Interface Management for Complex Capital Projects

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

In recent years, Interface Management (IM) practices have been emerging to address the challenges of managing complex capital projects. These challenges include the added complexity and scale of these projects, globalization, geographical distribution and various working cultures, and different internal and external risks. Oil sands, off-shore and nuclear are examples of this class of projects. Despite an emerging consensus on the effectiveness of IM for facilitating complex projects delivery, IM definitions, elements, and the way it has been implemented varies widely across the construction industry. Furthermore, identifying key interface points, integrating IM with the project schedule, and the relationship between IM implementation and project performance are significant questions that owners and contractors wish to have addressed.

Therefore, the objectives of this thesis are to develop a workflow driven process for IM, study its current status in the industry, develop an algorithm to identify key interface points and integrate IM with project schedule, and investigate the relationship between IM implementation and project performance. This research is mostly focused on industrial construction, though some data from other sectors is included.

In this thesis, the elements and fundamental definitions of Interface Management are proposed. Then, a workflow driven Interface Management System (IMS) is developed, which lays out a strategy to systematically identify and manage stakeholders' interfaces with the objective of more effective risk management in capital projects.

Once the IMS ontology is defined, the current state of IM in the construction industry is studied through data collection on 46 projects by conducting questionnaire based interviews. The interviewed projects are from different sectors of the industry, with various sizes and geographical locations. This study aims at identifying the project characteristics that lead to formal IM implementation in a project, current common IM practices in the industry, and criteria to assess the status and effectiveness of IM. Furthermore, the relationship between IM implementation and project performance in terms of cost and schedule growth is investigated by employing descriptive and statistical analysis tools. One observation was that those projects that implemented IM at a high level experienced lower cost growth and less variation in the cost growth.

This thesis also proposes a methodology to identify key interface points by recognizing the interdependency relationships between them and creating the Interface Points Network. By analyzing the network, two types of high impact and risk prone interface points are identified. Once the key interface points are recognized, they are linked to the interface milestones on the project schedule, to integrate the cyclic information of IMS with the conventional, sequential planning, scheduling and control paradigms (e.g. CPM). The proposed algorithms are validated on a representative offshore model project.

In summary, the proposed algorithms in this thesis provide a framework to improve project performance through better alignment between stakeholders, enforcement of contract terms, and effective sharing and distribution of risk-related information within formalized interface management framework. The empirical analysis also sets a foundation for construction organizations to assess their IM with regard to the current practices in the industry and a roadmap to improve their IM practices to more mature levels.

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Dedication

To my dear Ehsan,

my parents, Hayedeh and Abdi, and my brother, Amin

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Chapter 1

Introduction

1.1 Background and Motivation

“Many construction projects are becoming more complex and larger in scale than experienced in the past due to advances in technology and operations. These projects involve various stakeholders, globally distributed geographical locations and working cultures, who need to collaborate with one another throughout the project life cycle” (Shokri et al. 2013, 2012). In addition to the globalization and added complexity, the following factors also create challenges in the successful delivery of construction projects:

- “High-value engineering/low-cost centers
- Increased technical complexity
- Requirements for local content
- Complex contracting arrangements
- Competing organizational drivers that lead to poor results or outcomes
- Increased scope management complexity
- A less experienced workforce due to resource constraints” (CII, 2012)

These factors result in a paradigm shift that imposes great challenges in project delivery strategies and management practices. Moreover, working within a condensed schedule is another challenge that these projects are dealing with. The traditional project life cycle, prevalent still for most building and infrastructure projects (Figure 1.1), is relatively linear, and each phase starts once the previous one is complete. However, any changes in the consecutive phases require revisiting elements of previous phases and can involve significant rework and costs.

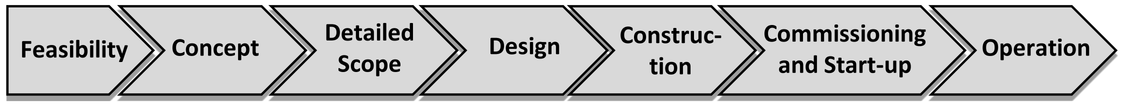


Figure 1.1 Traditional Project Life Cycle (CII, 2006)

In contrast, the industrial construction sector schedules must often be expedited due to market pull on the output of the facility being constructed. Most projects involve simultaneous and substantial overlapping of design, construction and procurement activities, as shown in Figure 1.2. Consequently some iteration is tolerated, and scheduling activities and tasks in this model are more difficult. Typically, projects based on this model are called "fast track projects".

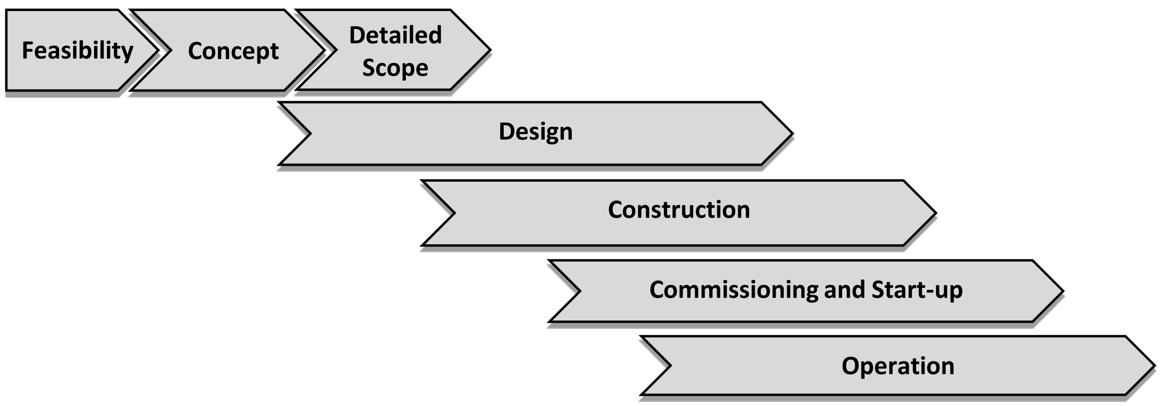


Figure 1.2 Project Life Cycle in Fast Paced Environment

The traditional and customary project planning methods and project management strategies are often inadequate for the fast track projects, because they are "linear, reductionist and deterministic and cannot cope with iterative working practices (especially design) and the complexities in realizing today's engineering projects" (Fellows and Liu 2012). For example, the Critical Path Method (CPM) for scheduling is no longer able to capture and reflect the real-time information and interactive activities for the project plan. "Therefore, effective planning, designing, constructing, operating and maintaining these projects requires good and novel management and sound technological foundation" (Shokri et al. 2011). "In response to these changes, electronic product and process management systems (EPPMS) have emerged to facilitate execution of mega projects by linking project stakeholders over a range of distances via the internet and system servers, formalizing and automating work processes, and automating the document management system" (Shokri et al. 2012).

In addition to the imposed challenges, these projects are prone to various internal and external risks during the planning and execution phases, due to the dynamic and unpredictable nature of construction projects. Risks can result in failure of a project to be delivered safely, on time, within budget and with acceptable quality. Therefore, success of these projects depends on effective management of risks through the projects' whole life cycle. Construction project management is often considered primarily the art of managing risk by experienced managers. Although various techniques have been developed to analyze and manage risks of a project, they are seldom employed explicitly in the construction sector because of their complexity as well as the uncertainty of their effectiveness. In the best cases, risks are identified and assessed at the early stages of a project, particularly via broader "front end planning" and project definition processes; however, further action is required to manage them through the project life cycle, as well as the risks that arise or are discovered during the course of construction. One of the major sources of project risk and failure can be miscommunication between project stakeholders, disciplines, and departments.

To address these complex challenges of multiple, geographically disbursed project stakeholders, and iterative processes and imposed risks, new approaches are being developed. For example, Interface Management (IM) practices are emerging as a major component of EPPMS, and are being adopted in many industrial mega construction projects with the purpose of managing interfaces, improving alignment between stakeholders and reducing project risks, issues and conflicts. This is achieved by providing a framework to identify the common boundaries between project stakeholders, improving coordination between them, facilitating the communication and collaboration channels between them, and automating work processes.

To clarify the potential benefits of IM during the iterative design stage in fast-track projects, an example of topside design in an offshore project is presented. Topside is a major component in an offshore project, which includes processing facility, utilities, living quarter, helideck drilling deck, and other modules, designed and fabricated by different contractors and shipped to the project location for installation. Every single module has its own specifications and weight. An important consideration in topside design and fabrication is to continuously monitor the topside gravity center. This is critical for the topside structure as well as its shipping. Furthermore, it is an important factor to meet the support capacity of the compliant tower without posing significant changes to the tower fabrication, shipping and foundation configuration (Borkar et al. 2006).

After the first design analysis, the dimension, location, and weight of various subcomponents and major elements of the topside would be known. However, any small changes and updates should be coordinated amongst the contractors involved in the topside design, fabrication, shipping and installation. For example, the utilities contractor could be unable to provide the generator following the original design specifications, resulting in a generator with more weight and larger dimensions than the designed one. This issue should be immediately communicated with the other contractors involved in the topside to update the design documents, modify other elements and/or their locations to keep the center of gravity and the topside weight in the acceptable range. The important role of Interface Management is to facilitate the communication and coordination between these contractors, even the ones that are not in a formal contractual relationship.

Despite the potential benefits of IM, it is sparsely addressed in the literature and industry practices. Therefore, this research is initiated by defining a framework for IM, called Interface Management System (IMS), as well as its related elements and definitions. Then, by referring to the proposed framework, the current state of IM in the construction industry is studied and a maturity model for IM implementation is proposed.

An explicit outcome of an IMS could be improving project performance by ability to identify project potential risks and reducing reworks. However, a systematic method is not found in the literature to prioritize interface points in a mega complex project with several hundreds or even thousands of interface points. In this thesis, a network-based algorithm is developed to identify the key interface points and link them to the project schedule to predict schedule-related risks by taking advantage of the circular and real-time information flow of IM. Finally, the impact of IM on improving project performance is investigated.

1.2 Research Objectives

Industry leaders in construction mega projects believe that interface management improves alignment between parties and reduce project issues and conflicts (Archibald, 1992, 2003). However, recognizing interfaces, monitoring interface progress and potential risks are significant challenges that the owners and contractors continuously struggle with. In addition, the effect of interface management on reducing and managing project risks and its know-how has not yet been addressed. In the proposed research, the hypothesis is “implementing interface management system (IMS) will lead to better performance in mega projects.” Based on the above discussion, the objectives to address the hypothesis are:

1. Develop a workflow-driven process for Interface Management (IM) in construction mega projects involving:
    - IM related definitions and elements
    - Interface management attributes
    - Definition of a workflow-driven process for IM system (IMS)
2. Investigate and evaluate the current status of IM in the construction industry involving:
    - The project characteristics leading to IM adoption in projects

- Current IM practices in construction projects
- Development of an IM maturity model

3. Develop a methodology to integrate IMS and project schedule in order to effectively manage project risks involving:
   - A network of interface points
   - Key interface points using graph theory concepts
   - A robust process to link key interface points to the project schedule as milestones
4. Investigate the relationship between IM adoption and project performance, involving:
   - The relationship between IM adoption and project cost growth, schedule growth, and other performance factors

1.3 Research Scope

IMS will be implemented within Electronic Product and Process Management System (EPPMS) framework. EPPMS, as a core tool in capital project execution, links project stakeholders in different geographical locations with the focus of "minimizing response time, maximizing choices" (Shokri et al. 2011). Through EPPMS implementation, "a web of project data can be created to automate processes, manage knowledge and assure process quality" (Shokri et al. 2011). EPPMS includes four main aspects of (1) improving supply nexus management, (2) reducing project risk through effective interface management, (3) automating project change management and (4) knowledge management. These four aspects are illustrated in Figure 1.3.

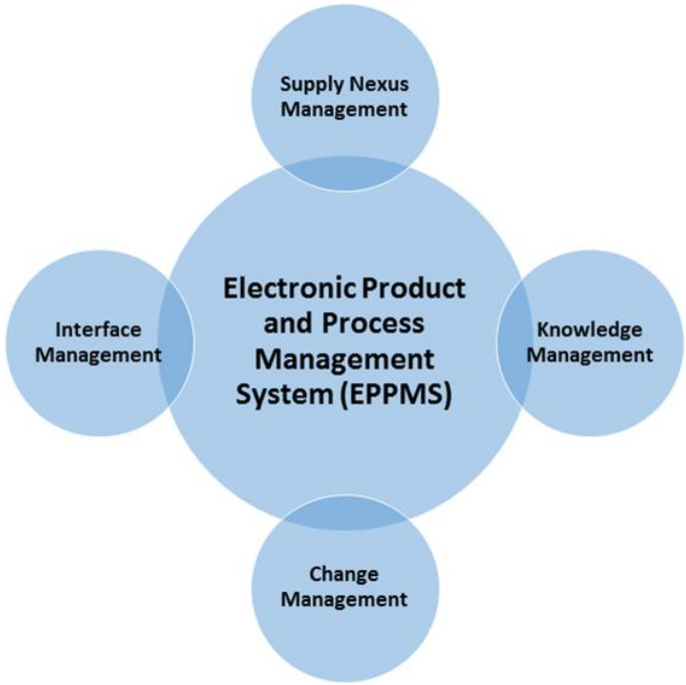


Figure 1.3 EPPMS Framework

EPPMS and IM are applicable within a wide range of projects and different sectors. However, projects with distributed stakeholders and project team, higher dollar value and more technical and organizational complexity can benefit more from the capabilities of IMS. Generally these projects are considered complex capital projects with the entire value of over 1 Billion dollars.

In this research, to assess the current state of IM in the construction industry and impact of IM on project performance, several projects with entire dollar values, ranging from $100 million to over $10 billion, are studied. Most of these projects were greenfield, and from different sectors of the industry, including industrial, infrastructure, transportation, and building sectors. Furthermore, for validation of the proposed method to identify key interface points and link them to the project schedule, the study employs a synthesized, simplified, and realistic representation of a full scale off-shore project. The main reason was due to proprietary considerations by their owners. However, the method is expandable to a full scale project with several hundred of interface points.

1.4 Research Methodology

The research presented in this thesis was motivated by the hypothesis stated in Section 1.2 that the execution of mega projects can be facilitated and improved, considering their increasing complexity. The research methodology is shown in Figure 1.4. As a first step, a comprehensive literature review has been done on the risk management of construction projects. The literature review reveals that a significant amount of construction project risks are because of miscommunication and ineffective management of collaboration between project parties and elements. Therefore, the research scope has been evolved to manage project risks through implementation of interface management principles. The literature review includes definition of interface and its categories, interface management and its application in construction project, responsibility allocation tools, fundamentals of risk management, and techniques of assessing risks.

In a close collaboration with Coreworx Inc., the research requirements, a comprehensive model of construction Interface Management System (IMS), and a methodology to determine the key interface points and linking them to the project schedule are fully developed. The model was reviewed by academic and industry partners to assure its feasibility and applicability. As well, collaboration was initiated with the Construction Industry Institute's (CII) Research Team (RT) 302: Interface Management, to analyze and study the current state of IM in the construction industry. The team studied and interviewed 46 projects. The interview results were analyzed and synthesized to describe the current status of IM, identify project characteristics to implement formal IM, and provide a maturity model for IM implementation in a project. Furthermore, the relation between IM implementation and project performance improvement was investigated.

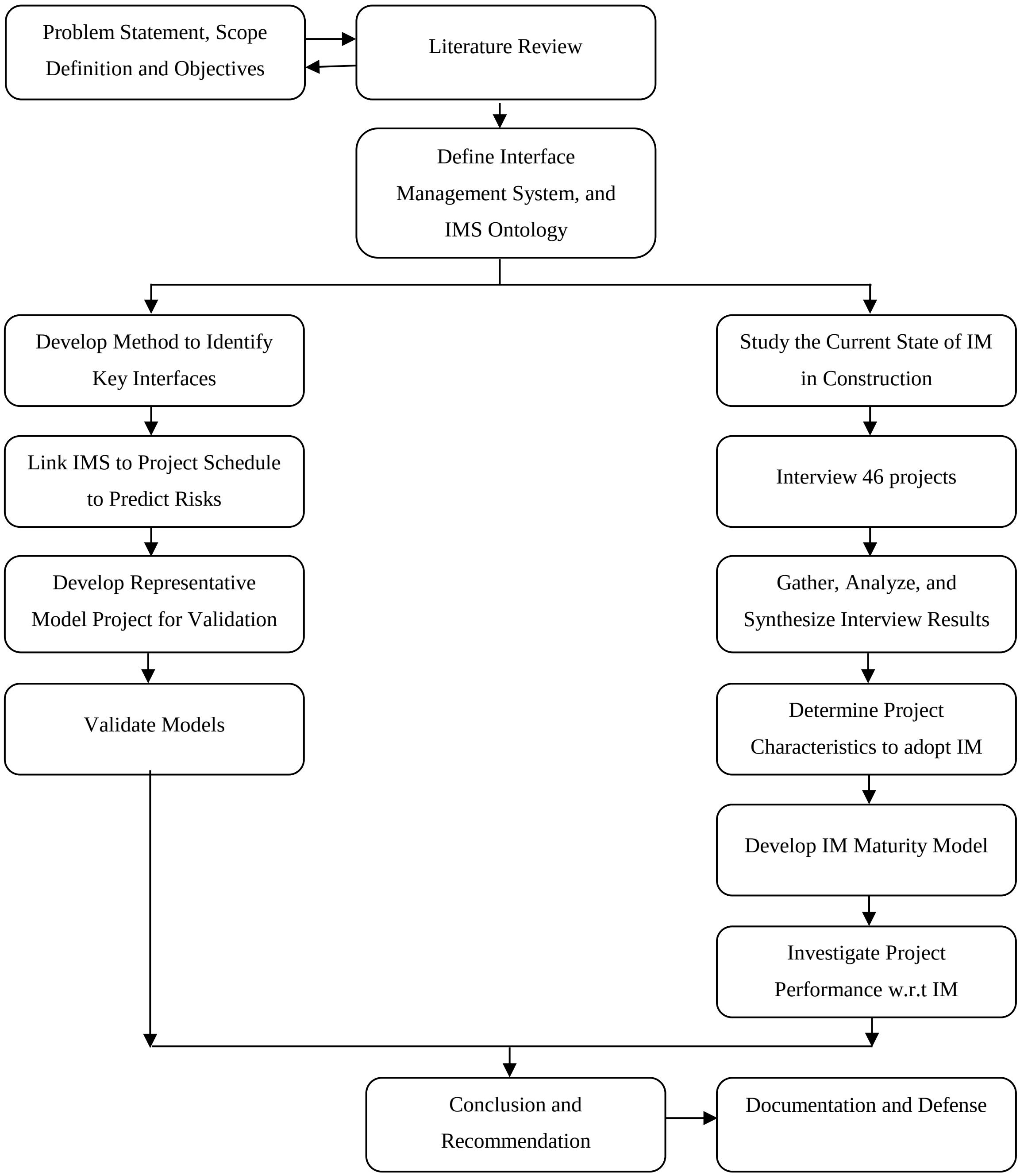


Figure 1.4 Research Methodology

1.5 Thesis Structure

This thesis is organized in eight chapters. An overview of the research problem, motivation, objectives, scope, and methodology of the research are provided in Chapter 1. Chapter 2 provides a literature review of the background knowledge on risk management principles in construction, different methods of risk assessment, history of IM, IM practices in construction, interface definition, and categories. Since this thesis is a combination of empirical and comprehensive study on the current practices in the construction industry and theoretical methodologies for IM improvement, Chapter 3 presents the research vision which is an overview on how the research efforts are accomplished and how they are connected. The knowledge gaps found in the literature are also mentioned in this chapter to give a strong justification on the research efforts.

In Chapter 4, the Interface Management ontology in terms of the interface definitions, attributes and different categories, as well as a workflow driven IMS process are described. Chapter 5 starts with the questionnaire outline that is used throughout the interviews to study the current state of IM in the construction industry. In addition, the descriptive and statistical analysis of interview results are presented in this chapter to define the project characteristics needed to formal IM implementation and IM maturity level in the construction projects.

In Chapter 6, a graph-based algorithm is proposed to identify key interface points by analyzing the interdependency relationships between them. It is followed by a robust process of mapping key interface points to the project schedule to anticipate and determine project schedule-related risks. In Chapter 7, the relation between project performance and IM implementation is studied. The projects are divided into two groups of low- and high-level IM implementation, based on their IM maturity level, and the ANOVA test is used to investigate if there is a significant difference between these two groups in terms of cost and schedule growth, as well as growth in the management, engineering and construction hours. Finally, Chapter 8 includes the conclusion, contributions and limitations of the research study, as well as recommendations for potential future development opportunities.

There are 5 appendices included in this thesis. Appendix A represents sample of interface point and interface agreement forms. Appendix B shows the questionnaire used in the interviews for the empirical analysis of IM state in construction industry. Appendices C, D, and E illustrate the descriptive and statistical analysis for the growth in management, engineering and design, and construction hours, respectively.

Chapter 2

Literature Review

Construction projects are becoming more complex and large in scale due to advances in technology and operations. They tend to be delivered remotely, involving several contractors with different geographical locations and working cultures, interacting with one another through the project life cycle. As a result, these projects are prone to various internal and external risks during the planning and execution phases. Risks can result in failure of a project to be delivered safely, on time, within budget and with acceptable quality. On the other hand, inefficient management of project communications and interfaces may also result in added cost or time of the project during the project execution, or may result in project failures after it has been delivered. Therefore, success of these projects depends on effective management of risks through the projects' whole life cycle, and efficient management of the involved parties and their interfaces.

This chapter synthesizes the studies in risk management and interface management in construction industry, and sets a background to point out the knowledge gap and the backbone of the research study.

2.1 Project Life Cycle and Front End Planning

Front End Planning (FEP) is considered the single most important process in the capital project life cycle (CII, 2006). According to CII, FEP is defined as "the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project" (CII, 2006). Its focus is on creating a strong, early link between the need of the business or mission, project strategy, scope, cost, and the schedule and on maintaining that link unbroken throughout the project life (CII, 2008). Industry research demonstrates that projects with rigorous FEP perform over 10% better in terms of cost, 7% better with respect to schedule performance, and 5% better relative to change orders. Likewise, for major capital projects of more than $1 billion in total installed cost, a 10% improvement in cost performance, directly attributable to an intensive FEP effort, represents $100 million in potential savings (Gibson, 2010). Front End Planning and its relation to the whole project life cycle are illustrated in Figure 2.1.

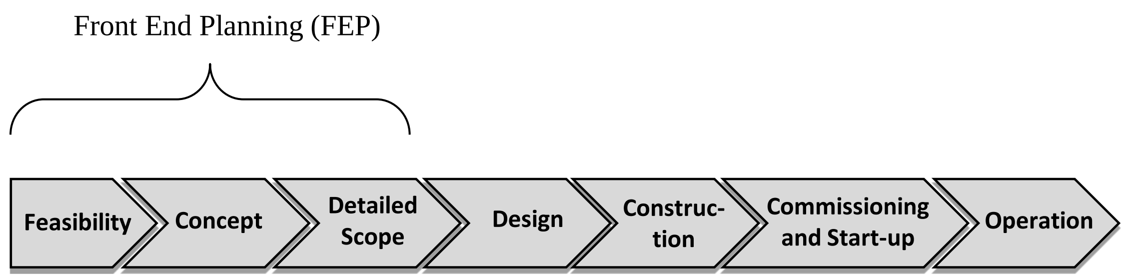


Figure 2.1 Project Life Cycle

Several rules are recommended to be followed by construction companies for successful implementation of Front End Planning (CII, 2006). After developing a well-defined Front End Planning process, the project scope should be completely outlined before moving to the design and construction stages. This process should be accompanied by analyzing the existing conditions at the project site, team building and alignment, and involvement of project stakeholders and employing appropriate front end planning tools. By active involvement of owner and contractors, risks associated with a project, its location, and new technology should be identified.

2.2 Risk Management in Construction

Risk management is an important factor in every system success. Through the risk management process, the uncertain and surprise events could be anticipated and appropriate activities can be developed to reduce their exposure. It also allows for the organization to effectively manage the contingency and allocate risks among parties.

2.2.1 Definition and Classification of Risk

The word “risk” has been used in the literature, but there is still not a clear and common definition. Risk is generally used in different meanings like hazard or uncertainty. The uncertainty brings up both positive and negative aspects of an event (PMI, 2008). Most of the literature considered risk with only its downside such as losses or damages (Al-Bahar and Crandall, 1990). In some research studies, the difference between risk and uncertainty is about the estimation of likelihood of an event. In the risky situations, the likelihood of events can be described reasonably. However, when dealing with uncertain situations, the potential impact cannot be defined with the known probability distributions (Haimes, 2005). To generalize, risk is considered an uncertain event/condition that, if it occurs, has a positive/negative effect on a project objectives, including time, cost, scope, or quality. In construction, contractors perceive risk as the likelihood of the unforeseen factors occurring, which could adversely affect the successful completion of the project in terms of cost, time and quality (Akintoye and MacLeod, 1997).

Risks are classified according to different criteria. Some literature classifies risk based on their sources. Tah and Carr (2001) used the hierarchical risk-breakdown structure (HRBS) to classify risks. In this study, risks are considered internal or external. The internal risks are either local or global. Local risks are specific to each work package and are related to labour, plant, subcontractor, materials, and site condition. The global internal risks are related to the whole project and include client, design, construction, environment, etc.

Zavadskas et al. (2010) used a similar approach to classify risks. They mentioned that the construction project risks are defined in three groups: external, internal and project risks. External risks include the factors that are imposed to the project from outside sources, e.g. political risks, economic risks, social risks and weather risks. Project risks are related to the project performance criteria such as time, cost, work quality, construction and technological risks. Internal risks include resource risk, project member risk, construction site risk and document and information risks.

2.2.2 Risk Management Process

Since the project successful completion is highly affected by risks, managing risks are of a serious importance. Risk management is a systematic approach to define and handle risks. It is the process of identification, assessment and prioritization of risks, followed by necessary actions to monitor, control and reduce the negative aspects of risks. In the literature (Tah and Carr, 2001; Al-Bahar and Crandall, 1990; Klemetti, 2006; Haimes, 2005), several steps are proposed for the risk management process, but all have the following four steps in common:

- Risk identification
- Risk Analysis and assessment
- Risk handling and response management
- Risk monitoring

2.2.2.1 Risk Identification

Risk identification is the first step of risk management. During this step, the sources, nature, and associated uncertainty of risks are identified. Risk identification is an iterative process (PMI, 2013), and is defined as "the process of systematically and continuously identifying, categorizing, and assessing the initial significance of risks associated with the project" (Al-Bahar and Crandall, 1990). Risks are generally identified through the participation of the project manager, project team members, risk management team (if assigned), subject matter experts from outside the project team, stakeholders, and risk management experts (PMI, 2013). The risk identification process can be accomplished by performing site visits, using checklists, obtaining input from key project participants, holding brainstorming sessions with an assembled risk team, interviewing experienced project stakeholders, performing root cause analysis, and extracting information from a repository of risk data compiled from previous experiences. (Tah and Carr, 2001; Al-Bahar and Crandall, 1990; PMI, 2013)

2.2.2.2 Risk Analysis and assessment

Once the risks are identified, they should be quantitatively and/or qualitatively assessed to provide managers with a tool to define the response strategies. “The key benefit of this process is that it enables project managers to reduce the level of uncertainty and focus on high-priority risks” (PMI, 2013). This step incudes two tasks: “(1) assessing the likelihood of what can go wrong through objective or subjective probabilities, and (2) modeling the relationship between the sources of risks and their impact on the system” (Haimes, 2005). “Risk analysis and assessment process is a link between systematic identification and rational management of the significant ones” (Al-Bahar and Crandall, 1990). “In fact, quantifying the probabilities and magnitude of adverse effects and their myriad consequences is the heart of system modeling” (Haimes, 2005). Data for assessing the probability and severity are mostly subjective, and are based on the assessors intuitive, and similar experiences. The general risk assessment formula is:

$$Risk = Probability \times Impact$$

As mentioned, risks can be assessed through quantitative and qualitative methods. The quantitative method requires analysis of historical data to get probability and severity of occurrence, which is not always available or feasible to acquire. Therefore, the qualitative method is also applied to assess risk. The probability-impact grid matrix is a simple tool to qualitatively analyse risks. Figure 2.2 illustrates a sample of a probability-impact grid. A numeric scale could also be used in the matrix, but without underlying data its meaning would be unclear and even misleading.

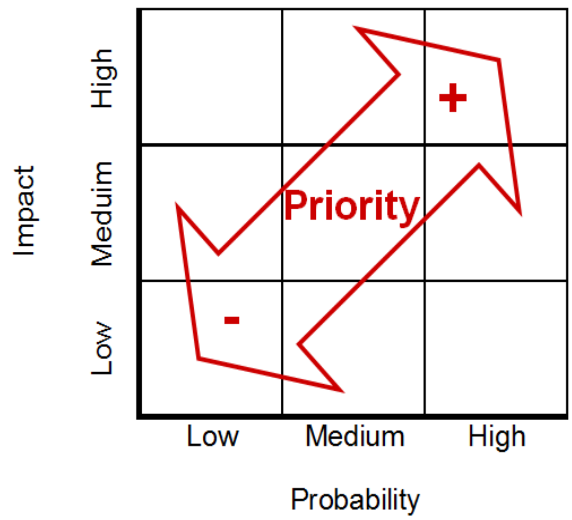


Figure 2.2 Sample of Probability-Impact Grid

After assessing the risk index (the cell in the grid), the risk factors are prioritized accordingly. The higher risk indices in the quantitative method are those of high priority, and need further action. In the probability-impact matrix, the top right corner indicates risk factors with higher priority, and the lower left corner specifies the ones that will be taken care of, only if there are sufficient resources.

Since quantitative risk analysis needs detailed analysis of historical data, it is both time and cost consuming. Therefore, project risks could be prioritized by employing qualitative risk analysis, and then the high priority risk may be further analysed using quantitative methods. In fact, qualitative risk assessment lays the foundation for performing quantitative risk analysis (PMI, 2013). Decision trees are mentioned as powerful tools to quantitatively assess risk and estimate the expected monetary value (PMI, 2013).

2.2.2.3 Risk handling and response management

"This step is decision-making step, where all costs, benefits, and risks are traded off to determine the level of acceptability of risk" (Haimes, 2005). After the assessment of risks is done, the risk management team would choose risks with higher risk measure. The objective of this step is to completely eliminate the risk or to reduce the adverse effect of risk as much as possible. Risk response planning includes determining the activities to reduce the risk consequences on a project and improve the opportunities. Generally, five types of responses are suggested to deal with risk: (1) risk avoidance, (2) risk mitigation, (3) risk transfer, (4) insurance, and (5) accept. (Al-Bahar and Crandall, 1990)

1. Risk avoidance: This strategy involves decision making in order to eliminate any threats or protect the project from their negative impacts (PMI, 2013). The most radical avoidance strategy may cause a project not to go ahead or to bid with a high price. Therefore the trade-off to employing this strategy could lead to reduced exposure to opportunity while avoiding risk, which may result in reduced revenue, cost savings opportunities, and chances to expand core competency.
2. Risk Mitigation: This strategy is about managing the adverse effect of risk by reducing its probability of occurrence or severity of impact to an acceptable threshold limits (PMI, 2008, 2013). Since efforts to reduce risk impact or probability are significantly more cost effective than dealing with risks after they occur, risk mitigation is as an important and the most proactive way of dealing with risks. Generally, attempt to reduce the probability of occurrence is more common than reducing the severity of impact. Examples of risk mitigation strategies are adopting less complex processes, conducting more tests, choosing a more stable supplier, or designing redundancy into a system (PMI, 2013)
3. Risk transfer: This strategy involves fully or partially transferring the negative impact of risk and ownership of the response to another party. Transferring risk does not eliminate the adverse impact of risk; in fact, another party becomes responsible for risk management. Risk transfers are possible through negotiation between project parties, including owner,

contractors, sub-contractors and materials/equipment suppliers. Common tools for transferring risk may include insurance, warranties, performance bonds and contracts (PMI, 2013). In various types of contracts, different parties are responsible for specific risks. As an instance, in lump sum or fixed cost contracts, seller is responsible for managing the negative impact of risks (PMI, 2013). Whereas, in cost type contracts, buyers are responsible for managing the negative impact of risks. In public-private partnership (PPP) contracts, the responsibility of managing negative risks is shared between owner and contractors.

4. Insurance: Insurance is the most direct method of transferring risk to a third party. In fact, in many projects purchasing insurance is a requirement of the business agreement. Insurance only transfers the potential negative monetary consequence of the risks to the third party; however, in other forms of risk transfer strategy the responsibility and ownership of the risk is also shifted to the third party.
5. Accept: This strategy is accepting the risk and dealing with its potential negative consequences when it occurs. This strategy is undertaken when it is not possible to eliminate or reduce the risk impact or probability of its occurrence, or when risk mitigations methods are not cost effective (PMI, 2013).

2.2.2.4 Risk monitoring

The final step of risk management process is to decide if the risk control strategy was effective or not. It also provides the risk management team with information on efficiency of the risk identification and assessment steps. Any feedback would go to the other steps. An overview of risk management process is illustrated in Figure 2.3.

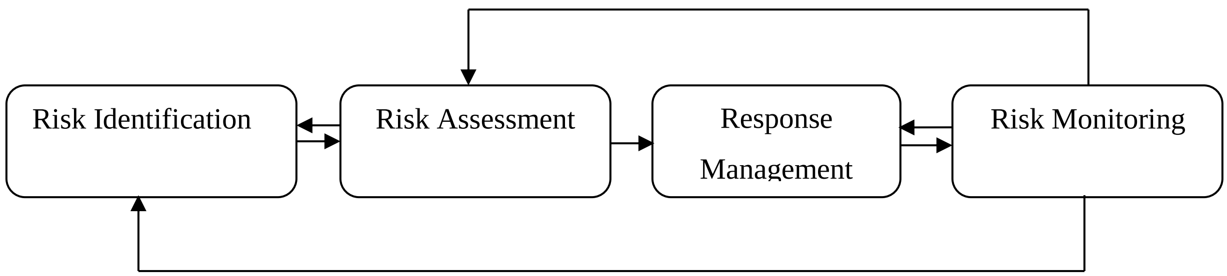


Figure 2.3 Overview of Risk Management

2.2.3 Risk Classification and Risk Sources in Construction Industry

Several studies have addressed the risks associated with construction projects and classified them into various categories. Thorough analysis of literature reveals the following categories and the potential variables for each category of construction risk (Tah and Carr, 2001; Zavadskas et al. 2010, Cohen and Palmer, 2004; Edwards and Bown, 1998; Dey, 2009, Al-Bahar and Crandall, 1990, Nasir et al. 2003).

- Environmental: Weather, earthquake, humidity, lighting, fire, seasons, flood
- Economic: Interest rate, inflation, recession
- Political: Community attitude, relevant low and regulation change, wars and civil disorders, permits and approval
- Labor: Labour union, labour strike, availability of labour, proficiency and skill level, injuries, productivity, wage scale
- Owner: Owner type, proficiency, financial stability, payments
- Contractors/subcontractor: Prequalification, proficiency and expertise, new technology, efficiency, contract type, equipment quality and availability, critical items import

- Design and technical: Tight schedules, design team efficiency, change of scope, design changes, design complexity, design specification, design documents
- Geotechnical: Archeological survey, local geotechnical history, geotechnical consultants, unexpected conditions
- Construction site: Location, external site activities, traffic conditions, on-site construction, traffic permits and approvals, working conditions
- Financial: project cash flow, owner financial history, contactor/subcontractor stability
- Material/equipment: delivery methods, security issues, safety of hazardous material, availability (delay, shortage, …)

Several reasons are affecting the mentioned risk categories, which are: (Zou et al, 2006, Zou et al, 2007, Dikmen et al., 2008, Jaafari, 2001, He, 1995)

- Poor management of subcontractors
- Lack of coordination between project participants/ Poor relation between parties
- Lack of concurrent communication framework between project participants
- Unavailability or delay in material supply
- Insufficient study of the project information and conditions
- Inadequate or insufficient access to information
- Vagueness of contract clauses
- Design variations
- Incomplete approval and other documents
- Unfamiliarity of local regulations and requirements
- Differences in legal relationships between project partners

Thorough analysis of the variables affecting construction risks reveals that a significant portion of project risks are because of miscommunication and misalignment between project team, stakeholders, and physical elements.

2.3 Communication Management in Construction

Project communication management is defined as, “the process that is required to ensure timely and appropriate planning, collection, creation, distribution, storage, retrieval, management, control, monitoring, and the ultimate disposition of project information” (PMI, 2013). Effective communication management is recognized as a critical management area for project success, yet a challenging one (Hwang and Ng, 2012; Bourne and Walker, 2004; Nitithamyong and Skibniewski, 2006). A major portion of project managers’ time is allocated to communicating with their team members and other stakeholders. Communication between project participants can be either internal or external, formal or informal, vertical or horizontal, official or unofficial (PMI, 2013). Due to the importance of communication between stakeholders in successful delivery of the project, the Project Management Body Of Knowledge (PMBOK) (PMI, 2013) sets a guideline for communication management in a construction project. This guideline includes three steps:

1. Plan communication management: During this step, the appropriate approach for project communication is identified, which is dependent on the stakeholder’s information needs and requirements, and the organization’s available assets. Communication planning should be done at early stages of the project life cycle to allow appropriate allocation of budget for this purpose (PMI, 2013).
2. Manage communications: “Manage Communications is the process of creating, collecting, distributing, storing, retrieving, and the ultimate disposition of project information in accordance to the communications management plan” (PMI, 2013). Project information could

be managed and distributed through hard-copy document management tools (e.g., reports, letters), electronic communication management tools (e.g., email, fax, phone), or electronic project management tools (e.g., portals, web-based systems) (PMI, 2013).

3. Control communication: In this step, project communications are monitored and controlled throughout the project life cycle to ensure effective distribution of information. Using information management software assists top managers to effectively distribute information between stakeholders and capture reports.

Although project communication management is defined as an important aspect of project successful delivery, construction projects are still facing risks that are caused by miscommunication between their stakeholders, especially in complex projects with several geographically distributed stakeholders. As well, PMBOK includes little detail on communication workflows, modes and processes. The negative impact of miscommunication is associated with higher cost in mega projects, which involve several stakeholders with geographical distribution.

2.4 Interface Management in Construction

Taking into account the increasing size and complexity of construction projects, significant fragmentation and involvement of several stakeholders, globalization, fast-paced project lifecycle, and major risk variables caused by these factors, management of construction mega projects faces significant challenges. Furthermore, “the peculiarities of building construction — poorly controlled building environment, complexity of construction, temporary multi-organization, and subcontracting and interdisciplinary nature — increase the number and types of interfaces in a project, and cause various interface issues” (Chen et al., 2006). Despite these developing challenges, on-time, on-budget delivery still remains a priority and a constant struggle for industry practitioners. In response to these challenges, interface management (IM) has recently emerged as a critical tool for greater oversight and success of construction megaprojects (Alarcon and Mardones, 1998; Al-Hammad, 2000; Nooteboom, 2004; Pavitt & Gibb, 2003; Shokri et al., 2011; Yun et al., 2012). Interface management is claimed to be “an effective tool in proactive avoidance or mitigation of any project issues, including design conflicts, installation clashes, new technology application, regulatory challenges, and contract claims, and would enhance the successful delivery of megaprojects” (Nooteboom, 2004, INTEC engineering report).

2.4.1 Origin of Interface Management

IM was first presented as a concept in 1967, defined based on systems approach, to analyze the contact points between relatively autonomous interacting organizations, and the corresponding interorganizational problems, within an aerospace project and an electric power pool project (Wren, 1967). “In the 1960s and early 1970s, IM generally referred simply to ensuring that the system interfaces matched (i.e. had the same specification, were nor missing any equipment, data, etc.)” (Morris, 1983). However, in the 1980s, in addition to the mentioned objective, IM was used to identify organizational, managerial and technical interfaces and to actively manage their interrelationships (Morris, 1983). In the same era, several research studies emphasize the identification of interfaces and managing them appropriately in the context of system and project integration (Archibald, R., 1992; Stuckenbruck, L. C. 1988). Despite its long history, IM has not been fully utilized in engineering and construction practices, mainly due to a lack of the necessary technological infrastructure required to organize and control effective amounts of interfacial information and data. However, due to the significant advancement in information and communication technologies in the last two decades, IM is slowly being adopted by industry in dispersed and varying forms. Several corporations initiate IM group within their management practices, developing interface manager and interface coordinator roles. The examples of IM procedures are implemented within the Mustang Engineering (Shirley and James, 2006) and Foster

Wheeler (Collins et al. 2010). IM topic was also studied by several researchers in the last decade to define the elements of IM, and its application in the construction projects. In this section, a brief description on IM elements, procedure and applications is presented based on the literature.

2.4.2 Definitions and classifications of Interfaces

One of the initial definitions of interface in the project management context was based on systems approach: "interfaces are the contact point between relatively autonomous organizations which are interdependent and interacting as they seek to cooperate to achieve some larger system objectives" (Wren, 1967). According to this definition, various sub-organizations are collaborating through interfaces to satisfy the goals of the system and their own. However, in general, interfaces are considered as the boundaries between independent but interacting systems, organizations, stakeholders, project phases and scopes, and construction elements (Chen et al., 2007; Healy, 1997; Lin, 2009; Lin, 2012; Morris, 1983; Stuckenbruck, 1988; Wren, 1967).

Interfaces are generated by dividing of work into sub-works which should be executed by different organizations or people (Stuckenbruck, 1988). Since they are created according to the project breakdown strategies and characteristics, they may have several feature and attributes. However, it has been always a challenge to define the types of interfaces due to their complexity, natures of different projects, multi-organizational composition of project teams, and lack of appropriate documentation procedures (Chen et al. 2010).

