The Journal of Engineering Research Vol. 12, No. 1 (2015) 53-68

Applying Interpretive Structural Modeling to Cost Overruns in Construction Projects in the Sultanate of Oman

K. Alzebdeh*[a], H.A. Bashir[b] and S.K. Al Siyabi[c]

[a] *Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University, Sultanate of Oman.*
[b] *Department of Industrial Engineering and Management, University of Sharjah, Sharjah, United Arab Emirates.*
[c] *Oman Tank Terminal Company, Muscat, Sultanate of Oman.*

Received 5 May 2014; accepted 6 January 2015

Abstract: Cost overruns in construction projects are a problem faced by project managers, engineers, and clients throughout the Middle East. Globally, several studies in the literature have focused on identifying the causes of these overruns and used statistical methods to rank them according to their impacts. None of these studies have considered the interactions among these factors. This paper examines interpretive structural modelling (ISM) as a viable technique for modelling complex interactions among factors responsible for cost overruns in construction projects in the Sultanate of Oman. In particular, thirteen interrelated factors associated with cost overruns were identified, along with their contextual interrelationships. Application of ISM leads to organizing these factors in a hierarchical structure which effectively demonstrates their interactions in a simple way. Four factors were found to be at the root of cost overruns: instability of the US dollar, changes in governmental regulations, faulty cost estimation, and poor coordination among projects' parties. Taking appropriate actions to minimize the influence of these factors can ultimately lead to better control of future project costs. This study is of value to managers and decision makers because it provides a powerful yet very easy to apply approach for investigating the problem of cost overruns and other similar issues.

Keywords: Project, Cost overrun, Interpretive structural modelling (ISM).

تطبيق النمذجة الهيكلية التأويلية لتجاوزات التكلفة في مشاريع البناء في سلطنة عمان

خ . الزبده، ح. أ. بشير ، س. ك السيابي

ملخص: تمثل تجاوزات التكلفة في مشاريع البناء مشكلة تواجه مديري المشاريع و المهندسين و العملاء في منطقة الشرق الأوسط. على الصعيد العالمي، ركزت العديد من الدراسات على تحديد أسباب هذه التجاوزات واستخدام الأساليب الإحصائية لتصنيفها وفقا لتأثيراتها. ولم تعتبر أي من هذه الدراسات التفاعل بين هذه العوامل مع بعضها البعض. هذه المقالة تختبر نموذج هيكلي تفسيري كتقنية قابلة للتطبيق لنمذجة التداخل المعقد بين هذه العوامل و المسؤولة عن تجاوز التكاليف في مشاريع البناء في سلطنة عمان. على وجه الخصوص تم تعريف العلاقات المتداخلة بين ثلاثة عشر من العوامل المتداخلة و المرتبطة بتجاوز التكاليف. تطبيق هذا النموذج الهيكلي التفسيري يؤدي إلى تنظيم هذه العوامل بوحدة بناء هرمية حيث يتم عرض هذه التداخلات بصورة مبسطة. تم إيجاد أربعة عوامل أساسية تؤدي إلى تجاوز التكاليف وهي عدم ثبات سعر الدولار الأمريكي و التغييرات في القوانين الحكومية و التقدير الخاطىء للتكاليف وضعف التنسيق بين أطراف المشروع . اتخاذ الإجراءات المناسبة للحد من تأثير هذه العوامل يمكن أن تؤدي في النهاية إلى تحكم أفضل بالتكاليف المستقبلية. تعتبر هذه الدراسة ذات قيمة للمديرين و متخذي القرار حيث تمدهم بنهج قوي و سهل التطبيق يفحص مشكلة تجاوز التكاليف وغيرها من القضايا المماثلة.

كلمات مفتاحية: المشروع، تجاوز التكاليف، نموذج هيكلي تفسيري

*Corresponding authors email: alzebdeh@squ.edu.om

1. Introduction

Cost overrun is one of the most critical risks in projects. It is defined as an excess of actual cost over budget and is common to all types of projects. For instance, Flyvbjerg *et al.* (2003) sampled 258 transport infrastructure projects in 20 countries and reported that 9 out of 10 projects had cost overruns, with overruns of 50–100% being common. Azhar *et al.* (2008) ascertained that cost overrun is a frequent phenomenon associated with almost all projects in the construction industry. This trend is more severe in developing countries where overruns sometimes exceed the anticipated cost of the project by 100%.

Several studies have been conducted worldwide to investigate and attempt to minimize the severity of the project cost overrun problem. These studies analysed cost overruns in projects in many different industries including civil and structural engineering construction (Mansfield *et al*. 1994; Kaming *et al.* 1997; Frimpong *et al.* 2003; Flyvbjerg *et al.* 2004; Koushki *et al.* 2005; Creedy 2006; Azhar *et al.* 2008; Enshassi 2009; Kaliba *et al.* 2009; Le-Hoai *et al.* 2008; Ali and Kamaruzzaman 2010; Wang and Yuan 2011). One of the common objectives of these studies was to identify the major factors causing project cost overruns in a particular country through opinion surveys of contactors, clients, and consultants. Researchers used statistical methods to rank the contributing factors according to their impacts without considering the interactions among these factors. Moreover, the studies suggested solutions and remedies without identifying the root causes of the overruns. Any attempt to address the cost overruns would be futile unless the root causes are identified because cost overruns are a net result of complex relationships between one or more factors**.** Given the limitations of previous works as highlighted above, this study proposes that interpretive structural modelling (ISM) be used to identify and analyse the interaction among the various factors causing project cost overrun, thus developing a hierarchy of factors that will help to identify the root causes of the problem.

ISM was first developed to identify the interrelationship among elements making up the structure of a system (Warfield, 1974; 1979). The ISM approach is multifaceted:

- It is interpretive, as the judgment of the group establishes the relationships among causal elements.
- It is structurally-oriented because the overall structure is extracted from a complex set of elements.
- As a modelling technique, it highlights specific relationships and portrays the overall structure in a digraph model.
- It serves as a communication tool for analysing complex systems and providing an understanding of their interacting elements.

ISM is a powerful technique that depicts the structure of a complex system through graphics as well as words. It helps one understand the complex relationships among elements within a system by documenting their order and the influence of one element on another. In a broad range of applications, ISM has been used extensively since its inception. Examples of its use in policy analysis appear in the early literature (Hawthorne & Sage, 1975; Brand et al., 1976; Kawamura & Christakis, 1976), and recent improvements in computer-based programs have expanded its applications to various fields. For example, using ISM, Sharma *et al.* (1995) developed a hierarchy of actions required to meet the objectives of a waste management project in India. Mandal and Deshmukh (1994) developed an interpretive structural model to analyse vendor selection criteria and demonstrate interrelationships between these criteria and their levels of importance. ISM was used by Singh *et al.* (2003) in knowledge management to study the complexity of relationships among elements of a manufacturing system. Bolanos *et al.* (2005) applied ISM in order to improve the decision making process among executives working in different functional areas. The ISM methodology was implemented by Ravi and Shankar (2005) to model and analyse the interactions among barrier elements in reverse logistics in automobile supply chains. In a study by Farooquie and Khan (2007), ISM was used to develop the structural relationship among planning factors that contribute to the success of heating, ventilation, and air-conditioning (HVAC) projects in India**.** Hasan *et al.* (2007) applied ISM to explore and establish a relationship among various barriers to adopting agile manufacturing. Wang *et al.* (2008)

applied ISM to investigate the obstacles to energy savings in China. Bashir (2010) adapted the methodology to remove redundant relationships in an activity on network (AON) project network. ISM was used by Iyer and Sagheer (2010) to identify the nature and degree of the interrelationship between risks during the development phase of public-private partnership projects in the Indian road sector. By applying ISM, (Sahney *et al.* 2010) proposed a quality framework for administrative staff in **India's higher education system.** Shankar *et al.* (2011) introduced ISM as a tool that can be used to help understand and manage urban planning issues. Talib *et al.* (2011) applied ISM to analyze the interaction among the barriers to total quality management implementation. Govindan *et al.* (2012) adopted ISM for selecting the best reverse logistics provider. Most recently, (Mathiyazhagan *et al.* 2013) developed a structural model of the barriers to implementing green supply chain management in the automobile industry in India. Also, (Ansari *et al.* 2013) applied ISM to analyze thirteen competing barriers to implement solar power installation in India.

The objective of this paper was to identify and rank factors responsible for cost overruns in construction projects. Applying ISM to identified factors involves modelling interactions among them and determining the root factors that act as the driving cause for initiating the cost overrun problem. Before proceeding, it is important to note that in ISM terminology, factors are called elements. Therefore, these two terms are used interchangeably in the remainder of the paper.

2. Methodology of ISM

Several professionals and project managers belonging to substantially large construction projects were contacted. Responses on key factors that they encountered during the course of planning and construction phases of their projects were collected. Furthermore, their opinions on the interrelations among the causing factors were recorded. To further analyze the interactions among these factors along with the goal of identifying the root causes of cost overruns, ISM was selected as a tool for the study; it has been proven effective and simple in other fields, including manufacturing, logistics, and socioeconomics. The technique also acts as a educating tool at the managerial level, facilitating better insight into the system under study.

The logical process flow of the ISM technique as applied to project cost overruns is presented in Fig. 1, which shows that the ISM methodology involves five major steps:

1. Identifying the factors causing cost overruns
2. Developing a structural self-interaction matrix
3. Constructing a reachability matrix
4. Partitioning the reachability matrix into different levels
5. Forming the ISM digraph

These steps were applied to factors that caused cost overruns in large construction projects carried out in Oman. A typical construction project’s performance was deemed unsatisfactory if the project’s final cost of completion exceeded the original budgeted estimate by more than 30%. Statistics on average cost escalation in construction projects worldwide are available in the literature (Flyvbjerg *et al*. 2003; Abdul Azis *et al*. 2013).

2.1 Identifying the Factors Causing Cost Overruns

The first step in applying ISM to the problem of project cost overrun is for experts to identify the causal factors and their interrelationships using methods such as brainstorming. According to (Rawlinson 1986), brainstorming is probably the best known of all the techniques available for creative problem solving. It is worthwhile to emphasize that studying variability in interrelationships among factors is beyond the scope of the current study.

Based on a brainstorming session conducted with professionals involved in projects under study, thirteen critical factors were identified as major causes of cost overruns. These factors are the instability of the US dollar, poor cost estimation, changes in governmental regulations, increased material costs, delays in material delivery, increased wages and equipment costs, poor communication within the project team and among project stakeholders, design changes during the construction phase, high staff turnover, schedule delays, and procurement changes. These factors will be detailed individually below.

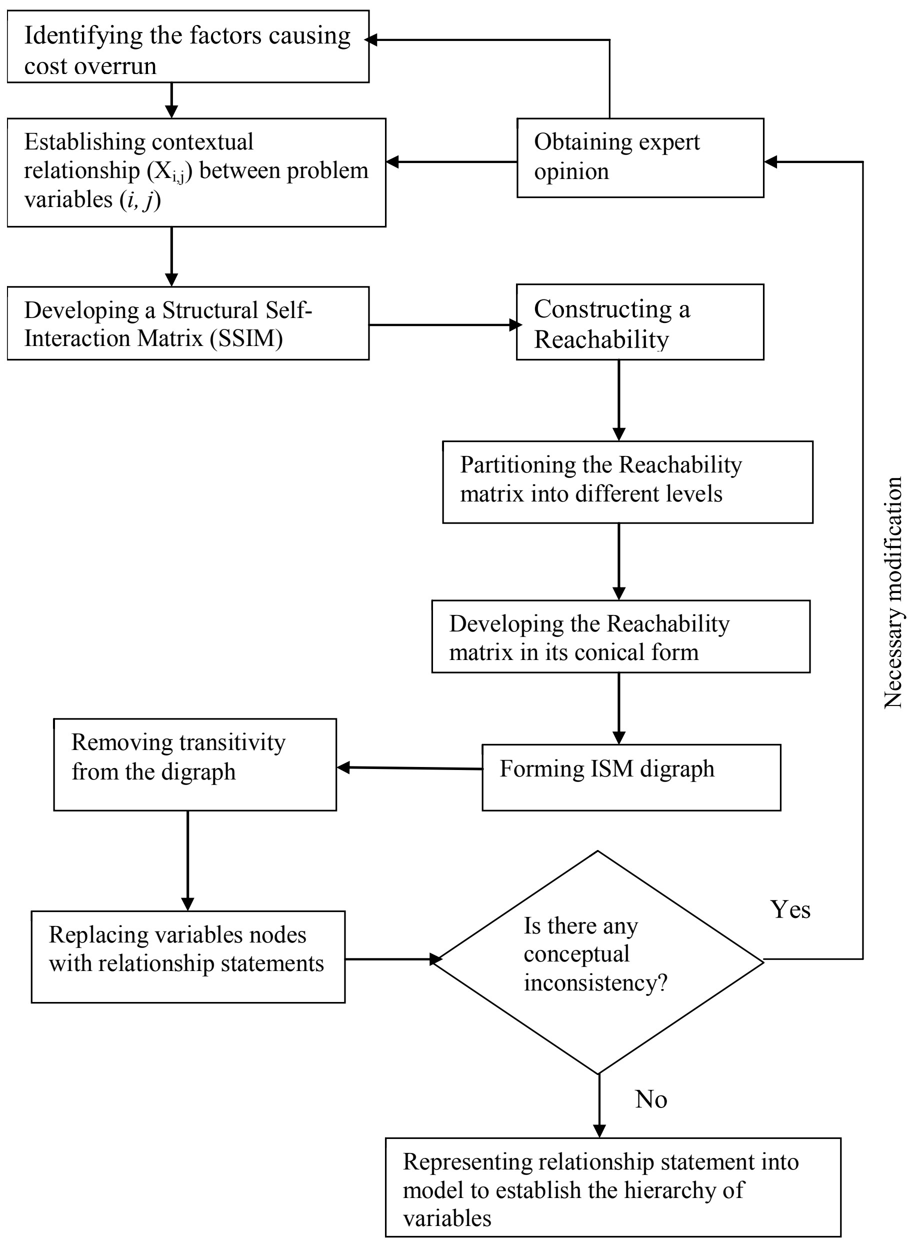

Figure 1. Flow diagram for developing ISM.

2.1.1 Instability of the US Dollar

Because Oman's currency is tied to the US dollar at a fixed exchange rate, it is common practice to use the US dollar as the primary currency in construction projects in Oman. Unfortunately, during the construction phase of the projects under consideration in the current study, the US dollar declined in value against other world currencies causing inflation; this resulted in a high turnover of staff and higher costs for staff wages, materials, and equipment. This can be attributed to the fact that materials and equipment were purchased from Europe and other foreign countries. Similarly, inflation forced experienced labourers to seek more attractive opportunities in construction and other fields.

2.1.2 Poor Cost Estimation

Many studies have identified poor cost estimation as one of the major causes of project cost overruns (Mansfield *et al*. 1994; Kaming *et al*. 1997; Le-Hoai *et al*. 2008). The initial cost of some projects under study was estimated using an analogy approach, one of the traditional estimation techniques. However, using only one estimation technique is limited in producing realistic estimates that become the basis of a project plan (Bashir 2008).

2.1.3 Changes in Governmental Regulations

Changes in governmental regulations are common external factors that affect the final cost of projects (Frimpong *et al*. 2003). During the execution phase of the projects considered in the current study, the Omani government introduced new customs regulations and procedures that caused changes in procurement and negatively impacted both costs and material delivery.

2.1.4 Increased Material Costs

During the current study, the prices of materials increased significantly during the construction phase for several reasons, including declines in the value of the US dollar, the imposition of new customs regulations and procedures, and procurement changes due to significant design changes.

2.1.5 Delays in Material Delivery

Since most of the construction materials and equipment required for the analyzed project were imported from overseas, their delivery times were negatively impacted by the new customs regulations and procedures introduced by the local government. The materials' delivery times were also negatively impacted by procurement changes which resulted from significant design changes during the construction phase.

2.1.6 Increased Wages

All the previously reviewed published research (Ogunlana and Promkuntong 1996; Kartam and Kartam 2001; Mansfield *et al*. 1994; Assaf *et al*. 1995; Ogunlana *et al*. 1996; Kaming *et al*. 1997; Odeh and Battaineh 2002; Frimpong, Oluwoye and Crawford 2003; Assaf and Al-Hejji 2006; Sambasivan and Soon 2007; Moura Teixeria and Pires 2007; Le-Hoai, Lee and Lee 2008; Azhar, Farooqui and Ahmed 2008; El-Sayegh 2008) have identified the increased wages as one of the risk factors in construction projects. During the execution phase of the projects under consideration in the current study, the industry in Oman experienced high staff turnover. Therefore, to attract new employees and retain existing ones, wages were substantially increased. In addition, the flourishing construction business contributed to a high demand for workers, which further pushed up their wages.

2.1.7 Increased Equipment Costs

Controlling costs has become a difficult task for construction equipment users in recent years. Along with the general upward trend in construction costs, including both materials and labor, construction equipment prices increased significantly during the current study's construction phase. Costs of mechanical equipment installed as part of the facility also increased by about 10%. Again, market volatility driven by the weakness of the US dollar has been a key driving force behind such cost increases. In addition, the equipment costs were affected by procurement changes.

2.1.8 Poor Communication within the Project Team

Proper communication among team members is crucial for the success of any project. However, projects examined in the current study were plagued by miscommunication among team members. This was mainly due to the fact that the project team members had different cultural backgrounds and work experience. The communication problem was compounded by the high staff turnover. Rework during the construction stage was one of the consequences of poor communication. Any problem with communication can lead to severe misunderstandings and, therefore, delays in the execution of a project (Sambasivan and Soon, 2007). Azhar *et al.* (2008) ranked the severity of the coordination within the project team as having a medium effect on the total cost of the project in Pakistani construction projects. Miscommunications between a project team's members were identified as one of the factors which led the project to time and cost overruns (Ogunlana and Promkuntong 1996; Kartam and Kartam 2001; Sambasivan Soon 2007).

2.1.9 Design Changes during the Construction Phase

Excessive design changes in the construction phase can cause significant disruption to a project and require changes in scheduling and procurement. In several projects, excessive change orders were issued as a result of poor communication among project stakeholders. Change orders were also identified by Creedy (2006) as one of the main causes of cost overrun in construction projects.

2.1.10 High Staff Turnover

Turnover, the rate at which a company gains and loses employees, can have a negative impact on project scheduling and costs. When a company loses employees, one or both of the following measures are usually taken: the working hours of current staff are extended or new employees are hired. The first measure may increase the stress on the remaining team members and lead to an increase in mistakes. As a result, the amount of rework may increase and the completion deadline may need to be extended. The second measure also causes schedule delays because it takes significant time to make new hires productive on a project as they are required to go through training programs (Bashir and Thomson 1999). According to (Schlesinger and Heskett 1991), the estimated cost of employee turnover for a company can reach up to 150% of employees' total remuneration.

At a typical project examined during the current study, cost overrun was compounded by the high turnover of project staff. This was mainly due to employee dissatisfaction with their compensation packages in light of the high inflation rates that had affected those regions and countries, including Oman, that tie their currencies to the US dollar.

2.1.11 Schedule Delays

Schedule delays are one of the most common problems in the construction industry worldwide. For instance, (Al-Khalil and Al-Ghafly 1999) reported that a high proportion (about 70%) of projects in Saudi Arabia experienced schedule delays. Another study in Saudi Arabia carried out by Assaf and Al-Hejji (2006) reported that 70% of experienced time overrun; their study also found that 45 out of 76 projects were delayed. According to (Faridi and Al-Sayegh 2006), 50% of construction projects in the United Arab Emirates (UAE) experience delays. In Malaysia, (Sambasivan and Soon 2007) reported that 17.3% of construction projects experience delays of more than three months. In addition to its negative impact on timely project delivery, project delays can cause cost overruns and disputes between project stakeholders. If not resolved, disputes can lead to arbitration and litigation.

The construction projects under study experienced a significant delay due to late material delivery, design changes during the construction phase, high staff turnover, procurement changes and poor communication among project stakeholders.

2.1.12 Procurement Changes

Procurement can be defined as the process used to acquire goods or services. It involves identifying the items to be procured, selecting suppliers, and contracting. According to several studies (Arditi *et al*. 1985; Mansfield *et al*. 1994; Ogunlana *et al*. 1996; Sweis 2008), procurement is critical to the successful completion of any project. Deficient procurement management and/or an excessive number of procurement changes can cause project delays and cost overruns.

During the construction phase of the projects in the current study, significant procurement changes had to be made due to new customs regulations and design changes; these, in turn, caused delays in material delivery and scheduling, and increases in material and equipment costs.

2.1.13 Poor Communication among Project Stakeholders

There is no doubt that proper communication among project stakeholders is crucial for a project's success. Consistent with the findings of (Sambasivan and Soon 2007), poor communication between the contractors, clients, and consultants for a project causes design changes during the construction phase and, subsequently, schedule delays.

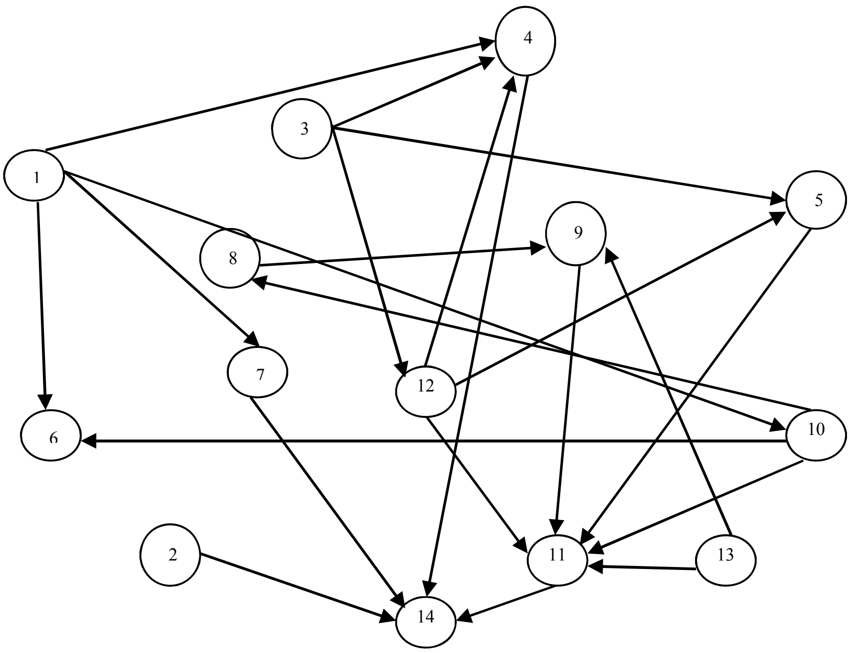

Figure 2. Digraph depicting the interrelationships among project cost overruns and causal factors.

2.2 Developing the Structural Self-Interaction Matrix (SSIM)

The interrelationships among the fourteen elements (project cost overrun and the above-mentioned thirteen causal factors) are represented in the diagram shown in Fig. 2, which represents the problem and its causal system. This could be further simplified and rearranged through a systematic methodology calling for converting the digraph into the structural self-interaction matrix (SSIM). The utility of the SSIM is that it can be used to develop a hierarchical restructuring of the diagraph. To develop this matrix, three symbols are used to denote the direction or influence of the relationship between factors *i* and *j*:

- F means that Factor *i* leads to Factor *j* (a forward relationship)
- B means that Factor *j* leads to Factor *i* (a backward relationship)
- N means that Factor *i* and Factor *j* are unrelated (no relationship).

Using the above-mentioned symbols, the SSIM for the project cost overrun is presented in Table 1.

Table 1. Structural self-interaction matrix (SSIM).

Factors	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1. Instability of the US dollar	N	N	N	N	F	N	N	F	F	N	F	N	N	
2. Poor cost estimation	F	N	N	N	N	N	N	N	N	N	N	N		
3. Changes in governmental regulations	N	N	F	N	N	N	N	N	N	F	F			
4. Increased material costs	F	N	B	N	N	N	N	N	N	N				

5. Delays in material delivery	N	N	B	F	N	N	N	N	N
6. Increased wages	F	N	N	N	B	N	N	N	
7. Increased equipment costs	F	N	B	N	N	N	N		
8. Poor communication within the project team	N	N	N	N	B	F			
9. Design changes during the construction phase	N	B	F	F	N				
10. High staff turnover	N	N	N	F					
11. Schedule delays	F	B	B						
12. Procurement changes	N	N							
13. Poor communication among project stakeholders	N								
14. Project cost overruns									

2.3 Constructing the Reachability Matrix

After development, the SSIM is transformed into a binary matrix—the initial reachability matrix—by substituting F, B, and N with 1 and 0. The rules for the substitution of ones and zeros are as follows:

- If the (*i*, *j*) entry in the SSIM is F, then the (*i*, *j*) entry in the reachability matrix becomes 1 and the (*j*, *i*) entry becomes 0.
- If the (*i*, *j*) entry in the SSIM is B, then the (*i*, *j*) entry in the reachability matrix becomes 0 and the (*j*, *i*) entry becomes 1.
- If the (*i*, *j*) entry in the SSIM is N, then the (*i*, *j*) entry in the reachability matrix becomes 0 and the (*j*, *i*) entry becomes 0.

Based on these rules, the initial reachability matrix is shown in Table 2. The final reachability matrix is then obtained by incorporating the transitivity links. That is, if element X is related to Y and Y is related to Z, then X is necessarily related to Z. The final reachability matrix, as well as the driving power and dependence level of each factor, are shown in Table 3. The driving power of a particular factor is the total number of factors which it may cause. The dependence level is the total number of factors which may contribute to causing it. For instance, Element 1 (instability of the US dollar) has the highest driving power, whereas Element 14 (project cost overrun) has the highest dependence level.

Table 2. Initial reachability matrix.

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Instability of the US dollar	1	0	0	1	0	1	1	0	0	1	0	0	0	0
2. Poor cost estimation	0	1	0	0	0	0	0	0	0	0	0	0	0	1
3. Changes in governmental regulations	0	0	1	1	1	0	0	0	0	0	0	1	0	0
4. Increased material costs	0	0	0	1	0	0	0	0	0	0	0	0	0	1

5. Delays in material delivery	0	0	0	0	1	0	0	0	0	0	1	0	0	0
6. Increased wages	0	0	0	0	0	1	0	0	0	0	0	0	0	1
7. Increased equipment costs	0	0	0	0	0	0	1	0	0	0	0	0	0	1
8. Poor communication within the project team	0	0	0	0	0	0	0	1	1	0	0	0	0	0
9. Design changes during the construction phase	0	0	0	0	0	0	0	0	1	0	1	1	0	0
10. High staff turnover	0	0	0	0	0	1	0	1	0	1	1	0	0	0
11. Schedule delays	0	0	0	0	0	0	0	0	0	0	1	0	0	1
12. Procurement changes	0	0	0	1	1	0	1	0	0	0	1	1	0	0
13. Poor communication among project stakeholders	0	0	0	0	0	0	0	0	1	0	1	0	1	0
14. Project cost overruns	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 3. Final Reachability Matrix.

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving Power
1. Instability of the US dollar	1	0	0	1	0	1	1	1	0	1	1	0	0	1	**8**
2. Poor cost estimation	0	1	0	0	0	0	0	0	0	0	0	0	0	1	**2**
3. Changes in governmental regulations	0	0	1	1	1	0	1	0	0	0	1	1	0	0	**6**
4. Increased material costs	0	0	0	1	0	0	0	0	0	0	0	0	0	1	**2**
5. Delays in material delivery	0	0	0	0	1	0	0	0	0	0	1	0	0	1	**3**
6. Increased wages	0	0	0	0	0	1	0	1	0	0	1	0	0	1	**4**
7. Increased equipment costs	0	0	0	0	0	0	1	0	0	0	0	0	0	1	**2**
8. Poor communication within the project team	0	0	0	0	0	0	0	1	1	0	1	1	0	0	**4**
9. Design changes during the construction phase	0	0	0	1	0	0	1	0	1	0	1	1	0	1	**6**
10. High staff turnover	0	0	0	0	0	1	0	1	1	1	1	1	0	1	**7**
11. Schedule delays	0	0	0	0	0	0	0	0	0	0	1	0	0	1	**2**
12. Procurement changes	0	0	0	1	1	0	1	0	0	0	1	1	0	1	**5**

13. Poor communication among project stakeholders	0	0	0	1	0	0	1	0	1	0	1	1	1	1	**7**
14. Project cost overruns	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Dependence Level	**1**	**1**	**1**	**6**	**3**	**3**	**6**	**4**	**4**	**2**	**10**	**6**	**1**	**12**	

2.4 Partitioning the Reachability Matrix

In this step, the final reachability matrix is partitioned by finding the reachability and antecedent sets for each element. The reachability set contains the element itself and other elements which it may cause, whereas the antecedent set contains the element and other elements which may cause it. Then, the intersection of the two sets is derived for all elements. The element(s) for which the antecedent set and intersection set are equal are placed at the bottom level in the ISM hierarchy. Once the bottom level elements are identified, they are separated from the rest of the elements. This process is repeated to find the next higher level of elements. The partitioning step is completed when the highest level of elements is reached. These identified levels are used to help build the digraph and final model. In the present case study, this process was accomplished in eight iterations. