for responding to the questionnaire are purposive sampling criteria. The criteria for selecting experts are based on two aspects (1) Work experience of more than ten years in large construction projects involving multiple interfaces or (2) Academia whose research expertise is related to mega construction projects. 102 Out of 109 responded surveys were considered valid. The first part of the questionnaire comprised demographic characteristics such as work experience, stakeholder organisation type, job role, and education qualification, shown in Table 2. The next part investigated the knowledge specific to IM barriers. After data collection, in order to rank the IM barriers, on the computing of relative importance index (RII) final set of barriers were (obtained from threshold value where RII is more significant than 0.70) confirmed for interpretive structural modelling analysis.

Table 2. **Respondent characteristics of Barriers to Interface Management Structured Questionnaire Survey**

Respondent Characteristics	Frequency	Percentage
Organization Type		
Researcher	13	13%
Project Management Consultants	12	12%
Design / Engineering Services	9	9%
General Contractor	48	47%

Table 2. continued

Respondent Characteristics	Frequency	Percentage
Owner/Client	14	14%
Sub-Contractor	4	4%
Vendor/Supplier	2	2%
Education Level		
Bachelor	43	42%
Masters	38	37%
Doctorate	5	5%
Post Graduate Diploma	16	16%
Designation in the Company		
Engineers / Junior Managers	24	24%
Mid-level Managers	20	20%
Senior level Managers	32	31%
Director/Assistant Vice President and other Top management roles	16	16%
Academicians	10	10%
Work Experience		
<5 years	12	12%
5-10 years	24	24%
10-15 years	30	29%
15-20 years	11	11%
>20 years	25	25%

PHASE III: EXPERT INTERVIEWS

The identified final set of barriers was subjected to expert opinions for the evaluation of contextual pairwise relationship as per interpretive structural modelling (ISM). The criteria for selecting experts were based on two aspects (1) Work experience of more than ten years in complex construction projects involving multiple interfaces or (2) Academics whose research expertise is related to mega construction projects. Experts satisfying the above two requirements were considered qualified as experts for subject matter opinions related to the current study. Invitation for evaluating the contextual pairwise association among the identified barriers was sent to forty eligible experts. The selection was based on purposive sampling as the experts possessing IM domain experience are scarce. Thirteen experts accepted the invitation to semi-structured interviews. The experts hailed from the community of general contractors, academia, consultants, and owner enterprises. The selected thirteen experts possess at least 10 years of experience working with IM-based large construction projects and were reliable as they provided ample explanations and familiarity on IM phenomenon. According to Braun and Clarke (2013), a qualitative study requires a minimum sample size of at least twelve to arrive at data saturation. Therefore, for this ISM study, a sample size of thirteen was considered adequate. ISM is a widely accepted methodology for determining relationships among particular elements that describe an issue or a problem (Warfield, 1974). The development of the relationship matrix was enabled with expert opinions resulting in the ISM model. The classical ISM model was developed initially with the final Interface Management adoption Barriers (IMB). However, owing to the lacuna in the detailed structuring of barriers, fuzzy protocols have been integrated for a detailed granularity of hierarchy levels of IMBs.

INTERPRETIVE STRUCTURAL MODELLING (ISM)-FUZZY MICMAC

For parameter prioritization and ranking purposes, there are ample multi-criteria decision-making methods like DEMATEL, VIKOR, AHP, TOPSIS and ANP. Also, quantitative methods like structural equation modelling map the interrelations among parameters through primary or secondary data sources. Fuzzy cognitive maps is another hybrid technique that embeds neural networks and fuzzy sets adopted from cognitive maps (Kosko, 1986) and models the cause and effects of a phenomenon. However, these methods lack hierarchical structuring of deployed parameters which specifically aid in the strategic formulation of various quality initiatives in industries (Yadav and Desai, 2016). ISM eradicates drawbacks as mentioned above and builds organized structure from bottom to top level, indicating input to output parameters in a hierarchical way (Piltan and Sowlati, 2016). The ISM's organised way of constructing a hierarchical portrayal of the system has been widely utilized in various research domains (Gorane and Kant, 2015). Additionally, it converts vague and tacit mental models into comprehensible models (Sushil, 2012) and involves structuring the model through an interactive learning method. Furthermore, ISM method is a qualitative model initiated utilizing the intellectual inputs from experts, aiding in construction of relationships between the parameters and ascertaining the influence of one parameter over the other (Chander, Jain and Shankar, 2013).

Interpretive Structural Modelling (ISM) builds organised structure from bottom to top, indicating input to output parameters hierarchically (Piltan and Sowlati, 2016). The ISM's organised way of constructing a hierarchical portrayal of the system has been widely utilized in various research domains (Gorane and Kant, 2015). Also, ISM qualitatively builds the relationships between the parameters and influence of one parameter over the other with expertise inputs (Chander, Jain and Shankar, 2013). Thus, the developed model depicts the structural hierarchy of a complex system in a graphical and verbatim mode. However, a significant structured model gives the outcome; the classical ISM lacks an in-depth delineation of the driver and dependent parameters. Therefore, researchers have engaged a hybrid ISM, and fuzzy MICMAC methodology to distinguish the input, intermediate, and outcome parameters (Mittal and Sangwan, 2014). The vagueness within a system is eliminated by incorporating fuzzy theory with MICMAC analysis, thereby enabling precise judgement (Chander, Jain and Shankar, 2013). The experts' MICMAC analysis with fuzzy inputs classifies the parameters into four quadrants exhibiting the autonomous, linkage, dependent, and driving types (Tripathy, Sahu and Ray, 2013).

As ISM retains characteristics that fulfill the objectives set in this study, it is utilized. For example, this ISM-fuzzy MICMAC model has been used to model barriers to implementing supply chain management and world-class factory performance measures (Gorane and Kant, 2015). Also, modelling risk assessment to offshore pipeline construction projects emphasizes proactive planning in the initiating phase (Wu, et al., 2015).

Results

IDENTIFICATION OF TOP CRITICAL BARRIERS TO INTERFACE MANAGEMENT (IM)

The structured questionnaire survey was synthesized after distribution to 354 participants online. One hundred and nine respondents completed, and seven were discarded due to repetition and incompleteness.

Therefore, the response rate was 29 % (102 valid responses). The survey respondents were construction stakeholders such as general contractor (46%), owner (14%), researcher scholar (13%), project management consultant (12%), designer (9%), sub-contractor (4%), and supplier (2%) which were diverse. The average work experience of respondents was 12 years, and the lower and upper limit of work experience noted was five years and 38 years. The respondents' job roles, such as senior-level managers comprised (31%), Junior-level managers (24%), Mid-level Managers (20%), Director/ Vice President (16%) and research / academia (10%), respectively as shown previously in Table 2. The internal consistency and reliability were checked through Cronbach's alpha. The Cronbach value for the questionnaire yielded 0.943, which was above the accepted measure of 0.7 (Hair, et al., 1998). RII was computed and used to rank the barriers. The barriers whose RII value greater than 0.70 has been the rationale for choosing the final set of barriers (hence 10 barriers met the criteria of RII value greater than 0.70, out of 30 barriers). Table 3 illustrates the top critical barriers to IM implementation.

Table 3. RII prioritized the top 10 Barriers to IM

Barrier Code	Barriers to Interface Management implementation from Literature Survey	R.I.I.	Rank
PRO	Process related issues	0.755	1
COM	Insufficient communication and coordination among project stakeholders	0.751	2
WPD	Improper work packaging design and subcontracting	0.724	3
CO	Frequent Change Orders	0.722	4
SRK	Lack of site-related knowledge	0.720	5
TA	Resistance to technology adoption	0.716	6
FCT	Improper forecast of project-specific issues related to technology and material	0.710	7
LEG	Local and legislation and regulation related issues	0.706	8
ED	Inappropriate engineering design	0.700	9
MI	Misaligned incentives among project stakeholders	0.698	10

MODELLING BARRIERS OF IM

The identified final set of barriers were subjected to expert opinions for interpretive structural modelling (ISM). The criteria for selecting experts were based on two aspects (1) Work experience of more than ten years in large construction projects involving multiple interfaces or (2) Academics whose research expertise is related to large construction projects. Invitation for semi-structured interviews was sent to forty eligible experts. The selection was based on purposive sampling as the experts possessing IM domain experience are scarce. Thirteen experts accepted the invitation to a semi-structured interview. The average experience of the experts was 21 years. The experts hailed from the diverse category of construction organisation and to prevent the subjectivity of expert opinions on aggregating the responses, the principle of "the minority gives way to the majority" is implemented as performed for previous similar research studies (Mathiyazhagan, et al., 2013; Li, et al., 2016).

Table 4. Expert characteristics for rating interdependencies among IM barriers

Expert	Age	Education Level	Experience (Years)	Job Designation	Employer/ Organization Type
Exp-1	55	Doctoral	37	Professor	Construction Management Research Institute
Exp-2	50	Doctoral	28	Professor	Construction Management Research Institute
Exp-3	36	Bachelor & Executive Program in BIM Implementation strategist	13	Design Manager	General Contractor
Exp-4	34	Bachelor	12	Planning & Contracts Management	General Contractor
Exp-5	64	Diploma	36	Sub Contract Lead	Sub-Contractor firm
Exp-6	36	Master in GIS, Diploma in Data Science	14	Manager	Design
Exp-7	46	Master	20	Senior Discipline Lead, Civil/ Hydraulics	Design
Exp-8	36	Masters and Executive Management	11	Assistant Professor	Construction Management Research Institute
Exp-9	42	Bachelor	20	Deputing General Manager	General Contractor
Exp-10	56	Bachelor	30	Deputing General Manager	General Contractor
Exp-11	38	Masters and Management, Executive Masters in Business Administration	17	Senior Manager	General Contractor
Exp-12	55	Bachelor	24	Senior Deputing General Manager	General Contractor
Exp-13	39	Bachelor	16	Senior Manager	General Contractor

METHODOLOGY OF ISM-FUZZY MICMAC

The methodology followed in ISM fuzzy MICMAC is as follows.

Step 1. The top 10 IM Barriers (prioritised as per RII value > 0.70) considered for the hierarchical model development are listed.

Step 2. From the identified top 10 IM barriers, the contextual relationship among the IM barriers was established through the involvement of subject matter experts in identifying the relationship.

Step 3. A structural-self interaction matrix (SSIM) was developed from the inputs from the subject matter experts which establish the pairwise relationships among the IM barriers under investigation.

Step 4. Initial reachability and final reachability matrices were developed from SSIM (converting the experts inputs as '0' and '1') and performing transitivity checks. Transitivity is the assumption of ISM methodology, which states that if a variable X is associated to Y and Y is associated to Z, then A is automatically associated to Z.

Step 5. As the traditional ISM does not permit assigning the strength of the pairwise relationship ranging between 0 and 1, the fuzzy MICMAC protocols were deployed. Also, fuzzy rules for enabling a detailed hierarchy of barriers.

Step 6. As an initial step to ISM–fuzzy MICMAC process, the Binary Direct Reachability Matrix (BDRM) was developed from the initial reachability matrix of step 4 by substituting the diagonal responses in the cell with '0'.

Step 7. The experts considered in step 2 were engaged in evaluating the contextual relationships between the barriers with a fuzzy scale ranging from 0, 0.25.0.5, 0.75, and 1.00 to derive the fuzzy direct reachability matrix (FDRM).

Step 8.Then, the fuzzy stabilized matrix was developed through defuzzification. The defuzzification was done by multiplying the BDRM and FDRM until stabilization was maintained.

Step 9. The driving (DR) and dependent powers (DP) were calculated by aggregating the values in the n and m direction of the last cell values in Table 9.

Table 5. Pairwise Relationship among barriers – SSIM (Structural Self Interaction Matrix)

→ n ↑m	PRO	COM	WPD	CO	SRK	TA	FCT	LEG	ED	MI
PRO		A	V	V	A	A	A	A	O	V
COM			X	V	A	O	O	O	V	V
WPD				V	X	O	A	A	O	V
CO					A	O	A	A	A	V
SRK						O	X	X	V	V
TA							X	O	O	V
FCT								O	V	V
LEG									O	V
ED										V
MI										

Step 10. The difference of (DR-DP) is arranged in ascending order which aided in developing the ISM fuzzy MICMAC model by arranging the barriers in different levels as depicted in Figure 3.

STRUCTURAL SELF-INTERACTION MATRIX (SSIM)

The contextual pairwise comparison between the identified IM barriers is conducted using the codes of V, A, X, O. Notation of the pairwise relationship between 'm' and 'n' was used, where 'm' means barrier along the y-axis and 'n' means barrier along the x-axis. The interpretation of the codes is illustrated below.

(a) V - indicates, barrier in 'm' (y-axis) direction will aid in achieving IM barrier 'n' direction (x-axis)
(b) A - indicates, barrier in 'n' (x-axis) direction will aid in achieving IM barrier 'm' direction (y-axis)
(c) X - indicates, barrier in 'm' (y-axis) and 'n' direction (x-axis) will aid in achieving IM barrier
(d) O - indicates, barrier in 'm' (y-axis) and 'n' direction (x-axis) possess no interdependency

Table 5 represents the SSIM developed for Interface Management implementation barriers

The beneath mentioned statements aid in understanding the working protocol of V, A, X, O. The subject matter experts would evaluate the interdependencies with the above codes and the interpretation of Table 5 using the symbols V, A, X, O is illustrated below as an example. A similar procedure was used by the experts for filling the matrix.

1. 'PRO' ('Process related issues') barrier in 'm' direction aids in achieving 'MI' ('Misaligned incentives among project stakeholders') barrier in 'n' direction; Such relationship is symbolized by 'V' within SSIM.
2. 'Whereas, 'FCT' ('Improper forecast of project-specific issues related to technology and material') barrier in 'n' direction aids in achieving 'CO' ('Change Orders') barrier in 'm' direction. Such relationship is symbolized by 'A' within SSIM.
3. 'Barriers 'WPD'('Improper work packaging design and subcontracting') and 'SRK' ('Lack of site-related knowledge') aid in achieving each other. Such relationship is symbolized by 'X' within SSIM
4. 'Barriers 'LEG' ('Local and legislation and regulation related issues') and 'ED' ('Inappropriate engineering design') possess no relation with each other, then it is symbolized by 'O'

INITIAL AND FINAL REACHABILITY MATRICES DEVELOPMENT

The synthesized SSIM was converted into an Initial reachability matrix (IRM) on replacing the values of V, A, X, O with binary values in the Matrix. The input symbols such as V, A, X, O are substituted with binary digits' 0' and '1'. The following protocols execute the substitution of 0 and 1:

1. The instance where *(m, n)* entry in SSIM prevails as V; *(m, n)* entry is converted into 1 and (*n, m)* entry is converted into 0 in reachability matrix.
2. The instance where *(m, n)* entry in SSIM prevails as A; *(m, n)* entry is converted into 0 and *(n, m)* entry is converted into 1 in reachability matrix.
3. The instance where *(m, n)* entry in SSIM prevails as X; *(m, n)* entry is converted into 1 and *(n, m)* entry is converted into 1 in reachability matrix.
4. The instance where *(m, n)* entry in SSIM prevails as O; *(m, n)* entry is converted into 0 and *(n, m)* entry is converted into 0 in reachability matrix.

The final reachability matrix (FRM) was established on the removal of transitivity in the IRM.IRM and FRM are depicted in Table 6 and Table 7.

Table 6. Initial Reachability Matrix

→ n ↑m	PRO	COM	WPD	CO	SRK	TA	FCT	LEG	ED	MI
PRO	1	0	1	1	0	0	0	0	0	1
COM	1	1	1	1	0	0	0	0	1	1
WPD	0	1	1	1	1	0	0	0	0	1
CO	0	0	0	1	0	0	0	0	0	1
SRK	1	1	1	1	1	0	1	1	1	1
TA	1	0	0	0	0	1	1	0	0	1
FCT	1	0	1	1	1	1	1	0	1	1
LEG	1	0	1	1	1	0	0	1	0	1
ED	0	0	0	1	0	0	0	0	1	1
MI	0	0	0	0	0	0	0	0	0	1

Table 7. Final Reachability Matrix with Driving Powers and Dependence Powers- Barrier variables

→ n ↑m	PRO	COM	WPD	CO	SRK	TA	FCT	LEG	ED	MI	Driving Power
PRO	1	1	1	1	1	1	1	1	1	1	10
COM	1	1	1	1	1	1	1	1	1	1	10
WPD	1	1	1	1	1	1	1	1	1	1	10
CO	0	0	0	1	0	0	0	0	0	1	2
SRK	1	1	1	1	1	1	1	1	1	1	10
TA	1	1	1	1	1	1	1	1	1	1	10
FCT	1	1	1	1	1	1	1	1	1	1	10
LEG	1	1	1	1	1	1	1	1	1	1	10
ED	0	0	0	1	0	0	0	0	1	1	3
MI	0	0	0	0	0	0	0	0	0	1	1
Dependence Power	7	7	7	9	7	7	7	7	8	10	

As shown in Table 7, the driving and dependence powers of the IMBs are computed by aggregating the rows and column values from the final reachability matrix as per the classical ISM method. The final reachability matrix is the basis for conducting a level partitioning process to form hierarchical barriers.

LEVEL PARTITIONING

Partitioning into levels was performed to form the structuring of barriers. Also, the reachability and antecedent sets were synthesized from FRM. The reachability set comprises IM barrier elements itself and those barrier elements that may aid in achievement; an antecedent set comprises IM barrier elements itself and the others which contribute to achieving it. Then, the IM barriers' intersection sets are derived. The IM barriers possess the same antecedent elements, and intersection elements are placed at the lower layers of the ISM structure. Additionally, these lower layer elements act as a solid catalytic input to the structured tier. These barriers assist in achieving the other barrier. An iterative process was conducted on knowing the lower-level elements until the top hierarchy barrier elements were performed along with the partitioning process. The overall leveling procedure enables the formation of a digraph comprising the transitive links.

FUZZY MICMAC ANALYSIS

According to the classical ISM-grounded framework, the binary inputs establish relationships amongst the IM barrier elements. During the development of the ISM-based model, any association among the IM barrier elements was keyed using 0 and 1. However, at par significance, it was substituted by 1. Also, an equal relationship between two IM barriers cannot be considered for all scenarios. On the one hand, few IM barriers possibly are strongly associated; on the other hand, the others might possess weak association. In order to overcome this issue, a fuzzy form of ISM was utilized in MICMAC analysis. The procedure to execute the fuzzy ISM is illustrated in subsequent sections. For forming the Binary Direct Reachability Matrix (BDRM), the interactions among the IM barriers were sourced from the initial reachability matrix as per the classical ISM method. Then, the diagonal responses were substituted by 0.

CONSTRUCTION OF FUZZY DIRECT REACHABILITY MATRIX (FDRM)

The diagrammatic representation of MICMAC scrutiny envisages only two-sided inputs, either '0' or '1' relationships amongst the downsized variables affecting experts' decision-making tolerance. Hence, for improving the sensitivity and precision of MICMAC exploration, the fuzzy set concept was integrated with the existing study. As per the integrated fuzzy-MICMAC analysis, additional interactions among the IM barriers were infused. The feasibility of the interaction matrix on considering the scale value between 0 to 1 was assumed.

The interpretation of the fuzzy scale for MICMAC analysis is categorized as follows:

1. '0' - No influence
2. '0.25' - Very low influence
3. '0.5' - medium influence
4. '0.75' - High influence
5. '1' - Very high influence

FUZZY MICMAC STABILIZED MATRIX

The procedure for fuzzy MICMAC analysis was accomplished from the developed fuzzy direct reachability matrix (FDRM is depicted in Table 8) from the experts using the fuzzy scale. The defuzzification was conducted by multiplying the matrices until stabilization is attained for the hierarchical development of driving and dependent power. A simplified Boolean operation applied the fundamental principle of fuzzy multiplication to multiplicate matrices (Gorane and Kant, 2015). According to the fuzzy set, the resultant of two fuzzy matrices is always a fuzzy matrix on multiplication. The following rule is applied to multiply the two matrices.

$$Z = X.Y = \max s\ [\min(x_{ms}, y_{ns})] \qquad \text{Eq.1.}$$

Where $X = x_{ms}$ and $Y = y_{ns}$

Table 8. Integrated Matrix of (Binary Direct Reachability Matrix, Fuzzy Direct Reachability Matrix and Stabilized Matrix) for barrier variables influencing IM implementation

→ n ↑m	PRO	COM	WPD	CO	SRK	TA	FCT	LEG	ED	MI	Driving Power (DR)
PRO	0,0,1	0,0.75,0.75	1,0.5,1	1,0.75,1	0,0.5,0.75	0,0.75,0.75	0,0.75,0.75	0,0.75,0.5	0,0.75,0.75	1,0.75,0.5	7.75
COM	1,1,1	0,0,1	1,0.75,1	1,0.5,1	0,1,0.75	0,0.25,0.75	0,0.5,0.75	0,0.5,0.75	1,0.75,0.75	1,0.75,1	8.75
WPD	0,0.75,1	1,0.75,0.75	0,0,1	1,1,1	1,0.75,1	0,0.5,0.75	0,0.5,1	0,0.25,0.5	0,0.75,0.75	1,0.5,0.75	8.5
CO	0,0.5,1	0,0.5,0.75	0,1,1	0,0,0.75	0,0.5,0.5	0,0,0.75	0,0.75,0.5	0,0.5,0.5	0,0.5,0.25	1,0.5,0	6
SRK	1,0.75,1	1,0.75,0.75	1,0.75,1	1,1,1	0,0,1	0,0.75,0.75	1,1,0.75	1,0.5,0.75	1,0.75,0.75	1,0.75,0.75	8.5
TA	1,0.75,1	0,0.5,0.75	0,0.5,1	0,0.5,1	0,0.75,0.5	0,0,0.75	1,1,0.75	0,0.25,.75	0,0.75,0.75	1,0.5,0.75	8
FCT	1,0.75,1	0,0.75,1	1,0.5,1	1,1,1	1,0.5,0.75	1,0.5,0.75	0,0,1	0,0.5,0.75	1,0.75,0.75	1,0.75,1	9
LEG	1,0.75,1	0,1,0.75	1,0.75,1	1,0.5,1	1,0.75,0.75	0,0.5,0.75	0,0.75,1	0,0,0.75	0,0.5,0.75	1,0.5,0.75	8.5
ED	0,1,1	0,1,0.75	0,0.75,1	1,0.75,0.75	0,0.75,0.5	0,0.5,0.75	0,0.75,0.75	0,0.75,0.5	0,0,0.5	1,1,0.5	7
MI	0,1,0	0,0.75,0	0,1,0	0,0.75,0	0,0.5,0	0,0.75,0	0,0.5,0	0,0.5,0	0,0.25,0	0,0,0	0
Dependence Power (DP)	9	7.25	9	8.5	6.5	6.75	7.25	5.75	6	6	

By using the above fuzzy multiplication rule, a stabilized matrix is achieved (Table 8). Table 8 is an integrated matrix wherein each cell possesses three values. The first value in each cell corresponds to Binary Direct Reachability, the middle value to Fuzzy Direct Reachability, and the last value to stabilized Matrix for barrier variables influencing IM implementation. On the one hand, the driving power of the IM barrier was assessed by aggregating the row' last value' entries of each cell for all possible interactions. On the other hand, the dependence power was achieved by summing each column entries' final value, as represented in Table 9.

Table 9. Effectiveness and Ranking of Variables

Barrier Variables	Driving Power (DR)	Dependence Power (DP)	(DR-DP)	Level
PRO	7.75	9	-1.25	III
COM	8.75	7.5	1.25	VI
WPD	8.50	9	-0.50	IV
CO	6.00	8.5	-2.50	II
SRK	8.50	6.75	1.75	VIII
TA	8.00	6.75	1.25	VI
FCT	9.00	7.5	1.50	VII
LEG	8.50	6	2.50	IX
ED	7.00	6	1.00	V
MI	0.00	7	-7.00	I

Table 9. outlines the ranking and effectiveness of barriers. First, the driving power (DR) and dependence power (DP) values have been sourced from Table 8. Then, the hierarchical structuring (level-wise ranking of barriers) was achieved by arranging the difference of (DR-DP) in ascending order.

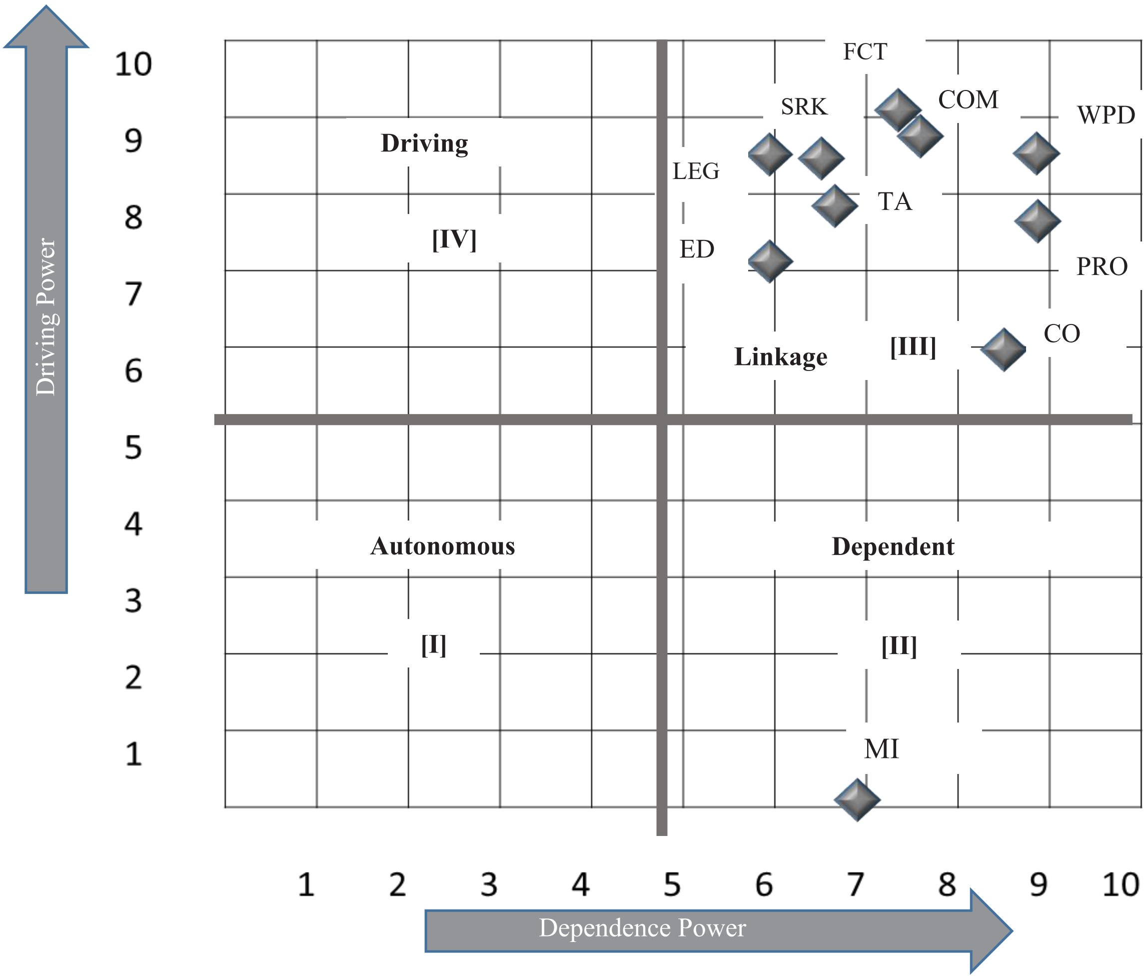

Figure 2. Classification of barrier variables using Fuzzy MICMAC Analysis

CLASSIFICATION OF BARRIER VARIABLES OF IM IMPLEMENTATION

The aggregate values obtained by row and column indicate the impact of each IM barrier towards effective implementation of Interface Management and form an avenue for the Interface coordinators to utilize for accurate decision making. Additional examination is enabled with a MICMAC analysis in a cluster chart, as portrayed in Figure 2. The graph was plotted with dependence and driving power values (as coordinates of x and y axis) of Table 9. The graph was categorized into four clusters demonstrating autonomous, linkage, strong driver, and dependent barriers. The detailed analysis of this cluster was subsequently elucidated. Employing fuzzy protocols for expert judgment for conducting MICMAC analysis, the finalized ten variables for IM execution barriers have been delineated into four classes. Then these variables were accommodated based on power analysis as driving and dependence class. The first quadrant zone pertains to autonomous class where the dominance of dependent and driving nature of the variables are minimal.

Also, these classes of variables are positioned near the origin and are aloof to the whole system. However, in this study, no variables belong to this zone. The next quadrant zone relates to those variables possessing high dependence, accordingly in the current study, the 'MI' variable 'Misaligned incentives among project stakeholders' is the only barrier belonging to dependent quadrant. The third quadrant zone encompasses linking variables possessing substantial driving and dependent characteristics. Significant number of IM barriers is located in this zone (i.e., the barriers PRO, COM, WPD, CO, SRK, TA, FCT, LEG, and ED). This indicates that any change in any of the barriers in Linkage zone will affect the other barriers and

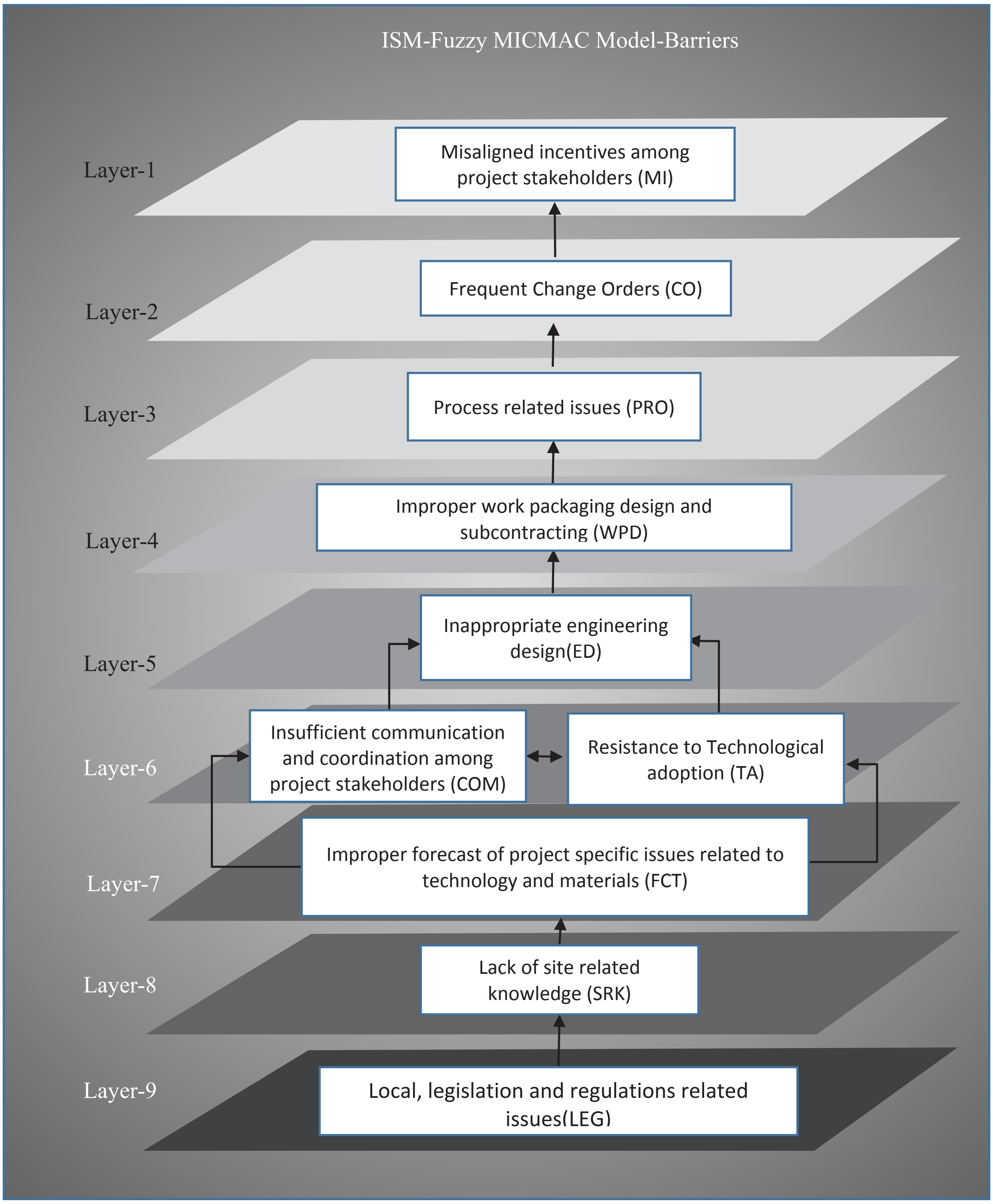

Figure 3. ISM Fuzzy MICMAC Model for Barriers to IM.

possess feedback on themselves. So, the barriers positioned in the Linkage quadrant are highly unstable. A consolidated structured framework was synthesized utilizing the 'driver' and 'dependent' powers determined from the defuzzification process. The subtraction of attained dependent powers from dependent powers was evaluated to infer the influential capacity of each variable (Mishra, et al., 2017) as depicted in Table 9. The least effective variables were located at the lowermost level of the framework. The consolidated framework of barrier variables affecting the implementation of interface management in construction operations can be inferred from the influential determined values as in Figure 2.

Discussion

The current study has established an attempt to identify critical IM barriers to Interface Management implementation in projects. Although research studies exist on identification of IM barriers, there is a lacuna in the investigation conducted on categorization and interdependencies of IM barriers. Nevertheless, the existing ISM-grounded model aids Chief Interface Managers and IM-based professionals comprehend the interrelationship structural framework for enhanced relationship management with construction actors, which aligns with the study conducted by Meng and Boyd (2017) for large and complex construction projects.

Initial barriers were subjected to ISM-Fuzzy MICMAC process and barrier variables were structured at different layers based on the driving and dependence power analysis from Table 8. Then, the difference between Driving and Dependence power values was the basis for the Layer-wise structuring of barrier variables ISM model (as per Table 9). Also, as per the data collection from the mixed methods in this study, it is evident that the three barrier variables of the ISM model such as Frequent Change Orders (CO), Process-related issues (PRO) and Misaligned incentives among project stakeholders (MI) were observed to be closer (i.e., as per Table 9, they are arranged in a consecutive levels) and hence grouped as 'Manifested Barriers' and labelled as Tier I. Similarly, the next two barriers i.e., 'Improper work packaging design and subcontracting (WPD)' and 'Inappropriate engineering design(ED)' are in close proximity to each other (arranged in succession as per levels of Table 9), hence grouped as ' Front end engineering and design (FEED) barriers' and labelled as Tier II. Likewise, the remaining barriers were grouped based on such similar proximity and labelled as Tier III, IV and V. On reflection, the alignment of the location of the barrier variables in model (Figure 4), it can be inferred that on grouping of proximity barriers there seems to be resonance on confluence of two theories, namely the institutional theory and transaction cost economics theory. The detailed discussion is illustration in further sections.

Also, the identified interdependencies among the IMBs enable concerned construction stakeholders to prioritize project risks (Kimiagari and Keivanpour, 2019), task inter-relationships (Fong and Lung, 2007) and the impact of trust on project key performance indicators (Yang and Cheng, 2021). Hence, this research presumes the importance of investigating with this context. The main finding of this research is that incompetent expertise on laws and regulations is a significant IM barrier. This IM barrier is at the lowermost of the ISM-fuzzy MICMAC model as per Figure 3. Lack of knowledge of local laws and regulations (which is the most influential factor) possesses an ultimate influence on increased construction cost (Habibi, Kermanshachi and Safapour, 2018). Additionally, employing a contracts professional deficient in local laws may negatively impact the contractual and risk management performance (Vu, et al., 2016; Pham, et al., 2020). Hence, construction projects intending to implement interface management should be cautious when practitioners unfamiliar with regulatory and region-specific legislations might be potential project disruptors.

Another critical finding is 'Misaligned incentives among project stakeholders' (the most dependent barrier). Therefore, management should avoid Frequent Change orders which is also a dependent barrier. This barrier significantly disrupts the project, causing schedule delay and additional cost due to rework

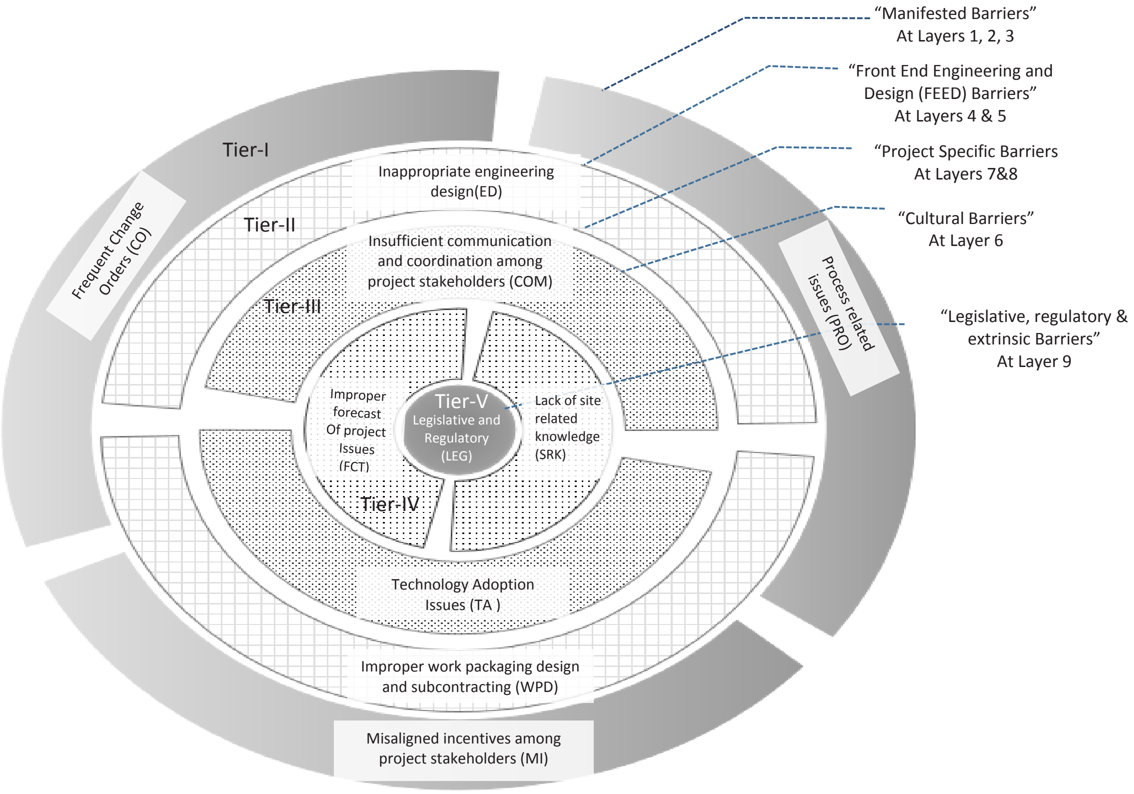

Figure 4. Multi-Layered IM implementation related Barriers

(Hanna, et al., 1999). Incorporating proper work packaging with a clear statement of work (SOW), effective collaboration and coordination with interdisciplinary teams and transparent processes can mitigate the change orders, thereby lessening cost impact.

DEVELOPMENT OF MULTI-LAYERED MODEL FROM ISM-FUZZY MICMAC MODEL

This study contributes to the existing knowledge by transforming the ISM-fuzzy MICMAC model into a 'multi-layered model of IM barriers' (as illustrated in Figure 4.) which aids the interface-related stakeholders in evaluating the interdependent barriers proactively. The nine-level model from Figure 3 is transformed to a five-layered model as there existed a resonance of alignment with institutional and transaction cost economics theories, on grouping few barriers. The grouping of the barriers was accomplished as per the order of the level without disturbing the hierarchy. The alignment of the barriers is further explained in the theoretical ratification section. Furthermore, using this Multi-layered IM barriers model, aids project stakeholders to acknowledge the gravity of the interface issues. The top ten critical barriers posited at different layers are labelled as 'Legislative, Regulatory and Extrinsic Barriers', 'Cultural Barriers', 'Front End Engineering and Design (FEED) Barriers', Manifested Barriers', and their explanation is discussed in subsequent sections.

LEGISLATIVE, REGULATORY AND EXTRINSIC BARRIERS

In this study, there is a lone barrier i.e., 'Local, legislation and regulations related issues (LEG) at layer IX, which forms the core issue of IM implementation. Issues such as land acquisition, access management, local regulatory compliances, and other institutional-related aspects fall under this 'LEG' category. As per this study, LEG forms the most effective barrier, and identifying and eradicating the issues related to this barrier at an early stage can mitigate further triggering of 'Cultural Barriers'. For instance, when a project manager from the contractor organisation encounters LEG-related issues in the early stages of a project, a complacent attitude is generally observed as there is ample time to complete the project. However, this model highlights it as a precursor to other layered interface issues and alerts them to resolve immediately as the severity of risk is low.

PROJECT-SPECIFIC BARRIERS

This tier possesses two barriers (problems like incompetent site-related knowledge (SRK) and improper forecast of project specific issues related to technology and materials (FCT)) which are posited at VII and VIII layers). These types of issues are typically site-specific and can be addressed through the skill development of construction practitioners using Virtual Reality or Immersive training. Also, use of data-driven and visualization processes such as 'Building Information Modelling' will enhance the situational awareness of construction practitioners.

CULTURAL BARRIERS

There are two significant barriers (issues such as technology adoption resistance (TA), and communication hiccups (COM) which are posited at layers VI. These can be grouped as cultural barriers involving soft skills and change management aspects. Hard skills relate to accomplishing tasks using project management tools, while soft skills refer to interpersonal relations with individuals or groups of stakeholders. The recent complexity of current infrastructure projects necessitates the acquisition of soft skills as equally important to hard skills. This is because soft skills foresee latent uncertainties, which when hard skills alone are deployed, are masked. It is evident in the current study that TA and COM barriers are located at the same layer VI, which indicates the equal importance of hard and soft skills and is in line with (Söderlund and Maylor, 2012), who emphasized supplementing leadership and soft skills with hard skills for successful project delivery. Consequently, with the 'Multi-layered IM barriers', when a chief interface manager identifies the cultural-related issues, the project is posited in a medium category of risk and can be resolved at the project level with minor support from top management.

FRONT END ENGINEERING AND DESIGN (FEED) BARRIERS

As per Figure 4, the nature of barriers gradually moves from the core 'broad legislation/ regulatory associated' barriers to 'cultural' and then to 'project control specific' barriers such as improper work packaging design, management of sub-contractors (WPD) and inappropriate engineering design (ED). These two barriers (located at layers IV and V as per Figure 3) constitute technical skills-oriented and can be meticulously controlled at project sites with appropriate skills through practical training and development. Again, with the 'Multi-layered IM barriers', when a chief interface manager identifies the FEED-related barriers, the project is bound to be posited at high risk. The mandatory intervention of senior management can lessen the negative impact on the project.

MANIFESTED BARRIERS

Barriers such as 'misaligned incentives among stakeholders' (MI), 'Frequent Change Order' (FCO), and 'process-related issues' (PRO) (located at layers I, II and III as per Figure 3) have been substantiated as issues due to IM barriers at lower layers. Nevertheless, again, with the 'Multi-layered IM barriers', when a chief interface manager/Project Manager identifies the 'Manifested' related barriers, the project is posited at severe risk, marred by scope creep, cost, and schedule overruns.

The development of the multi-layered IM barrier model (as per Figure 4) from the current study aligns with the crossbreed of two theories, namely the institutional theory and transaction cost economics theory. According to the Institutional Theory of Organisation, the social structure resilience is explained with the behaviour of the social elements as coercive, normative and mimetic (DiMaggio and Powell, 1983). In line with this theory, the core barrier at layer V i.e., legislative and statutory-based, resonates with 'coercive,' while the cultural-based barrier at layer IV as 'normative' and project specific and Front-End Engineering Design (FEED) based barriers at layers III and II as 'mimetic'. However, the barriers at layer I are substantially related to constraints in minimising the cost due to frequent change orders and misaligned incentives for the contractors. This resembles the transaction cost economics theory (Williamson, 1989) that posits the achievement of optimum organisational structure with minimum transactive exchange costs. Therefore, the proposed 'Multi-layered IM barriers' in this study provides a theoretical contribution in understanding the interconnectedness. Moreover, it provides insights for practitioners and the scholarly community with a pragmatic depiction of layered IM issues while implementing IM practice. During IM implementation, it is improper for management to pin point random IMBs and eradicate them. Before eliminating IMBs, the Chief Interface Manager must be thoroughly acquainted with the hierarchical actions to be considered and their respective importance and interrelations. The 'Multi-layered IM barriers' model points out the classification of IMBs that requires attention from the practitioners, based on the four category barriers against which to measure their current project status. These pose the bottleneck against effective IM implementation and successful project delivery. Practitioners should focus on higher driving factors as the root cause of the other IMBs with more extraordinary dependency powers. Identifying these driving power IMBs, enables senior management to chart out a plan to formulate strategies for surmounting their impacts during IM implementation.

Conclusion

This study presents a significant contribution through a systematic 'Multi-layered IM barrier framework' to establish pairwise interrelations among identified IMBs. The framework serves as a gauge for project managers to understand the interdependencies among the identified parameters, compare their project interface issues with the model, and correct actions accordingly. Therefore, this study presumes significance. One of the main findings of this study is the identification of significant barriers to effective IM implementation such as, unfamiliarity with laws and regulation, incompetent site knowledge, incapacity to predict and solve project issues on technology and novel materials, inept soft skills and change management issues which project planners and execution team should reflect upon. The aforementioned IMBs have greater driving power and lower levels of the ISM model are likely to be the potential root cause for the remaining IMBs. Therefore, the top management should address these IMBs prudently. These IMBs possess greater driving powers and are tackled on priority mode, as these IMBs influence other dependent IMBs in the structured ISM model. To lessen the impact of these IMBs, management should institute longstanding strategic planning and focus on these barriers, not only tackle the bottom-level barriers. The study's findings are crucial for practitioners, research communities and policymakers, for IM implementation. Thus, the designed model delivers a practical approach to the issues that arise during IM implementation. Therefore, the consolidated ISM-fuzzy MICMAC driven model developed in this study serves as a mechanism for higher management to discern the IMBs and identify which ones possess greater dependence and driving power. Furthermore, the incorporation of fuzzy theory improved the sensitivity of MICMAC analysis relative to the classical model.

The research outcomes can guide upper management to emphasize the identified IM barriers for effective and efficient implementation of IM practices. The developed classical ISM model and Fuzzy MICMAC model are based on the subjectivity of industry and academic experts, and any bias induced might influence the outcome. A validation questionnaire survey of the identified IMBs can be performed to comprehend thorough insights. Moreover, a developed hypothetical model can be validated through structural equation modelling.

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