In general, interfaces are considered either internal (within a single contract or scope of work) or external (between contracts or scopes of work) (Chen et al., 2007; Healy, 1997; Lin, 2009). Interfaces are further classified into different categories by researchers to serve specific purposes. For instance, Pavitt and Gibb (2003) divided interfaces into three categories: physical, contractual, and organizational:

- *Physical interfaces*: these are the actual physical connections between two or more construction elements or components. This kind of interface is identified during the design stage, and its complexity is dependent upon the detailed design. Example: two pipes are connected to each other.
- *Contractual interfaces*: they occur where two or more stakeholders are interconnecting through the contractual agreement. For example, in the construction supply nexus management, every two work-packages create a contractual interface, which could be a physical interface, as well. These interfaces are defined in the planning phase and should be monitored throughout the project lifecycle.
- *Organizational interfaces*: they are the interactions between various parties involved in a construction project (Pavitt and Gibb, 2003). They also include the relationship between individuals and parties involved in the construction process from its initial conception to its final handover. Efficient management between these parties is essential for the successful completion of a project (Pavitt and Gibb, 2003).

In addition to these categories, functional and resource interfaces are introduced by Chen et al. (2007).

- *Functional interfaces*: they are the functional requirements/influences presented by one functional element/system upon another function element/system.
- *Resource interfaces*: they represent the interaction between equipment, labour, materials, space, or information necessary to design and construct the product and its components.

Social interfaces are also introduced to capture the interactions of human involvements in complex projects. To define how the project parties will work together through social interfaces, social contracts are generated to clarify the approaches for consultation, decision making, dispute resolution, and re-evaluation and renegotiation (Crumrine et al, 2005).

Furthermore, the interfaces could be categorized as static or dynamic, depending on the ongoing relationship between sub-systems, or the project breakdown pattern (Morris 1983).

- *"Static interfaces*: they are on-going and are not a function of the way the project develops but represent relationships between on-going subsystems (e.g. engineering and procurement)" (Morris, 1983)
- *"Dynamic interfaces*: they arise only as a function of the pattern of activity interdependencies generated by the way the project develops" (Morris, 1983). These interfaces are really important, because they are time-dependent and the early interfaces have a marginally significant effect on the subsequent ones.

2.4.3 Interface Management Definition

Interface Management is the process of managing communications, responsibilities and coordination of project parties, phases, or physical entities which are interdependent (Nooteboom, 2004). Interface Management is an ongoing process and should be considered dynamic throughout the life of project with the goal of maintaining the balance between scope, time, cost, quality, and resources (Crumrine et al, 2005). The supporting reason is that as a system grows, its interfaces change; new relationships are established and system linkage must assume new patterns and structures (Wren, 1967).

A generic approach is introduced for Interface Management, which includes four steps (Lin, 2009; Caglar and Connolly, 2007; Mortaheb et al., 2010; Pavitt and Gibb, 2003):

- *Interface Finding and Identifying*: Checking for new or existing interfaces of the projects.

- *Interface Communicating*: Requesting, responding and tracing the needed information/tasks between inter-related parties.
- *Interface Recording*: Recording of all information about the identified interface.
- *Interface Closing*: Closing action when the interface is reconfirmed without further identification or tracing. (Lin, 2009)

2.4.4 Applications of Interface Management in Construction Industry

2.4.4.1 General Applications of Interface Management

Several studies, following the IM generic approach, proposed procedures for IM in different construction stages. They employed various tools and techniques to improve IM. As an example, IM was used on a five billion dollar oil and gas recovery and processing project in the United Arab Emirates to monitor and control organizational interface points (Collins et al., 2010). In another example, an IM approach was defined for China's Build-Operate-Transfer (BOT) projects, by identifying the 6 main factions of BOT projects, and their correlation with interface factors (Chan et al. 2005).

In a general systematic approach, an Interface Object Model (IOM) was introduced to "systematically identify interface modeling objects, incorporate them into hierarchical data structure, and to define data dependencies for applications" (Chen et al., 2010). Here, the interface object hierarchy is categorized into physical, functional, contractual/organizational and resource interfaces. Each category further is broke down considering the context of application. For example physical interfaces include three categories of connected, in-contact and not-in-contact. And for each category, more subcategories are defined. The IOM model was tested by managing physical interface objects for a foundation wall installation.

In other applications, Interface Management models were used to improve the performance of one or more discipline in a project. For example, Interface Management was applied to improve project safety and reduce the effect of hazardous processes. After the interfaces are identified, they are assessed based on their criticality with regard to their effect on process safety, quality, environment, and reputation. Then, the result is summarized in the Interface Matrix, which includes the information source on the column, and information receivers on the row. The criticality of the information is mentioned in the cell related to the specific source and receiver. Figure 2.4 illustrates a sample of the Interface Matrix. Later on, the efficiency of the current interface management process is evaluated at each interface according to several criteria, including roles and responsibilities, communication methods, document management system, cultural issues, and etc. When the critical interfaces are identified, a standard protocol will be developed for managing them. (Kelly and Berger, 2006)

	Information receiver				
	Receiver 1	**Receiver 2**	**Receiver 3**	**.....**	**Receiver n**
Information Source	Filed operator 1 (P)	Panel operator for other unit (P)	Permit office (P)		
Control room operator	Fire Chief (P)	Environmental coordinator	Plant safety officer		
Emergency coordinator	Chemical company order desk				
Purchasing agent					
⋮					
Source n					

Figure 2.4 Example of Interface Matrix (Kelly and Berger, 2006)

Chen et al. 2007, used Interface Management as a facilitator for implementing lean construction and agile project management, through managing and controlling boundaries between project teams. This integrated approach assists in defining the human dynamics and communication strategies in agile project management (Chen et al., 2007).

IM was also implemented to create effective and timely communication between MAC (Main Automation Contractor) and MEC (Main Electrical Contractor) (Caglar and Connolly, 2007). Here, the Interface Management process is designed in such a way to provide a unified method for documentation and tracking of exchanged data between parties. In this approach, the communication is done through developing interface agreements between interested parties. Interface agreements are two-sided arrangement between parties, and include a set of information needed from one party, and should be provided by the other party. The needed information should be clearly defined, specific, detailed, and received by a specific date. Interface agreements could arise from several sources like members of a project team, contract requirements, responsibility matrices, customer requirements, third party vendors/suppliers and other project stakeholders (Caglar and Connolly, 2007). Another example is creating error-free communication between architecture, mechanical and electrical engineering, and air conditioning systems engineering (Siao et al. 2011)

Some studies have addressed interface issues considering one or more aspects of interface type or attribute. Most are focused on the interfaces between two groups of project stakeholders, such as contractors and owners (Al-Hammad 1990), contractors and subcontractors (Al-Hammad 1993), owners and designers (Al-Hammad and Al-Hammad 1996), design and construction (Alarcon and Mardones, 1998), and an MAC (Main Automation Contractor) and an MEC (Main Electrical Contractor) (Caglar and Connolly 2007). Finally, Fellows and Liu (2012) analyzed and addressed organizational interfaces caused by fragmentation.

2.4.4.2 Web-based Interface Management

Some studies took advantage of web technology to develop and improve IM practices at design and construction phases of the project. A network-based interface management model was proposed by Lin (2009, 2012) by using portals and web-based systems. In the network based interface map (NBIM), once the interface events are identified, their attributes including topic, date, description, owner, ID, interface packages, record, responds, and interface partners are described. This tool has several modules for recognizing interface authorities, progress monitoring, alert management, online communication, document management, and reporting (Lin, 2009; Lin 2012). The objective of NBIM is to improve construction processes and minimizing rework and total project duration. NBIM was applied and verified on a Taiwanese construction office building project.

In a similar approach, a web-matrix based interface management (WMIM) was developed to enhance IM during the construction phase of a project (Siao and Lin, 2012). WMIM is integrated with a multilevel interface matrix, which “includes a construction event matrix, an interface presentation matrix and a construction interface network” (Siao and Lin, 2012). Multilevel interface matrix is created through four steps: (1) define assignments for project participants in construction event matrix, (2) define direct interface relation between participants, (3) present interface issues in an interface presentation matrix, and (4) present whole interface conditions between participants. The proposed methodology was tested on a pilot project by a Taiwanese contractor on a high-tech building project and the results verified more effective IM during the construction phase.

Another web-based IM was developed by Senthilkumar et al. 2010 to improve IM during design phase. The design interface management system (diMs) is integrated with dependency structure matrix, and is implemented in six steps: (1) identification of project entities, (2) identification of physical interfaces between these entities, and (3) identify the interfacing teams for every component and subcomponent, (4) record the identified interfaces and related issues in the design interface agreements (DIA), (5) link interfaces with the drawings, and (6) monitoring DIAs.

2.4.5 Causes for Poor Interface Management

Several studies emphasized that implementing Interface Management at the early stages of the project will result in higher performance in terms of project scope, time, and schedule (Nooteboom, 2004; Caglar and Connolly, 2007; Chen et al., 2007). However, not all of the Interface Management implementation practices were successful. Several researchers analyzed the factors that lead to interface problems among project stakeholders, and result in Interface Management failure during planning and execution phases (Huang et al., 2008; Crumrine et al, 2005; Lisong, 2009, Mortaheb and and Rahimi 2010; Weshah et al. 2013). Some of these studies employed factor analysis methodology to categorize the interface problems in construction (Huang et al., 2008; Weshah et al. 2013).

The causes for Interface Management failure and interface-related problems could be because of two factors: Know-how and environmental factors. Know-how factors are the result of management, experience and coordination problems.

- *Management problems*: issues implied to the project as a result of managerial deficiencies
    - Lack of communication and coordination between project parties (Huang et al., 2008)
    - Inefficient decision-making process (Huang et al., 2008, Mortaheb et al., 2012)
    - Incomplete design or project plan (Huang et al., 2008)
    - Poor definition of project interfaces
    - Mismanagement of responsibilities
    - Poor social interface management (Crumrine et al, 2005)
    - Cultural conflicts (Lisong, 2009)
- *Experience problems*: occur if the project parties lack flexibility in dealing with the project:
    - New technology (Huang et al., 2008)
    - Changes to the project scope (Huang et al., 2008)
    - Inaccurate project budget information and inconsistency between project requirements and budget (Huang et al., 2008)
    - The inconsistent interest and targets (Lisong, 2009)

- *Coordination problems*: issues which are due to the lack of a management system for planning and scheduling, updating project information, and creating collaborative environment between project parties:
    - Poor social interface management (Crumrine et al, 2005)
    - Misunderstanding of integration and fusion between project parties as a system components
    - Imbalanced, lagged information and troubled communication (Lisong, 2009)
    - Poor coordination and communication between project parties (Mortaheb et al. 2010)

Environmental factors are imposed to a party by other project parties or external parties, and they include contract, acts-of-god, and regulations.

- *Contract problems*: issues consist of several problems appearing in the contract execution:
    - Unclear details in the drawings
    - Incomplete contract
    - Design change
    - Unclear scope definition (Mortaheb et al., 2010)
- *Acts-of-God*: involved natural reasons, which are not in human control:
    - Weather problems
    - Geological problems
    - Increase in the material price
- *Regulation problems*: are caused by the unfamiliarity of the related parties with local rules, including local laws or regulations as well as the government audit system (Huang et al., 2008).

Figure 2.6 illustrates the classification of reasons for the Interface Management failure.

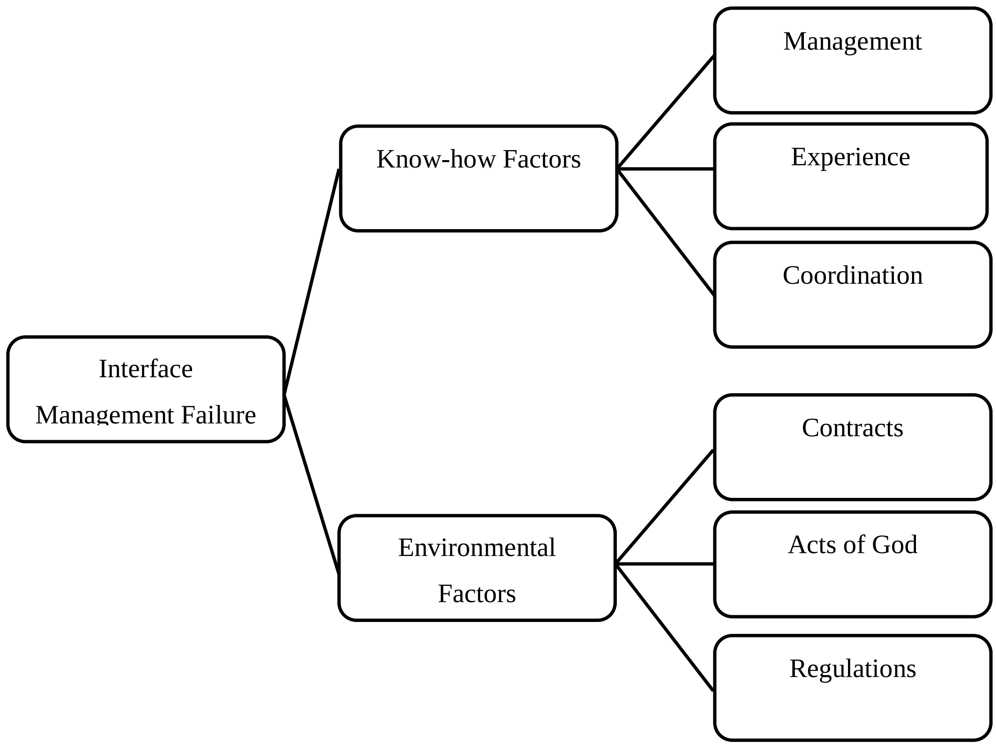


Figure 2.5 Reasons for Interface Management failure (Huang et al., 2008)

2.4.6 Benefits of implementing Interface Management

Implementing Interface Management at early stages of the project would improve project performance in terms of quality, cost, time and safety. The benefits of implementing Interface Management are (Chen et al., 2007; Kelly and Berger, 2006; Caglar and Connolly, 2007, Coreworx Inc):

- Creating better alignment between project teams and stakeholders
- Facilitating the communication and cooperation of project stakeholders
- Improving project performance through building a deep understanding of the requirements, needed information, and deadlines

- Improving quality through providing a framework for appropriate understanding of inter-related needs
- Maintaining the project within the schedule, as all parties become aware of the information and involved tasks to accomplish at the early stages of the project
- Reducing additional costs of the project through adding visibility on project description, roles, and common boundaries
- Improving project safety
- Reducing the shortcomings and conflicts

2.5 Social Network Analysis

Social Network Analysis (SNA) is considered as an appropriate approach to visually represent and mathematically analyze the relationships and interactions between dependent entities. "SNA was introduced by Moreno (Moreno 1960) to capture and visualize the social relationship between children (Scott 2012)," (Shokri et al. 2013). "A social network consists of a finite set or sets of actors and the relation or relations defined on them," (Wassermann and Faust 1994, Pryke 2012). Graphs are used in SNA to represent the inter-relationships between individuals or organizations, and they can be used as a quantitative tool to formulate the interactions between several individuals or organizations (Shokri et al. 2013). In a graph, or sociogram, an individual or organization is represented on a node or actor (Wassermann and Faust 1994, Pryke 2012). The relation between the actors is illustrated on the links or edges, and the relation is defined as "the collection of ties of a specific kind among members of a group," (Wassermann and Faust 1994, Pryke 2012). For a two-sided relationship, a simple line is drawn between two nodes. However, a directed edge is used for a one-sided relationship. The edges could represent information transfer, responsibilities of actors, collaboration between entities, etc.

To formalize and analyze the relations between entities in a social network, several concepts of graph theory are adopted by SNA. Two of these concepts are:

- Density: it indicates the actual amount of interaction (edges) between entities in a network. (Pryke, 2012; Wassermann and Faust, 1994, Chinowsky et al., 2008)
- Centrality: this is related to the distribution of relations between nodes in a network. It shows how involved an actor is in relationship with other actors. (Pryke, 2012; Wassermann and Faust, 1994, Chinowsky et al., 2008)

In the past two decades, SNA concepts have been used in the construction industry in different areas of project management, project performance assessment, procurement and supply chain management. Integrating social networks and traditional project management concepts concludes that knowledge exchange and information sharing are the core factor in achieving high performance teams and project outcomes (Chinowsky et al., 2008; Chinowsky et al.; 2010, Chinowsky 2011; Ruan et al., 2012). SNA concept was also used to model the construction project coalition in the supply chains, which enables the identification and classification of construction procurement methods (Pryke, 2004). "One of the outcomes of studying construction projects using social network concepts was that roles of the project actors and the relationship between them are not clearly defined (Pryke, 2012)" (Shokri et al., 2013).

2.6 RASCI Chart and Its Application

Studying several Interface Management process in different industries and in the literature illustrates that there is a high emphasis on defining and allocating roles and responsibilities during the Interface Management process (Collins et al., 2010). A tool has been developed by CII, called Participants Involved Tool, to indicate which organizations are involved in interfaces between project functions (estimating, scheduling, planning, cost control, change management, progressing and forecasting) and project phases (Front End Planning, design, procurement, construction and start-up) (CII, 2011). In addition, the organization which has leadership responsibility in every function/phase interface is also indicated in this tool. However, the roles of other organizational parties are not represented here.

RASCI matrices are introduced as effective tools for defining, assigning and managing the responsibilities for specific organization roles in dealing with project interfaces (Crumrine et al, 2005). In order to emphasize the importance of supportive roles in project success, a new version of RACI matrices are introduced covering supportive roles, called RASCI matrices.

RASCI stands for:

- **R** (Responsible): The person ultimately responsible for the work to be completed. This could be the person who actually performs the work or directs others to do the work.
- **A** (Accountable): The person who has the legitimate authority to approve the adequacy of the work and make the final decision.
- **S** (Supportive): The people who provide resources or administrative supports to the work or coordinate the logistics.
- **C** (Consulted): The people who are needed to be consulted with for their knowledge, and expertise, such as labour relations, legal, quality assurance.
- **I** (Informed): The people who need to know the status of the work or the decisions that were made, whether it be a matter of courtesy or to help them better schedule their own work or the work of others.

The typical approach to fill out the RASCI chart is as follows:

- Identify all the tasks/activities involved (The left column)
- Identify all the roles in the organization (The top row)

- For each task/activity, define who is R, A, S, C, and I (Related cell)

Table 2.1 illustrates an example of RASCI chart.

Table 2.1 Sample of RASCI Chart

	KEY PEOPLE			
TASKS	R	I	A	
	I	R	A	C
	R	A		S

Each cell indicates the role of every person with regard to each specific task/process. After filling out the cells, the RASCI chart is analyzed horizontally and vertically.

Horizontal analysis shows the gaps and overlaps in the project organization. A gap occurs when a task/process does not have any responsible role (R). On the other hand, in cases where there is more than one responsible role (R) for each task, an overlap happens. In addition to the gaps and overlaps, roles R–A and A–R should not be reversed among activities for the same individuals of the project team (Gregoriou et al., 2010).

Vertical analysis shows the work load of each key person in the organization. The responsibilities should be assigned evenly between key personnel, considering their organizational level, expertise and deadlines.

In the literature, RASCI charts are used with the purpose of distributing responsibilities for different project entities, or tasks of schedule (Rahi, 2005; Hartman and Ashrafi, 2004). For the Interface Management application, RASCI chart can be employed to assign responsibilities for identification and execution of each interface. Applying RASCI matrices creates visibility on the responsibilities of common boundaries between project parties, and eliminates the ambiguity in roles of various parties in performing tasks.

2.7 Summary

This research has summarized the relevant research efforts regarding risk management and interface management in the construction industry. For risk management, the definitions and classifications of risk, generic risk management processes, and sources of risks in construction projects were studied. Also, communication management has been briefly addressed to emphasize the importance of effective communication in successful delivery of projects. Finally, the definitions of interfaces, their classification, and general procedure for interface management have been presented. In the next chapter, the knowledge gaps found in the literature, as well as the structure of this research are presented.

Chapter 3

Research Vision

This chapter presents an overview of the research vision developed based on the knowledge gaps found in the literature and through study of several capital construction projects. This research is a combination of empirical and theoretical studies. The empirical part focuses on the current state of IM in the construction industry, and investigates the project characteristics that lead to formal IM implementation and the current approaches for IM. The relationship between IM implementation and project performance is also studied through gathering empirical data. The theoretical part mainly focuses on improving IM practices through a methodology to identify key interface points. It also explores the integration of IM with the project schedule, as a tool to identify schedule-related risks in mega projects. After the knowledge gaps review and research need, this chapter presents the research approach and methodologies to address the identified needs.

3.1 Knowledge Gaps

Construction project risk management has been addressed comprehensively in the literature. These studies are mainly focused on improving one or a couple of risk management steps (Cohen and Palmer, 2004) or they propose methods to enhance risk management systems (Tah and Carr, 2001; Zavadskas et al., 2010; Dey, 2009; Al-Bahar and Crandall, 1990). However, analysing categories of risks in construction and their affecting factors illustrates that a significant portion of project risks are because of lack of appropriate coordination between project participants, ineffective or delayed communication between project parties and failure in describing the requirements of the deliverables. These deliverables could be a piece of information, design documents, permits, and physical objects. Construction projects lack a system which could facilitate alignment and communication between the stakeholders while providing visibility on the common boundaries. Interface management models can be effective in addressing this problem. However, IM, its elements and processes are not well-defined in the literature and construction industry. In this research, the IM elements are defined, and then a workflow-driven Interface Management System (IMS) is proposed. The purpose of IMS is to create an effective tool to reduce or eliminate the sources of risks which are caused by inefficient communication between project elements.

Furthermore, there is a lack of a comprehensive study to show the current state of IM in the construction industry, the undertaken IM procedures and the effectiveness assessments methods. Currently, every organization employs its own understanding of IM, which varies significantly between organizations. In this research, with collaboration with CII, a comprehensive study is performed to investigate the current state of IM in the industry, and propose an IM roadmap for the organizations with various levels of IM implementation.

The other knowledge gap is about identifying the critical interfaces in a project with formal IM and linking them to the project schedule. A mega project may involve several hundreds, even thousands, of interface points. An explicit outcome of an IM system could be an ability to identify schedule-related risks using the dynamic information flow between stakeholders. However, due to the high number of interface points and their changing nature, it is not possible to find the absolute correlation between each interface point and every task on a project schedule. A thorough analysis of literature and several interviews with the industry leaders in implementing IM indicate that currently there is not a systematic approach to identify key interface points. The interfaces are identified based on the top management experience, once they are prone to create a problem. Therefore, it is necessary to develop algorithms to identify high risk interface points to effectively manage them and mitigate their potential impact. Furthermore, the identified high risks interface points can be linked to the schedule, to reduce the computational complexity of the mapping process. Accordingly, in this study, through introducing the precedence relationship and interdependency concept between interface points, and generating the network of interface points, key interface points are identified. In turn, the benefit is early alert notification of any failure or delay at any of the precedent interface point. This benefit would be feasible by analysing the information flow and communication network of the project stakeholders.

Finally, the effect of IMS on improving project performance remains to be studied and validated. To address this issue, this research studies performance criteria for several projects with different IM implementation levels. The intent is to determine whether there is a significant difference or trend of better project performance in the projects with more formal IM implementation. The performance criteria include cost growth, schedule growth, engineering hours, management hours and construction hours growth.

3.2 Research Approach

This research is an amalgamation of empirical and theoretical analysis of current Interface Management (IM) practices in the construction industry and future development opportunities to improve the performance of IM. The research includes four major sections: (1) providing IM definitions and a workflow-driven process for interface management system (IMS), (2) studying the current state of IM in the construction mega projects, (3) identifying key interface points and integrating IMS with project schedule to identify potential risks, and (4) investigating the correlation between implementing IM and improving project performance. These four sections are described in detail in chapters 4 to 7, as stated in section 1.5.

3.2.1 Empirical Analysis of Interface Management Status in Construction Industry

Taking into account the increasing scale and complexity of capital projects and necessity of effective management of several stakeholders throughout the project life cycle, Interface Management practices is a growing field in the construction industry. Accordingly, a Research Team (RT 302) was initiated within the Construction Industry Institute (CII) in May 2012 to investigate the potential answers to this essential question:

> *"What practices, techniques, and processes are most effective for improving the critical interfaces among globally dispersed project teams, multiple project partners, and an increasingly diverse labour force?"*

The team consists of 16 members from 15 companies, and 4 members from two universities, as shown in Table 3.1.

Table 3.1 List of Involved Companies in RT 302

Involved Companies and Universities in RT 302 Interface Management	
Air Products and Chemicals, Inc.	Petrobras
Alstom Power Inc.	Smithsonian Institution
Architect of the Capitol	Tenova
Coreworx Inc.	URS Corporation
Dresser-Rand Company	Wood Group Mustang
Jacobs	WorleyParsons
Lauren Engineers & Constructors, Inc.	University of Michigan
McDermott International, Inc.	University of Waterloo
Ontario Power Generation	

The primary purpose of the RT 302 is to identify and establish the definitions and best practices of Interface Management (IM) through the capital project delivery life cycle (e.g., dealing with the risks that arise or are discovered during the life cycle). The following objectives are defined in response to this purpose:

- Creating a common language, definitions, and elements of IM
- Finding the representative project characteristics that can determine the need for IM
- Identifying important principles and proper timing to guide the establishment of IM
- Identifying effective IM practices that can be applied broadly to diverse projects
- Proposing several indicators that measure the effectiveness of IM

The research described in this thesis is basically the first formal attempt to find and establish general definitions and effective practices for IM in the construction industry.

To address the research objectives, the following research methodology is employed. The first step is to collect useful data from diverse case projects with and without formal IM. RT 302 member companies participated to provide these case projects, and the initial target was to collect data from 30 to 50 projects. At the end of data collection, the RT 302 was successful in gathering data from 46 projects. These projects are all from different sectors of the industry, with various sizes, and geographically distributed. For data collection purpose, a questionnaire was developed by the team. This questionnaire aims at recognizing the project characteristics required to implement formal IM in a project, examining the current state of IM and identifying mechanisms to quantify its effectiveness. The questionnaire, its structure, and data analysis are presented in Chapter 5 (as stated in section 1.5).

The questionnaire consists of three principal parts. The first part is for collecting the general characteristics of the company's past/current project (with different sections for owner and contractor). The second part is for studying the Interface Management practices and processes of the organization. The third part is for surveying the factors affecting Interface Management performance. Prior to the questionnaire itself, the definitions related to the Interface Management are gathered and provided.

For interviews, each industry team member of RT 302 proposed a couple of projects. Each project was briefly studied by the team and a list of potential projects to be interviewed were identified. Each interview was conducted by at least one academic team member, the industry team member, and the interviewee, who was personnel within that project, e.g. interface manager, project manager. Each interview takes about 90-120 minutes. Some interviews were face-to-face; however, most of them were done over the phone.

To assure the clarity and effectiveness of the questionnaire, 4 interviews were done as pilot studies. Then the questionnaire was reviewed and improved according to the feedback of pilot studies, and its final version was used for the rest of interviews.

Once the data collection were accomplished, the second step included analyzing all the transcripts gathered from these interviews to synthesize universal definitions, common practices, and perceived indicators for IM performance. The detailed descriptive and statistical analysis of the interview results to support the hypotheses is presented in Chapter 5. Some assistance and collaboration in this process was rendered by the University of Michigan team members.

One section of the questionnaire is related to the project performance measures. These are used to investigate the relation between IM implementation level and the project performance using ANOVA statistical method. The results of this study are presented in Chapter 7.

3.2.2 Interface Management System Ontology

"An Interface Management System (IMS) is defined as a systematic approach to effectively identify and handle interfaces (especially critical ones) through the whole project lifecycle, with the objective of facilitating the alignment process between stakeholders by defining the interface characteristics, responsibilities of involved parties, and the required time of deliverables" (Shokri et al., 2012). Despite the foregoing efforts and confidence in the efficiency of IM demonstrated by significant investment by large corporations, significant research questions remain. These questions are:

- Well-defined IM processes, definitions, elements, and interface categories and activities throughout the project life cycle
- Reliable processes and algorithms for identification of high risk interface points.
- Robust processes for integrating iterative (or cyclical) IM systems with conventional, sequential planning, scheduling and control paradigms such as CPM.

A mega project may involve several hundreds, even thousands, of interface points. However, a systematic approach remains to be developed for IM in the construction industry. Each company has developed its own IM practice, and modifies it with respect to project characteristics. Therefore, a need exists for a holistic approach for identifying and managing interfaces in a complex project. This need is also emphasized by RT 302 Interface Management team. Despite the lack of a systematic approach for IM, it is generally accepted that IM system leads to more effective identification of schedule related risks using the dynamic information flow between stakeholders. However, due to the high number of interface points and their changing nature, it is not possible to find the absolute correlation between each interface point and every task on a project schedule.

In addition to systematic IM, it is necessary to develop algorithms to identify high risk interface points to effectively manage them and mitigate their potential impact. Furthermore, the identified high risks interface points should be linked to the schedule, to reduce the computational complexity of the mapping process. To address these research questions, an ontology for IM is first developed in order to provide a set of common definitions for IM components, elements and attributes. A workflow-driven framework for Interface Management System (IMS) is then described. Workflow refers to the process of identifying tasks, flow of information and activities throughout the system. According to the Workflow Management Coalition (WfMC), founded in 1993, a workflow is "the computerized facilitation or automation of a business process, in whole or part", and is "concerned with the automation of procedures where documents, information or tasks are passed between participants according to a defined set of rules to achieve, or contribute to, an overall business goal." In recent years, the need of workflow processes to facilitate construction management practices is emphasized (Kazi and Charoenngam, 2003; Chinowsky and Rojas, 2003; Wilson et al. 2001; Boddy et al., 2007).

The six-step workflow process for the IMS is: (1) interface identification, (2) documentation, (3) transfer, (4) communication, (5) monitoring and control, and (6) closing. In addition, IMS elements, its associated activities during project life cycle, and different types and categories of interfaces are defined and presented in Chapter 4.

Once the IMS ontology is defined (Chapter 4), and the current state of IM is establishes (Chapter 5), the future areas of IM improvement are investigated. A systematic graph-based approach is introduced to identify high risk interface points. The identified high risk interface points are linked to the interface milestones on the schedule, so as to integrate the dynamic information flow of IMS and linear sequence of activities of CPM (Chapter 6). In addition, the functionality of the methods is demonstrated through a model off-shore project.

3.2.3 Interface Management and Project Performance Indicators

The ultimate IM goal is to create in-time awareness on project potential risks and lead to more effective risk management in capital projects. Since project risks are affected by several other factors, at this stage of the research it is not feasible to investigate the direct correlation between IM and risk management. Therefore, correlation between IM and project performance factors in terms of cost and schedule growth is investigated within the interviewed projects. In addition, the research studied the impact of IM on the growth of design and engineering, construction and management hours. For this purpose, the projects are categorized into two groups of low- and high-level IM implementation, and using the Analysis of Variance (ANOVA) statistical method, the impact of these two groups on improving project performance is studied (Chapter 7).

Chapter 4

Interface Management Ontology

Despite the growing need for IM practices in mega construction projects, there are no commonly agreed-upon definitions for IM and its elements. Therefore, the first effort of this thesis was to develop the fundamental definitions for different elements of IM based on literature review and expert discussions. Furthermore, different levels and attributes of interfaces are also developed. Once the fundamental definitions are set, a process-driven framework is defined for the Interface Management System (IMS).

4.1 Elements of IMS

In order to achieve a successful implementation of IM, it is necessary to identify its elements. In a mega project, several interfaces are created because of its complexity and the needs of various stakeholders. These interfaces could be physical or virtual. A systematic IM is required to effectively manage these interfaces. In this study, the following definitions and elements are given for IM (these definitions will appear on the CII Implementation Guideline for Interface Management in summer 2014):

- Interface Management (IM): IM is the management of communications, relationships, and deliverables among two or more interface stakeholders.
- Interface Stakeholder: A stakeholder involved in a formal interface management agreement within an interface management plan for a project.
- Interface/Interface Point (IP): An IP is a soft and/or hard contact point between two interdependent interface stakeholders. An interface point is also a definition of part of the project's scope split as defined by project documents.

- Interface Agreement (IA): IA is a formal and documented communication between two interface stakeholders, including the deliverable description, need dates, and required actions.
- Interface Action Items (IAI): IAI includes the tasks/activities that are performed to provide the agreement deliverables defined in each interface agreement.
- Interface Control Document/Drawing (ICD): ICD is the documentation that identifies and captures the interface information and the approved interface change requests. ICDs are useful when separate organizations are developing design solutions to be adhered to at a particular interface.

Figure 4.1illustrates the hierarchy and relation between elements of an IMS (Shokri et al. 2012).

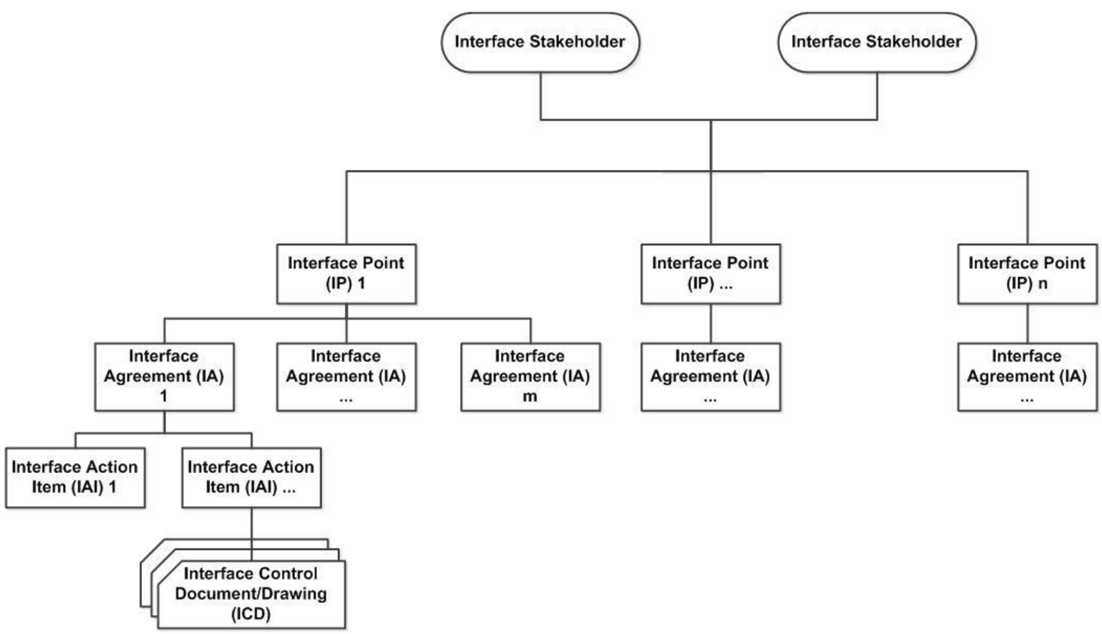


Figure 4.1 Hierarchy of Interface Management Elements

According to this hierarchy, interface stakeholders are involved in several interface points, and they may need several deliverables (pieces of information or tasks) to efficiently handle the interface point. Therefore, in every interface point, numerous interface agreements are generated. The interface agreement will document the deliverables required by one party of another party, in order to effectively handle the interface point. As a result, each interface stakeholder is dealing with several interface points, and interface agreements, coupling with an interface point.

4.2 Attributes of IMS Elements

4.2.1 Nature of Interfaces

In general, interfaces are classified into soft and/or hard, and defined as follows:

- Soft Interface: Soft interfaces typically involve the exchange of information such as design criteria, clearance requirements or utility needs between delivery teams or between a delivery team and an external party. Examples of soft interfaces are language and cultural aspects, regulatory and permit issues. (Adopted from Khadimally, 2011)
- Hard Interface: Hard interfaces represent physical connections between two or more elements, components or systems. Examples of hard interfaces are structural steel connections, pipe terminations, or cable connections (e.g.Tie-In Points). (Adopted from Khadimally, 2011)

4.2.2 Scope of Interfaces

Generally, interfaces reflect communications which take place within or between different parties in each project, with the purpose of transferring information or accomplishing a task. Major part of communications takes place between stakeholders within the scope of a project. They are classified into inter- project and intra-project interfaces. In addition to the inter- and intra-project interfaces, there is a significant amount of interactions between each stakeholder directly involved in the project and the other independent entities outside of the project, including government, local infrastructure systems, local and international organizations, called extra-project interfaces. Therefore, Interface points are analyzed at three levels (Collins et al., 2010):

- Inter-project Interface: Interfaces between different stakeholders directly involved in project planning and execution (e.g. owner-contractor, contractor A-contractor B, …).
- Intra-project Interface: Interfaces within the organization of each independent stakeholder, involved in a project (e.g. department 1 and Department 2 of a contractor, between subcontractors of a contractor).
- Extra-project Interface: Interfaces between the project stakeholders and other organizations which are not directly involved in project execution. A good example for this type on interface could be permits of government or environmental organization.

These three levels of interfaces are illustrated in Figure 4.2, 4.3 and 4.4.

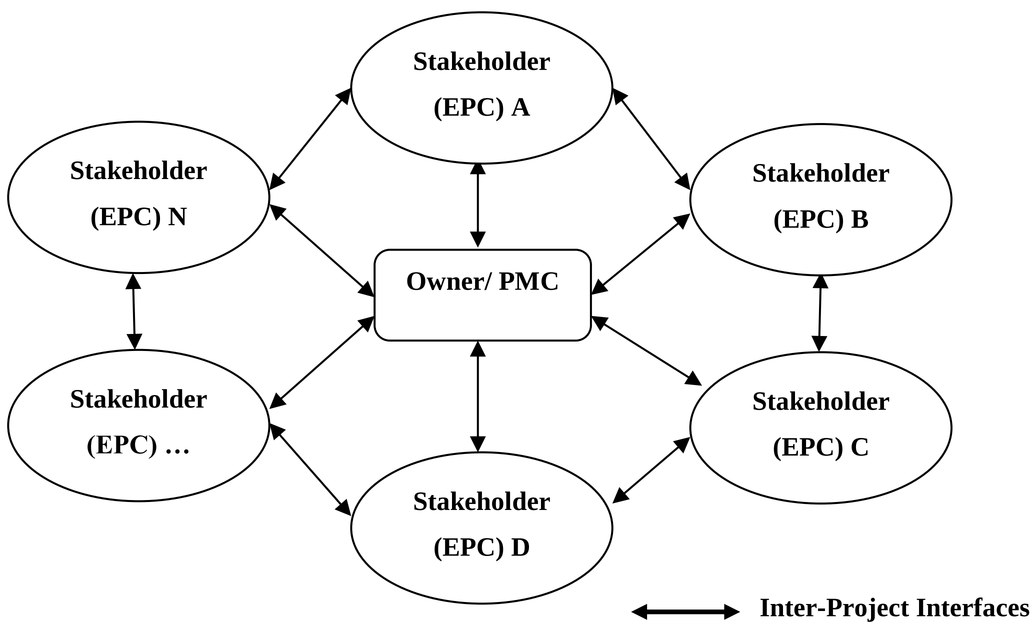


Figure 4.2 Levels of Project Interfaces: Inter-project Interfaces

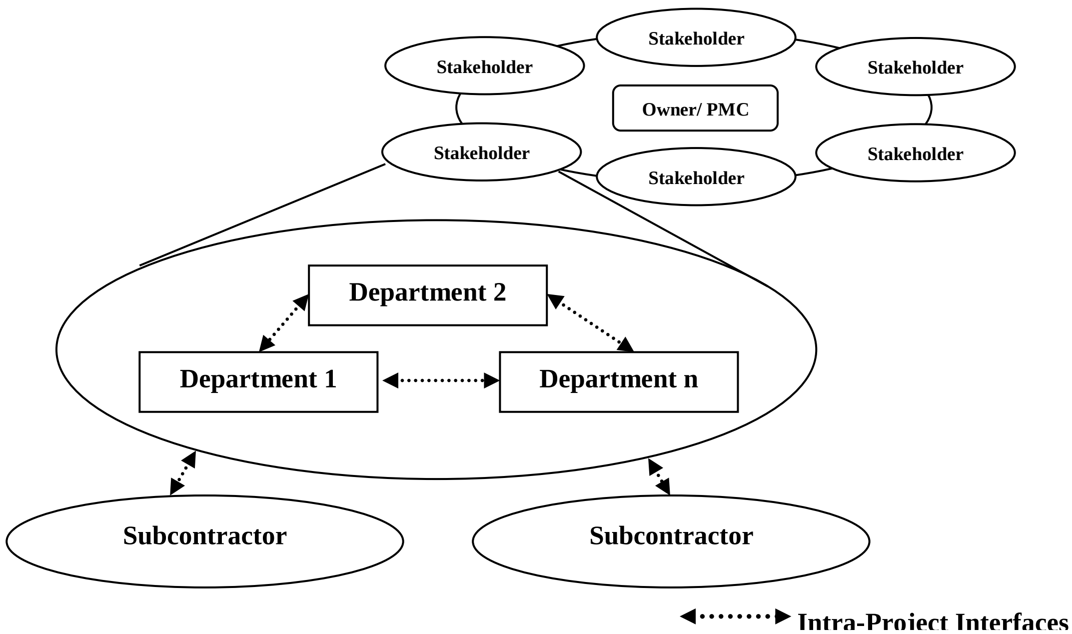


Figure 4.3 Levels of Project Interfaces: Intra-project Interfaces

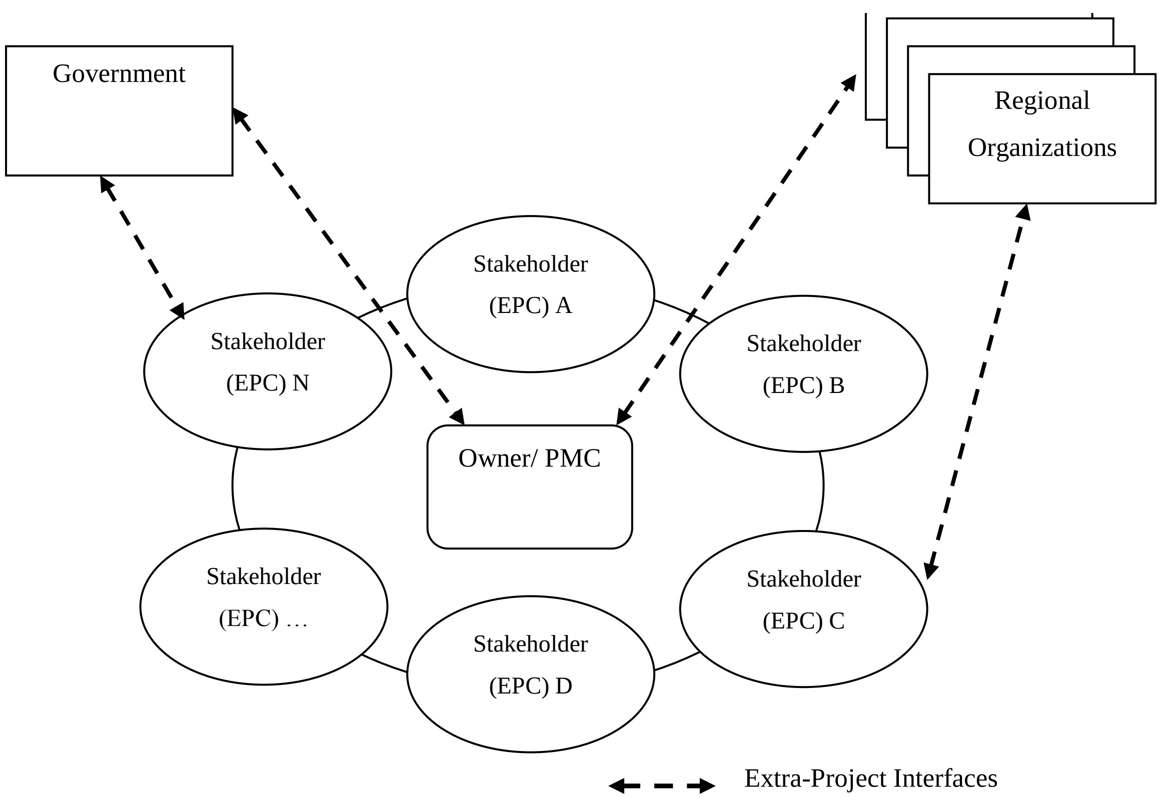


Figure 4.4 Levels of Project Interfaces: Extra-project Interfaces

4.2.3 Categories of Interfaces

All the inter-, intra-, and extra-project interfaces could have different contexts, which are introduced for classifying project interfaces: (Chen et al. 2006, Collins et al. 2010, Pavitt and Gibb 2003).

- Physical and functional interfaces
- Contractual and Organizational interfaces
- Resource interfaces
- Regulatory interfaces

To illustrate with an example, assume that two EPC contractors are awarded two scope packages, in which two pipelines should be connected at point A. The connection between these two pipelines generates an inter-project physical interface point. In another case, a contractor is awarded a pipeline project, which should be connected to the shut off pump, previously installed at the location of the project. Therefore, the owner and contractor will have an inter-project physical and functional interface point.

By analyzing and monitoring the status of physical and functional interfaces, risks related to technical and design issues could be addressed. Contractual and organization interfaces could be monitored to recognize the risks related to the contractors' performance, on-time supply of material/equipment, categories. Risks related to the availability of labor and equipment, and simultaneous operations are recognizable by tracking resource interfaces.

The regulatory category is mentioned independently due to its importance in the success of the project execution. Acquaintance with local and international regulations and getting appropriate permits on time plays a key role in mega projects' startup and execution. The project may be stopped or postponed due to getting improper permits, or obtaining them with delay.

4.2.4 Levels of Interfaces

Interfaces with various nature and categories can be defined at different hierarchical levels, as shown in Figure 4.5, within the project. The level of interfaces is highly dependent on their complexity, and the required actions to handle them.

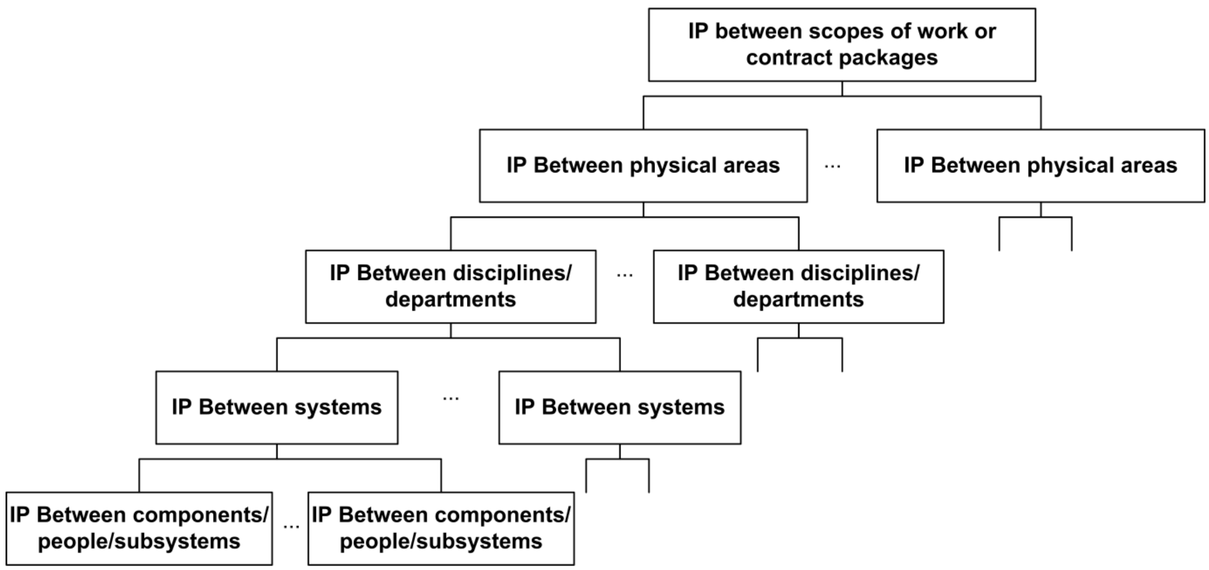


Figure 4.5 Hierarchy of IP Levels

4.3 When to adopt IMS?

IM is an iterative process; IPs are identified and created throughout the project life cycle. Ideally, most of the IPs should be identified during FEP of the project. Early identification of interfaces will lead to better understanding of potential project risks and promoting project success. The reason is that early identification of IPs and facilitating the exchange of required information and deliverables will result in added visibility of common boundaries between stakeholders. It should lead to better understanding of potential project risks and promoting project performance too.

Front End Planning (FEP), considered as the most important step in the capital project life cycle, is the best stage to start identifying the interface points. It is recommended to identify participants involved in interfaces during FEP (CII, 2011). Figure 4.6 illustrates the relation between IMS, project life cycle and FEP.

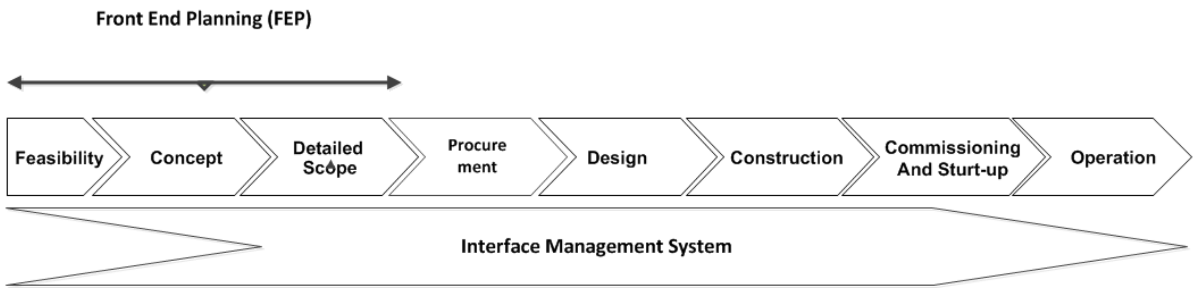


Figure 4.6 IMS and Project Life Cycle

A significant part of extra-project interfaces are identified at this stage. During strategic decision making, interfaces with external organizations, for example financial institutions, and environmental agencies, would be examined. Moreover, through analysis of site location, the interfaces with companies currently working at the project site, and the local infrastructure should be recognized.

Process design basis, initial equipment design, and procurement design are the outputs of FEP. Therefore, a major number of potential interfaces between project elements, including physical components, contractors and subcontractors, are recognized at the FEP stage. According to the interviews with Coreworx customers, it is feasible to recognize about 80 - 90% of extra- and inter-project interfaces during FEP, design and procurement stages.

Although it is recommended to identify interface points at the early stages of the project, it should be noted that each interface point has its own life cycle. Not all the IPs stay active during the whole life of project nor are identified during FEP. Interface points could be identified/created at different phases of the project.

4.4 IMS People

A successful Interface Management program requires collaboration and commitment of all management levels and key personnel. However, to reinforce IM implementation in a project, several key roles are defined, as follows:

- Interface Coordinator: “The interface coordinator is responsible to anticipate potential problems and communication breakdowns, interpret the potential impact of events and foster resolution among the parties while actions are still controllable.” (Shirley, R.R. et al., 2006)
- Interface Manager: “The Interface Manager has overall responsibility for implementation and maintenance of the interface management plan throughout the project life cycle by developing and implementing project specific Interface Management work processes, capturing the necessary interface agreements, monitoring progress, ensuring that schedule requirements are maintained and identifying/initiating any change requests that may arise out of the interface requirements.” (Caglar, J. and Connolly,M. 2007)

In addition to these positions, several interface and project engineers are involved in implementing IMS and providing deliverables. In fact, IM is implemented by Interface Managers, Coordinators and engineers by referring to the Master Interface Plan (MIP). The MIP represents strategies and processes, developed by a project management team, to manage inter-, intra- and extra-interfaces throughout the project lifecycle, including design and engineering, procurement, construction, commissioning and closeout. (Adopted from Khadimally, 2011)

4.5 IMS Tools

Several tools support successful implementation of an IMS. Some of these tools are generic for all organizations, however, others may be modified and implemented at different levels considering the maturity of the organization's IMS.

4.5.1 Master Interface Plan

The Master Interface Plan (MIP) is a document intended to describe in detail how to manage IPs and IAs. It includes the management procedures and activities to effectively deliver internal and external IPs throughout the project life cycle. It may include the common types of IPs in the project, deliverables, and the responsibilities of interface stakeholders. The contents of a typical MIP include:

- Definitions of IM, Interface Points (IPs), and Interface Agreements (IAs)
- Purpose of IM
- Maturity level of IM in the project
- IM process
- Common types of IPs in the project
- Roles and responsibilities
- Sample IP and IA forms

4.5.2 Interface Management Recording

IPs and IAs can be recorded, traced and managed using different tools. Spreadsheets and registers are the basic tools for registering and managing IPs within a project. If an organization implements a more mature level of IM, online and web-based forms are used to record IPs and IAs. In order to record IPs, the following requirements should be considered:

- IP reference number

- IP title
- Description of IP
- IP category and level
- Involved interface stakeholders and responsibilities
- IP creation and approval dates
- Status

As discussed in Section 4.1, each IP may include several Interface Agreements (IAs) that serve as the documented form of communicating the deliverables. In addition, the spreadsheet and registers for tracking IAs may also include:

- Description of IA deliverable
- Creation date of IA
- Need date
- Forecasted date
- Delivery date
- Closing date

Samples of Interface Data Register, IP and IA form are shown in Appendix A.

4.5.3 Interface Management Software

IM software is a fundamental element of mature and formal IM implementation. The minimum requirements for IM software are:

- Web-based
- Workflow enabled
- Meta data captured to enable search

- Filtering
- Traceability
- Reporting functionality
- Revision tracking
- Historical recording
- Archivable

There are several potential improvement areas for mature Interface Management Software, including the following:

- Integration with project schedule to ensure alignment of IAs and IPs with required dates on project schedule
- Integration with change management to transfer and track significant changes to and from the IM process to the project management team
- Integration with risk management to forecast potential risk and provide appropriate mitigation approaches

4.6 Framework for Workflow Driven Interface Management System

"An Interface Management System (IMS) is defined as a systematic approach to effectively identify and handle interfaces (especially critical ones) through the whole project lifecycle, with the objective of facilitating the alignment process between stakeholders by defining the interface characteristics, responsibilities of involved parties, and the need time of deliverables" (Shokri et al. 2012) . IMS framework will be executed through six steps:

- Step 1- Interface Identification: This step includes identifying as many interfaces as possible in the project.

- Step 2- Interface Documentation: Interface information is defined in this step. This information includes the interface characteristics, involved parties, deadlines, needed documents, etc. It should be mentioned that this step is an ongoing process during the whole IMS.
- Step 3- Interface Transferring/Package issuing: When the contract has been awarded, all the identified interfaces and their documented information are being transferred to the appropriate parties.
- Step 4- Interface Communication: During this step, project parties will start communicating with each other through issuance of Interface Agreements, to effectively manage the identified interfaces. This step will be executed under the jurisdiction of the Interface Manager and involve all interfacing parties.
- Step 5- Monitoring and Control: during this step, the performance of IMS and contractors in providing interface deliverables is assessed by providing on-screen indicators and notifications.
- Step 6- Interface Closing: The interface is considered closed if all involved parties agree on the efficiency, accuracy and completion of communicated information/tasks and deliverables.

These steps are executed automatically, via workflows in an EPPMS, and over the internet. The owner and all contracting parties have access to internet-based software, and their access level is based on their role in handling each interface point. The workflow of the IMS is illustrated in Figure 4.6. The monitoring step is not shown in this flowchart, since it is running in parallel with all phases, depending on the performance index definition.

4.6.1 Step 1: Interface Identification

The interface points could be created because of contractual obligation, actual connection of two objects, or regulations. Project interfaces are identified through the whole project life cycle. In fact, interface identification is an ongoing process; however the early identification of interfaces will lead to better understanding of potential project risks and promoting project success. Interfaces are typically identified by a group of experts of the project, using the design documents, work breakdown structure (WBS), contract documents, project specification, etc (Chua and Godinot, 2006).

4.6.2 Step 2: Interface Documentation

Once the interface points are identified, the information related to each interface point must be defined. This information includes attributes of the interface point (nature, scope, levels and categories of IPs), its related discipline/area/department and the interconnecting parties. After identifying the involved organizations, a RASCI matrix is used to define the responsibilities of the people (of each organization) involved in interface point execution. RASCI stands for Responsible, Accountable, Support, Consulted and Informed, respectively (see section 2.6). The description of roles for the interface execution is as follows:

- Responsible: The party responsible for the interface overall performance, and approves the accuracy of interface point characteristics.
- Accountable: The party, who generates the interface agreement, has the legitimate authority to approve the adequacy of the work and make the final decision to close the agreement.
- Supportive: The party who gives support to facilitate the process accomplishment (e.g. the party who may have to grant the other parties access to the site).
- Consulted: The party who responds to the interface agreements and provides the deliverables.

- Informed: The parties who need to know the status of the interface agreement, whether it be a matter of courtesy or to help them better schedule their own work or the work of others

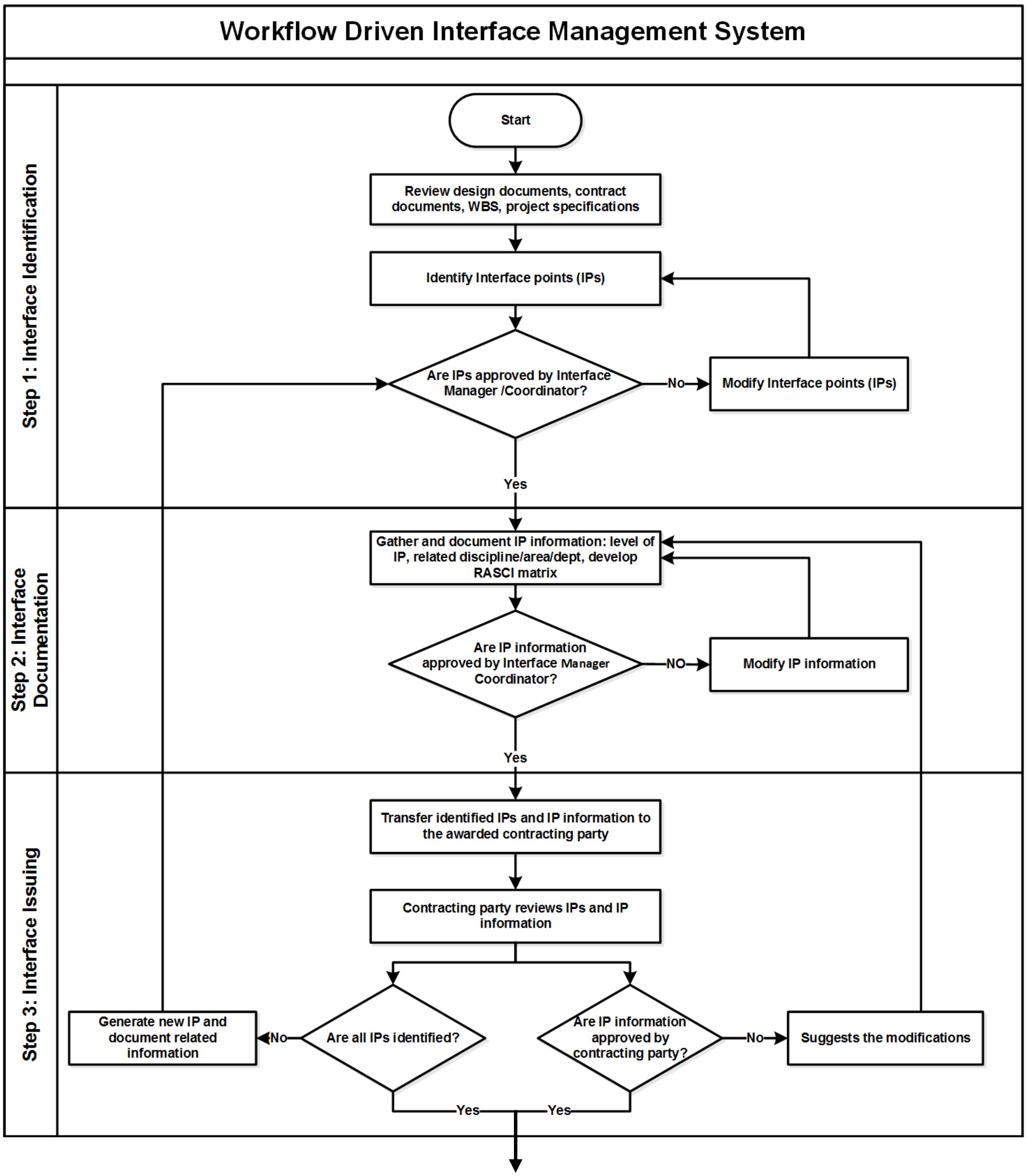


Figure 4.7 IMS Workflow

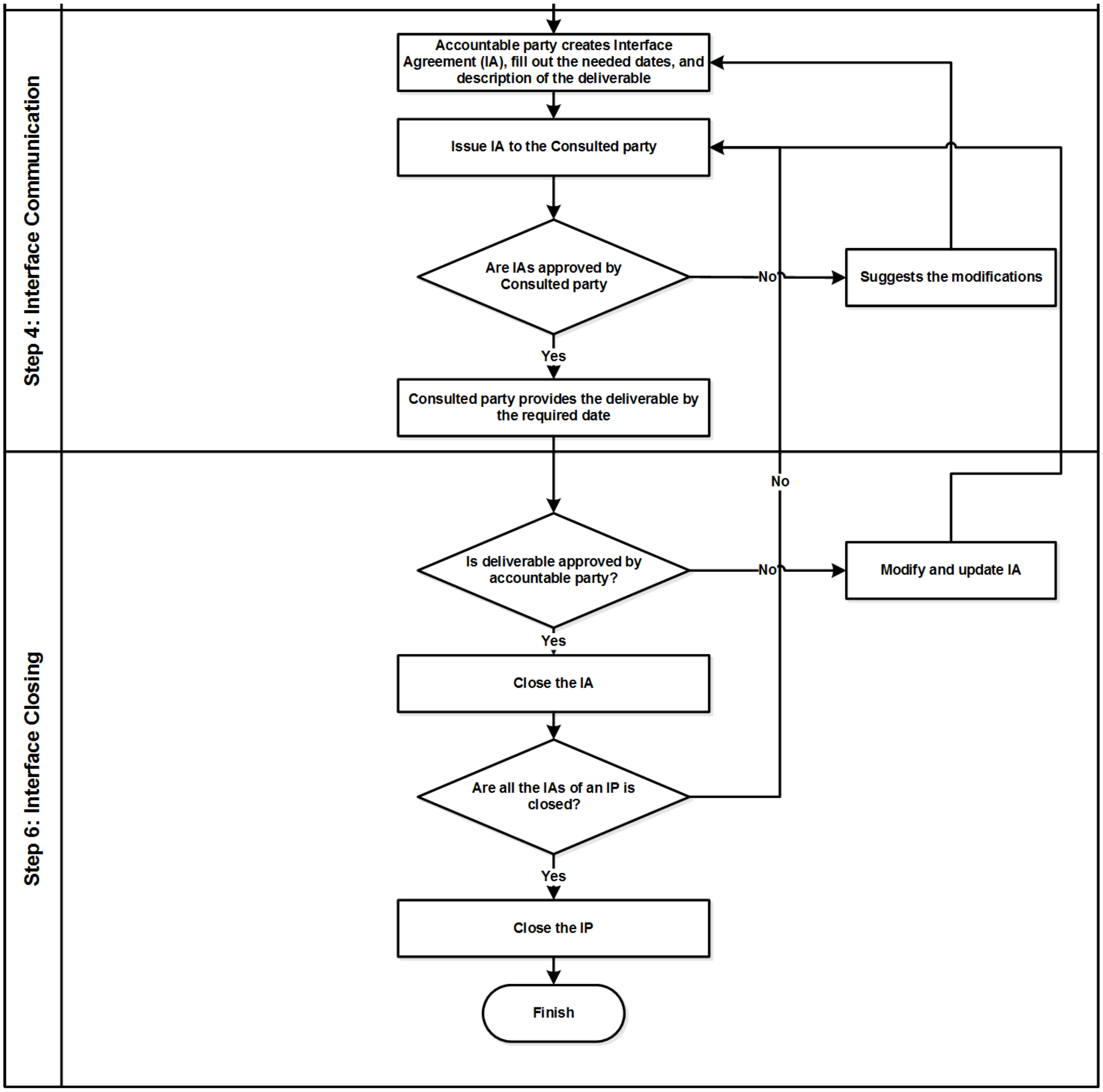


Figure 4.7 IMS Workflow (continued)

The main purpose of using a RASCI matrix is reducing risk by increasing visibility of the roles and responsibilities related to each interface point identification and execution. The visibility is achieved by clear definition of roles and responsibilities, boundaries between roles, balancing of the responsibilities and regular controls. As a result, the ambiguity of roles and tasks of each party involved in an interface point is eliminated.

A sample of a RASCI chart in a construction project is shown in Table 4.1 (a general representation of RASCI chart is illustrated in table 2.1). The left column includes interface points, and the top row includes all the persons/parties who may be involved in identifying interface points (here, owner is meant in a very general way, as mega projects would likely have a consulting firm acting as the agent or representative of the owner). The cross-sectional cell indicates the responsibility of each party with regard to each interface point, if there is a relationship. Note that each interface point should be assigned only one Responsible person.

Table 4.1 Sample of RASCI Chart

	Owner	PMC	Discipline i	...	Designer
IP 1	R	A	S		I
IP 2		R,A	S		C
IP 3	A	R			S
⋮					
IP n		C	S		A,R

The major portion of the information related to the interface point is gathered during the FEP (Front End Planning) stage, and prior to contract award. Then, interface points are grouped according to the contract packages. After contract award, the interface points are transferred to the awarded contracting party.

4.6.3 Step 3: Interface Issuing

When the contracting party has been awarded the contract, all the identified interface points and related information are transferred to that party. This includes all the interface points for which the contracting party is responsible, accountable, consulted, or support. In other words, the interface points, and roles of the contracting party with regard to each interface point should be transferred to that party.

The awarding contractor will review the interface points, their description and related information, and will approve their adequacy and accuracy. The contractor may also identify new interface points which were not recognized by the owner, or may modify some of the existing interface points. Any modifications to existing interface points, or newly identified interfaces may require approval by the Interface Manager at the owner's organization.

4.6.4 Step 4: Interface Communication

After the identified interfaces are transferred to the awarded parties, all involved parties should go through the identified interface points, and approve the accuracy and sufficiency of provided information. This step can be a risk itself, and it is necessary to assure that the involved parties are responding to this step. If new interfaces are recognized during this stage, the Interface Manager of the responsible party requests to add more interface points, and this request is required to be accepted by respondent party, and approved by Interface Coordinator for issuance.

The interface communication is done through issuing Interface Agreements. An Interface Agreement is issued by the accountable party, and the consulted party reviews the agreement, and accepts whether he/she can provide the deliverable within the mentioned time framework. If the consulted party is not clear on the requested deliverable, or has some reservations or concerns about the deadline, he/she will ask for more clarification on the deliverable or request a change to the deadline. This process is a negotiation between parties and continues until all involved parties are satisfied with the content of agreement and deadline.

The communication process works as follows: A specific information or task is requested by a team member of accountable party. This request is generated in the form of Interface Agreement and sent to the accountable Interface Coordinator or Manager. She/he reviews the details of the agreement, as well as the required date. Then this agreement is sent to the Interface Manager of consulted party, and he/she reviews the requirements of the agreement. With collaboration of team members, Interface Manager of consulted party accepts the agreement, or requests clarification. The interface agreement goes back and forth between the two parties, until they agree on the requirements of the agreement. At this time, the Interface Manager of the consulted party is responsible for providing the information and/or deliverables by the agreed upon deadline. This process is time bonded: involved parties must come to an agreement within a certain time frame in order to prevent any unwanted delays. If they do not come to an agreement within the allocated time frame, the owners' Interface Manager is notified and becomes involved.

4.6.5 Step 5: Monitoring and Controlling

Effectiveness of IMS depends on the time of providing needed deliverables and their quality and accuracy. In order to monitor the performance of IMS, some on-screen indicators and notifications are provided. A workflow IMS provides the capability of automating alerts and notifications, and using different data source based on the position of the person who is monitoring the IMS performance status.

4.6.5.1 Early Notification of Deadline for Contracting Parties:

Due to importance of providing needed deliverables within the requested time, notifications are sent to the Interface Managers about the deadline within a predefined time intervals (for example, 60 days and 2 weeks in advance to deadline).

Furthermore, each Interface Manager is provided by an on-screen indicator which depicts the closed, in progress, and overdue Interface Agreements as well as the interfaces which are close to their deadline. The Interface Manager of the contracting party is able to track the interface agreements related to his/her scope package. He/she is also able to drill down in each category to find out more about which team member is responsible to that agreement, the reason of delay, and other relevant information.

4.6.5.2 Contractor Performance Tracking for Owner:

At each point of time, the Interface Manager at the owner side is able to track the performance of the contractors he/she has been assigned, according to the status of interface agreements. A sample of this on-screen indicator is illustrated in Figure 4.8. He/she also can drill down in each category for further information about the reasons of delay for each contractor. Therefore, this indicator can be considered as an input to evaluation of contractor performance.

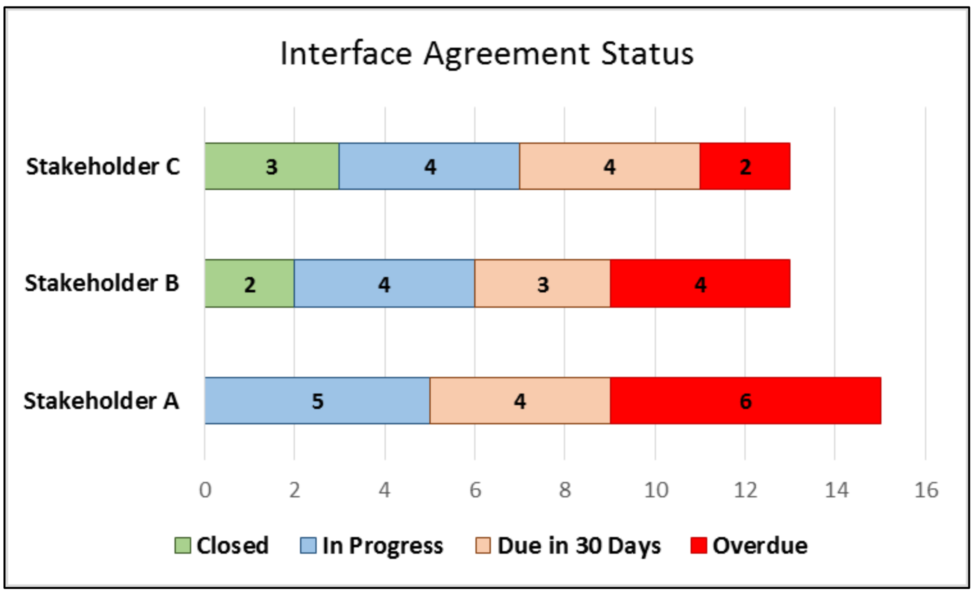


Figure 4.8 Interface Agreement Early Warning

4.6.5.3 Circulation of Interface Agreements:

During the interface communication step, interface agreements are circulated between accountable and consulted parties until they both agree on the quality, adequacy and accuracy of the needed information/task, and the due date. The circulation of interface agreements is inevitable to some extent. However, in cases with a large number of circulations of agreements between involved parties, Interface Coordinator will follow up on the status of Interface Agreement, and resolve the conflict, if any.

The other potential indicators are as follows:

- Constant changes to interface point's information and interface agreements: This indicator can be measured by the number of changes for information related to interface points and interface agreements. The high value of this measure could be because of incomplete design documents, improper interface identification, or inefficiency of interfacing parties.
- Constant changes to the interface agreements due dates: This can be a defined by the average number of changes to the due date of an interface agreement during its original duration. The high value of this measure could illustrate incomplete design documents, ineffective approval process, unrealistic deadline, or inefficiency of interfacing parties in providing deliverables.
- Un-met milestones: The number of un-met milestones for interface agreements and interface points of each contractor/subcontractor per month. This value could illustrate the performance of a contractor in deadline with agreements, and providing deliverables.
- A large number of change requests: The average number of change request for interface agreements related to each contractor per month.
- Increasing number of Requests For Information (RFI): The number of RFIs per contractor/subcontractor per month.
- Average response time to RFI: The average response time to RFIs of interface agreements per contractor/subcontractor.
- Delay in response to RFIs and change orders: The average time between receiving RFIs and change requests for an interface agreement and responding to them for each contractor/subcontractor.

4.6.6 Step 6: Interface Closing

The interface agreement is considered closed if the accountable party approves the accuracy and adequacy of the received deliverables. If the accountable party is not satisfied with the provided deliverables, the Interface Manager along with his/her team members will update the interface agreement, and will ask for more appropriate information/task. The consulted party will review the updated interface agreement and inform the accountable party of his acceptance, objections or concerns. The deadline for the interface agreement can be rescheduled with the acceptance of both parties, and the other involved parties will be informed of the modifications and updates. In fact, this process is a negotiation between parties involved at the interface point. If the accountable and consulted parties are not able to resolve the issue and accept the response provided to the agreement, the owner's Interface Manager is notified and can step in to help in the conflict resolution process.

4.7 Summary

Mega projects are complex because of the scope, size and numerous stakeholders collaborating during the project life cycle. These projects face conflicts and issues because of misalignment between stakeholders, and insufficient communication process between them. Interface Management is introduced as an effective approach in dealing with these problems. Implementing Interface Management during the early stages of a project will improve project performance in terms of quality, cost, time and safety by providing a framework for appropriately understanding the inter-related requirements, needed information, and deadlines. Furthermore, it helps to reduce additional costs of the project through adding visibility on project description, roles, and common boundaries.

In summary, the proposed IMS provides a tool to improve project performance through better alignment between stakeholders, enforcement of contract terms, and effective sharing and distribution of interrelated information within formalized interface management framework, as well as collaborative problem solving amongst interested parties.

Chapter 5

Current State of Interface Management in the Construction Industry

As the complexity and globalization of capital projects has increased, IM seems to be a growing field in the area of construction project management practices to address the interface related risks in the current project delivery environment. However, IM implementation methods vary widely across the construction industry and corporations, and there in a lack of agreed upon definitions and practices. Lack of a consistent understanding and common approach to IM leads to create false expectations of IM and its impact on improving in project performance or communication between stakeholders. This chapter reviews the research efforts and associated results conducted by the CII RT 302 during 2 years life of the project.

5.1 Data Collection Methodology

The CII RT 302 Interface Management team initiated working on the Interface Management topic in May 2012. The primary purpose of the RT 302 is to identify and establish the definitions and best practices of Interface Management (IM) through the capital project delivery life cycle (e.g., dealing with the risks that arise or are discovered during the life cycle). The following objectives are defined in response to this purpose:

- Creating a common language, definitions, and elements of IM
- Finding the representative project characteristics that can determine the need for IM
- Identifying important principles and proper timing to guide the establishment of IM
- Identifying effective IM practices that can be applied broadly to diverse projects
- Proposing several indicators that measure the effectiveness of IM

To address these objectives, the RT 302 decided to collect useful data from diverse projects with and without formal IM. RT 302 companies were asked to nominate projects for data gathering purpose. The initial target was set to 30-50 projects. The nominated projects were studied by the team, and a list of potential projects to be interviewed was identified.

Each interview was conducted by at least one academic team member, the industry team member, and the interviewee(s), which was aimed to be the key personnel within that project, e.g. interface manager, project manager. The industry team members scheduled the interviews, and acted as a mediator between the academic team member and interviewee. Some interviews were face-to-face; however, most of them were carried out over the phone, each taking about 90-120 minutes.

5.2 Data Collection Tool

For data collection purposes, a questionnaire was developed by the RT 302 team. This questionnaire was reviewed rigorously by the team members, and finalized after going through 45 revisions. The final version was then approved by the Office of Research Ethics at both the University of Waterloo and University of Michigan. The questionnaire aims to recognize the project characteristics required to implement formal IM in a project, examine the current state of IM and identify mechanisms to quantify its effectiveness. It consists of three major sections:

1. Introduction to CII RT 302: this section talks about the RT302 team, objectives of the research team and questionnaire, and confidentiality statement
2. Definitions: This section includes all definitions related to Interface Management and procedures to answer some questions
3. Data collection questionnaire: this section includes the questionnaire itself, which should be answered by the interviewees throughout the interview

Every section of the questionnaire along with the questions proposed in each section were designed in such a way to ensure that they are aligned with the essential question and objectives of the RT 302. The questionnaire package is provided in Appendix B.

5.2.1 Data Collection Survey/Questionnaire

This survey aimed to recognize the factors required to implement IM in a project, examine the current state of IM and identify mechanisms to quantify its effectiveness. The results of the survey would help develop practices to improve collaboration between organizations in a project, as well as effective sharing and distribution of risk-related information within an Interface Management network. The survey consists of three principal parts.

5.2.1.1 Project General Information

The first part of questionnaire collects information about the basic characteristics of the project, which are:

- Project name and location
- Owner(s)
- Project nature: to describe if the project is greenfield or brownfield project
- Project type: to determine the project type, including chemical manufacturing, stadium, museum, dam, metals refining/processing, oil exploration/production, oil refining, natural gas processing, highway, power generation, water/wastewater, consumer products manufacturing, etc.
- Number of top level scope packages: to determine how the project has been broken down to packages
- Number of Joint-Venture partners: to determine how many organizations are involved in the project ownership

- Project execution locations: to define distribution of the project engineering, fabrication, and construction in terms of physical locations
- Number of involved interface stakeholders: to define the estimated number of stakeholders at the high level project organization, which have interface relationships with each other. Four ranges of 1-5, 5-15, 15-30 and over 30 interface stakeholders are defined
- Number of owner's prime contractors: to determine the number of prime contractors at the high level project organization. Four ranges of 1-5, 5-10, 10-20 and over 20 prime contractors are defined

Once the general project information is gathered, the following questions are asked both based on owner and contractor point of view, depending on the interviewee's role within the project.

- Project dollar value: to define the project size in terms of total cost. Five price ranges are defined for the total project: less than 500 million dollars, 500 million to 1 billion dollars, 1 to 5 billion dollars, 5 to 10 billion dollars, and over 10 billion dollars. If the interviewee represents a contractor, the price ranges are less than 100 million dollars, 100 to 500 million dollars, 500 million to 1 billion dollars, 1 to 5 billion dollars, 5 to 10 billion dollars, and over 10 billion dollars
- Project current stage: to define the current stage of the project whether it is ongoing; including Front End planning, Design, Procurement, Construction, Commissions and start-up or it is completed. The interviewees are also asked to determine the percentage of completion for each stage
- Project delivery strategies: to report the delivery strategies of the project, such as Design, Bid, Build (DBB); Design, Build (DB); procurement, construction (PC); Engineering,

Procurement, Construction (EPC); Engineering, Procurement, Construction, Management (EPCM); Construction; Build, Own, Operate (BOO), etc.

- Project contracting strategies: to report the contracting strategies of the project, including Reimbursable work, Cost plus fixed fee, Cost plus fixed percentage, Cost plus variable percentage, Target estimate, Unit price, Guaranteed maximum cost, Lump-sum, etc.

In addition to project general information, project performance information are also inquired in this section. The purpose of these questions is to determine if the projects with IM perform better in terms of performance metrics.

- Project cost-related information: to report on the initial predicted project cost and actual project cost as of specific point of time (interview date or previous monthly/quarterly report if the project is still ongoing).
- Project schedule-related information: to report on the initial predicted project duration and actual project duration as of specific point of time (interview date or previous monthly/quarterly report if the project is still ongoing).
- Project construction hours information: to report on the forecasted construction hours and actual construction hours as of specific point of time (interview date or previous monthly/quarterly report if the project is still ongoing).
- Project management hours information: to report out the forecasted project management hours and actual project management hours as of specific point of time (interview date or previous monthly/quarterly report if the project is still ongoing).
- Project engineering/design hours information: to report out the forecasted engineering/design hours and actual engineering/design hours as of specific point of time (interview date or previous monthly/quarterly report if the project is still ongoing).

Finally, RT 302 identified 17 factors that contribute to the project risk and interface complexity. The interviewees are asked to rank the contribution of these factors to their project on scale of 1 to 10, 1 representing the lowest contribution and 10 represents the highest contribution. These factors are:

- Cost (e.g. highly-competitive bid)
- Schedule (e.g. condensed cycle time)
- Scope (e.g. extended/unfamiliar, Poorly defined scope)
- Execution Risk (e.g. unknowns)
- JVs (EPCs/Owners)
- Technology (e.g. "new'" stuff)
- Large (or Excessive) number of Suppliers / Subcontractors
- Multiple Engineering Centers
- Government (e.g. rules/ regulations/permits/bureaucracy)
- Multiple EPCs / Interface Points
- Purchase of Engineered items
- Multiple Languages
- Lack of previous experience of collaboration with one or more of other contactors
- Use of dissimilar design codes and software packages for design documents/drawings between contractors
- Poorly-defined battery limits of the involved parties
- Poorly-defined requirements of the involved parties
- Poorly-defined responsibilities of the involved parties

5.2.1.2 Interface Management Practices

The second part of the questionnaire studies the interface management practices within the organization, if there are any implemented.

First, the key attributes of IM are identified, and ranking is requested based on the importance. These attributes are as follows:

- Definition of deliverables
- Definition of roles and responsibilities
- Quality and Clarity of information flow
- Timely flow of information
- Agreeable deadlines
- Managed collaboration
- Responsibility allocation
- Knowledge exchange
- Traceability

Then, the IM practice is studied for the projects with formal IM. Throughout the questions, the following concepts are investigated:

- Representative project life cycle: whether the project follows linear life cycle strategy or fast-track strategy.
- IM adoption phase: the phase of the project that IM has initiated.
- IM Software: to study the software/systems the project employing for IM implementation.
- Integration with project change management: to investigate whether the IM system is integrated with project change management system and how changes to the interface points and agreements are communicated with the project change management system.

- Integration with project schedule: to explore whether the IM system is integrated with project schedule to set agreements due dates in accordance with the project schedule, and transfer the cyclic information of IM system to the linear information flow of project schedule.
- Mutual expectations: to report how the mutual expectation of interface stakeholders are recorded, monitored and accomplished. An example would be Interface Agreement.
- Conflict resolution: to explore what is the conflict resolution practice around interface points and agreements, whether the owner is involved or not.

For the projects without IM in practice, the following questions are investigated:

- Representative project life cycle: whether the project follows linear life cycle strategy or fast-track strategy.
- IM adoption phase: what would be the phase to initiate IM in the project, if they had implemented IM.
- Communication methods: to explore how the communication between interface stakeholders are executed, monitored, and managed.
- Mutual expectations: to report how the mutual expectation of interface stakeholders are recorded, monitored and accomplished, without having a formal IM process.
- Conflict resolution: to explore what is the conflict resolution practice around issues related to the common boundaries.

For the projects with formal IM practices, the following questions are further explored:

- IM key personnel: to report if they have assigned interface manager, interface coordinator, translator/cultural mediator, or project engineers for interface-related tasks.

- Core competencies: to investigate what are the core competencies for each interface stakeholder. These competencies are experience, good facilitation skills, multi-disciplinary, do whatever it takes, leadership skills, and technical competencies.
- Numerical measures: to explore the total number of IPs including internal and external IPs, hard and soft IPs, average number of IAs per IP.
- Prioritization: To explore if the IPs are prioritized or managed with the same priority. The factors for prioritization are based on top management experience, associated with higher cost, having higher risk, related to an activity on the critical path, related to specific discipline, or if the IP is between more two interface stakeholders.

5.2.1.3 Interface Management Performance

The third part of questionnaire focuses on how the status and performance of IM can be assessed within the project. This part is asked of the interviewees who implement IM in their projects. The starting question for this part is satisfaction of the project with respect to its IM practice. Then, the interviewees are asked to describe one or two risk examples which were avoided by having an IM system in their project. Then, the interviewees are asked to assess the applicability of several factors that are identified as important factors to measure the performance and status of project IM practice. These factors are:

- Percentage of closed interface points of the ones that should be closed, at any point of time
- Percentage of interface points identified after FEED of total project Interface points
- Percentage of closed interface agreements of the ones that should be closed, at any point of time
- Number of overdue interface agreements at any point of time

- Number of change orders precipitated during the execution of interface agreements per agreement at any point of time
- Number of cultural clashes at any point of time
- Number of formal escalations or disputes at any point of time
- Average number and standard deviation of revisions per document or drawing
- Amount of contingency release at any point of time
- Percentage of completed engineering, when IM is started
- Turnaround time for inquires
- Quorums at interface meetings
- Residual risk before and after implementing IM
- Number of non-conformance reports issued because of interface issues

The expectation of the best Interface Management System is then investigated. Finally, it is investigated whether the project contingency should be changed with regard to IM practice in a project or not. The intent was to discover if companies were pricing the risk reduction related to IM implementation.

5.3 General Analysis of Projects

Data from 13 companies for 46 projects were obtained for this research. These projects are from different sectors of the industry, with various sizes, organizational structures and geographical distributions. Based on the characteristics of the interviewed projects, a fairly comprehensive range of projects were covered for studying the current status of IM. Table 5.1 provides general information on the studied projects.

To have a representative sample for IM study, the interviewed projects are selected from different geographical locations. Figure 5.1 shows the geographical distribution of the interviews related to these projects.

Table 5.1 Projects General Characteristics

Project General Characteristics		Number of Projects
Acting Party	Owner	18 (40%)
	Contractor	28 (60%)
Project Nature	Greenfield	31 (67%)
	Brownfield	15 (33%)
Project Phase	Ongoing	30 (67%)
	Completed	16 (33%)

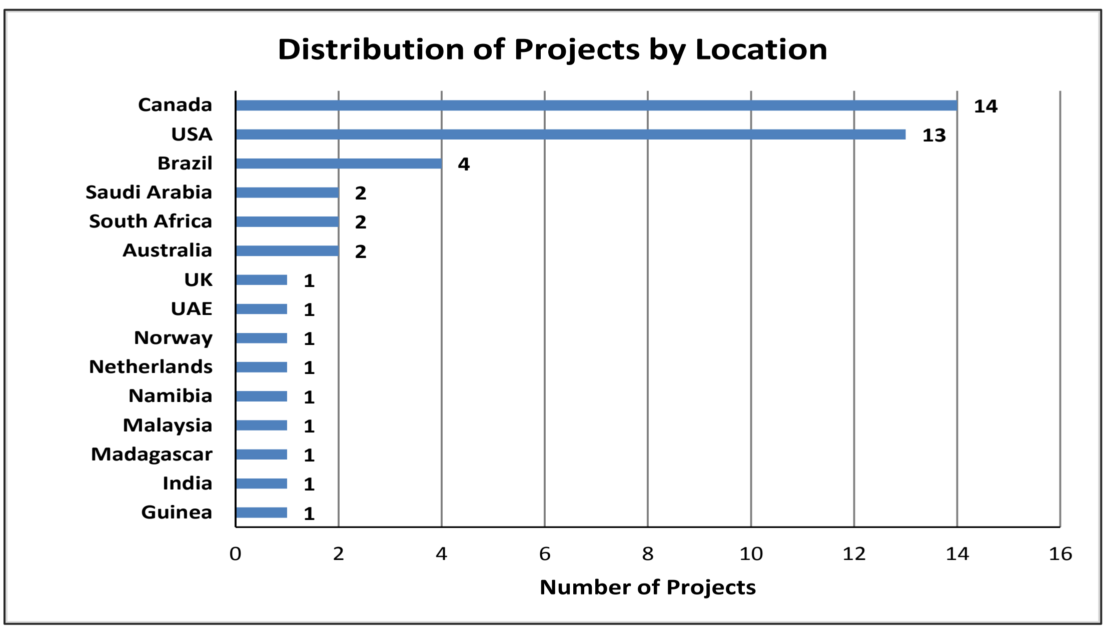


Figure 5.1 Geographical Distribution of Projects

Furthermore, to investigate the current application of IM in various sectors of construction industry, these projects are selected from wide range of project types, as shown in Figure 5.2

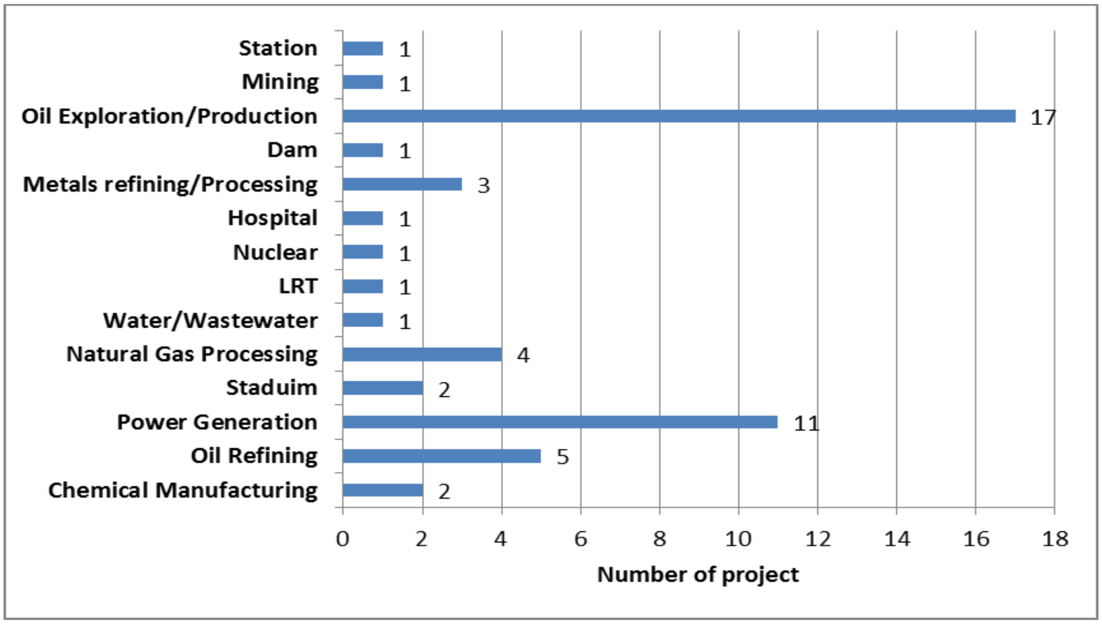


Figure 5.2 Distribution of Projects by Types

The size of projects varied from less than 500 million dollars to over 10 billion dollars, as shown in Figure 5.3.

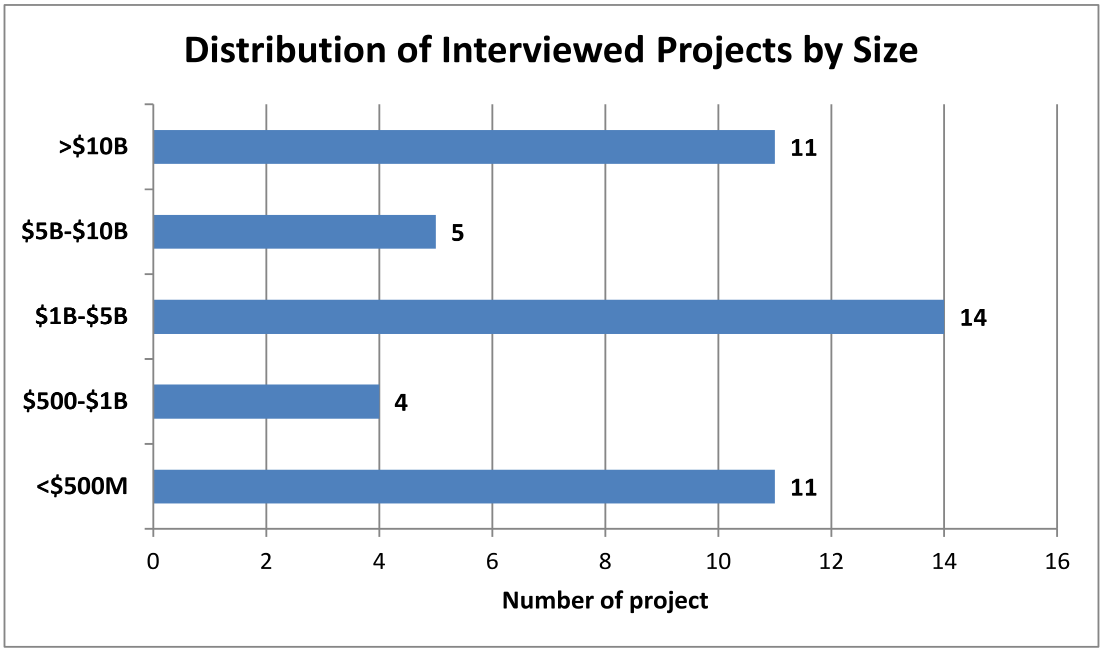


Figure 5.3 Distribution of Projects by Size

These projects are also studied according to their delivery and contracting strategies. Each project may employ several contracting and delivery strategies, which are recorded in the interviews. The most adopted delivery strategies are Engineering, Procurement, Construction (EPC), and Engineering, Procurement, Construction, Management (EPCM). And, the most employed contracting strategies are lump-sum and reimbursable work. The distribution of different delivery strategies and contracting strategies for these projects are illustrated in Figure 5.4 and Figure 5.5, respectively.

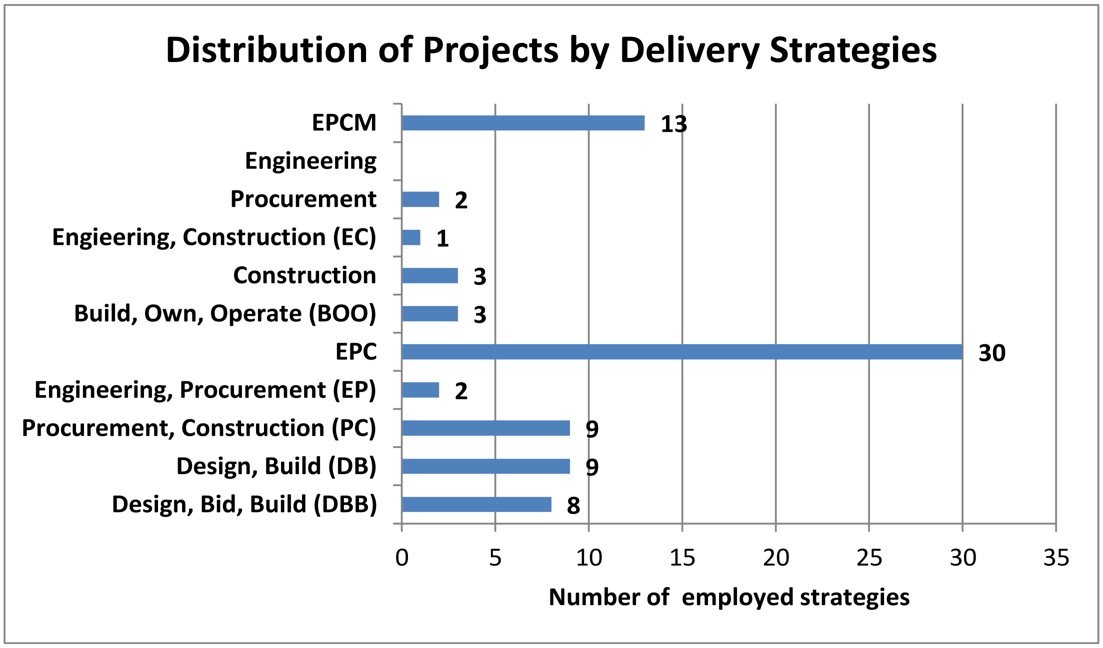


Figure 5.4 Distribution of Projects by Delivery Strategies

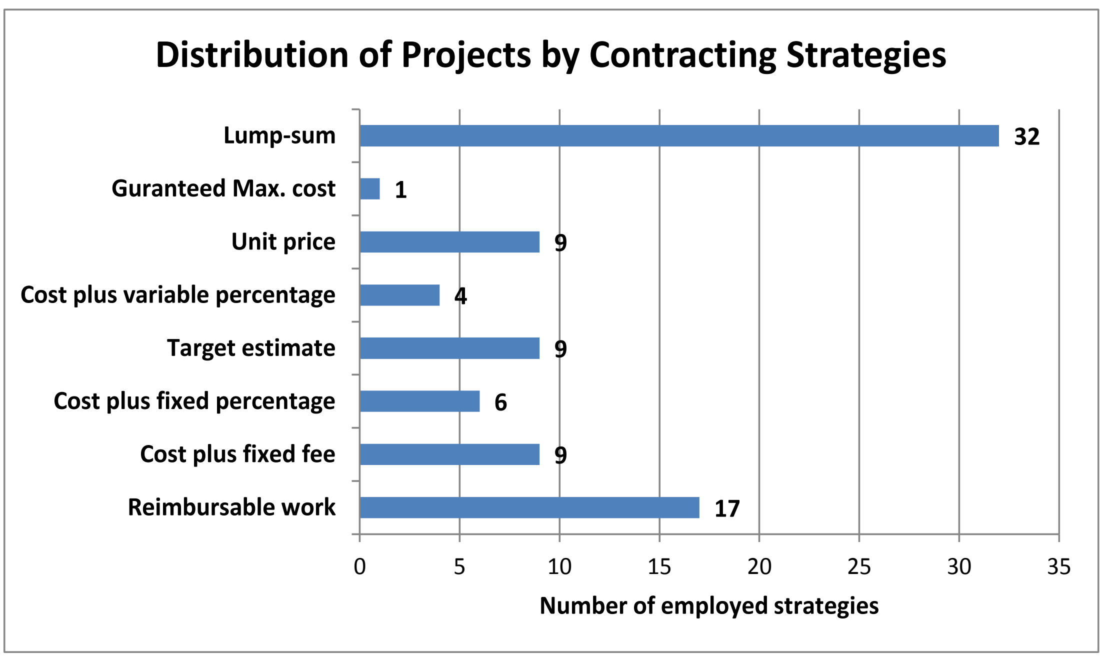


Figure 5.5 Distribution of Projects by Contracting Strategies

In addition to the contracting and delivery strategies, these projects are studied according to their organizational characteristics. Figure 5.6 shows the average number of top level scope packages, number of JVs/Owner and number of execution locations for the interviewed projects. Figures 5.7 and 5.8 illustrate the distribution of the projects according to the number of interface stakeholders and number of prime contractors.

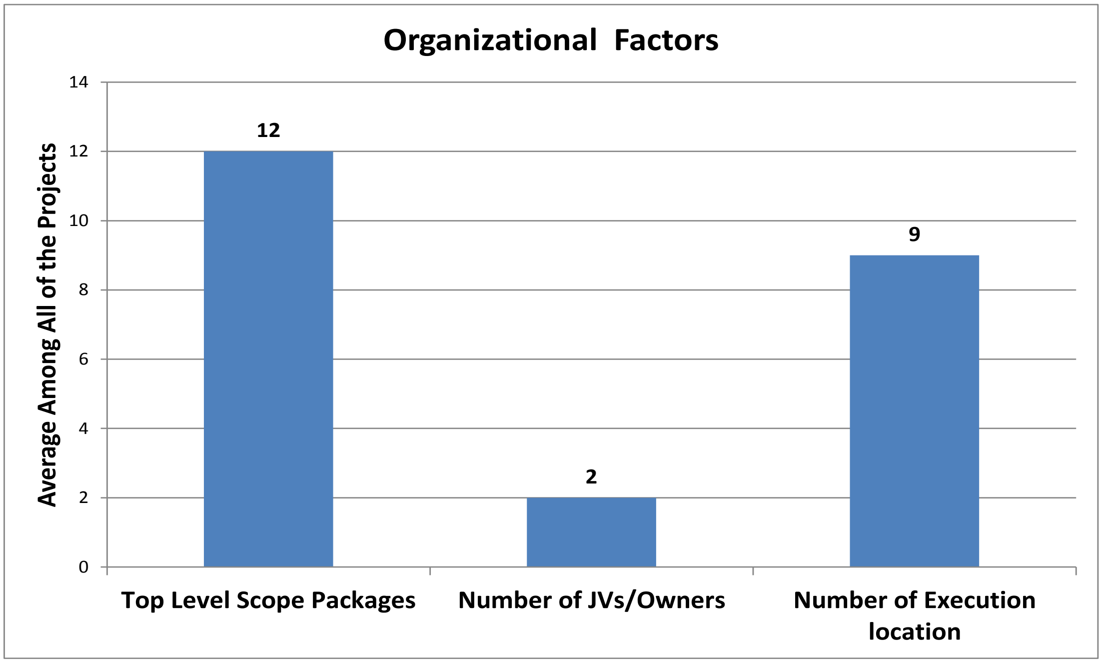


Figure 5.6 General Organizational Characteristics of Interviewed Projects

In addition to descriptive analysis of projects' general information, a correlation analysis is performed between these factors, as shown in Table 5.2. Analysis of the correlations shows that project dollar value is positively correlated with the number of JVs/owners (at the 95% confidence level) and the number of interface stakeholders (at the 99% confidence level). In other words, projects with higher value tend to involve more interface stakeholders and JVs throughout their life cycle. Furthermore, the number of execution locations is positively correlated with number of top level scope packages at the 99% confidence level. It means that the projects with higher number of top level scope packages are more geographically distributed. Finally, the number of interface stakeholders is positively correlated with the number of JVs at the 95% confidence level, and the projects with higher number of joint ventures involved generally have more interface stakeholders to deliver the project.

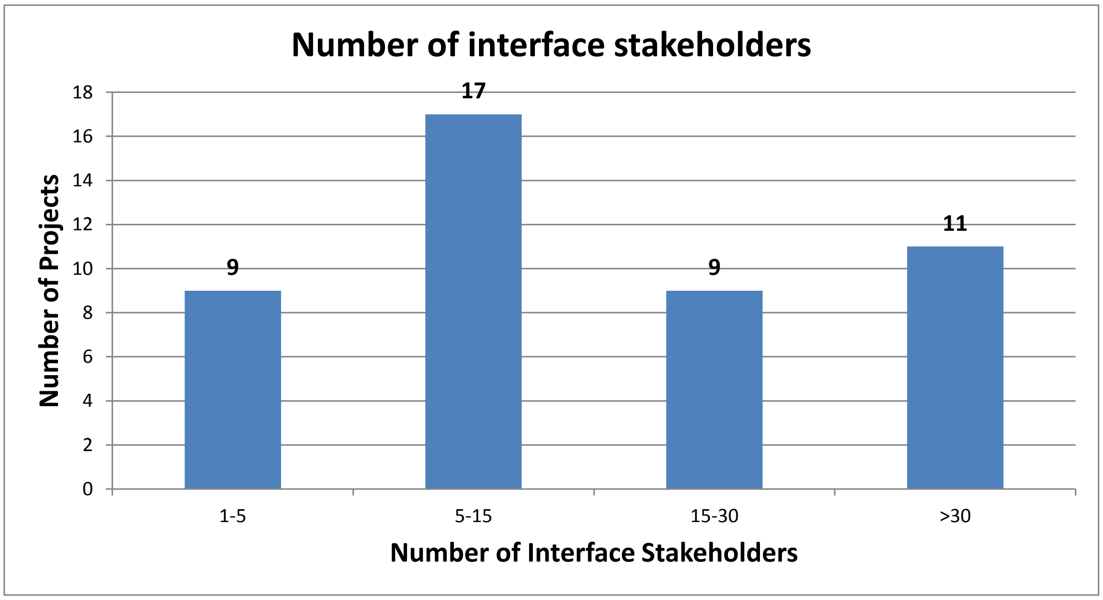


Figure 5.7 Distribution of Projects by Number of Interface Stakeholders

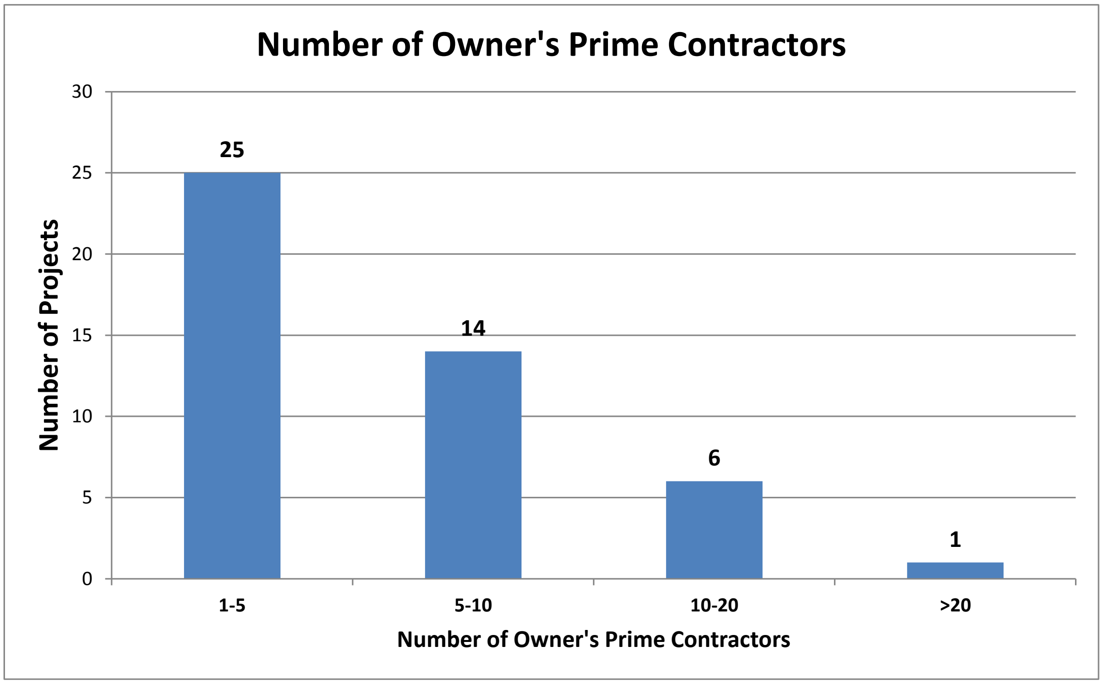


Figure 5.8 Distribution of Projects by Number of Prime Contractors

Table 5.2 Correlation Analysis Between Project General Information

Correlation Between General Characteristics of Projects	*Value*	*Top Level Scope Packages*	*Number of JVs/Owners*	*Number of Execution location*	*Number of interface stakeholders*	*Number of owner's prime contractors*
Value	1.00					
Top Level Scope Packages	-0.19	1.00				
Number of JVs/Owners	*0.36	-0.01	1.00			
Number of Execution location	-0.20	**0.64	-0.14	1.00		
Number of interface stakeholders	**0.47	0.03	*0.34	0.27	1.00	
Number of owner's prime contractors	0.29	0.00	-0.10	-0.07	0.16	1.00

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

5.4 Who adopts Interface Management?

5.4.1 Project General Characteristics

5.4.1.1 Descriptive Analysis

For the descriptive analysis purpose, the interviewed projects were studied according to several characteristics, such as project nature and type, number of execution locations, prime contractors and interface stakeholders. Then, the correlation of these factors and IM adoption was investigated. Out of 46 projects, 26 of them adopt IM processes within their management practices. As mentioned in a previous section, the majority of interviewed projects were greenfield projects (67%), from different construction sectors, including building and industrial sectors. However, a descriptive analysis of interview results illustrated that the projects with IM were all from the industrial sector, including oil exploration/production, oil refining, power generation, and metals refining/processing (Figure 5.9).

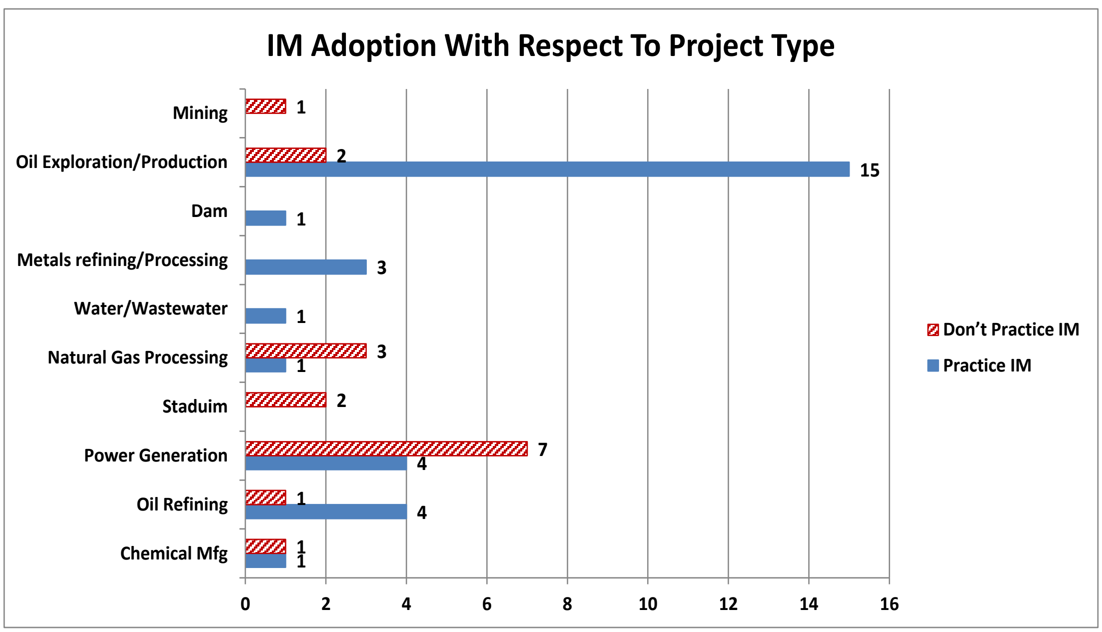


Figure 5.9 IM Adoption With Respect To Project Type

These projects were also studied according to their entire dollar value. In general, the projects ranged from $100 million to over $10 billion. However, the analysis of interview results illustrated that the majority (84%) of the projects with IM have values over one billion dollars (Figure 5.10).

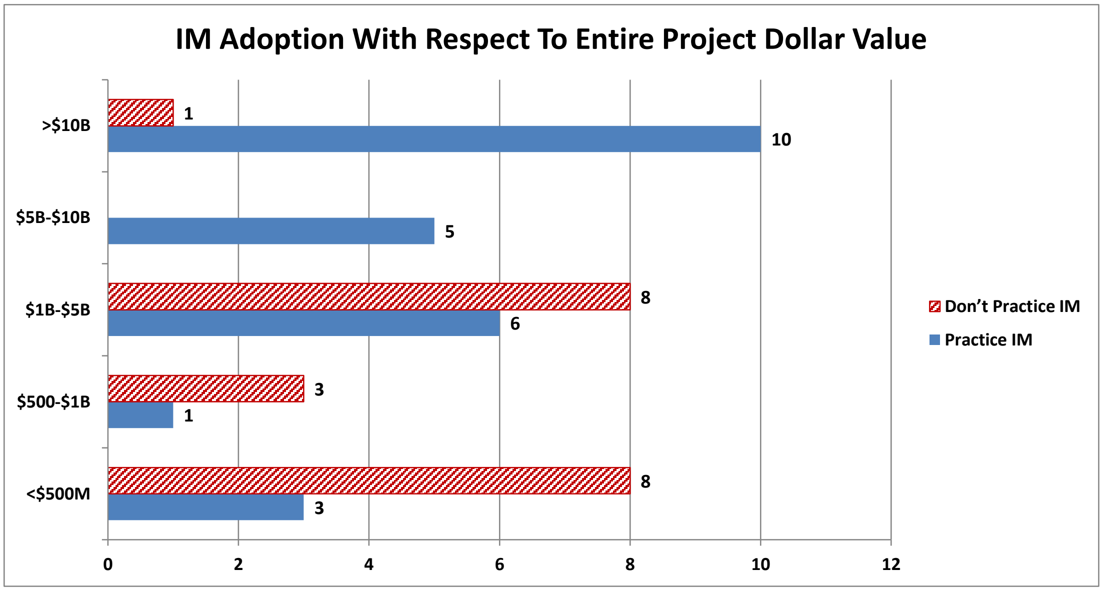


Figure 5.10 IM Adoption With Respect To Entire Project Dollar Value

In terms of delivery strategies, projects with and without formal IM employ different strategies with almost the same distribution. However, projects which practice IM within their management processes extensively employ Engineering, Procurement, Construction (EPC) and Engineering, Procurement, Construction, Management (EPCM). Distribution of delivery strategies for both groups of projects with and without formal IM is illustrated in Figure 5.11. Similar analysis is performed to investigate the contracting strategies for both groups of projects. In both groups, Lump-sum and Reimbursable work contracting strategy are the most employed strategies, as shown in Figure 5.12. It should be mentioned that more than one strategy is chosen for each project.

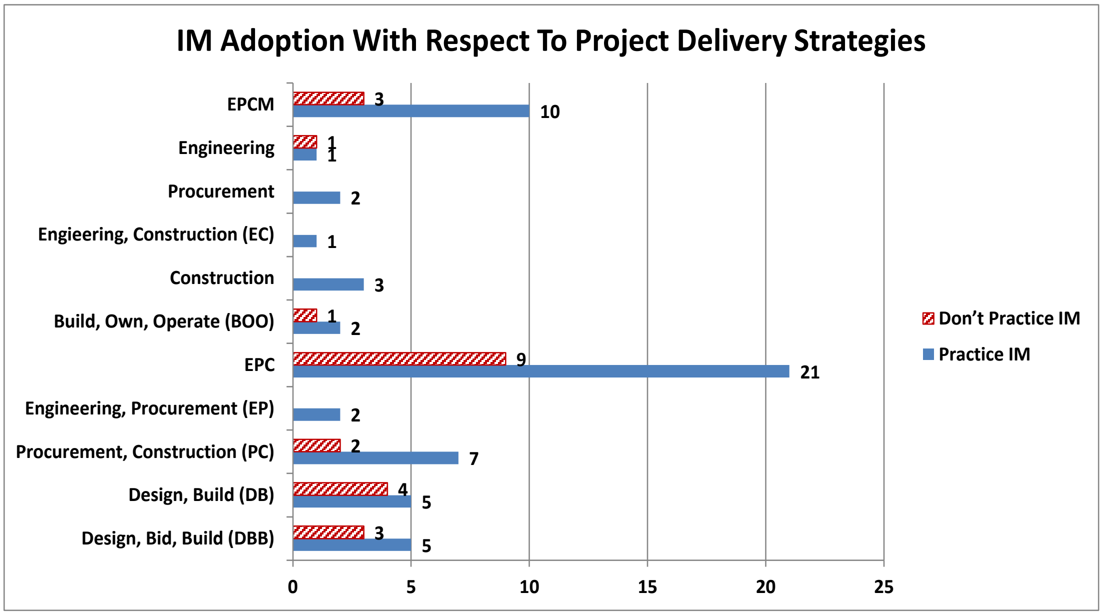


Figure 5.11 IM Adoption With Respect To Project Delivery Strategies

Geographical distribution and dealing with several stakeholders are believed to be the major reasons of adopting IM in a project. The projects are analyzed according to the average number of scope packages, number of joint-ventures (JVs) at the owner organization and average number of execution locations. The projects which adopt IM, on average, have more complex organizational structure compared to the ones without IM, as shown in Figure 5.13.

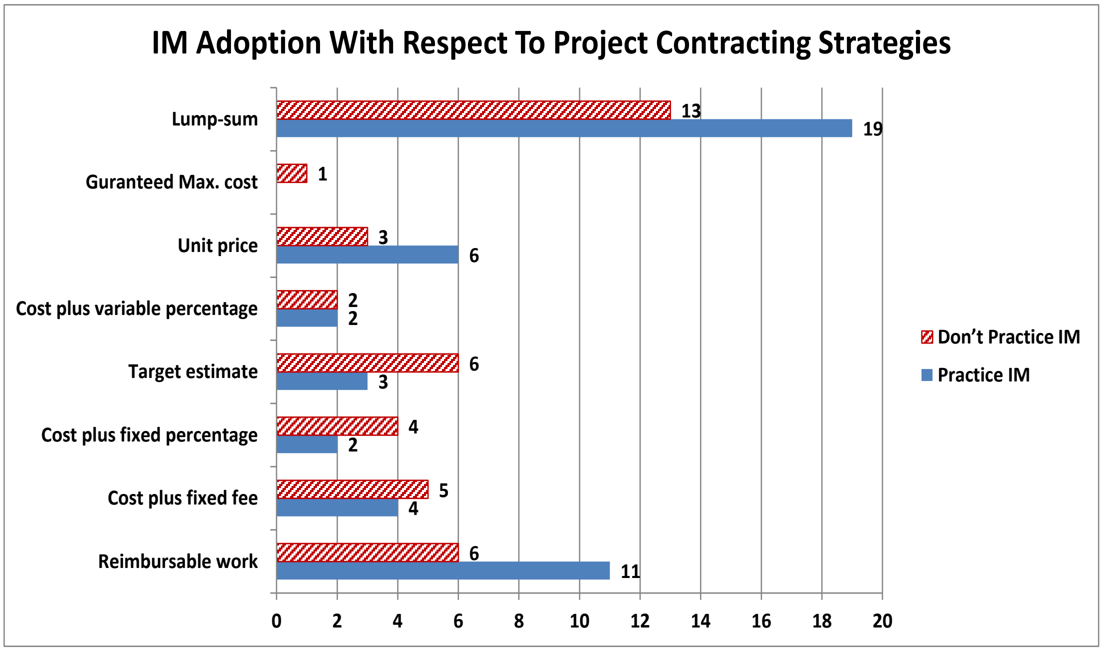


Figure 5.12 IM Adoption With Respect To Project Contracting Strategies

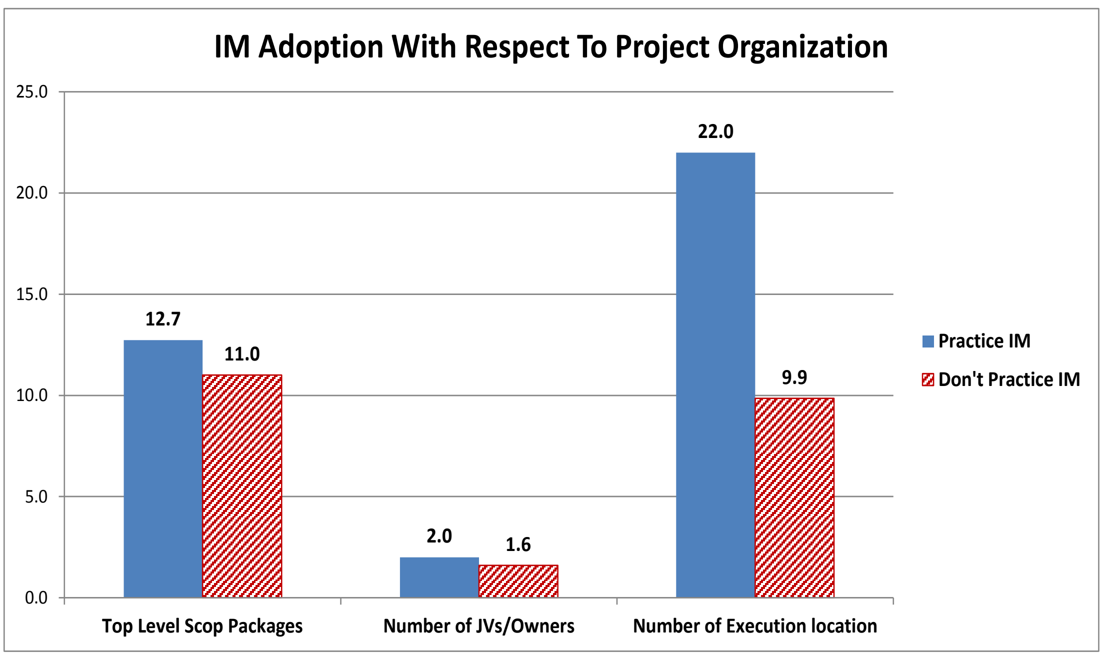


Figure 5.13 IM Adoption With Respect To Project Organization

Furthermore, the projects with IM practice tends to have more interface stakeholders within their organization (Figure 5.14).

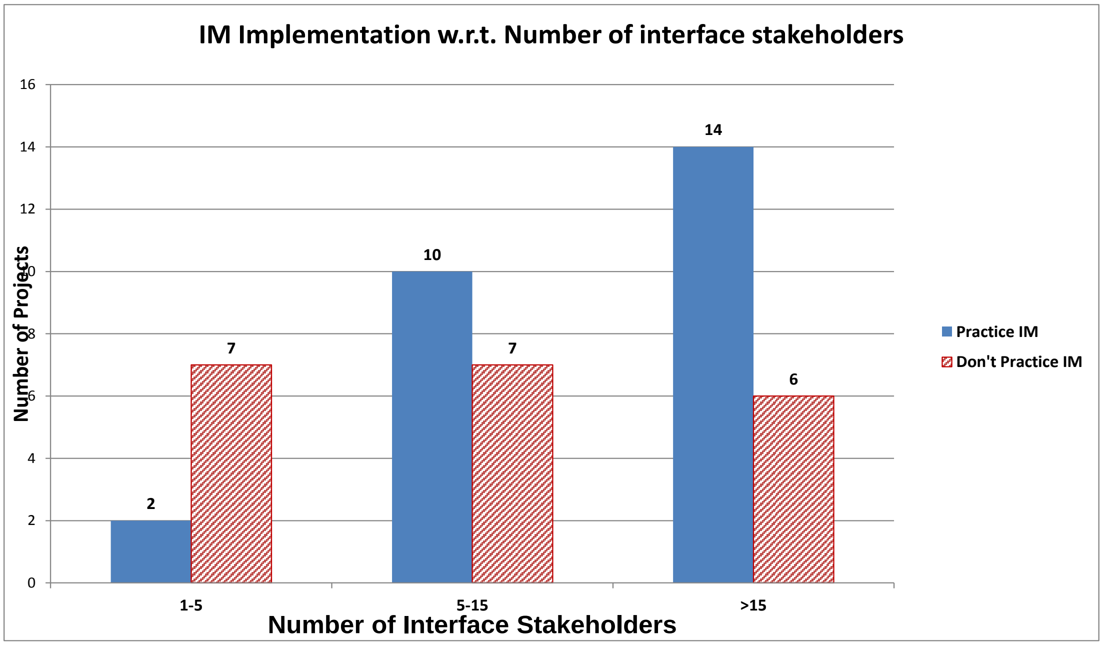


Figure 5.14 IM Adoption With Respect To Number of interface stakeholders

5.4.1.2 Statistical Analysis

A correlation analysis is performed to investigate the correlation between IM adoption and the factors discussed in the previous section. The results of correlation analysis are illustrated in Table 5.3. According to the correlation results, IM adoption has a positive significant correlation with project dollar value at a 99% confidence level and with number of interface stakeholders at a 95% confidence level. In other words, projects with higher dollar value and larger number of interface stakeholders tend to have IM implemented in their management practices.

Table 5.3 Correlation Between IM Adoption and General Characteristics of Projects

Correlation Between IM Adoption and General Characteristics of Projects	*IM Adoption*
Value	**0.56
Top Level Scope Packages	0.00
Number of JVs/Owners	0.24
Number of Execution location	0.14
Number of interface stakeholders	*0.33
Number of owner's prime contractors	0.03

***Correlation is significant at the 0.05 level (2-tailed).**

****Correlation is significant at the 0.01 level (2-tailed).**

5.4.2 Project Life Cycle and Delivery Model

The projects generally follow two delivery models: Design-Bid-Build (DBB), which is linear and sequential approach with each phase completing before the next phase begins to have greater cost certainty; and Design-Build (DB), which is parallel and concurrent approach where multiple phases may overlap each other to achieve an improved schedule. The projects using the second approach are also called fast-track projects. The life cycle of projects with these two approaches are represented in Figure 1.1 and Figure 1.2, respectively. The interviewed projects were studied according to their representative life cycle, and 15% of projects follow the linear delivery model, and the remaining 85% are classified into fast-track projects. Moreover, 88% of the projects which adopt IM also follow the second delivery model.

5.4.3 Project Risk and Complexity Factors

The factors contributing to the interviewed projects' risk and complexity are analysed and the descriptive analysis (Figure 5.15) shows that, in addition to cost, schedule and execution risk, the top five risk and complexity factors in general are:

- Scope
- Government

- Multiple engineering centers
- Multiple EPCs
- Large number of stakeholders

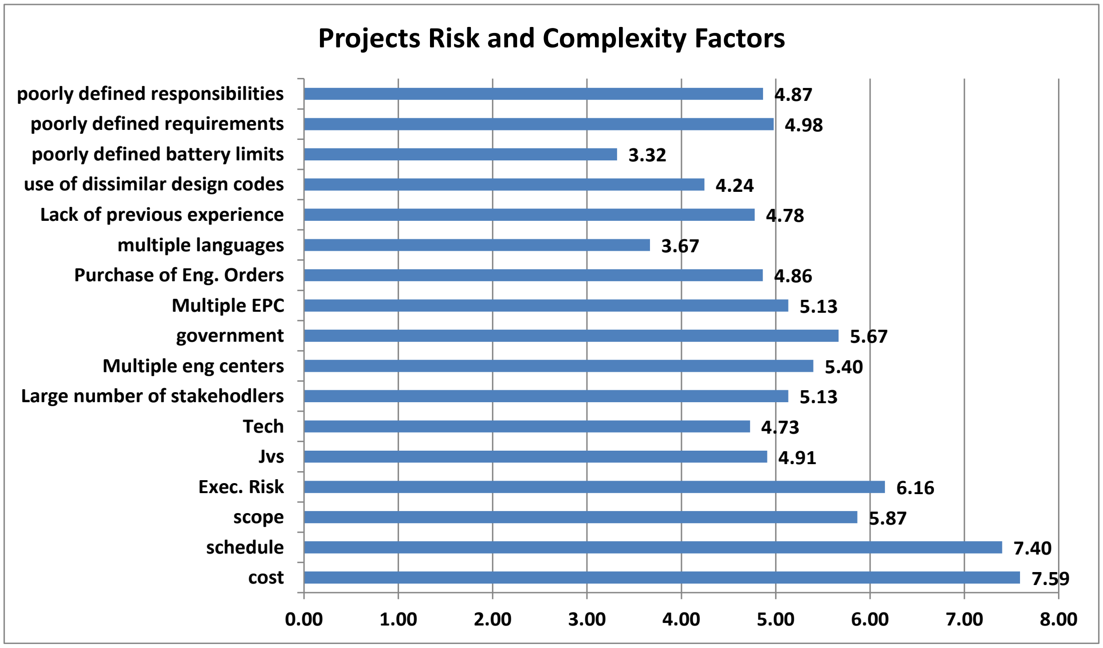


Figure 5.15 Contribution of Projects Risk and Complexity Factors

Detailed analysis of these factors revealed that they all can be addressed and mitigated by having a systematic IM system in place. In addition, these factors are studied with regard to IM adoption within the projects. A descriptive comparison, as shown in Figure 5.16, illustrates that generally companies with IM rate poorly defined battery limits, multiple languages, multiple EPCs, and government of higher contribution to the project interface and risk complexity. In these projects, IM is used as a tool to mitigate the negative impact of the high-ranked risk and complexity factors.

On the other side, the companies which do not practice IM rate technology, lack of previous experience with other parties, large number of stakeholders and use of dissimilar design codes and standards as the top factors.

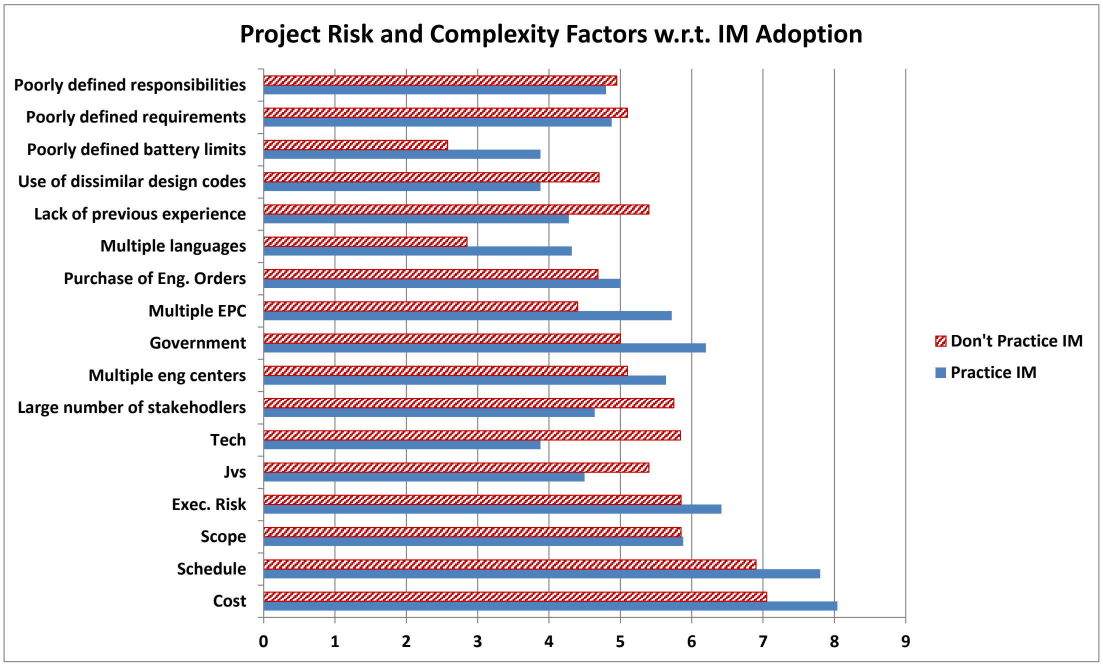


Figure 5.16 Contribution of Projects Risk and Complexity Factors with regard to IM adoption

The correlation between risk and complexity factors are investigated, as illustrated in Table 5.4. The results show that these factors are highly correlated. In addition to the general correlation between interface risk and complexity factors, the association between these factors and IM adoption is also investigated. According to the correlation results (Table 5.5), only "poorly defined battery limits" is correlated with IM adoption.

Table 5.4 Correlation between Interface Complexity and Risk Factors

Correlation Between Interface Complexity and Risk Factors	cost	schedule	scope	Exec. Risk	Jvs	Large number of stakehodlers	Multiple eng centers	government	Multiple EPC	Purchase of Eng. Orders	multiple languages	Lack of previous experience	use of dissimilar design codes	poorly defined battery limits	poorly defined requirements	poorly defined responsibilities
Cost	1.00															
Schedule	*0.32	1.00														
Scope	0.23	**0.51	1.00													
Execution Risk	0.23	0.25	0.29	1.00												
JVs	0.27	0.11	0.14	0.13	1.00											
Large number of stakehodlers	0.09	*0.30	**0.39	0.18	0.22	1.00										
Multiple eng centers	0.07	**0.41	*0.30	0.02	0.26	**0.51	1.00									
Government	0.22	**.50	0.11	0.16	0.17	0.09	0.17	1.00								
Multiple EPC	-0.02	0.13	0.08	*0.33	0.18	*0.37	**0.48	0.24	1.00							
Purchase of Eng. Orders	-0.07	0.28	0.22	0.16	0.09	0.29	*0.31	0.27	0.08	1.00						
Multiple languages	0.21	0.23	0.09	-0.19	-0.05	-0.04	0.26	0.15	-0.09	0.16	1.00					
Lack of previous experience	0.09	0.23	0.23	0.07	0.28	0.23	*0.35	0.10	0.11	0.19	**0.55	1.00				
Use of dissimilar design codes	0.01	0.20	0.19	0.12	0.19	0.08	0.22	0.04	0.06	-0.11	*0.35	**0.44	1.00			
Poorly defined battery limits	-0.11	0.13	0.25	0.03	*0.32	0.22	*0.38	-0.02	*0.32	0.10	0.20	0.14	0.24	1.00		
Poorly defined requirements	-0.02	0.22	**0.5	*0.38	**0.39	0.20	0.13	0.15	0.26	0.09	0.11	0.26	*0.34	**0.46	1.00	
Poorly defined responsibilities	-0.16	0.26	**0.48	0.18	**0.41	0.18	0.22	0.23	0.16	0.16	0.24	*0.31	**0.51	**0.46	**0.83	1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5.5 Correlation between Interface Complexity and Risk Factors and IM Adoption

Correlation Between Interface Complexity and Risk Factors and IM Adoption	IM Adotion
Cost	0.10
Schedule	0.06
Scope	0.00
Execution Risk	0.20
JVs	-0.08
Large number of stakehodlers	-0.18
Multiple eng centers	-0.03
Government	0.08
Multiple EPC	0.22
Purchase of Eng. Orders	-0.09
Multiple languages	0.11
Lack of previous experience	-0.23
Use of dissimilar design codes	-0.02
Poorly defined battery limits	*0.38
Poorly defined requirements	0.08
Poorly defined responsibilities	0.11

***Correlation is significant at the 0.05 level (2-tailed).**

****Correlation is significant at the 0.01 level (2-tailed).**

5.5 What is the Current IM Practice in the Construction Industry?

5.5.1 IM Attributes

Out of nine IM attributes, definition of deliverables, definition of roles and responsibilities, quality and clarity of information flow, and timely flow of information are ranked as the top ones. While comparing the ranking given by all the interviewees, the project who adopt IM and the ones which don't, the same trend is noticed in the importance of IM attributes. The result of IM attributes rankings are shown in Figure 5.17.

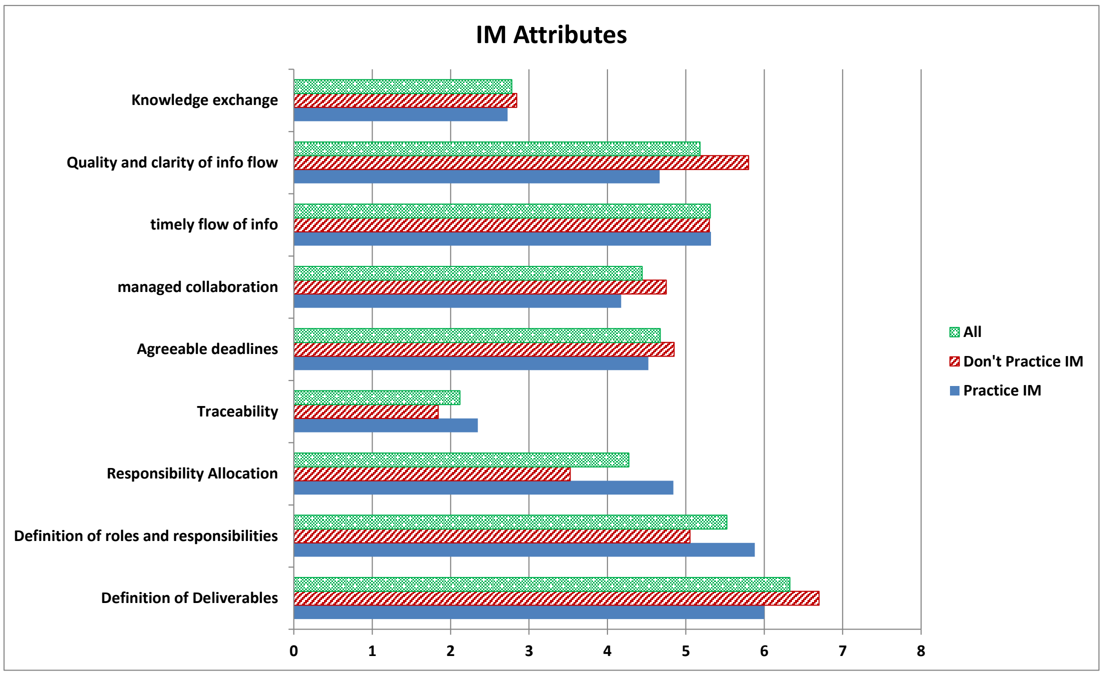


Figure 5.17 Ranking of IM Attributes

The correlation analysis also illustrates that there is a significant correlation between these attributes. Although traceability has the lowest rank, the correlation analysis shows that it is positively correlated with all other IM attributes, and if all the other attributes are done appropriately, traceability will become feasible. The results of correlation analysis are illustrated in Table 5.6.

Table 5.6 Correlation Between IM Attributes

Correlation Between IM Attributes	*Definition of Deliverables*	*Definition of roles and responsibilities*	*Responsibility Allocation*	*Traceability*	*Agreeable deadlines*	*Managed collaboration*	*Timely flow of info*	*Quality and clarity of info flow*	*Knowledge exchange*
Definition of Deliverables	1.00								
Definition of roles and responsibilities	0.18	1.00							
Responsibility Allocation	-0.06	**0.45	1.00						
Traceability	0.09	0.16	*0.36	1.00					
Agreeable deadlines	0.19	0.02	0.01	**0.46	1.00				
Managed collaboration	0.03	0.09	**0.39	**0.49	-0.01	1.00			
Timely flow of info	-0.15	**-0.38	-0.28	*0.31	0.00	-0.05	1.00		
Quality and clarity of info flow	0.09	-0.24	*-0.36	*0.30	0.25	-0.10	**0.45	1.00	
Knowledge exchange	0.18	-0.07	*0.35	**0.63	0.23	**0.46	0.16	0.20	1.00

***Correlation is significant at the 0.05 level (2-tailed)**
****Correlation is significant at the 0.01 level (2-tailed)**

5.5.2 IM Initiation Phase

The early implementation of IM helps the projects to identify potential risk sources and mitigate them. The interviewed projects were studied according to their representative life cycle (Figures 1.1 and 1.2), and the phase in which IM should be implemented. Table 5.7 shows the summary of analysis. According to the analysis, the majority of interviewed projects had a fast track life cycle. Front End Planning (FEP), which includes feasibility, concept and detailed scope, was the most selected phase to adopt IM, identify interface points, and assign roles and responsibilities accordingly.

5.5.3 IM Practices

As mentioned previously, 57% of interviewed projects claimed to have formal IM in their management practices. According to the interviews, most of the owners have implemented IM, and the contractors who have adopted IM mentioned that it was one of their contract requirements.

Table 5.7 Summary of Interview Results on IM initiation Phase

		Feasibility	Concept	Detailed Scope	Design	Construction	Commissioning & Start-up	Operation
All Projects	**Linear life cycle (15%)**	17%	33%	33%	17%	0%	0%	0%
	Fast Track life cycle (85%)	15%	34%	36%	10%	5%	0%	0%
Projects with IM	**Linear life cycle (12%)**	0%	33%	67%	0%	0%	0%	0%
	Fast Track life cycle (88%)	9%	43%	43%	5%	0%	0%	0%

5.5.3.1 General Procedures for Interface Management

Several approaches are undertaken by projects to identify interfaces and manage them throughput the project life cycle. Here are the details for these approaches:

- At the basic level, the major interfaces are identified during FEP. Other interfaces are recognized and dealt with at the time that two interface stakeholders need to collaborate with one another. In this approach, major interfaces are discussed and monitored in the meetings between the involved stakeholders. However, there are not regular interface meetings scheduled for this purpose. Generally, there is not specific position allocated for IM and project managers and engineers deal with interface issues. Interfaces are recorded and tracked in the meeting minutes and sometimes using spreadsheets.
- At the second level, the organization has a predefined procedure to manage interfaces within their project management practices. These procedures are either stand alone or in conjunction with other management procedures, e.g. communication management. The interfaces are generally recorded in spreadsheet, paper-based interface forms or other

database software packages and tracked manually. Project managers, coordinators and engineers are assigned to Interface Management tasks based on part-time arrangements. Any changes to the interfaces and interface-related issues are discussed in the interface meetings, which are held on a regular basis. However, there is not specific procedure to link interface management with project schedule, change management or risk management, neither to identify key interface points.

- At the highest level, a well-defined procedures are outlined for Interface Management along with other project management practices. This documented procedure is generally recorded in Master Interface Plan or Interface Management Plan. It includes step by step guideline on how to identify interfaces, what are the common types of interfaces, what are the responsibilities of interface stakeholders, when and how to hold interface meetings. Generally, Interface Managers and coordinators are assigned to these projects, with several years of interface-related experience. Interface are recorded and managed in an automated, sometimes work-flow driven, IM software. The software could be commercial or in-house version. Still, there is not specific procedure to link interface management with project schedule, change management or risk management, neither to identify key interface points. However, the link between IM and project schedule and change management is examined and followed up manually in scheduled/emergency interface meetings.

5.5.3.2 Interface Management Personnel

According to the data gathering results, currently, there is not standard procedure to select IM-related positions in a project and number of people required for each position. However, the core competencies for each IM position are investigated in the questionnaire. Figure 5.18 illustrates the percentage of the identified six core competencies for IM positions (Interface Manager, Interface Coordinator, Translator/Cultural mediator and Project Engineer).

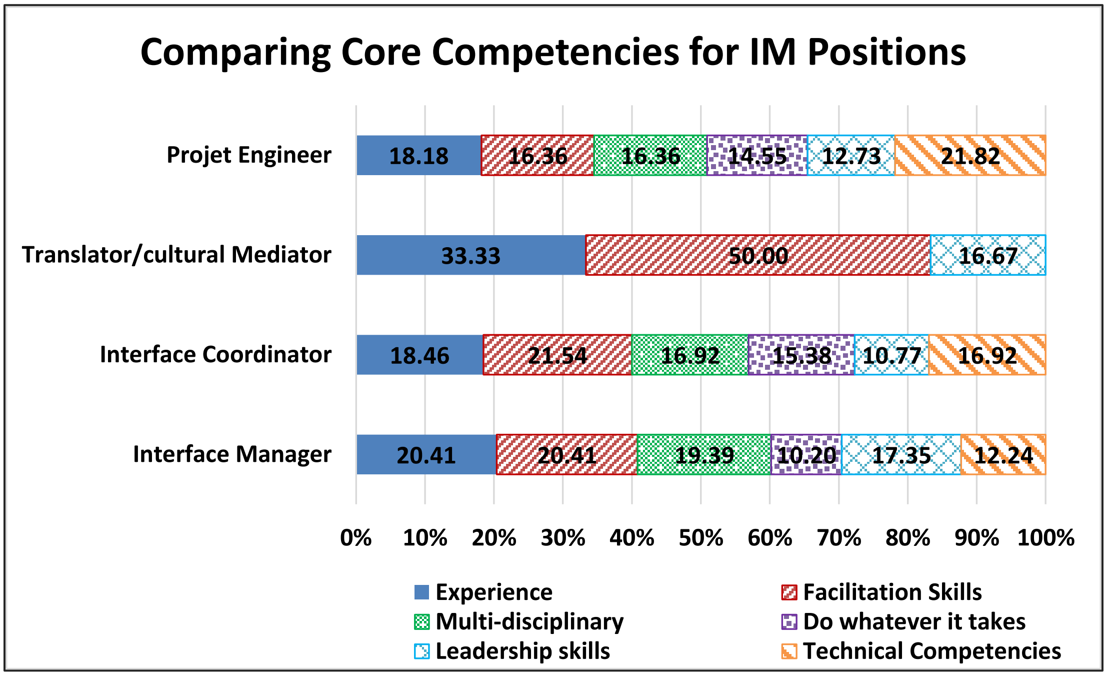


Figure 5.18 Percentage of Core Competencies for IM Positions

5.5.3.3 Estimated Number of Interface Points and Agreements

As mentioned in previous sections, there is not a common procedure to identify interface points in the construction industry. Therefore, each organization follows its own procedure to define the nature (soft and hard), scope (inter-, intra-, and extra-project interfaces), type and level of interface points. As a result, the survey shows different ranges for the number of IPs and IAs, as low as 10 IPs to the maximum of 1000 IPs. However, based on expert opinion from Coreworx Inc, a 2-Billion dollar offshore project on average has 2000 IPs and 5 IAs per IP.

5.5.3.4 Critical Interface Points

Currently, the construction organization do not employ a specific approach to rank the IPs based on their criticality. Generally, the IPs/IAs are considered critical as they are approaching to their closing dates. In this situation, they are discussed in the interface meetings. However, the interviewees are asked to select the criteria the may impact the criticality of IPs. The investigated criteria include top management experience, associated with higher cost, associated with higher risk, related to an activity on the critical path, related to a specific discipline/area, and an IP between more than 2 parties. Figure 5.19 illustrates the ranking of these criteria according to the interviewees.

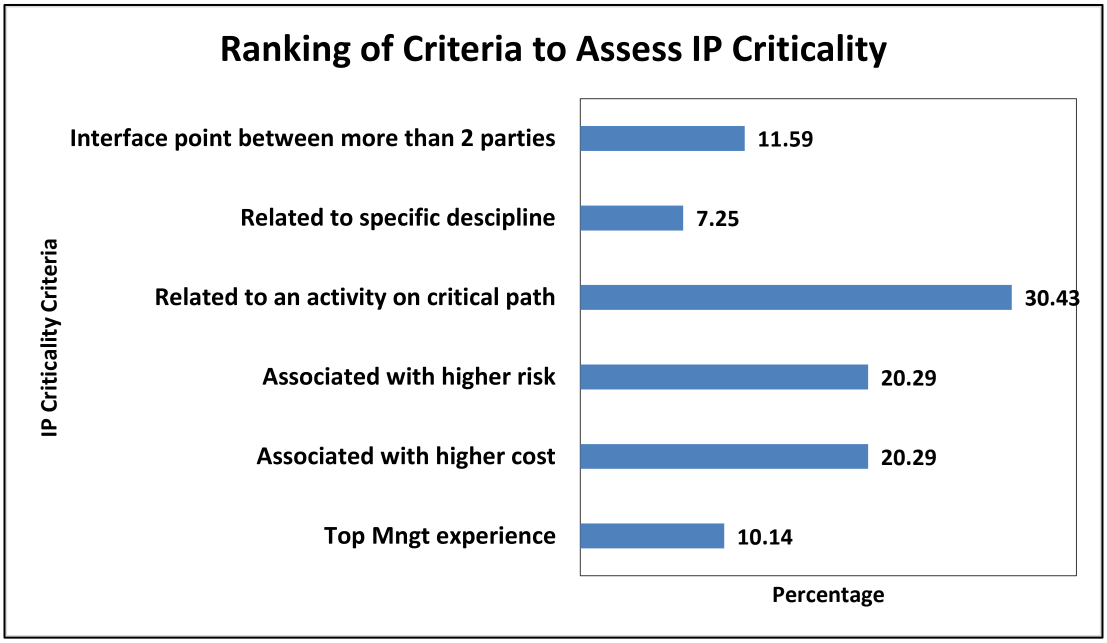


Figure 5.19 Ranking of Criteria to Assess IP Criticality

5.5.3.5 IM Maturity Model

The detailed analysis of IM implemented in construction projects illustrates that there is not a distinct line between formal and informal IM. However, IM implementation matures gradually within an organization and project. The maturity model for IM implementation is a recommended stepwise process to move an organization to a desired state of IM implementation. The desired state can be derived from the identification and simultaneous consideration of project interface risk and its potential consequences. The proposed maturity model is based the group work of RT 302 to which this author contributed, and will be presented in the RT 302 Implementation Resource (2014).

The basic elements to consider when implementing IM are: business processes, enabling tools/systems, qualified people/practitioners, and sustaining culture. The stages of the maturity process for each of the basic elements start with Stage 0 (the starting point for an organization that is just venturing into IM implementation) through Stage 4 (the end point where IM is fully implemented across the organization in appropriate projects). The stages can also be viewed as a progression from informal to formal interface management (i.e., IM formality). A definition, categorized by basic element, follows:

- Business Processes: The way in which IM is implemented in projects, normally documented in company- or project-level processes and procedures.
    - Stage 0: Ad hoc project-derived processes to meet specific coordination requirements in that project.
    - Stage 1: Industry best practice adoption referring to CII RT 302 IMIGe and other sources.
    - Stage 2: Mature a best practice on several pilot projects.
    - Stage 3: Measure the impact of processes on key project performance indicators (e.g., cost and schedule), which could be aggregated across projects.
    - Stage 4: Integrate IM processes with other dependent project processes such as project schedule and cost, change management, risk management, and document review.
- Enabling Tools/Systems: Tools/systems that support the IM processes implemented in a project.
    - Stage 0: Traditional means of communication and tracking of issues and related agreements through means such as emails, file folders, and lists.

    - Stage 1: Manual tracking of agreements and action items via, for example, spreadsheets and databases.
    - Stage 2: Tool/system has a fundamental degree of automation and workflow (e.g. Document sharing/communication systems, engineering platforms and customized database).
    - Stage 3: Standalone and fully automated system with workflow tracking and status tracking (e.g. commercially available IM management product, highly customized document sharing/communication system or a database-based system).
    - Stage 4: Standalone and fully automated system sharing key common data with project schedule, change management, and risk management systems.

- Qualified People/Practitioners: The people with skills and experience who utilize the work processes and systems to effectively create an IM environment on a project and who can sponsor company-wide organization and adoption of IM implementation.
    - Stage 0: Coordinators or "project engineers" have coordination roles for discrete project issues or scopes of work in interfaces.
    - Stage 1: Utilize experienced project coordinators with appropriate multi-discipline background.
    - Stage 2: Select professionals with IM experience who can be either formally trained in IM or externally sourced.
    - Stage 3: Establish an IM function as a formal part of a project management organization to promote the role of interface managers.
    - Stage 4: Establish an IM career path with the defined skills and experience, and drive a development program of future interface managers in the organization.

- Sustaining Culture: The sustaining organization and behavior where IM is a routine part of the project execution practice
    - Stage 0: The notion of IM is neither in the organization nor any of the projects.
    - Stage 1: Establish a few good example projects where IM has been effectively used during execution. Use the persons involved in these example projects as IM advocates (or ambassadors).
    - Stage 2: Use IM advocates as mentors to other projects where an IM process can be of benefit.
    - Stage 3: Through the establishment of best practices, robust IM systems and several IM advocates drive a thought process change toward interface identification and management on all projects.
    - Stage 4: A sustaining organization for IM is in place and IM benefits are clearly enumerated at the enterprise level.

5.6 How the Status and Performance of IM is Assessed

Projects with IM practices implemented are asked to rank the usefulness of identified criteria to assess the status and performance of IM within the projects. According to the interview results, the following criteria are selected as the useful ones in assessing IM, and are listed in rank order along with their scores (scores are out of 5):

- Turnaround time for inquires (4.33)
- Quorums at interface meetings (4.16)
- Number of non-conformance reports issued because of interface issues (4.05)
- Number of overdue interface agreements at any point of time (4.00)
- Residual risk before and after implementing IM (3.96)

- Percentage of interface points identified after FEED of total project Interface points (3.77)
- Percentage of closed interface agreements of the ones that should be closed, at any point of time (3.50)
- Number of change orders precipitated during the execution of interface agreements per agreement at any point of time (3.50)
- Number of formal escalations or disputes at any point of time (3.43)
- Percentage of closed interface points of the ones that should be closed, at any point of time (3.33)
- Average number and standard deviation of revisions per document or drawing (3.24)
- Percentage of completed engineering, when IM is started (3.21)
- Amount of contingency release at any point of time (2.90)
- Number of cultural clashes at any point of time (2.20)

5.7 Summary

Lack of common definitions for IM and its knowhow imposes variation and difficulties in IM implementation in the construction industry. To address this issue, RT 302, supported by CII, initiated its research efforts in May 2012. RT 302 studied 46 projects by conducting face-to-face and phone interviews. Every interview was performed by an academic and an industry team member, and was facilitated by a questionnaire developed by the team. A summary of the findings follows:

- Formal IM is found to be more implemented in the industrial projects (e.g. oil and gas, power generation),
- Formal IM is more prevalent in projects of higher dollar value.
- EPC and EPCM are the most common delivery strategies, and lump sum and reimbursable work are the most common contracting strategies for IM projects.

- IM is more prevalent on projects with a higher number of interface stakeholders, top level scope packages and execution locations.
- Project total cost and number of interface stakeholders are positively correlated with the IM implementation in the projects.
- Projects with IM practices mostly have fast-pace Design-Build life cycles.
- Government, “dealing with multiple EPCs” and “multiple engineering centers” are ranked the top three factors that affect risk and complexity of the projects who implement IM.
- Definition of deliverables, definition of roles and responsibilities and timely flow of information are ranked as the most important attributes of a successful IM.
- Front End Planning is recognized as the most appropriate phase to initiate IM.
- There is not a distinct line between formal and informal IM. However, there is a progression in IM implementation, which is defined as the IM maturity model.
- There is not a specific method to identify high risk interface points. However, association with the project schedule and activities on the critical path is recognized as the most appropriate way to determine the criticality of interface points.
- “Turnaround time for interface related inquires”, “quorums at interface meetings”, and “number of non-conformance reports issued because of interface issues” are the most useful criteria to assess the performance of IM.

Chapter 6

Interface Management System and Risk Management

A mega project may involve several hundreds, even thousands, of interface points. An explicit outcome of an IM system could be an ability to identify schedule related risks using the dynamic information flow between stakeholders. However, due to the high number of interface points and their changing nature, it is not possible to find the absolute correlation between each interface point and every task on a project schedule. Therefore, it is necessary to develop algorithms to identify high-risk interface points to effectively manage them and mitigate their potential impact. Furthermore, the identified high-risk interface points can be linked to the schedule, to reduce the computational complexity of the mapping process.

6.1 Interface Management Impact on Project Risk

Implementation of an IMS is considered an effective approach to increase visibility on mega project execution through clear definitions of tasks, roles and responsibilities, and boundaries. At each interface point, the boundary between stakeholders is defined, as well as the exact definition of each stakeholder’s tasks. Through the interface agreement, each stakeholder knows exactly his responsibility, tasks and the needed date. Because of the added visibility on the common tasks between project interface stakeholders as well as facilitated communication between them, the project faces reduced amounts of rework, which results in cost and time savings. Furthermore, the quality of the deliverable is enhanced because of the in-time sharing of relevant information.

Focusing on the impact of an IMS on the project schedule is an explicit way to illustrate the time saving and risk reduction in project management. Risk reduction will be gained mainly by providing early alerts and enough time for project parties to plan for and recover from the potential failures that happened at the precedent interface points. Linking IMS with a project schedule can be elaborated by introducing two scenarios representing typical interfaces in construction mega projects. (These scenarios were developed in collaboration with the Coreworx management team).

Scenario 1 Example: During the design phase, the delay in completion of a key interface agreement impacts a critical path activity for another contractor.

Contractor A and B are awarded the scope packages of a terminating pipeline that spans two scope packages. Therefore, an interface point is created at the point that two scope packages meet each other. According to the interface agreement, Contractor A should confirm the specifications of their high pressure titanium piping material to Contractor B during the design stage.

The originally accepted date of receiving the requested information falls on the critical path of contractor B. Contractor A is not able to provide the information by the deadline, and informs contractor B of the delay. Therefore, Contractor B is able to identify schedule variance and also the delay which will be caused on their next dependent activity- procurement of the long-lead-time titanium. To summarize, by integrating the key interface point with the schedule of involved parties, procurement of Contractor B would be informed of a delay caused by the failure in completing the interface agreement between Contractor A and B.

Scenario 2 Example: During the commissioning phase, the delay in material delivery for Contractor A results in a delay of an interface point that impacts Contractor B.

Contractor A and B are awarded the scope packages of two pipelines which should be connected by a flanged joint, illustrated in Figure 6.1. The interface point includes testing the flanged joint on piping between two scope packages. One of the key interface agreements between two contractors is about the details of how each of them will complete tightness testing for the flanged joint during commissioning phase. Another deliverable is the test result.

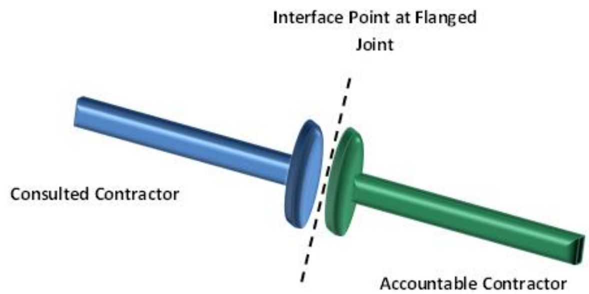


Figure 6.1 Flanged Joint: Interface Point between Two Contractors

This interface point falls on the critical path of both contractors. Contractor A experiences a delay in delivery of the piping materials, meaning that the piping installation and the interface agreement closing will also be delayed. Therefore, the Interface Manager of Contractor A will issue a change order request to Contractor B in order to modify the deadline of interface agreement. The Interface Manager of Contractor B will review the change order and reasons for delay, and approves the updated deadline. To summarize, by integrating the key interface point with the schedule of both contractors, not only Contractor A is notified of the delay in procurement of piping, but also notifies Contractor B of the delay which is caused because of the procurement.

6.2 Interface Network Representations

In this section, to enable the mapping process between IMS and project schedule, two necessary network representations are defined. Networks are appropriate approaches to illustrate the flow and dynamics of information. They allow for the use of mathematical measures to analyze the quantitative relationships between stakeholders of the project, and also provide a visual representation of the relationships and attributes between project participants, shown on the nodes (Chinowsky et al. 2008). These two presented graphs could also be explained using the Social Network Analysis (SNA) concept.

In an IMS, interface points represent the interactions between stakeholders in a project. These interactions can be reflected in a Stakeholders Interface Network (SIN). In a SIN, the stakeholders are represented on the nodes, and the edges show the interface points between them. The interface points can be related to different disciplines or areas, with various levels and attributes (physical, functional, organizational, etc.). The numbers on the edges represent the number of IPs between every pair of stakeholders. Figure 6.2 illustrates a network of 10 stakeholders and 157 IPs (which represents the SIN for the model project defined later in Section 6.5). The number of IPs between every pair of stakeholders is shown on the edges. The thickness of edges is associated with the number of IPs between that pair of stakeholders. The necessity of this representation becomes apparent in subsequent sections of this thesis.

The SIN only demonstrates the static information of the number of stakeholders and the interactions between them. However, to capture the information dynamics between stakeholders, a network of IPs is generated, which is called the Interface Points Network (IPN) (Figure 6.5, which represents the IPN for the model project defined in Section 6.5). In an IPN, nodes represent the IPs and the edges represent the interdependency between the IPs, as a sort of meta-relationship. Since, the IPs and their interdependencies are changing over time through the project life cycle; the IPN is a representation of project dynamic relationships.

In an IPN, the interdependency includes any logical relationship between every pair of IPs. The relationships may include:

- Dependency of information flow
- Time dependency
- Space dependency
- Sequence of tasks

- Physical/dimensional/functional systems dependency

Furthermore, the interdependencies can be classified into two categories: Hard, and soft:

- Hard interdependency: This type depicts a strong relationship between two interface points. In other words, any changes in an interface point will lead to certain changes in its succeeding interface points. For example, changing the diameter of a pipeline on one side of an IP should be reflected in the diameter on the other side and at the connecting flange.
- Soft interdependency: This type illustrates the relationships which are partially dependent on each other. Any change in the preceding interface point may lead to changes or alterations in its successors. An example is a change in the load being supported by a foundation.

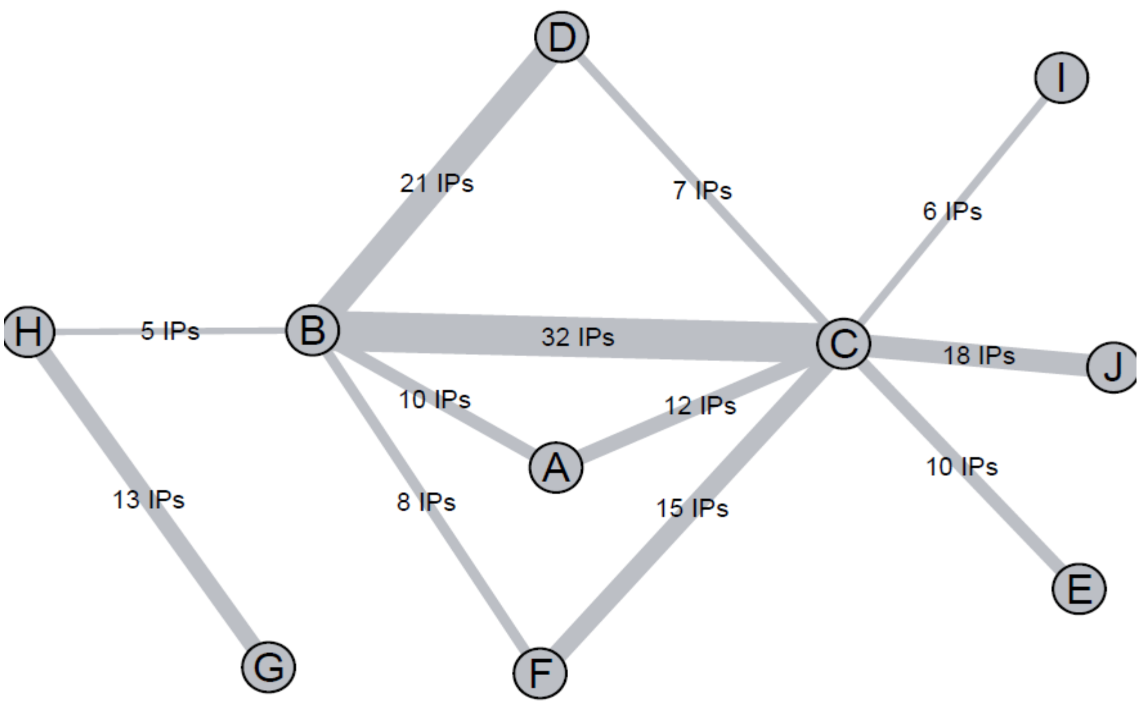


Figure 6.2 Sample of Stakeholders Interface Network (SIN)

The interdependencies of IPs are recorded in the sparse "IP Interdependency Matrix" (Table 6.1, which represents the IP Interdependency Matrix for the model project defined in Section 6.5). In this matrix, preceding/affecting IPs are presented in the rows. The columns illustrate the succeeding/affected IPs. If IP_i affects IP_j, the interrelated cell is assigned 1, otherwise, it is assigned 0. Since, the direction of interdependencies are recorded, the IP Interdependency Matrix is not symmetric. The impact of hard or soft interdependencies is not considered in this research. However, hardness is a useful factor to find critical IPs along with other criteria such as relation of IP to a specific discipline, IPs between more than two parties, association with higher cost, etc. Equation 6.1 illustrates the mathematical definition to fill out the "IP Interdependency Matrix".

$$\forall x, y: \begin{Bmatrix} e_{x,y} = 1, & \text{If node (IP) x impacts node y} \\ e_{x,y} = 0, & \text{Otherwise} \end{Bmatrix} \qquad \text{Equation 6.1}$$

In the IPN, the direction of the edge is from preceding/affecting IP towards the succeeding/affected IP. Considering the types of interdependencies, IPs can have bidirectional relationships with each other. This characteristic of the IPN is very important, especially at the design stage, and for projects with condensed schedules, in which the design and construction phases overlap, and procurement begins during design. These cases require an ongoing collaboration between different departments or stakeholders, and cannot be monitored by CPM, in which every pair of tasks ultimately must have sequential relationships. However, in an IMS, the interactions between IPs (not just stakeholders) can be documented and monitored. A sample of an IPN is illustrated in Figure 6.5. In this graph, nodes represent IPs between every pair of stakeholders. As an example, BC_1 stands for IP_1 between stakeholders B and C. Edges show the interdependency between every pair of IPs, with the attributes of dependency written on the edges.

Table 6.1 A sample of Interdependency Matrix

		Succeeding/Affected IP (IP_j)															
		IP1	**IP2**	**IP3**	**IP4**	**IP5**	**IP6**	**IP7**	**IP8**	**IP9**	**IP10**	**IP11**	**IP12**	**IP13**	**IP14**	**IP15**	**IP16**
Preceeding/Affecting IP (IP_i)	**IP1**	--	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	IP2	0	--	1	0	0	0	0	0	0	0	1	0	0	0	0	0
	IP3	0	1	--	0	0	0	0	0	0	0	1	0	0	0	0	0
	IP4	0	0	0	--	1	0	0	0	0	1	1	0	0	0	0	1
	IP5	0	0	0	1	--	0	0	0	0	0	1	0	0	0	0	1
	IP6	0	0	0	0	0	--	0	0	0	0	0	0	0	1	0	0
	IP7	0	0	0	0	0	0	--	1	1	0	0	0	0	0	0	0
	IP8	0	0	0	0	0	0	1	--	1	0	0	0	0	0	0	0
	IP9	0	0	0	0	0	0	1	1	--	0	0	0	0	0	0	0
	IP10	0	0	0	0	0	0	0	0	0	--	0	0	0	0	1	1
	IP11	0	1	1	0	0	1	0	0	0	0	--	1	1	1	0	0
	IP12	0	0	0	0	0	1	0	0	0	0	1	--	1	1	0	0
	IP13	0	0	0	0	0	1	0	0	0	0	1	1	--	1	0	0
	IP14	0	0	0	0	0	1	0	0	0	0	1	1	1	--	0	0
	IP15	0	0	0	0	0	1	1	1	0	1	0	0	0	1	--	1
	IP16	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	--

6.3 Key Interface Points

A mega construction project is a network of several hundreds of interdependent interface points. Therefore, the risk of failure of any interface point highly depends on the failure of its predecessors. The probability of failure at each interface point is not simply the summation of failure probability at its predecessors; it is growing exponentially with the increase in the number of the precedent interface points. In Figure 6.3, it is shown that interface point "i" is interdependent with interface points 1,2,…,n.

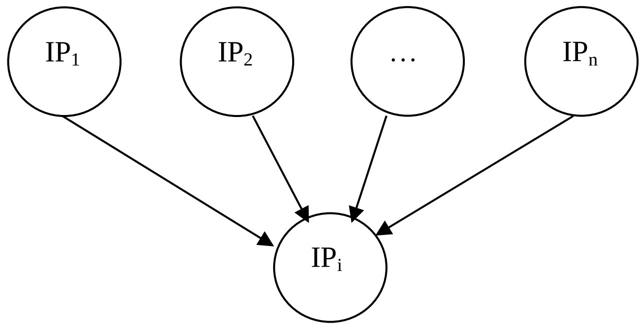


Figure 6.3 A Typical Interdependency between Interface points

To define the probability of failure at interface point "i", let's assume that:

- A: Failure event at IP_1,
- B: Failure event at IP_2,
- C: Failure event at IP_n,
- P_f: Probability of failure at IP_i

Therefore, the probability of failure at interface point "i" is:

$$P_f = P(A \cup B \cup \ldots \cup C) = 1 - P(\bar{A} \cap \bar{B} \cap \ldots \cap \bar{C}) = 1 - P(\bar{A})P(\bar{B}) \ldots P(\bar{C})$$

Where, $P(\bar{A}) = 1 - P(A)$

Here, it is assumed that all the failures of predecessors are independent events, which is not correct in reality. However, for the ease of calculation, and illustration of the relationship between failure of a system and its predecessors, it is assumed that event A, B, …, C are independent.

By increasing the interdependencies, the probability of failure is also increased, and gets closer to 1. It means that in a system with a large number of interdependencies between interface points, the failure of the network is inevitable. This fact is illustrated in Figure 6.4.

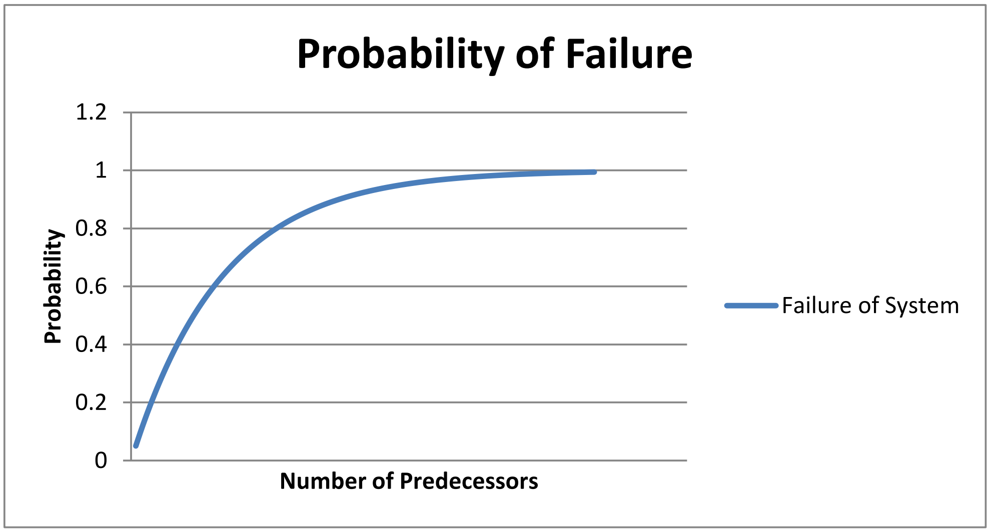
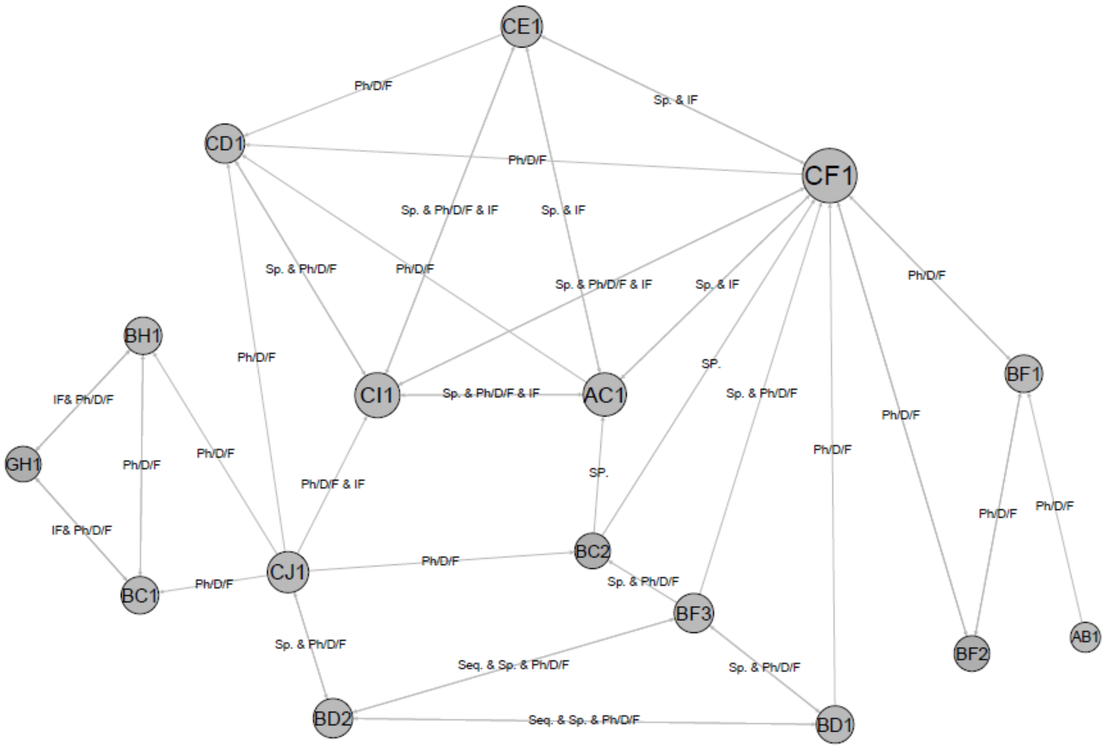


Figure 6.4 Failure Probability of A Network Based On The Number of Predecessors

Considering the above mentioned argument about the failure probability of a network, it seems logical to focus on the key interface points which have a high number of interdependencies with other interface points, for the risk monitoring purpose.

Once the IPN is created for a project, potentially key IPs are identified in the network considering the graph theoretic centrality concept as a measure of risk because of cascading impact potential. In practice, treating an IP as "key" is ultimately a decision based on the judgment of the project leaders. Since the IPN is directional, two types of key IPs are recognized:

- High impact Interface point: This represents an IP with higher number of successors compared to other IPs. In other words, any change, delay or failure in accomplishing this IP may result in delays or discrepancies in the execution of its successors.
- Risk prone Interface point: This represents an IP with a higher number of predecessors compared to other IPs. This IP is affected by a significant number of interface points. As a result, it is prone to change or delay if any change, delay or failure occurs at its predecessors.



Legend of the attributes on edges:

Sp.: Space dependency; Ph/D/F: Physical/dimensional/functional systems dependency

IF: Dependency of information flow; Seq.: Sequence of tasks

Figure 6.5 Sample of Interface Points Network (IPN)

By analyzing the indegree of a node, number of arcs leading into a node, and outdegree of a node, the number of arcs leading away from the node, potentially high impact and risk prone interface points can be identified. The judgment mentioned above and links to the project risk register will also drive the identification of key IPs. Considering the definitions of indegree and outdegree, the following indicators are defined:

- Impact Factor of IP_i (IF_i):

$$IF_i = \frac{outdegree\ of\ the\ current\ IP_i}{Total\ number\ of\ edges\ in\ the\ IP\ digrapgh} \times 100$$ Equation 6.2

- Risk Factor of IP_i (RF_i):

$$RF_i = \frac{indegree\ of\ the\ current\ IP_i}{Total\ number\ of\ edges\ in\ the\ IP\ digrapgh} \times 100$$ Equation 6.3

Impact Factor and Risk Factor are equivalent to the centrality concept in SNA. Centrality is associated with the distribution of relations between nodes in a network (Pryke 2012, Wassermann and Faust 1994). Identifying high impact and risk prone IPs is an iterative process, and should be done during different phases of the project. A couple of reasons support this notion:

- The IPs have different life cycles, and each IP can be considered as a key IP only in one phase of the project.
- An IP could be closed during one phase of the project and not carry on to the other stages.

6.4 Integration of IMS and Project Schedule

Once the key IPs are identified, owners require that these IPs be linked to related activities to feed the project schedule. To do this, and beyond the almost epistemological question of whether cyclical and sequential networks should be linked, several questions must be addressed:

- Should the activities be linked with IPs or IAs?
- Should links be one-to-one or many-to-one?
- Who will manage the changes on the IMS and the project schedule and their interdependencies?

To begin, it is not practical to map every activity directly to every IP or IA. The main reason is that in a mega project with several thousands of activities and a couple of hundreds or thousands of IPs and IAs, it is not feasible to map the links between them. In addition, frequently rescheduling the

CPM network based on the interdependencies will also quickly become infeasible, if too many are mapped. It is therefore proposed here to map only the key IPs to the project schedule. Thus, the number of relationships to maintain are reduced significantly. However, since the key IPs are recognized by defining the dynamics of the relationships in the network of all IPs, the information of all other IPs are also carried into the key ones. Moreover, to reduce the complexity of the calculations, and to add visibility, an Interface Milestone is added to each discipline/scope/area of work in an AACE level-3 schedule, which "includes all major milestones, major elements of design, engineering, procurement, construction, testing, commissioning and/or start-up" (Schedule Levels, Major Projects, http://www.mosaicprojects.com.au/PDF/Schedule_Levels.pdf, last checked June 8, 2013). A level-3 schedule is usually created by the stakeholders, spans the whole of the project, and is used to "communicate the execution of deliverables for each of the contracting parties" (AACE International 2010). This level shows "the interfaces between key workgroups, disciplines, or crafts involved in the execution of the stage" (AACE International 2010), and is used to provide input for monthly meetings. Therefore, all key IPs related to that discipline, scope, or area of work are linked to the Interface Milestones, along with their associated need or closing dates. Need or closing date of an IP is considered as the latest need date of its IAs.

Any changes to the delivery date of mapped IPs are reflected in the Interface Milestone. As long as these dates are smaller or equal to the Interface Milestone, the project is performing according to the schedule. However, if the delivery dates are greater than the Interface Milestone, then the system will send an alert to the parties involved in that IP. Depending on the criticality of the issue, an Emergency Interface Meeting is requested. Otherwise, the issues will be discussed in the Interface Meetings to investigate the methods to reduce or mitigate the schedule-related risk. The process of linking IMS to project schedule is illustrated in Figure 6.6.

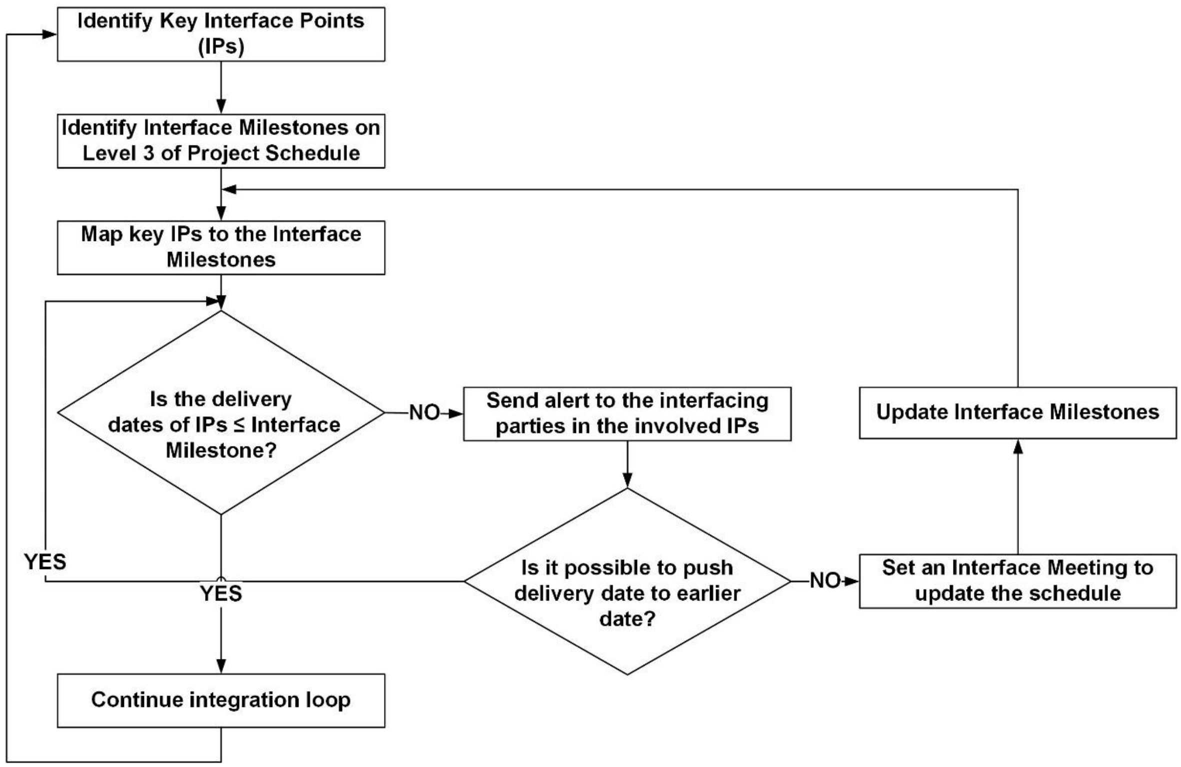


Figure 6.6 IMS and Project Schedule Integration

6.5 Validation of Proposed Model: Demonstration of Functionality

The proposed Interface Management System, network of identified IPs and methodology to identify key IPs are all tested and verified using a synthesized (from several real projects), simplified, but realistic representation of a full scale off-shore project. Since projects accessed in the research were deemed proprietary by their owners, this model project was created. However, its validity as a representative project was established through consultation with industry and academic experts, including members of the Construction Industry Institute (CII) Research Team 302 (https://www.construction-institute.org/scriptcontent/rts2.cfm?section=res&RT=302).

6.5.1 Project Overview

6.5.1.1 Major Components

The development is comprised of three basic components; (1) the topside facilities, (2) the umbilicals and risers, and (3) the seabed facilities. The subsea network lies about 1000 m below the surface and consists of 32 wells that will be drilled during the life of the project. Each well is controlled by a subsea “Christmas tree”, and they are connected to the flowlines through four manifolds. Approximately 100 km of risers and flowlines, 60 km of static and dynamic umbilicals providing electric power, and 4 hydraulic/chemical lines are to connect the subsea network to the topside. The topside contains the production facility, the drilling deck, the utilities (including control systems and power units) and the living quarters. In addition, a floating storage and offloading (FSO) unit is moored next to the platform for storage of the produced oil and gas products. An overview of the project is provided in Figure 6.7.

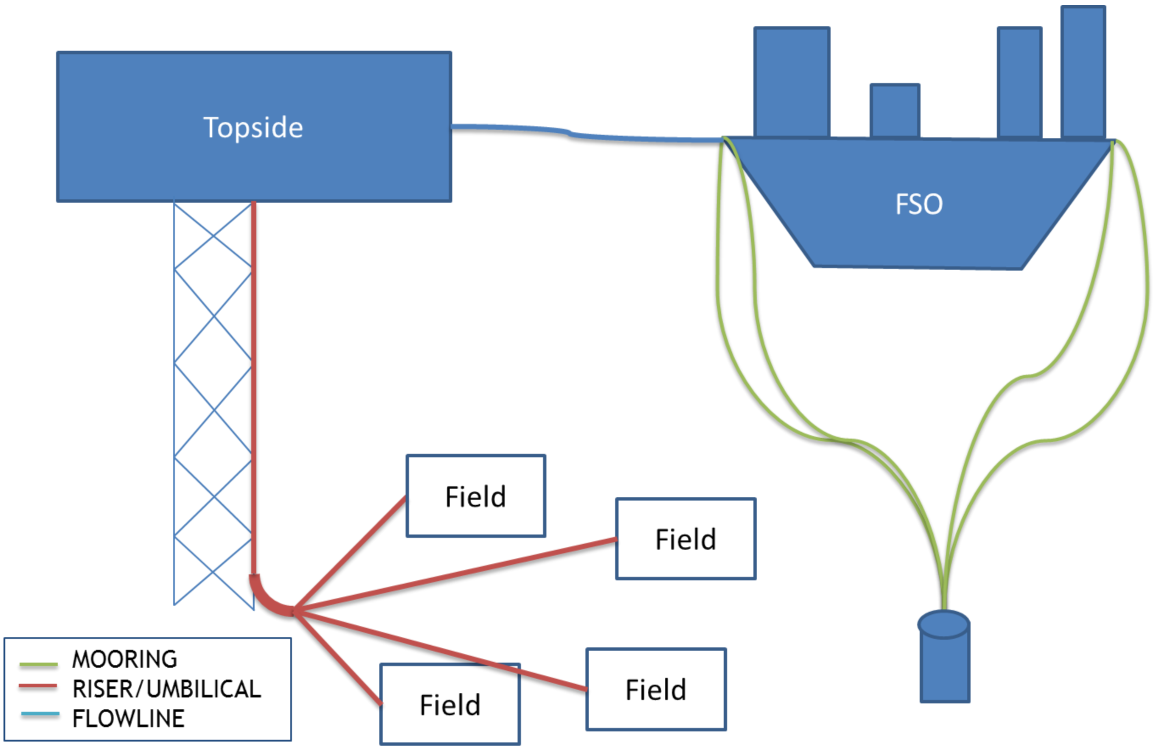


Figure 6.7 Project Overview

6.5.1.2 Estimate and value

The project has an estimated value of two billion dollars. This was obtained by comparing public data on costs for different projects, as shown in Table 6.2.

6.5.2 Project Description

6.5.2.1 Topside

The topside consists of four basic components: the processing facility, the drilling deck, the utilities and process support system and the living quarters. These components are described in further details in the following sections. Figure 6.8 shows an overview of the topside elements.

Table 6.2 Similar Project Costs

COST	SITE	DESCRIPTION
$1.4 billion	Sanha/Bamboco Development, Angola	FPSO LPG storage capacity of 135,000 m^3
$1 billion	Cohasset-Panuke Nova Scotia	22.5 km of subsea pipelines Jackup platforms
$5-8 billion	Hibernia – Newfoundland and Labrados	178,000 bpd 80 m deep Gravity-based concrete structure 30 wells
$3 billion	Sable – Nova scotia	5 fields 10.4 million m^3/day
$2.8 billion	Terra Nova – Newfoundland and Labrador	28,620 m^3/day
2.35 billion	White Rose – newfoundland	123,500 bpd FPSO Six wells
$3.5 billion	Agbami Oilfield, Nigeria	250,000 bpd FPSO
$34 billion	Ichthys	36,000 bpd 876 million m^3/day

6.5.2.1.1 Processing facility

The processing facility is where the oil, gas and water obtained from the wells are treated so that they can be transported. The risers are connected to the Reception and Separation Unit, where the oil, gas and water are separated from each other. The gas is then compressed in the Gas

Compression Unit and then goes to the Gas Dehydration Unit. From there, it is taken to the FSO through flowlines. The oil goes from the separation unit to the surge tank and then to storage at the FSO. The produced water from this process goes to the produced water conditioner, where it is filtered. This water is reused for injection into the wells or thrown overboard. An overview of the Processing facility is shown in Figure 6.9.

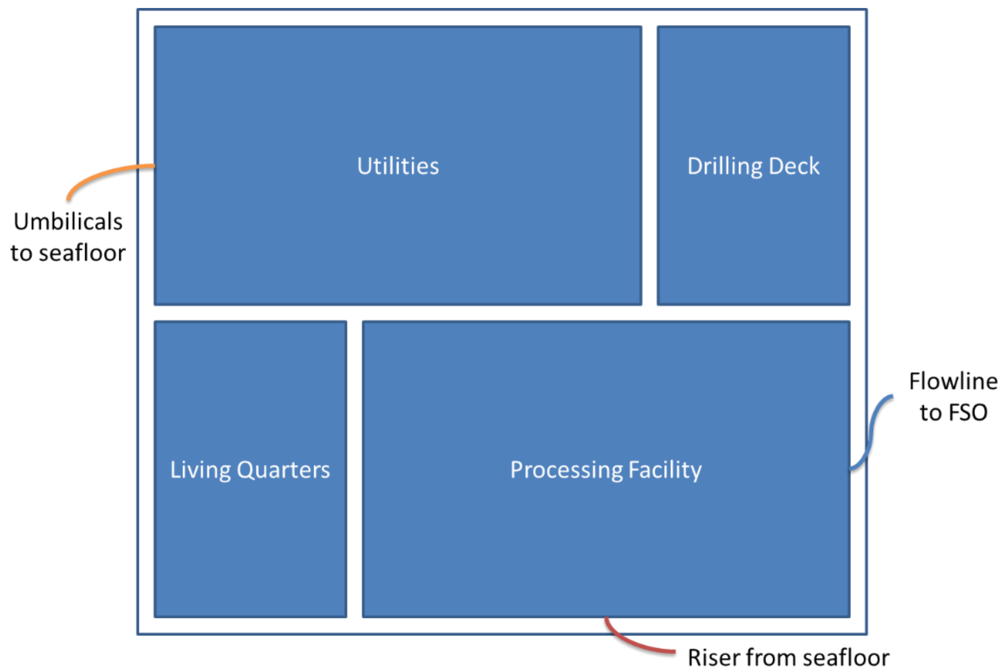


Figure 6.8 Overview of Topside

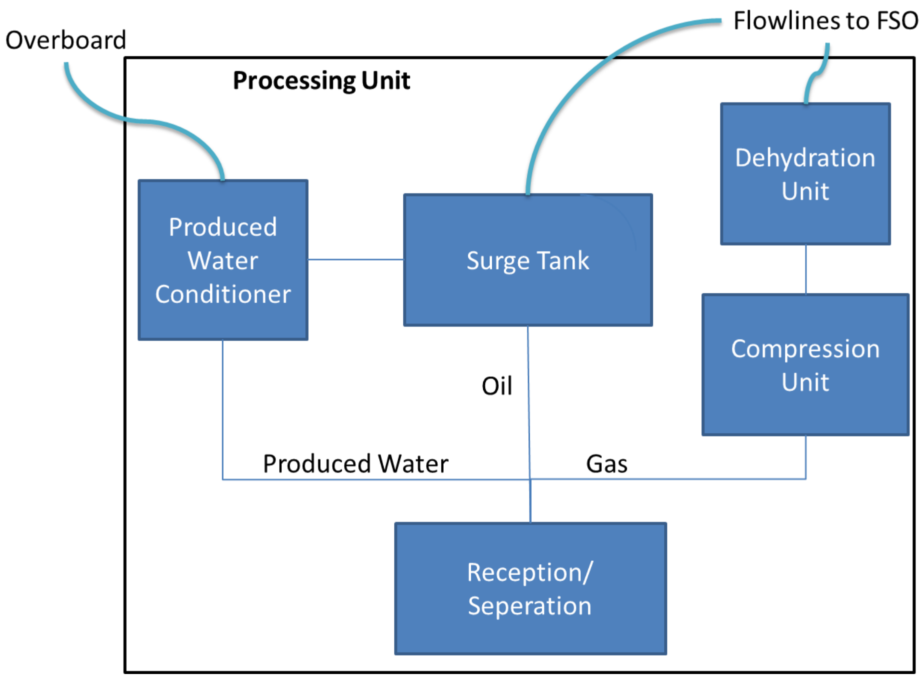


Figure 6.9 Overview of Processing Facility

6.5.2.1.2 Drilling deck

The drilling deck is another component of the topside. It consists of the following:

- Derrick/Drillstring
- Drawworks
- Rotary Table and Topdrive
- Mud tanks
- Mud pumps

The drillstring is the combination of drill pipes used to make the drillbit turn at the bottom of the wellbore. The derrick is the structure used to support the crown blocks and the drillstring. The drilling line is reeled in and out by the drawworks. The Topdrive is the primary system for rotating the drillstring, and the rotary table is used as a backup system. Drilling mud is required during drilling to lubricate the drill bit, seal the wall of the well and control pressure inside the well. The mud tanks are where the drilling mud is stored, and the mud pumps are used to bring the mud back up to the surface.

6.5.2.1.3 Utilities

The utilities section is where all of the controls are located. It is comprised of the following components, as seen in Figure 6.10:

- Topside Umbilical Termination Unit
- Master Control Unit
- Processing Control Unit
- Hydraulic Power Unit
- Chemical Injection Unit
- Uninterruptible Power Supply

The topside umbilical termination unit is where all of the umbilicals terminate on the topside and provides interface with the Master Control System (MCS), hydraulic power unit, chemical injection unit and interruptible power supply. This project has four umbilicals that carry electric power to each of the fields (one to each manifold). In addition, it has four umbilicals that carry hydraulic power and chemical supply to each of the fields. The processing control unit operates the processing facility.

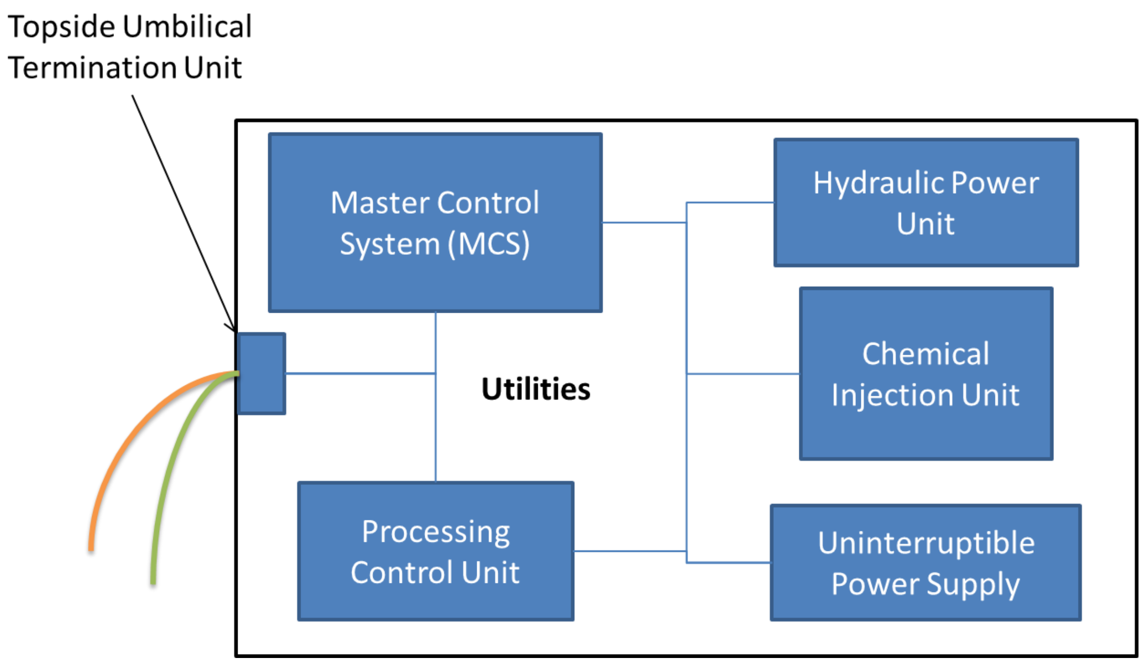


Figure 6.10 Overview of Utilities

6.5.2.1.4 Living quarters

The topside also contains living quarters for the crews installing, operating and maintaining the project.

6.5.2.2 Seabed

On the seafloor, there are four fields serviced by this project. Each field has eight wells whose flow is directed through a central manifold. Each manifold has a control module to operate the valves. The umbilicals (one electrical, one hydraulic/chemical) go to the umbilical termination unit on the manifolds, where the supply is redirected to each of the wells through flying leads. Each well is controlled by a separate Christmas tree, as shown in Figure 6.11. Each of the umbilicals and risers have a J-tube connecting the vertical portion of the pipe on the compliant tower to the horizontal portion on the seafloor.

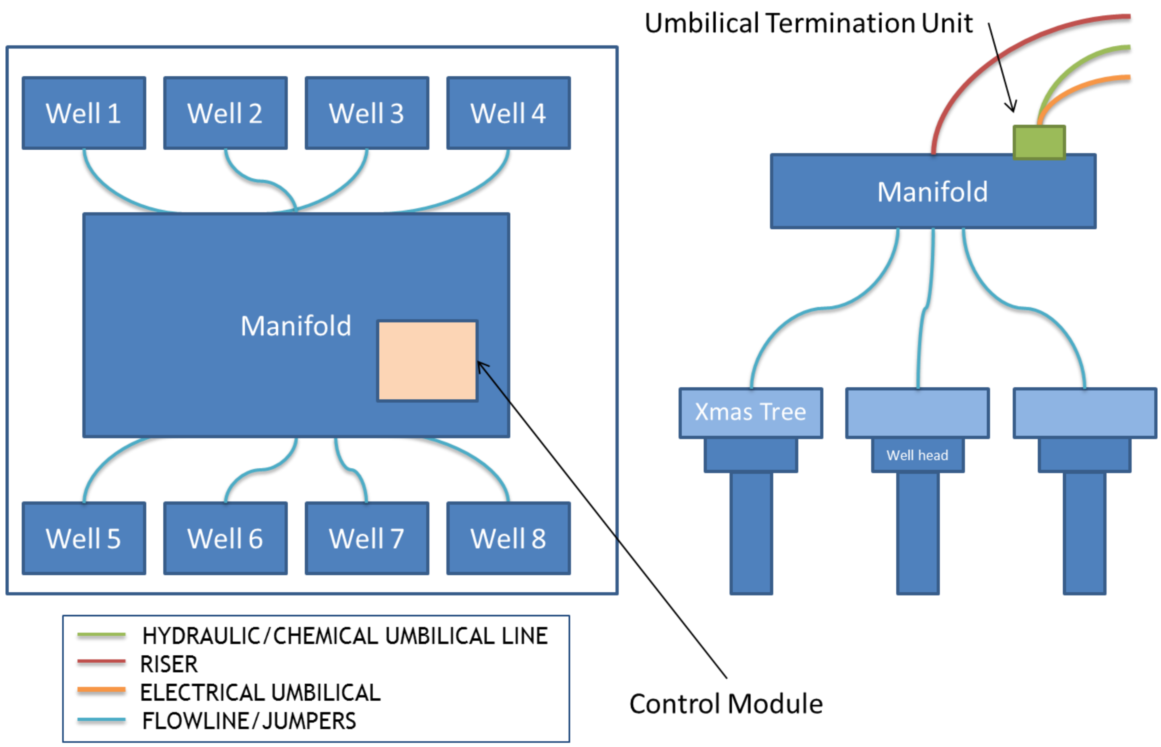


Figure 6.11 Overview of Subsea Field

6.5.2.3 Floating Storage and Offloading (FSO) Unit

The Floating Storage and Offloading (FSO) unit is a boat where the produced oil and gas is stored. The FSO has a capacity of 300,000 barrels with an estimated loading rate of 18,000 barrels per day (bpd).

To maintain its position with respect to the platform, a spread mooring system is installed, with a mooring line of steel wire rope and a suction pile anchor. The spread mooring system prevents the unit from weathervaning.

6.5.3 Project Breakdown

The project is divided into ten major scope packages (Table 6.3). Each scope package is awarded to a specific contractor.

Table 6.3 List of Scope Packages for Hypothetical Project

ID	Package	ID	Package
A	Drilling and Completions	**B**	Subsea Elements (Flowlines, Umbilicals and structures)
C	Topside platform and Processing facility (fabrication)	**D**	Compliant tower (Fabrication and Shipping)
E	Living Quarters (Fabrication and Shipping)	**F**	Control Units
G	Mooring	**H**	FSO
I	Topside Integration and Shipping	**J**	Processing Facility Valves and Connectors

6.5.4 Interface Point Identification and Documentation

Considering the breakdown of scope packages and their relationship with each other, 16 high level IPs between packages are identified for this project (Table 6.4).

6.5.5 Interface Point Interdependency Matrix

Once the IPs are identified, the interdependency of the IPs should also be developed. The interdependency concept is clarified by using two examples.

Table 6.4 List of High Level Interface Points for Model Project

IP ID	IP Name	High Level IP description	Area/Discipline	Contractors/ Packages
1	AB1	Wellhead and Well	Subsea Well System	A, B
2	BF1	Umbilical connection between UTU and X-tree	Subsea Well System, Electrical	B, F
3	BF2	UTU and manifold	Subsea Well System, Electrical	B, F
4	BF3	J-tube, pipeline and umbilical	Subsea Well System, Pipeline, Electrical	B, F
5	BD1	J-tube and Compliant tower	Subsea Well System, Pipeline, Electrical	B, D
6	CD1	Topside and Compliant tower	Topside	C, D
7	BH1	FSO Pipeline connection to topside	Pipeline	B, H
8	BC1	Topside Pipeline connection to FSO	Pipeline	B, C
9	GH1	Mooring and riser hook up to FSO	Mooring	G, H
10	BC2	Processing facility connection to risers	Topside, Pipeline	B, C
11	CF1	Utilities and Topside	Topside, Electrical	C, F
12	AC1	Drilling deck and Topside	Topside	C, A
13	CE1	Living quarters and Topside	Topside	C, E
14	CI1	Topside shipment	Topside	C, I
15	CJ1	Valves for the processing facility	Topside	C, J
16	BD2	Riser connection to compliant tower	Compliant tower	B, D

The first example considers the interdependency between IPs related to topside and the compliant tower. Topside is fabricated according to the design documents, with a specific weight and center of gravity. These factors are critical to meet the support capacity of the compliant tower without posing significant changes to tower fabrication, shipping and foundation configuration (Borkar et al. 2006). Therefore, each facility of the topside has a specific weight range. Assume that the contractor responsible for providing the generator in the utilities (Contractor F) is not able to provide the generator with the predefined specification, and the new generator weighs more than the designed one. As a result, IP_{11} (Utilities and Topside) faces an issue that should be resolved to keep the weight and center of gravity of the topside within the range. If this issue cannot be resolved, the topside fabrication contractor (C) has two options:

- Consult with the other contractors responsible for facilities on the topside to reduce the weight.
    - Living quarters contractor (E) through IP13 (Living quarters and Topside)
    - Drilling deck contractor (A) through IP12 (Drilling deck and Topside)
- Communicate the change to the compliant tower fabrication contractor (D) and the topside shipping contractor (I), through IP6 (Topside and Compliant tower) and IP14 (Topside shipment) respectively.

Therefore, it can be concluded that IP_{11} is a successor for $IP_{6, 12, 13, 14}$. The same discussion is applicable to all the IPs affecting the topside center of gravity.

A second example is related to the pipeline system. Pipeline diameter and elevation are recorded in the design documents and transferred to all the involved stakeholders. In this example, a change order is submitted to change the pipeline diameter for the processing facility. However, this change has not been communicated in time to the contractor providing valves for the processing facility (Contractor J). As a result, contractor J is not able to deliver the valves on time. This will pose a significant cost on the topside contractor (C), since valves of the processing facility need to be installed on the topside structure before completely assembling the other units and shipping it to the installation site. Because of the valve delivery delay, the project team may need to hire a special crew or postpone the topside shipping to the site. Therefore, in this example, IP_{15} (Valves for the processing facility) is a predecessor for IP_{14}.

Using the same strategy, the interdependencies of the IPs are recognized for this project. The interdependencies are represented in Table 6.1. Once the interdependency matrix is created, the high impact and risk prone IPs are identified by running the analysis on Table 6.1 (which actually represents this model project), with regard to Equations 6.2 and 6.3. The Impact Factor (IF_{11}) and Risk Factor (RF_{11}) for IP_{11} are illustrated here. The analysis results for all IPs are shown in Table 6.5.

$$IF_{11} = \frac{\sum_{j=1}^{16} e_{11j}}{\sum_{i=1}^{16}\sum_{j=1}^{16} e_{ij}} \times 100 = \frac{6}{48} \times 100 = 13\%$$

$$RF_{11} = \frac{\sum_{i=1}^{16} e_{i11}}{\sum_{i=1}^{16}\sum_{j=1}^{16} e_{ij}} \times 100 = \frac{7}{48} \times 100 = 15\%$$

The analysis of interdependency matrix shows that the interface point between topside and utilities (IP_{11}), and the valves for the processing facility (IP_{15}) are the high impact IPs, and any changes in the design, fabrication, installation and delivery of these IPs will result in a change in other IPs. On the other hand, the interface point between topside and utilities (IP_{11}) has the highest rank in the risk prone IPs. Although it has a high impact on other IPs, it is highly dependent on other IPs as well. Any changes in the processing facility, seabed equipment and other functioning units may pose a major change in this IP. Therefore, these two IPs should be regularly monitored to predict the early changes in the project and prevent potential delays.

Table 6.5 High Impact and Risk Prone IPs for Topside

IP ID	Impact Factor (%)	High Impact IP Rank	Risk Factor (%)	Risk Prone IP Rank
1	2	5	0	6
2	4	4	6	4
3	4	4	4	5
4	8	2	4	5
5	6	3	4	5
6	2	5	10	2
7	4	4	6	4
8	4	4	6	4
9	4	4	4	5
10	4	4	4	5
11	13	1	15	1
12	8	2	6	4
13	8	2	6	4
14	8	2	10	2
15	13	1	4	5
16	6	3	8	3

6.5.6 Integrated Project Schedule and IMS

Once the key IPs are identified, the top ones are imported to the Interface Milestones in the project schedule. The management team will determine the key IPs as described earlier. In this example, the high impact and risk prone IPs with rank 1 are imported to the project schedule. Figure 6.12 shows a snapshot of the project schedule with the interface milestones.

Each IP in the model project is associated with more than one IA, and all IAs are expected to be closed at the agreed deadline at each stage of the project lifecycle. Therefore, the closing date of the IP is considered as the latest closing date of the agreements. The same closing date is transferred to the schedule to be compared with Interface Milestone. This process is easily automated within an electronic product and process management system.

If the need or closing dates of IPs are earlier than the Interface Milestone, the project is performing according to schedule. However, if the need or closing dates are projected to a later time than the Interface Milestone, then the project management, project control and IM team need to investigate the discrepancy and mitigate the potential schedule related risk.

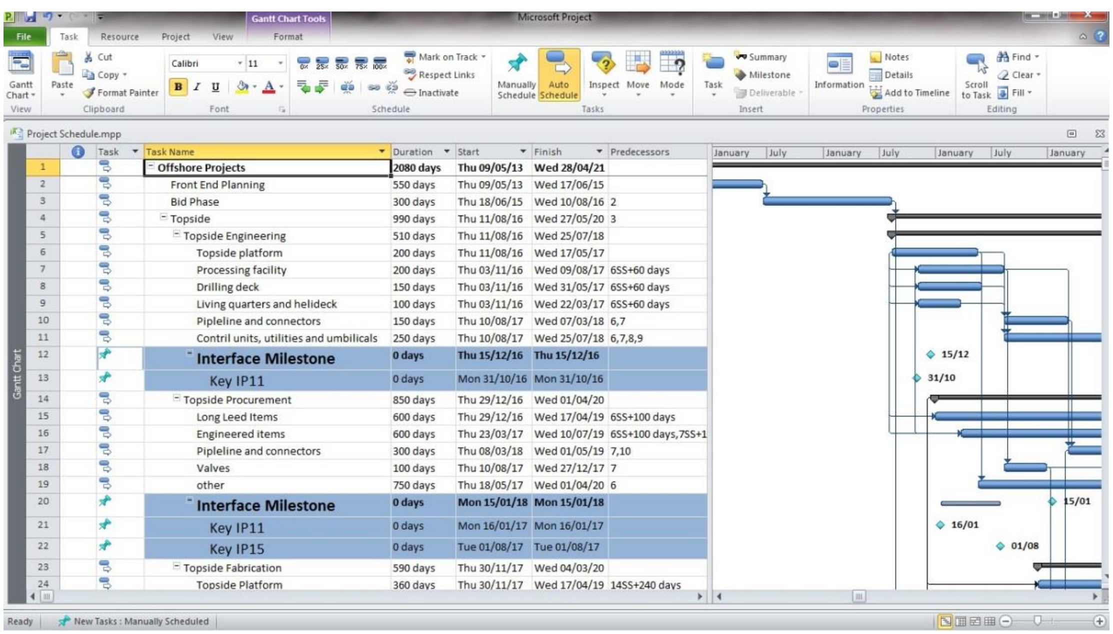


Figure 6.12 Project Schedule Incorporated with Interface Milestones

6.6 Summary

In this chapter, a systematic algorithm is introduced to identify potentially key IPs at each phase of the project. This algorithm considers the interdependency relationships between IPs, and identifies high impact and risk prone IPs by employing graph theory concepts. In addition, a robust process is developed to link iterative IMS to project schedule, by introducing Key Interface Milestones. In practice, the relations between some IPs and the activities on the project schedule are addressed in the interface meetings, once IPs are close to their due dates or already overdue. However, the advantage of the proposed process is to integrate the cyclic information of IMS with the conventional, sequential planning, scheduling and control paradigms (e.g. CPM) to provide an in-time alert of the potential schedule-related risks. The functionality of the proposed model and algorithms is demonstrated using a model example, which is a simplified, but realistic representation of a full scale off-shore project.

Chapter 7

Interface Management System and Project Performance

Industry leaders believe that in a project with multiple stakeholders involved, a common IM system will allow for the alignment of interests among the interface stakeholders providing common goals, effective communication, added visibility, improved oversight, and the timely resolution of conflicts. It should also help reduce risk. As a result, the projects will achieve improved performance. In this chapter, first the benefits of IM will be explained. Then, the effect of IM on improving project performance will be investigated.

7.1 Benefit of Interface Management

According to industrial reports, IM implementation leads to improving project performance (Nooteboon, 2004). It follows logically that almost any project that is highly complex—such as an urban light rail project or an offshore oil platform—could merit the application of IM. Analysis of the data acquired through the RT-302 research indicates that IM increases alignment, facilitates communication channels as well as real-time visibility and oversight, and formalizes the distribution of potential "risk-creating" information between stakeholders. These outcomes may result in the effective delivery of the project and in improved project performance (e.g., reduction in cost and schedule growth). In fact, statistical analysis presented in the later sections indicates some weak but promising correlations between IM implementation and project performance. Determining the direct effect of IM implementation on reducing project total cost was not feasible during this research, since project cost is a function of many other interdependent factors. Some anecdotal explanations of the possible mechanisms of such a relationship do exist however. From the interviews performed during the course of this research, three anecdotal sources of evidence are mentioned here that reference project cost performance and its relationship with appropriate implementation of IM:

- In a project with a total cost of 1-5 Billion dollars, identifying and managing IPs between interface stakeholders resulted in less rework and early completion of the design by approximately 5 months, which was equivalent to 25 million dollars in savings.
- In a project with a total cost of 5-10 Billion dollars, the design was subcontracted to several engineering contractors. In a design package of 45 million dollars, the early identification of major IPs between the Engineering contractor and Procurement contractor resolved a procurement issue which resulted in 10 million dollars of savings.
- In a project with a total cost of 5-10 Billion dollars, the lack of appropriate IM and not recognizing a supply and quality issue between the engineering-and-procurement stakeholder and the construction stakeholder resulted in a penalty of 10 million dollars per week incurred over several weeks.

Project performance improvement is a function of several factors, which are facilitated by IM implementation. These factors are briefly discussed as follows:

- Alignment of stakeholders: A significant outcome of a successful IM system is increasing the alignment of interface stakeholders by having regular, face-to-face meetings and the Master Interface Plan (MIP). The methods and strategies for managing interfaces are recorded in the MIP. Therefore, all interface stakeholders are working toward common goals, by following clear guidelines, which results in reducing potential conflicts, and managing them effectively.
- Facilitation of communication channels: Communication is the key success factor in today's globally dispersed construction projects, in which each stakeholder deals with multiple parties, in different geographical locations that can also lead to cultural and language differences. IM facilitates communication between stakeholders by creating a

formalized framework for the effective sharing and distribution of information. Not only do stakeholders know how to communicate, but they also know what information should be communicated, to whom, and when. This will lead to real-time visibility and oversight in the project. In other words, interface stakeholders can gain real-time and shared global visibility over the deliverables by defining clear roles and responsibilities, agreeing upon deadlines to provide interface-related deliverables, and accessing real-time project information.

- Mitigation of Interface-related aspects of project risk: In addition to creating increased alignment and coordination between stakeholders, a common understanding of interfaces, deliverables, and associated deadlines achieved by the adoption of formalized IM in a project assists in the early identification of interfaces, specifically during Front End Planning (FEP), and the management of interfaces throughout the whole life cycle of a project. Interface stakeholders are able to effectively share and distribute the risk related to detailed information through formalized IM. This should lead to reducing project redundancies, uncertainties, and surprises for all parties engaged in the IM process.

7.2 Relationship of IM Implementation with Project Performance

IM implementation generally follows a gradual transition between informal IM towards formal IM (Refer to section 5.5.3 IM practices). To investigate the correlation between IM implementation and project performance, the interviewed projects are divided into two groups of high-level and low-level IM implementation. The classification are done according to the maturity model, as follows:

- Low-level IM implementation: projects at stages 0 and 1 of the maturity model, which indicate no IM practice and very informal IM respectively.

- High-level IM implementation: projects at stages 2, 3 and 4 of the maturity model, which represent semi-formal to very formal IM practices.

To investigate the impact of IM on improving project performance, five criteria are assessed: cost growth, schedule growth, management hours growth, engineering hours growth and construction hours growth. Equations 7.1 to 7.5 illustrate the formulation to calculate these five criteria, respectively. These equations are defined to measure the performance (CII, 2002):

$$Project\ cost\ growth = \frac{A_C - P_C}{P_C}$$ Equation 7.1

Where A_C: Actual total project cost,

P_C: Initial predicted project cost

$$Project\ Schedule\ growth = \frac{A_D - P_D}{P_D}$$ Equation 7.2

Where A_D: Actual total project duration,

P_D: Initial predicted project duration

$$Project\ management\ hours\ growth = \frac{A_{MH} - P_{MH}}{P_{MH}}$$ Equation 7.3

Where A_{MH}: Actual project management hours,

P_{MH}: Total forecasted project management hours

$$Project\ engineering/design\ hours\ growth = \frac{A_{EH} - P_{EH}}{P_{EH}} \qquad \text{Equation 7.4}$$

Where A_{EH}: Actual project engineering/design hours,

P_{EH}: Total forecasted project engineering/design hours

$$Project\ construction\ hours\ growth = \frac{A_{CH} - P_{CH}}{P_{CH}} \qquad \text{Equation 7.5}$$

Where A_{CH}: Actual project Construction hours,

P_{CH}: Total forecasted project Construction hours

Two main aspects are of interest in assessing the performance: (1) explore the distributions of performance criteria in each group of high- and low-level IM implementation and compare them, and (2) investigate the difference between means of these two groups.

7.2.1 Box-and-whisker Plot

Box-and-whisker plots, also called boxplots, are simple descriptive statistics that graphically show the distribution of data and outliers in each category. They are categorized in the exploratory data analysis tools (Bluman, 2008). “The purpose of exploratory data analysis is to examine data to find out what information can be discovered about the data such as center and the spread” (Bluman, 2008). In the boxplots, the measure of tendency is based on median and the measure of variance is the magnitude of the interquartile ranges. The box in the center of the diagram shows the middle 50% of the data distribution. The lower and upper edges of the box illustrate the first and third quartiles, respectively (Lomax, 2007; Chapman and Hall, 2002). “The lines extending from the box, called whiskers, display data outside of the middle 50%” (Lomax, 2007). Whiskers extend to 1.5 times the height of the box at both sides, which is known as range (in IBM SPSS software). If no data exists within this range, whiskers show the minimum or maximum values of the data set. A boxplot shows the lowest, the highest, median, and the first and third quartile of a data set, as well as the outliers. A general illustration of a boxplot is illustrated in Figure 7.1.

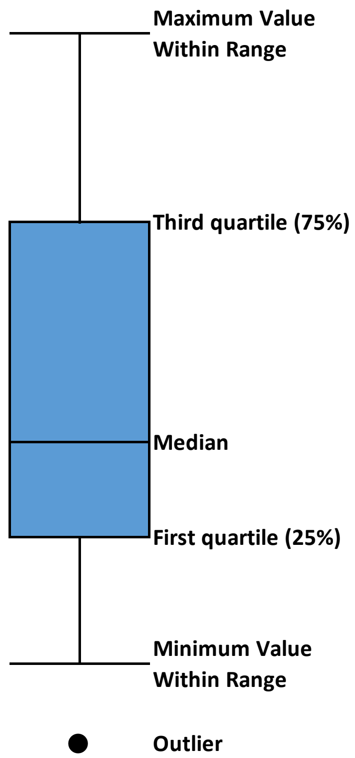


Figure 7.1 Boxplot General Illustration

- Median: The numerical value that separates the higher half of a data sample from the lower half.
- First quartile: The numerical value that represents the middle number between median and the smallest number of a data sample.
- Third quartile: The numerical value that represents the middle number between median and the largest number of a data sample.
- Whiskers: The data points which are either 1.5 times more or less than the height of the box (In IBM SPSS software).

- Outliers: The values that do not fall in the whiskers.
- Extreme Outlier: The data points which are either 3 times more or less than the height of the box (In IBM SPSS software).

7.2.2 Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is a statistical method to test if there is variation between the means of two or more groups. In ANOVA, two different estimates of the population variance are made: between-group variance (to find variability between the means of groups) and within-group variance (to find variability of the observations within a group combined across groups) (Bluman, 2008; Johnson and Bhattacharyya, 2009; Lomax, 2007).

ANOVA uses an F test to test the hypothesis. The observed F value is calculated by dividing the mean squares of between-group estimate by mean squares of within-group estimate. It indicates whether there is more variation between groups than there is within groups (Lomax, 2007). In the ANOVA, the null hypothesis is that there is not a significant differences between the samples of the population. "If there is no difference in the means, the between-group variance estimate will be approximately equal to the within-group variance estimate" (Bluman, 2008), and the observed F value will be approximately one. In this case, we cannot reject the null hypothesis. However, an F ratio over 1 indicates a larger variation between-groups, and we can conclude that there is at least one mean different from the others. Then, the observed F is compared with the critical F value to indicate the significance of the test. Since the significance test is one-tailed, a test is considered significant if the observed F is greater than the critical F at a specific confidence level (Lomax, 2007). The ANOVA is called one-way ANOVA when only one factor is considered in the analysis. Three standard assumptions of independence, normality, and homogeneity of variance are applied in ANOVA test. For the purpose of this thesis, one-way ANOVA is used.

7.2.2.1 Hypothesis

The objective of this chapter is to investigate whether or not the high-level IM implementation, on average, is associated with better performance in terms of cost growth, schedule growth, management hours growth, engineering hours growth and construction hours growth. Therefore, the null and alternative hypotheses are described as follows for cost growth:

$$H_0\colon \mu_{CG_H} = \mu_{CG_L}$$

$$H_1\colon \mu_{CG_H} \neq \mu_{CG_L}$$

Here, μ_{CG_H} represents the cost growth mean for the high-level IM implementation group, and μ_{CG_L}represents the cost growth mean for the low-level IM implementation group. For IM, it is expected the μ_{CG_H} has lower value comparing to μ_{CG_L}. The same hypotheses can be defined for the other performance criteria.

7.3 Cost Growth

The interviewed projects were asked to report their actual total project cost and the initial predicted cost. This was straightforward for the completed projects. However, for the ongoing projects, the recent quarterly report is recorded to calculate the cost performance. In total, 37 cost performance results were gathered. The missing ones either belong to the projects at the very early stages of their life cycle or are due to confidentiality issues.

7.3.1 Cost Growth Boxplot

The boxplot diagram of cost growth for the groups of low-level and high-level IM implementation is shown in Figure 7. 2. It shows that in both low-level and high-level IM implementation groups, the data are symmetrically distributed around the median. However, the low-level group involves several outliers. These outliers are all associated with higher cost growth, and shows that in the projects without formal IM, the project may experience a very high percentage of cost growth. Furthermore, the median value for the high-level IM implementation group is less than the low-level group.

Comparing the average of cost growth for both groups shows that the high-level IM implementation group has a much lower mean compared to the low-level group (0.037 vs. 0.1844), as shown in Figure 7.3. Also, the variation of data in this group is almost half of the low-level IM implementation group.

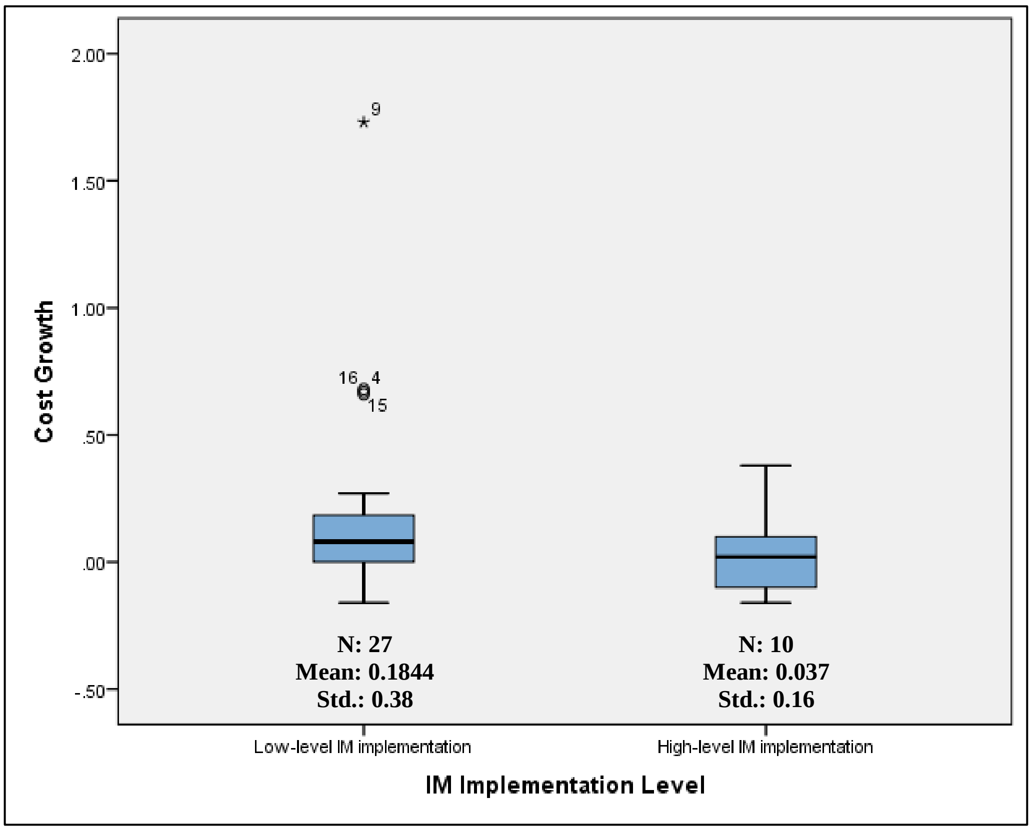


Figure 7.2 Boxplot Diagram for Cost Growth

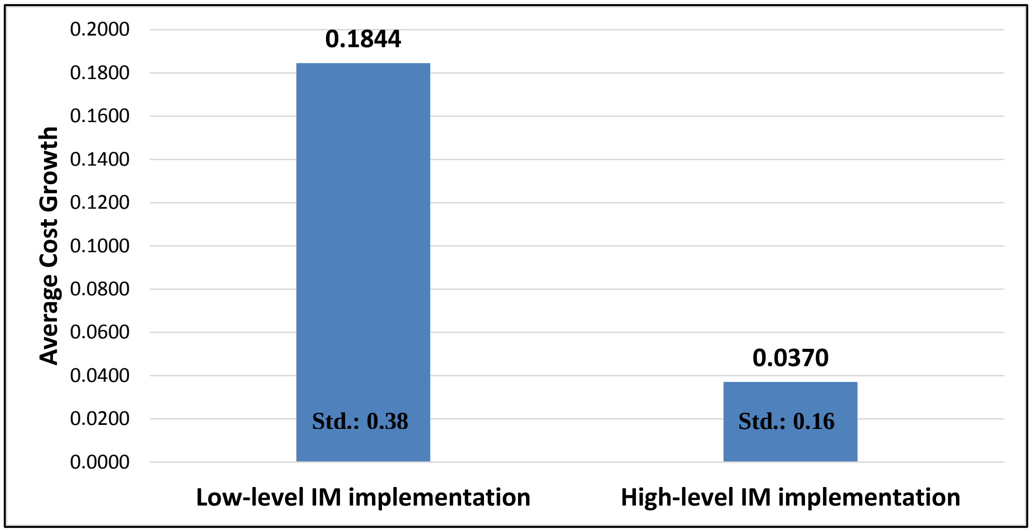


Figure 7.3 Average Cost Growth for low-level and High-level IM Implementation Groups

7.3.2 Cost Growth ANOVA

The two groups of low-level and high-level IM implementation are studied based on ANOVA to investigate if there is a significant difference between the means of these two groups. The descriptive statistics and the results for the ANOVA test, at the 95% confidence level, for the two groups are shown in Table 7.1. The sample sizes for the low-level and high-level IM implementation groups were 27 and 10, respectively. The observed F value is greater than 1, indicating that there is a difference between the low-level and high-level IM implementation group. The P value of the test is 0.2487 (>0.05), the observed F value is smaller than the critical F value (1.3762<4.1213), which does not show a statistically significant difference between the means of these two groups. Table 7.2 illustrates the descriptive statistics and ANOVA test results at the 90% confidence level, which still does not show a significant difference. However, the significant difference between the means and standard deviations of two groups and the trend illustrates that by having a larger sample size, we may achieve the statistical significance.

Exploring the ANOVA test for different confidence levels shows that, at the 75% significance level, the observed F value is greater than the critical F value (1.3762>1.3683), and the ANOVA analysis results shows a statistically significant difference between these two groups (Shown in Table 7.3). The reason could be a small sample size, and lack of appropriate data which are representing the project performance, due to projects being at the early stages of their life cycle.

Table 7.1 Cost Growth ANOVA Test Results for Low- and High-level IM Implementation Groups at 95% Confidence Level

SUMMARY (95% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	27	4.9752	0.1843	0.1450
High-level IM Implementation	10	0.3759	0.0376	0.0249

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1570	1	0.1570	1.3762	0.2487	4.1213
Within Groups	3.9925	35	0.1141			
Total	4.1495	36			***Not Significant***	

Table 7.2 Cost Growth ANOVA Test Results for Low- and High-level IM Implementation Groups at 90% Confidence Level

SUMMARY (90% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	27	4.9752	0.1843	0.1450
High-level IM Implementation	10	0.3759	0.0376	0.0249

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1570	1	0.1570	1.3762	0.2487	2.8547
Within Groups	3.9925	35	0.1141			
Total	4.1495	36			***Not Significant***	

Table 7.3 Cost Growth ANOVA Test Results for Low- and High-level IM Implementation Groups at 75% Confidence Level

SUMMARY (75% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	27	4.9752	0.1843	0.1450
High-level IM Implementation	10	0.3759	0.0376	0.0249

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1570	1	0.1570	1.3762	0.2487	1.3683
Within Groups	3.9925	35	0.1141			
Total	4.1495	36			***Significant***	

7.4 Schedule Growth

7.4.1 Schedule Growth Boxplot

The boxplot diagram of schedule growth for the groups of low-level and high-level IM implementation is shown in Figure 7. 4. It shows that in both low-level and high-level IM implementation groups, there are a high variation around the median. The median value for the high-level and low-level IM implementation groups are almost the same (0.14).

However, comparing the average of cost growth for both groups shows that the high-level IM implementation group has higher mean and standard deviation comparing to the low-level group, as shown in Figure 7.5. This may be explained by the fact that the projects with high-level IM implementation are associated with much higher dollar value, and the schedule growth for the capital projects are generally larger compared to the project with smaller dollar value. They also experience deliberate pauses due to market timing strategies. Furthermore, there are fewer projects with high-level IM implementation in the data set, and most of them are at Front End Planning and early stages of detailed design. The schedule growth for these projects might exhibit improvement, if the data were captured at the later stages of their project life cycles. The reason is that by having an appropriate level of IM in the project, the project team expects to have less rework in the construction phase, and eventually better performance in terms of schedule.

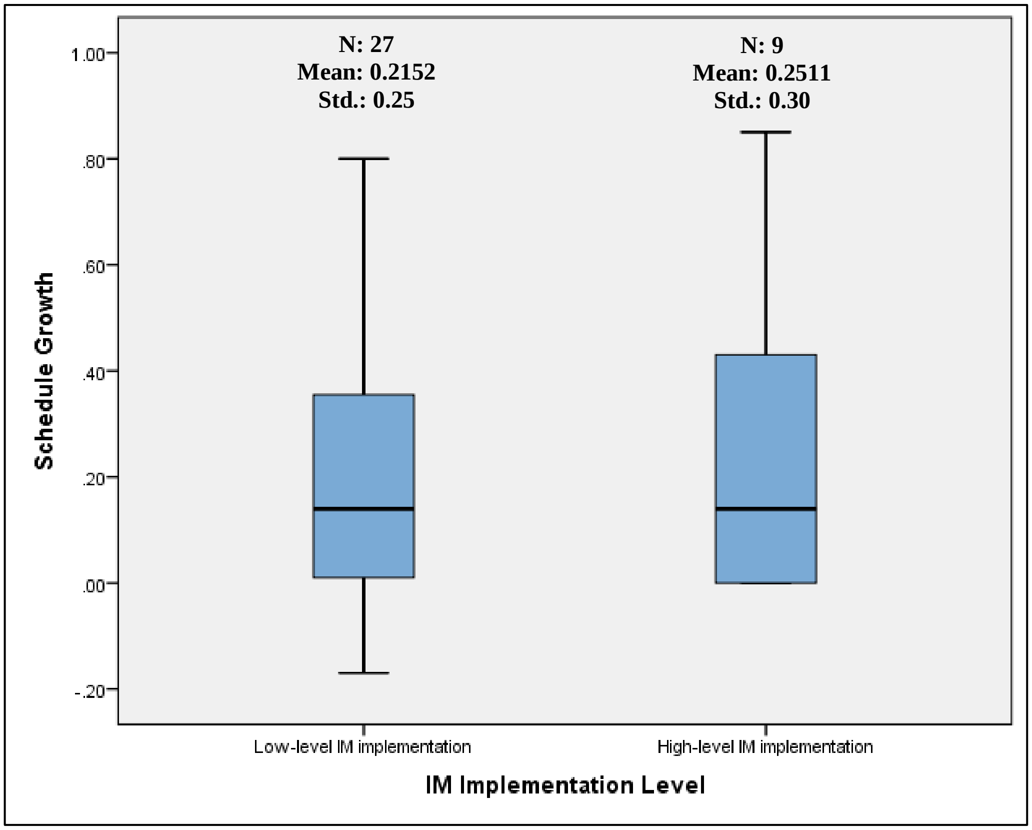


Figure 7.4 Boxplot Diagram for Schedule Growth

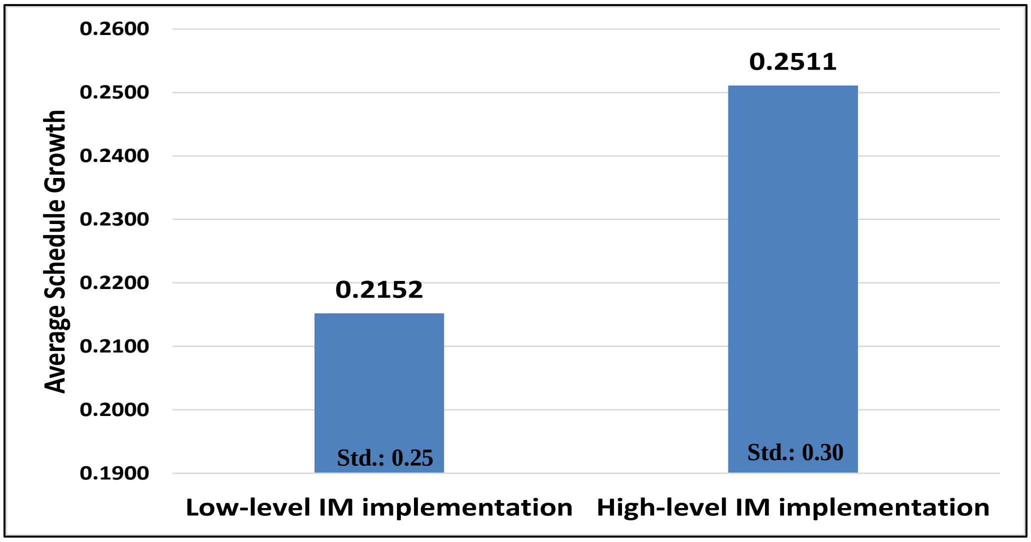


Figure 7.5 Average Schedule Growth for low- and High-level IM Implementation Groups

It is also probable that if one or two outliers were removed from this data set for any reason, the results would be different. This demonstrates that the fragility of what is a large data set compared to norms in this field of research, but is small in terms of what would be considered scientifically rigorous empirical analysis given the complexity of the phenomenon being studied.

7.4.2 Schedule Growth ANOVA

ANOVA is used to investigate if there is a significance between the means of these two groups of low- and high-level IM implementation. The descriptive statistics and the results for the ANOVA test, at the 95% confidence level, for the two groups is shown in Table 7.4. The sample sizes for the low- and high-level IM implementation groups were 27 and 9, respectively. The observed F value is less than 1, indicating that there is a small difference between means of these two groups. The P value of the test is 0.7312 (>0.05), the observed F value is smaller than the critical F value (0.1199<4.13), which does not show a statistically significant difference between the means of these two groups. Table 7.5 illustrates the descriptive statistics and ANOVA test results at the 90% confidence level, which still does not show a significant difference.

Table 7.4 Schedule Growth ANOVA Test Results for Low- and High-level IM Implementation Groups at 95% Confidence Level

SUMMARY (95% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	27	5.8215	0.2156	0.0622
High-level IM Implementation	9	2.2559	0.2507	0.0916

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0083	1	0.0083	0.1199	0.7312	4.1300
Within Groups	2.3495	34	0.0691			
Total	2.3578	35			***Not Significant***	

Table 7.5 Schedule Growth ANOVA Test Results for Low- and High-level IM Implementation Groups at 90% Confidence Level

SUMMARY (90% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	27	5.8215	0.2156	0.0622
High-level IM Implementation	9	2.2559	0.2507	0.0916

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0083	1	0.0083	0.1199	0.7312	2.8592
Within Groups	2.3495	34	0.0691			
Total	2.3578	35			***Not Significant***	

Exploring the ANOVA test for different confidence levels shows that even at the lower confidence levels (e.g. 50%), the two groups of low- and high-level IM implementation don't show a significant difference between their means. This could be because of the relatively small sample size for the high level group, or unbalanced sample sizes. For robust results, it is suggested to gather more data for the projects with low and high-level IM implementation, and do the analysis on a more balanced data set.

7.5 Project Hours Growth

The growth in the management hours, design and engineering hours and construction hours are considered as the criteria to assess the growth in the project performance in terms of a cost category which many experts consider to be controllable. According to the IM definitions and its perceived benefits, the projects with high level IM ideally should have more accurate design and experience less growth in the management and construction hours. This is mainly due to identifying interface pains at early phases of the project and anticipating the potential risks around them, which should result in less rework during construction and less conflicts and issues to be solved by the management team. The boxplots and ANOVA analysis results for management, engineering and design, and construction hours growth are shown in Appendix C, D, and E.

In all three cases, the data for the low-level IM implementation are significantly dispersed around the mean, and except for management hours, they include several outliers in the low-level group. The ANOVA results do not indicate a significant difference between the means of growth for the low- and high-level group at the 95% confidence interval; however, for lower confidence intervals, significant differences are observed between the means. For the hypothesis that a higher level of IM implementation is significantly related to lower growth of hours than low-level IM implementation, the following confidence intervals apply:

- Management Hours Growth: Significant at the 90% confidence interval
- Engineering and Design Hours Growth: Significant at the 65% confidence interval
- Construction Hours Growth: Significant at the 80% confidence interval

Since the sample sizes for the low- and high-level IM implementation group are different and unbalanced, and the number of projects at the high-level IM implementation group is very limited, the ANOVA analysis may not show the significant differences between these two groups. However, the trend shows that the projects with high level IM implementation tend to have better performance in terms of hours and on average less growth and surprises in the management, engineering and construction hours growth.

7.6 Summary

The interviewed and surveyed projects are divided into the two groups of low-level IM implementation and high-level IM implementation. The classifications are according to the maturity levels introduced in Chapter 5. Cost growth and schedule growth as well as management, engineering and construction hours growth are studied as a measure of project performance. Boxplots are used to schematically and descriptively compare two groups and their variations. The ANOVA is performed to investigate if there is a significant difference between the means of growth between these two groups.

In general, projects with low-level IM implementation tend to show more dispersed values, include more outliers, and have higher means of growth compared to the projects with high-level IM implementation. However, due to the limited sample sizes, and variance in the data, the ANOVA does not show a significant difference between means at a standard confidence level of 95%. Nonetheless, the results themselves are useful because they show observable differences in these two different implementation levels, and they indicate that further research into IM is likely worthwhile.

Chapter 8

Conclusions and Future Work

8.1 Conclusions

This research presented a workflow driven process for Interface Management (IM) in complex construction projects, entitled the Interface Management System (IMS). Furthermore, IM-related definitions, elements, and classifications were introduced. IMS provides a framework to link project stakeholders over a range of distances, as well as to formalize and automate the communication channels between them. It also provides added visibility on the roles and responsibilities of each stakeholder and the need dates of the interface deliverables, which ultimately results in facilitating project execution and improving its performance.

Furthermore, the current state of IM in the construction industry was studied by collecting data from 46 construction projects. This study considered three aspects: (1) general characteristics of projects that lead to implementation of IM, (2) common IM practices in the industry, and (3) criteria to assess the status and effectiveness of IM in a project.

According to the analysis of data collection results, it was observed that:

- Large, complex, industrial projects are very active in adopting IM (e.g. oil and gas, power generation).
- Formal IM is more prevalent in projects with higher dollar value, and a larger number of interface stakeholders, top level scope packages, and execution locations.
- Fast paced Design-Build projects tend to adopt IM, and Front-End Planning is recognized as the most appropriate phase at which to initiate IM.
- Every organization adopts a form of IM with respect to characteristics of its projects.

- There is not a distinct line between formal and informal IM. However, there is progression in IM implementation, which is defined using maturity models presented in this thesis.
- There is not a systematic approach to define critical interface points. In fact, the criticality of interface points are generally identified based on top management experience.
- Turnaround time for interface related inquires, quorums at interface meetings and number of non-conformance reports issued because of interface issues are the most useful criteria to assess the performance of IM.

Since a complex mega project may include several hundreds, even thousands of interface points, it is important to identify key interface points. In this research, key interface points were considered the ones for which their failure or delay would cause a significant impact on the project performance and other interface points. For this purpose, a graph theory-based algorithm was proposed to identify the high impact and risk prone interface points in the network of interface points, using the centrality concept. The identified key interface points were mapped to the key interface milestones on the project schedule to be used as a tool to predict the schedule-related risks in a mega project. The functionality of the proposed model and algorithms was demonstrated using a model example, which was a simplified, but realistic representation of a full scale off-shore project. The conclusions of this section were as follows:

- The Interface Points Network (IPN) captures the information dynamics between project stakeholders by recording the interdependency between interface points.
- The identified key IPs in the IPN could be considered as a measure of risk because of cascading impact potential.

- Linking IMS with the project schedule integrates the cyclic information of IMS with the conventional, sequential planning, scheduling, and control paradigms (e.g. CPM) to provide an in-time alert of the potential schedule-related risks.

Finally, the research investigated the relationships between different levels of IM implementation and project performance. According to this analysis:

- The projects in the high-level IM implementation group have a much lower mean of cost growth compared to those in the low-level group (0.037 vs. 0.1844). Also, variation of data in the high-level IM implementation group is almost half of that in the low-level IM implementation group (standard deviation of 0.16 vs. 0.38).
- In general, analysis of project performance reveals that the projects in the high-level IM implementation group are less scattered around the mean, and include less outliers. On the other hand, the performance of projects with low-level IM implementation tend to be more dispersed, and include more outliers.
- Although the performance analysis results show observable differences between two groups of low-level and high-level IM implementation, more data is required to observe a significant difference between means of these two groups, at the standard confidence level of 95%.

8.2 Contributions

The contributions of this research are summarized in four major areas: (1) developing an Interface Management ontology, (2) studying the current state of IM in the construction industry, (3) developing an algorithm to identify key interface points and map them to the project schedule, and (4) studying the relationship between project performance and various levels of IM implementation. A brief description of these contributions is discussed in this section:

1. **Interface Management Ontology**: This study established definitions and elements of IM, which were developed based on a comprehensive literature review, and were modified and accredited by industry experts. By employing these definitions and classifications, a workflow-driven process was presented for IM. IMS shows a generic approach and can be built in electronic and web-based systems. The major advantages of this approach are added visibility on the roles and responsibilities, an open communication framework, clear deadlines and definition of deliverables and traceability.
2. **Current State of Interface Management**: Throughout this research a wide range of construction projects were studied with respect to their IM practices. The research first identified the project general characteristics and their correlation with IM adoption. Then, the current IM practices were investigated, and a maturity model for IM was developed, which can be used by organizations to improve their IM practices. Finally, several criteria were identified and their applicability was analyzed in assessing the state of IM in a project.
3. **Key Interface Points Identification and Integration with Project Schedule**: In the current IM practices, the key interface points are identified based on top management experience and opinions. Furthermore, there is not a systematic approach to map interfaces with the project schedule. This research presented an algorithm to identify key interface points and link them to the schedule: Based on this algorithm, the network of interface points is built based the interdependency relationships between interface points. Using network centrality concept, the high impact and risk prone IPs are identified. Then, these IPs are linked to the interface milestones on the project schedule. Therefore, the cyclic information flow of IM is linked to the linear information transfer of project schedules. Any changes to the interface points that cause deviations from the milestones will be

flagged as potential schedule risks. The other contribution of this study was to demonstrate the functionality of this algorithm on a representative offshore model project – built on a synthesis of several full-scale offshore projects.

4. **Relationship between Project Performance and Interface Management**: This study presented an empirical analysis between IM implementation and project performance. For this purpose, the performance metrics were gathered from construction projects, and using descriptive and statistical tools, the relationship between project performance and IM implementation levels were investigated.

8.3 Limitations

This thesis was a combination of theoretical and empirical analysis of IM in construction industry. Throughout this research, the following limitations were taken into account:

- No agreed-upon definitions and processes were developed for Interface Management in the construction industry. Therefore, it was challenging to get appropriate responses from the interviewees. Although the IM elements and processes were introduced before the interview, it was difficult for the interviewees to adjust their answers to some of the questions. In some cases, it was needed to perform a post-interview follow-up to clarify some responses.
- The number of projects with high level IM implementation were limited. Some of these projects were at the early stages of their life cycle, and it was not possible to gather their performance information. Furthermore, some projects were not willing to give performance data due to proprietary and confidentiality issues. As a result, the statistical analysis did not show observable differences of performance between high-level and low-level IM implementation groups.

- The proposed algorithms to identify key interface points and link them to the project schedule were verified on a representative model project. Validation and implementation of these algorithms were not performed on a full-scale project due to lack of a project with appropriate maturity level of IM, as well as the proprietary and confidentiality considerations.

8.4 Recommendations for Future Work

Interface Management is a new, but rapidly evolving and emerging practice in Construction Management. Therefore, there are significant improvement opportunities in this field. The following recommendations for future research are proposed based on this thesis:

- Currently, the majority of construction projects are at the stage 1 or 2 of IM maturity. A few of the interviewed projects were at stage 3 of maturity level. More projects with high-level IM implementation are required to conclude a significant difference between means of cost and schedule growth for the two groups of low-level and high-level IM implementation, at standard confidence levels.
- Future research will be able to investigate the significant difference between performances of projects with five levels of IM maturity, if adequate projects provide data.
- It is recommended to verify the functionality of proposed algorithms to identify key interface points and map them to the project schedule on a full-scale complex project.
- This study considered the interdependency between interface points as a measure of identifying key interface points. However, several other factors also influence the criticality of an interface point. These factors are associated with high risk and high cost, involvement of more than two parties, etc. The complete list of influencing factors on

criticality of an interface point should be prepared, and an algorithm should be defined based on these factors, to provide a more comprehensive measure for key IP identification.

- Integration of IM with current project management practices, such as risk management and change management, is a promising research area.
- To quantitatively calculate the risks of IPs, it is recommended to perform Monte Carlo analysis on the Interface Points Network (IPN). As well, this approach could be used to estimate the risk reduction through implementing IM in a project.
- It is recommended to explore the relation between Interface Management and Integrated Project Delivery (IPD) concept.
- Application of IM projects outside the industrial field is also recommended. Infrastructure projects are appropriate candidates to benefit from IM implementation.

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Appendix A

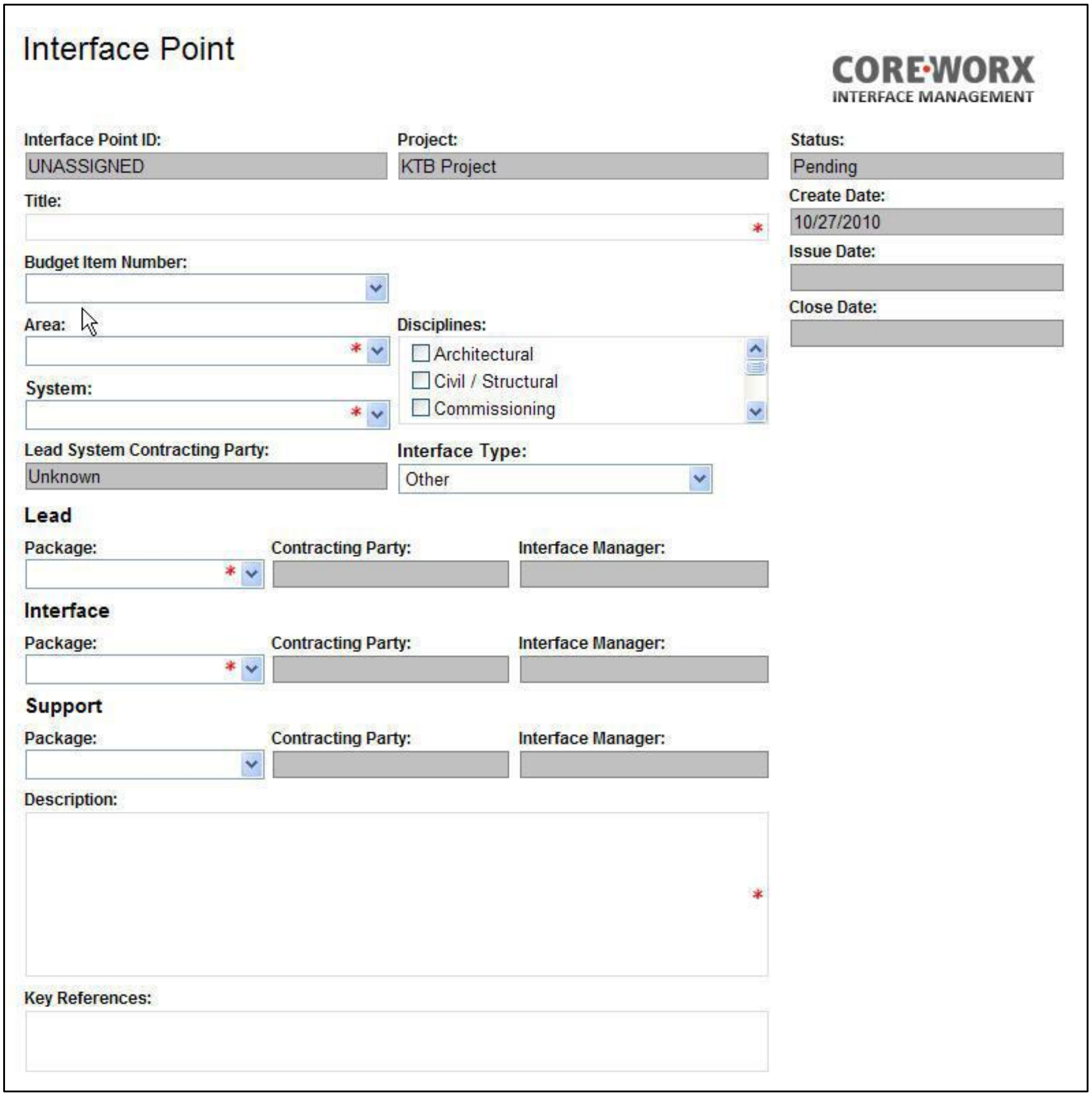
Samples of Interface Data Register, IP and IA Forms

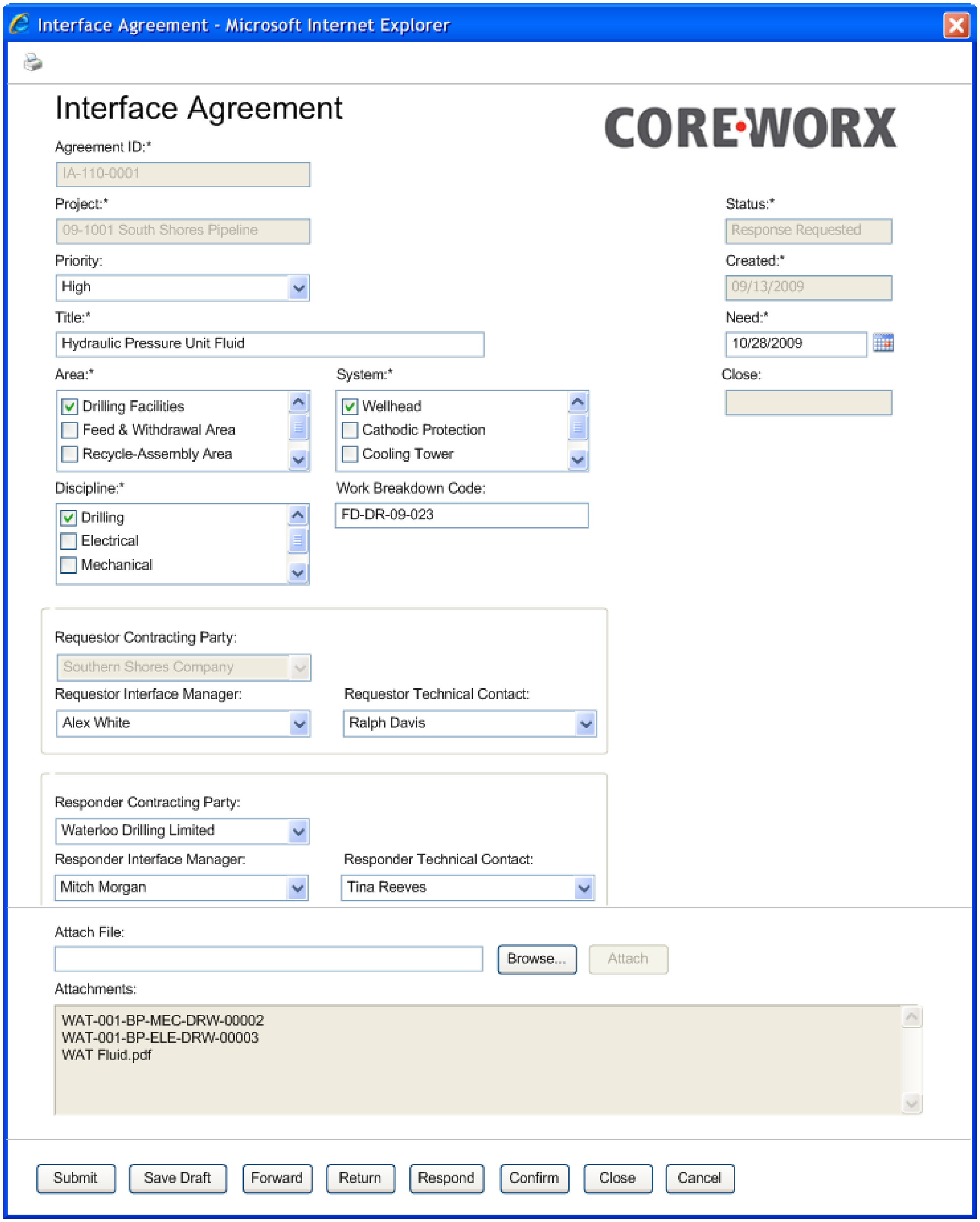
Interface Data Register

Project Name

Status Date:

General Information						Dates				Status		
IA No	Title	Rev. No.	Date	Receiver/ Supplier	Technical Contact	Need	Forecast	Delivery	Close	Status	Comments	Crit. Flag
XX-YY-001	Example Interface Agreement Listing for the Interface Management Plan	1	25-Feb 2013	Receiver	R. Engineer	25-Feb 2013		25-Feb 2013		Initiated	Receivers Row and Comments on the Interface Agreement	False
				Supplier	S. Engineer		25-Feb 2013		25-Feb 2013		Suppliers Row and Comments on the Interface Agreement	
XX-YY-002	Example Interface Agreement Listing for the Interface Management Plan	1	25-Feb 2013	Receiver	R. Engineer	25-Feb 2013		25-Feb 2013		Released	Receivers Row and Comments on the Interface Agreement	True
				Supplier	S. Engineer		25-Feb 2013		25-Feb 2013		Suppliers Row and Comments on the Interface Agreement	
XX-YY-003	Example Interface Agreement Listing for the Interface Management Plan	1	25-Feb 2013	Receiver	R. Engineer	25-Feb 2013		25-Feb 2013		In Progress	Receivers Row and Comments on the Interface Agreement	False
				Supplier	S. Engineer		25-Feb 2013		25-Feb 2013		Suppliers Row and Comments on the Interface Agreement	
XX-YY-004	Example Interface Agreement Listing for the Interface Management Plan	1	25-Feb 2013	Receiver	R. Engineer	25-Feb 2013		25-Feb 2013		Closed Out	Receivers Row and Comments on the Interface Agreement	False
				Supplier	S. Engineer		25-Feb 2013		25-Feb 2013		Suppliers Row and Comments on the Interface Agreement	


Interface Point
CORE·WORX
INTERFACE MANAGEMENT
Interface Point ID:
UNASSIGNED
Project:
KTB Project
Status:
Pending
Title:
Create Date:
10/27/2010
Budget Item Number:
Issue Date:
Area:
Disciplines:
Close Date:
Architectural
Civil / Structural
Commissioning
System:
Lead System Contracting Party:
Unknown
Interface Type:
Other
Lead
Package:
Contracting Party:
Interface Manager:
Interface
Package:
Contracting Party:
Interface Manager:
Support
Package:
Contracting Party:
Interface Manager:
Description:
Key References:


Interface Agreement - Microsoft Internet Explorer
Interface Agreement
CORE•WORX
Agreement ID:*
IA-110-0001
Project:*
09-1001 South Shores Pipeline
Status:*
Response Requested
Priority:
High
Created:*
09/13/2009
Title:*
Hydraulic Pressure Unit Fluid
Need:*
10/28/2009
Area:*
Drilling Facilities
Feed & Withdrawal Area
Recycle-Assembly Area
System:*
Wellhead
Cathodic Protection
Cooling Tower
Close:
Discipline:*
Drilling
Electrical
Mechanical
Work Breakdown Code:
FD-DR-09-023
Requestor Contracting Party:
Southern Shores Company
Requestor Interface Manager:
Alex White
Requestor Technical Contact:
Ralph Davis
Responder Contracting Party:
Waterloo Drilling Limited
Responder Interface Manager:
Mitch Morgan
Responder Technical Contact:
Tina Reeves
Attach File:
Browse...
Attach
Attachments:
WAT-001-BP-MEC-DRW-00002
WAT-001-BP-ELE-DRW-00003
WAT Fluid.pdf
Submit
Save Draft
Forward
Return
Respond
Confirm
Close
Cancel

Appendix B

Data Collection Tool (Questionnaire)

CII

CII RT302 Interface Management Survey Questionnaire

UNIVERSITY OF WATERLOO

UNIVERSITY OF MICHIGAN

Interface Management Survey

Interface Management Research Project

The Interface Management research project (RT 302) is performed by Construction Industry Institute (CII). CII, based at The University of Texas at Austin, is a consortium of more than 100 leading construction companies (owner and contractor). Its objective is to enhance the effectiveness of capital projects through research and industry alliances. The PIs (Principal Investigators) of this project are Professor Carl Haas of the University of Waterloo and Professor SangHyun Lee of the University of Michigan. This research focuses on identifying and establishing definitions and best practices of Interface Management (IM) through the capital project delivery life cycle. The objectives of this project are to: (1) create a common language, definitions, and elements of IM, (2) find representative project characteristics that can determine need for IM, (3) identify important principles and proper timing to guide establishment of IM, (4) identify effective IM practices that can be applied broadly to diverse projects, and (5) propose several indicators that measure effectiveness of IM.

Objective of Survey

This survey aims to recognize the factors required to implement IM in a project, examine current state of IM and identify mechanisms to quantify its effectiveness. The result of the survey will help develop practices to improve collaboration between organizations in a project, as well as effective sharing and distribution of risk-related information within an Interface Management network.

Confidentiality

- Participating in this survey is VOLUNTARY.
- The data provided by participating companies in this survey will be CONFIDENTIAL and used ONLY FOR RESEARCH PURPOSES.
- The provided data will not be communicated in any form to any organization other than CII authorized academic researchers and designated CII staff members.
- To protect the confidentiality of companies submitting data, ONLY AGGREGATED DATA WILL BE PRESENTED/PUBLISHED.

Report of Survey Result

- The results of the research project will be presented in a detailed research report.
- Participants will be provided an electronic copy of the project's research summary, which is planned for issue in the Fall of 2014.

Structure of Survey Questionnaire

This survey consists of three principal parts. The first part is for collecting the general characteristics of your company's past/current project. The second part is for studying the Interface Management practices and processes of your company. Finally, the third part is for surveying the factors affecting Interface Management performance. For each section, you will be asked optional/open-ended questions.

Prior to the survey itself, the definitions related to the Interface Management are gathered in the following section. Please refer to these definitions as needed to provide additional clarity to terms used in the survey.

Definitions related to the Survey

Cost Performance Related Definitions:

Owner:

- Budget amounts include contingency and correspond to funding approved at the time of authorization. This is the original baseline budget, and should not be updated to any changes.
- The **total project budget** amount should include all **planned** expenses (excluding the cost of land) form pre-project planning through startup, including amounts estimated for in-house salaries, overhead, travel, etc.
- The **total actual project cost** should include all actual project costs (excluding the cost of land) from pre-project planning through startup, including amount expended for in-house salaries, overhead, travel, etc.

Contractor:

- The data are only related to your scope of work. Budget amounts should include contingency and correspond to the estimate at the time of contract award. This is the original baseline budget, and should not be updated to any changes.
- The **total project budget** amount should be the **planned** expenses of all phases performed by your company, including amounts for in-house salaries, overhead, travel, etc., but excluding the cost of land.
- The **total actual project cost** should be the **actual** project costs for phases performed by your company, including amounts expended for in-house salaries, overhead, travel, etc., but excluding the cost of land.

Cultural Clash: A cultural clash is defined as a miscommunication or mis-alignment of objectives due to differing languages, differing sets of unwritten cultural expectations, and/or differing value systems.

External Interface: External interfaces are those identified between two or more scopes of work. (Chen et al., 2007; Lin, 2009)

Hard Interface: Hard interfaces represent physical connections between two or more elements, components or systems. Examples of hard interfaces are structural steel connections, pipe terminations, or cable connections (e.g.Tie-In Points). (Adopted from Khadimally, 2011)

Interface/Interface Point (IP): An interface point is a soft and/or hard contact point between two interdependent interface stakeholders. An interface point is also a definition of part of the project's scope split as defined by project documents.

Interface action items: Interface action are the tasks/activities that are performed to provide the agreement deliverables defined in each interface agreement.

Interface Agreement (IA): A formal and documented communication between two interface stakeholders, including the deliverable description, need dates, and required actions.

Interface Coordinator: "The interface coordinator is responsible to anticipate potential problems and communication breakdowns, interpret the potential impact of events and foster resolution among the parties while actions are still controllable." (Shirleyl, R.R. et al., 2006)

Interface Management: Interface Management is the management of communications, relationships, and deliverables among two or more interface stakeholders.

Interface Management Plan: Interface Management Plan represents strategies and processes, developed by a project management team, to manage internal and external interfaces throughout the project lifecycle, including design and engineering, procurement, construction, commissioning and closeout. (Adopted from Khadimally, 2011)

Interface Manager: "The Interface Manager has overall responsibility for implementation and maintenance of the interface management plan throughout the project life cycle by developing and implementing project specific Interface Management work processes, capturing the necessary interface agreements, monitoring progress, ensuring that schedule requirements are maintained and identifying/initiating any change requests that may arise out of the interface requirements." (Caglar, J. and Connolly,M. 2007)

Interface Stakeholders: A stakeholder involved in a formal interface management agreement within an interface management plan for a project.

Internal Interface: Internal interfaces are those identified within a single scope of work. (Chen et al., 2007; Lin, 2009)

Project Life Cycle (CII website, Front End Planning: Glossary of Terms)

- Feasibility: "The first phase of the planning process. The primary objectives of this phase are to define business objectives, identify potential alternatives and to outline steps and resources necessary to continue concept phase development. Its primary output is a decision whether the potential project is economically and technically feasible for the organization. It is also known as business planning, strategic planning, FEL I, etc".
- Concept: "The second phase of the planning process. It is primarily concerned with defining, evaluating and selecting best alternative(s) for site, technology and acquisition strategy. It is also known as alternative selection, conceptual design, programming, FEL II, etc".
- Detailed Scope: "The third phase of the project planning process. The primary objectives of this phase are to define the technical scope of the project, further develop project execution plans and develop a definitive cost estimate and schedule suitable for project authorization for detailed design and/or construction. Its primary output is the design basis. It is also known as schematic design and design development, scope finalization, preliminary engineering, definition phase, FEL III, sanctioning process, Schedule A package, etc".
- Construction: The fifth phase of the project life cycle. It includes procurement and installation activities.

Schedule Performance Related Definitions:

Owner: the dates for the planned schedule should be in effect at the project authorization.
Contractor: the dates for the planned schedule should be those in effect at the estimate time of contract award.

Soft Interface: Soft interfaces typically involve the exchange of information such as design criteria, clearance requirements or utility needs between delivery teams or between a delivery team and an external party. Examples of soft interfaces are language and cultural aspects, regulatory and permit issues. (Adopted from Khadimally, 2011)

Stakeholders: "Person or organization (e.g. customer, sponsor, performing organization, or the public) that is actively involved in the project, or whose interests may be positively or negatively affected by execution or completion of the project. A stakeholder may also exert influence over the project and its deliverable." (PMBOK, 4th edition, 2008)

Hierarchy of Interface Management Elements

Several Interface Points are created between every pair of Interface Stakeholders, considering the complexity of their interaction. Each Interface Point includes one or more Interface Agreements. Finally to deliver the agreement requirements, several actions items are defined for each Interface Agreement. The Hierarchy of these three elements are illustrated in Figure 1.

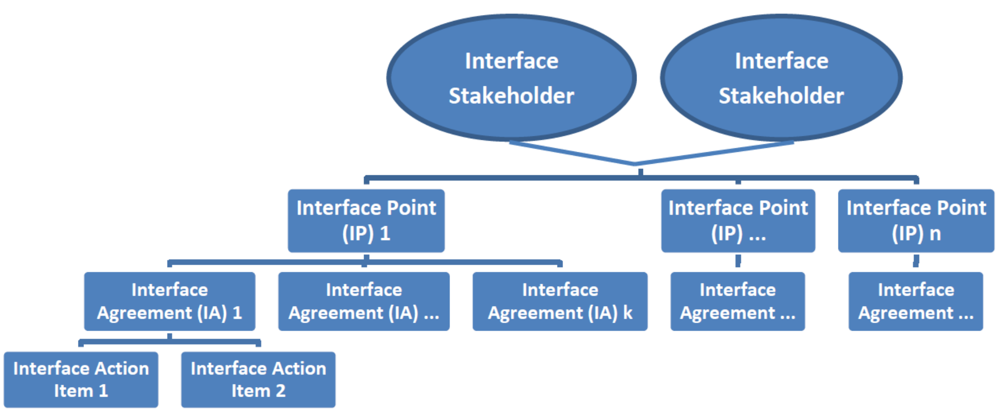
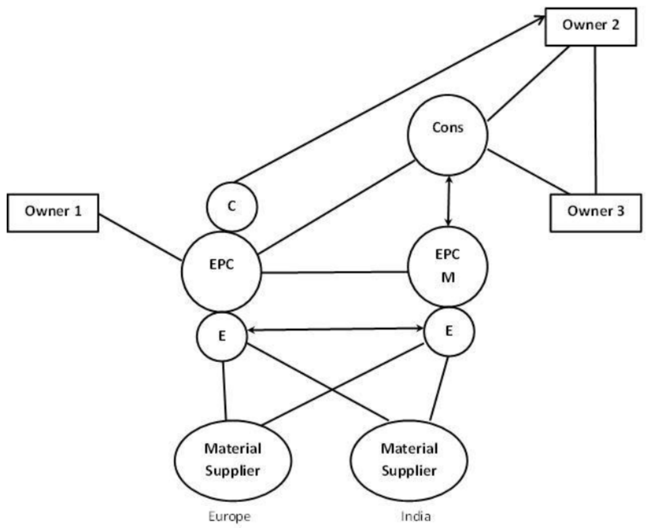


Figure 1. Hierarchy of Interface Management Elements

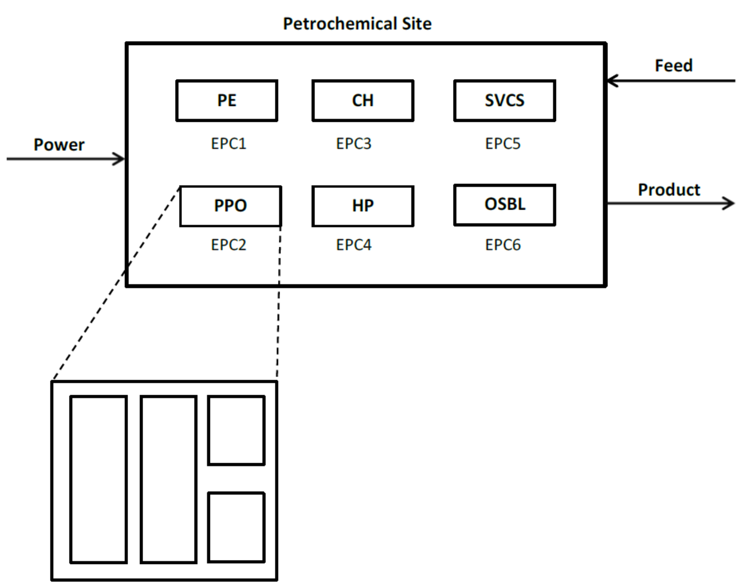
Samples of Project Organization Schematic Representation (These samples can be used for Part 1, Q10 and Q25 in the questionnaire):



C: Construction

E: Engineering

EPC: Engineering, Procurement, Construction



Part 1: Project General Information

Date on Interview: ....

Section 1.1. General information about the entire project

1. Project Name

2. Owner

3. Project Location

4. Greenfield or Brownfield project? Greenfield ☐ Brownfield ☐

5. Project type
Chemical Mfg. ☐ Oil Refining ☐ Power Generation ☐
Stadium ☐ Natural Gas Processing ☐ Water/Wastewater ☐
Museum ☐ Highway ☐ Consumer Products Mfg. ☐
Metals Refining/Processing ☐ Dam ☐
Oil Exploration/Production ☐ Other ☐

6. Dollar value of the entire project (Total installed or Capital cost)
<$500M ☐ $500M-$1B ☐ $1B-$5B ☐ $5B-$10B ☐ >$10B ☐

7. The current stage(s) of the entire project and percentage(s): If the project is in multiple stages, please answer all of them below.
Front End Planning ☐
(0-20% ☐, 20-40% ☐, 40-60% ☐, 60-80% ☐, 80-100% ☐, NA ☐)
Design ☐
(0-20% ☐, 20-40% ☐, 40-60% ☐, 60-80% ☐, 80-100% ☐, NA ☐)
Procurement ☐
(0-20% ☐, 20-40% ☐, 40-60% ☐, 60-80% ☐, 80-100% ☐, NA ☐)
Construction ☐
(0-20% ☐, 20-40% ☐, 40-60% ☐, 60-80% ☐, 80-100% ☐, NA ☐)
Commissioning & Start-up ☐
(0-20% ☐, 20-40% ☐, 40-60% ☐, 60-80% ☐, 80-100% ☐, NA ☐)
Completed ☐

8. Delivery strategy/strategies of the entire project (check all that apply)
Design, Bid, Build (DBB)☐ Design, Build (DB)☐ Procurement, Construction (PC)☐
Engineering, Procurement, Construction (EPC)☐ Build, Own, Operate (BOO)☐
Construction☐ Engineering, Procurement, Construction Management (EPCM)☐
Others:

9. Contracting strategy/strategies of the entire project (check all that apply)
Reimbursable Work ☐ Cost Plus Fixed Fee ☐ Cost Plus Fixed Percentage ☐
Target Estimate ☐ Cost Plus Variable Percentage ☐ Unit Price ☐
Guaranteed Maximum Cost ☐ Lump-sum ☐

10. Please draw the top level schematic illustration of the entire project organization, focusing on the relations between stakeholders and their primary locations. (**Please refer to the examples on page 4**)

11. Number of top level scope (contract) packages in the entire project

12. Number of JV Partners/Owners

13. Estimated number of project execution locations (including engineering, fabrication, and construction)

14. Which countries are representing the project execution locations?

15. Number of involved interface stakeholders (including owners) and their geographical locations:
1-5 ☐ 5-15 ☐ 15-30 ☐ >30 ☐
Locations:

16. How many Owner's prime contractors are participating in the entire project?
1-5 ☐ 5-10 ☐ 10-20 ☐ >20 ☐

Section 1.2. General information about your company's scope (Answer this section only if your company represents as a contractor)

17. Dollar value of your company's scope (Only contractor):
<$100M□ $100M-$500M□ $500M-$1B□ $1B-$5B□ $5B-$10B□ >$10B□

18. The current stage(s) of your company's scope and percentage(s): If your project is in multiple stages, please answer all of them below. (Only contractor)
    - Front End Planning □
        (0-20% □, 20-40% □, 40-60% □, 60-80% □, 80-100% □, NA □)
    - Design □
        (0-20% □, 20-40% □, 40-60% □, 60-80% □, 80-100% □, NA □)
    - Procurement □
        (0-20% □, 20-40% □, 40-60% □, 60-80% □, 80-100% □, NA □)
    - Construction □
        (0-20% □, 20-40% □, 40-60% □, 60-80% □, 80-100% □, NA □)
    - Commissioning & Start-up □
        (0-20% □, 20-40% □, 40-60% □, 60-80% □, 80-100% □, NA □)
    - Completed □

19. Delivery method of your company's scope (Only contractor):
Design, Bid, Build (DBB) □ Design, Build (DB)□ Procurement, Construction (PC)□
Engineering, Procurement, Construction (EPC)□ Construction □
Engineering, Procurement, Construction Management (EPCM) □
Others:

20. Contracting method(s) of your company's scope (Only contractor, check all that apply)
Reimbursable Work □ Cost Plus Fixed Fee □ Cost Plus Fixed Percentage □
Target Estimate □ Cost Plus Variable Percentage □ Unit Price □
Guaranteed Maximum Cost □ Lump-sum □

21. Contracting method(s) of your company's subcontractors (Only contractor, check all that apply)
Reimbursable Work □ Cost Plus Fixed Fee □ Cost Plus Fixed Percentage □
Target Estimate □ Cost Plus Variable Percentage □ Unit Price □
Guaranteed Maximum Cost □ Lump-sum □

22. How many purchase orders for engineered items has your organization forecasted for this project.

23. Please draw the top level schematic illustration of the organizations under your company' scope, focusing on the relations between stakeholders and their primary locations (**For instances, please refer to the examples on page 4**)

Section 1.3. Project performance of your Company's Scope (As of today)

24. Initial Predicted Project Cost (Total Project Budget) ($)_______________

25. Total Actual Project Cost ($) ______________________________

26. Initial Predicted Project Duration (Total Planned Project Duration) (Weeks or Months) _______________

27. Total Actual Project Duration (Weeks or Months) _______________

28. Total Forecasted Construction Hours _______________________

29. Actual Construction Hours ______________________________

30. Total Forecasted Project Management Hours __________________

31. Actual Project Management Hours _______________________

32. Total Forecasted Design/Engineering Hours __________________

33. Actual Design/Engineering Hours ________________________

Section 1.4. Project complexity assessment: scope and risk factors

34. Please answer the following 2 questions for each of the items below:

(a) How much does this factor contribute to the complexity and risk of your current project scope? (1 for the lowest contribution and 10 for the highest contribution)

a. Cost *(e.g. highly-competitive bid)*
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
b. Schedule (e.g. condensed cycle time)
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
c. Scope (e.g. extended/unfamiliar, Poorly defined scope)
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
d. Execution Risk (e.g. unknowns)
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
e. JVs (EPCs/Owners)
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
f. Technology (e.g. "new'" stuff)
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
g. Large (or Excessive) number of Suppliers / Subcontractors
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
h. Multiple Engineering Centers
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
i. Government (e.g. rules/ regulations/permits/bureaucracy)
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
j. Multiple EPCs / Interface Points
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
k. Purchase of Engineered items
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
l. Multiple Languages
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
m. Lack of previous experience of collaboration with one or more of other contactors
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
n. Use of dissimilar design codes and software packages for design documents/drawings between contractors
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
o. Poorly-defined battery limits of the involved parties
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
p. Poorly-defined requirements of the involved parties
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....
q. Poorly-defined responsibilities of the involved parties
   1□ 2□ 3□ 4□ 5□ 6□ 7□ 8□ 9□ 10□ Rank ....

(b) Please rank the top five scope and risk factors you think are the most critical for your project scope

Part 2: Interface Management Practices

Section 2.1. General Information

35. Please rank the importance of the following Interface Management attributes.

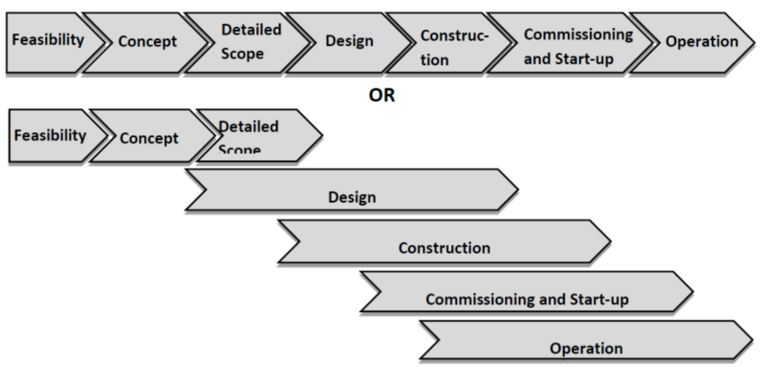
.... Definition of deliverables	.... Traceability	.... Timely flow of information	.... Other:
.... Definition of roles and responsibilities	.... Agreeable deadlines	.... Quality and Clarity of information flow	
.... Responsibility allocation	.... Managed collaboration	.... Knowledge exchange	

36. Was/is an IM process/practice defined during the course of the project? (Please answer the questions on either "Yes" column or "No" column)

Yes □

If "Yes", please answer the following questions:

a. In what phase/stage is the interface management process in your project initiated? (e.g., right after the bidding process was over, when the actual construction begins). (Please select the life cycle that better fits your project.)



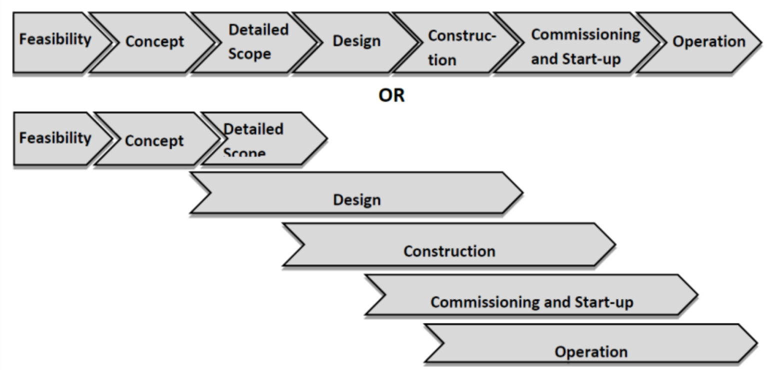
b. Do you employ an interface management system/software for managing the interfaces? Yes □ No □

c. Is your IM integrated with the formal change management plan? Please elaborate.

No □

If "No", please answer the following questions:

a. Considering the definition of IM, do you employ a similar approach within your company's scope? If yes, in which stage does your company initiate it? (Please select the life cycle that better fits your project.)



b. What is your main method for handling the communications between parties? (e.g., emails, spreadsheets, phone calls, stand-up meetings, etc.)

c. How are the deliverables of communications and mutual expectations between contracting parties met and followed-up in your company's scope?

d. Is your IM integrated with the project schedule? Please elaborate.	d. What is your approach for schedule conflict resolution between your company and other contractors?
e. Do you have a formal process to define the mutual expectations (e.g. Interface Agreements) between contracting parties? Please elaborate.	
f. What is your approach to conflict resolution around the interface agreements?	

Section 2.2. Specialized Information on IM (Only for a company which has a formal practice for Interface Management)

37. a. What positions are assigned for IM functions? How many person hours are allocated to each IM function/position? What are the core competencies for these positions?

Role	Full-time/Part-time	Person Hours per year	Core Competency					
			Experience	Good facilitation skills	Multi-disciplinary	Do whatever it takes	Leadership skills	Technical competencies
Interface Manager	FT □ PT □							
Interface Coordinator	FT □ PT □							
Translator/Cultural Mediator	FT □ PT □							
Project Engineer	FT □ PT □							
....	FT □ PT □							

b. How do you justify these functions/positions?

38. Please provide the following general information about interface points and agreements with respect to your scope package.

Interface Management Elements	Number for Scope Package
Total number of identified interface points	
Internal Interface points	
External Interface points	
Hard interface points (Physical, functional, …)	
Soft interface points (Organizational, Cultural, …)	
Interface points between more than two parties	
Average number of interface agreements for an Interface point	
....	

39. Which are the criteria you consider in order to prioritize the interface points? Can you please elaborate more on the process?

Top management experience	
Associated with higher cost	
Having a high risk	
Related to the activity on the critical path	
Related to specific discipline	
Interface point between more than 2 parties	
....	

Part 3: Interface Management Performance

Section 3.1. Information on Interface Management Performance

40. How much are you satisfied with your current IM practice in your project? (Only for a company which has a formal practice for Interface Management)
Very Little (0-20%) □ Little (20-40%) □ Somewhat (40-60%) □ Much (60-80%) □ Very Much (80-100%) □

41. According to your experiences, can you give us **three** examples and their monetary impact on risks that are/were avoided due to existence of a good Interface Management practice? (e.g. delay, cost overrun, quality or safety problem)

42. Of the following items, which is useful to assess the current state of IM?

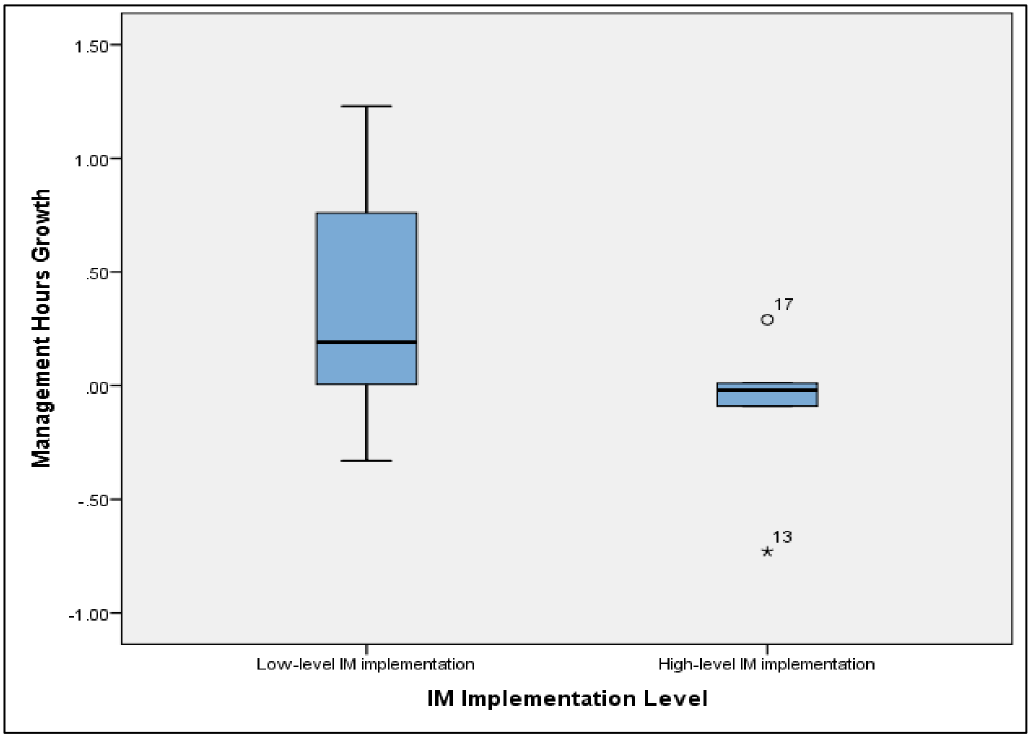
Criterion	Not useful at all	Slightly useful	Somewhat useful	Useful	Highly useful	Not Applicable
a. Percentage of closed interface points of the ones that should be closed, at any point of time	□	□	□	□	□	□
b. Percentage of interface points identified after FEED of total project Interface points	□	□	□	□	□	□
c. Percentage of closed interface agreements of the ones that should be closed, at any point of time	□	□	□	□	□	□
d. Number of overdue interface agreements at any point of time	□	□	□	□	□	□
e. Number of change orders precipitated during the execution of interface agreements per agreement at any point of time	□	□	□	□	□	□
f. Number of cultural clashes at any point of time	□	□	□	□	□	□
g. Number of formal escalations or disputes at any point of time	□	□	□	□	□	□
h. Average number and standard deviation of revisions per document or drawing	□	□	□	□	□	□
i. Amount of contingency release at any point of time	□	□	□	□	□	□
j. Percentage of completed engineering, when IM is started	□	□	□	□	□	□
k. Turnaround time for inquires	□	□	□	□	□	□
l. Quorums at interface meetings	□	□	□	□	□	□
m. Residual risk before and after implementing IM	□	□	□	□	□	□
n. Number of non-conformance reports issued because of interface issues	□	□	□	□	□	□
n. Other						

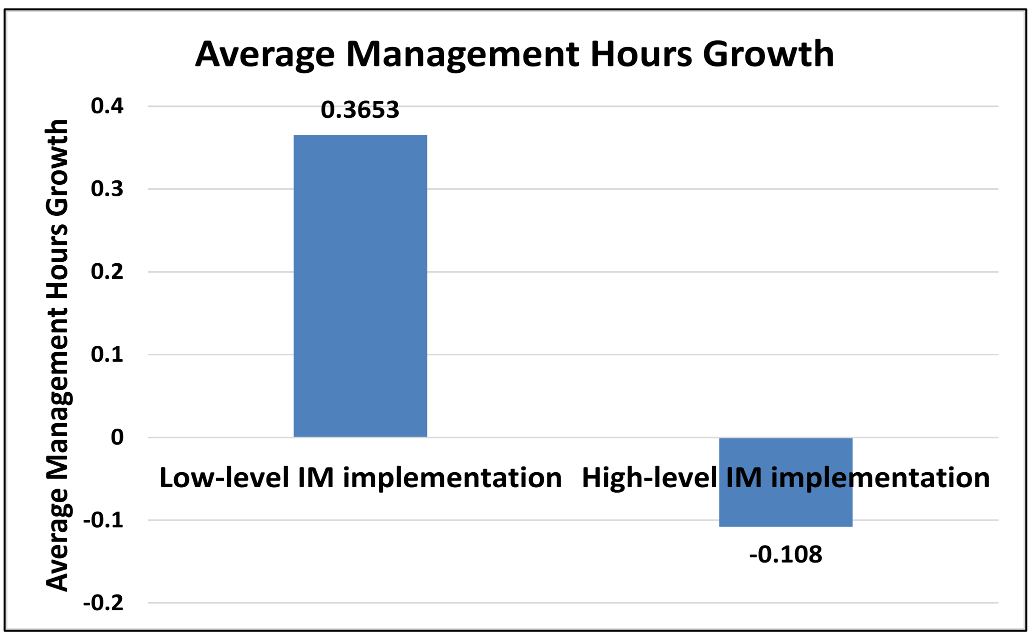
43. What are your expectations of the best Interface Management Practice?

44. Will you consider changing the contingency with IM? (Considering reduced risk, added cost, ...). If yes, how?

Appendix C

Boxplot and ANOVA Results for Management Hours Growth





SUMMARY (95% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	19	6.9621	0.3664	0.2258
High-level IM Implementation	5	-0.5403	-0.1081	0.1436

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.8912	1	0.8912	4.2265	0.0519	4.3009
Within Groups	4.6388	22	0.2109			
Total	5.5299	23			***Not Significant***	

SUMMARY (90% Confidence Interval)

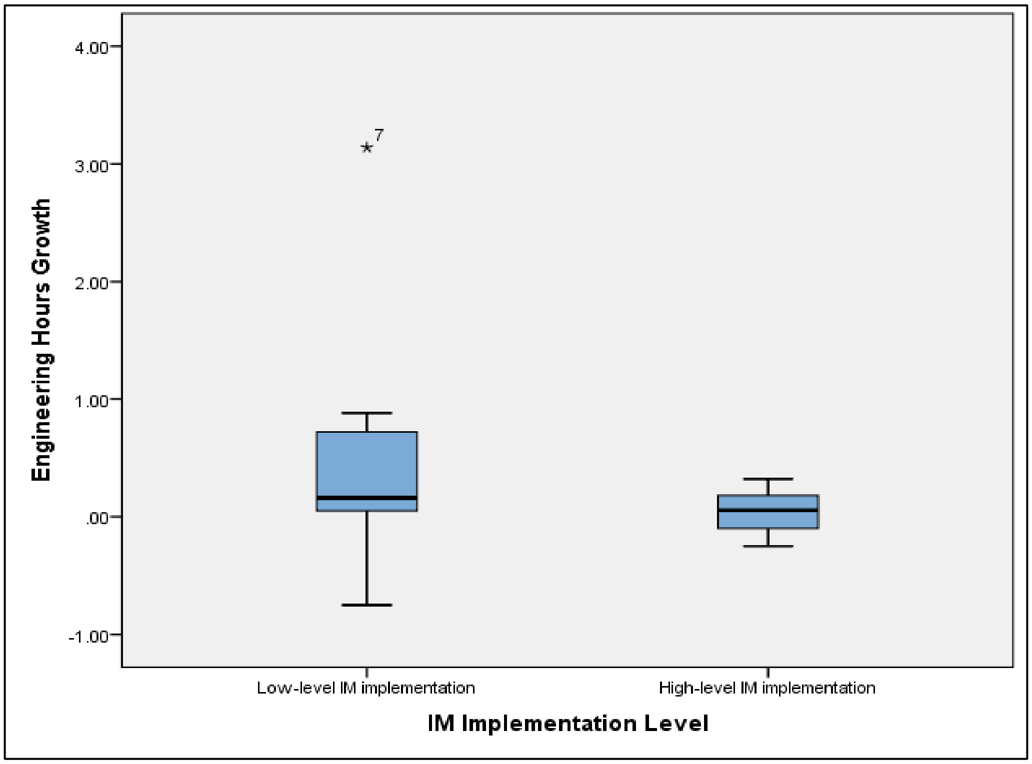
Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	19	6.9621	0.3664	0.2258
High-level IM Implementation	5	-0.5403	-0.1081	0.1436

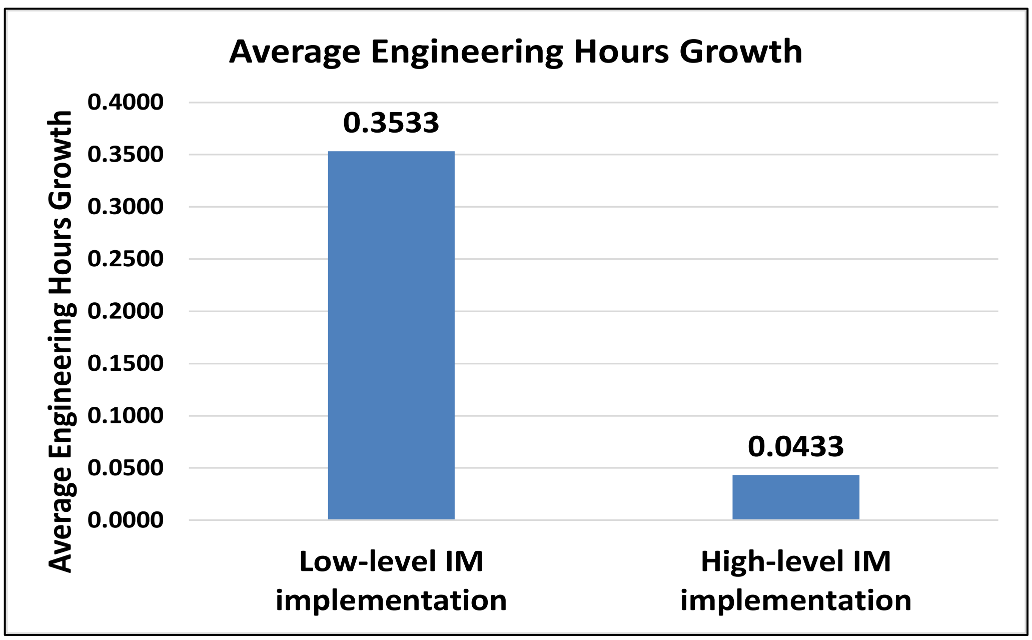
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.8912	1	0.8912	4.2265	0.0519	2.9486
Within Groups	4.6388	22	0.2109			
Total	5.5299	23			***Significant***	

Appendix D

Boxplot and ANOVA Results for Engineering Hours Growth





SUMMARY (95% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	21	7.4129	0.3530	0.6018
High-level IM Implementation	6	0.2517	0.0420	0.0413

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.4515	1	0.4515	0.9220	0.3461	4.2417
Within Groups	12.2417	25	0.4897			
Total	12.6931	26			***Not Significant***	

SUMMARY (90% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	21	7.4129	0.3530	0.6018
High-level IM Implementation	6	0.2517	0.0420	0.0413

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.4515	1	0.4515	0.9220	0.3461	2.9177
Within Groups	12.2417	25	0.4897			
Total	12.6931	26			***Not Significant***	

SUMMARY (65% Confidence Interval)

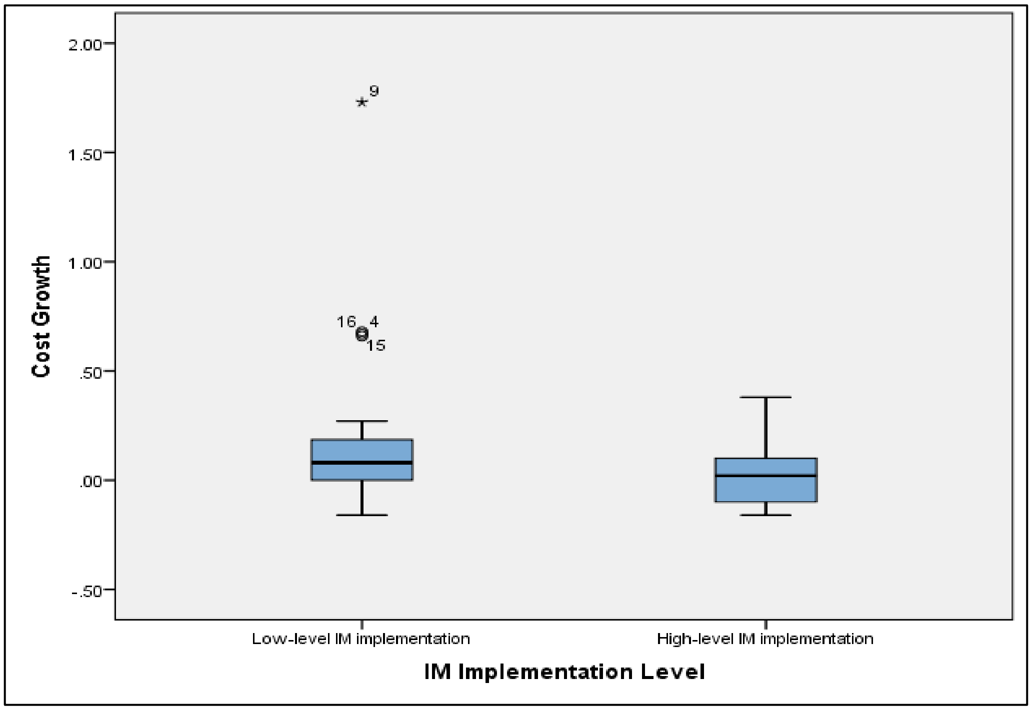
Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM Implementation	21	7.4129	0.3530	0.6018
High-level IM Implementation	6	0.2517	0.0420	0.0413

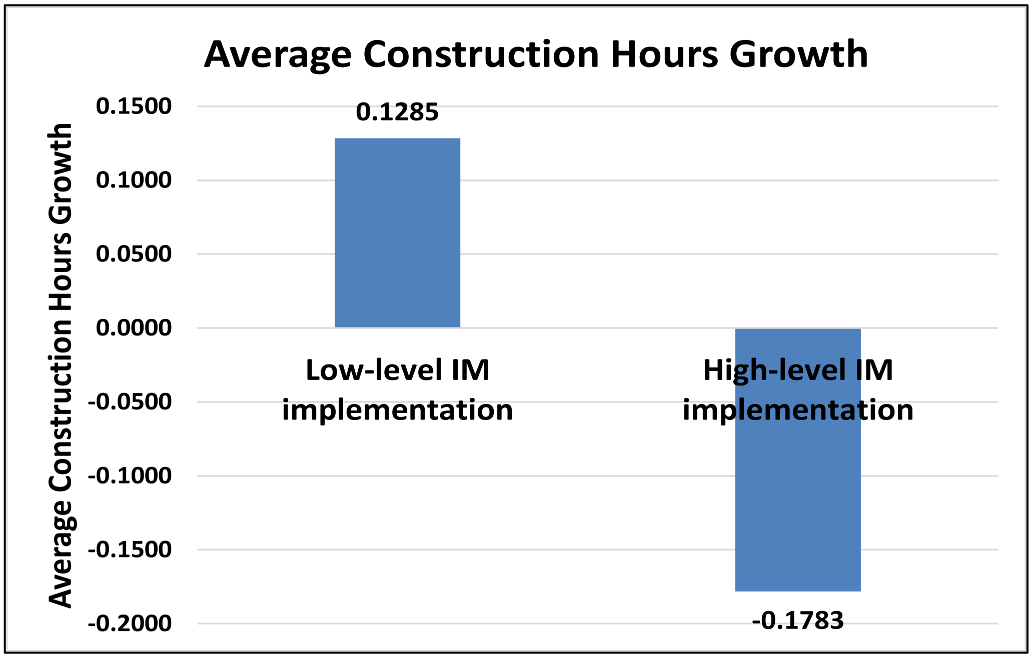
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.4515	1	0.4515	0.9220	0.3461	0.9071
Within Groups	12.2417	25	0.4897			
Total	12.6931	26			***Significant***	

Appendix E

Boxplot and ANOVA Results for Construction Hours Growth





SUMMARY (95% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM	13	1.6682	0.1283	0.1708
High-level IM	6	-1.0756	-0.1793	0.2226

ANOVA

ırce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Gro	0.3884	1	0.3884	2.0876	0.1667	4.4513
Within Grouբ	3.1630	17	0.1861			
Total	3.5514	18			***Not Significant***	

SUMMARY (90% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM	13	1.6682	0.1283	0.1708
High-level IM	6	-1.0756	-0.1793	0.2226

ANOVA

ırce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Gro	0.3884	1	0.3884	2.0876	0.1667	3.0262
Within Grouբ	3.1630	17	0.1861			
Total	3.5514	18			***Not Significant***	

SUMMARY (80% Confidence Interval)

Groups	*Count*	*Sum*	*Average*	*Variance*
Low-level IM	13	1.6682	0.1283	0.1708
High-level IM	6	-1.0756	-0.1793	0.2226

ANOVA

ırce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Gro	0.3884	1	0.3884	2.0876	0.1667	1.7779
Within Grouբ	3.1630	17	0.1861			
Total	3.5514	18			***Significant***	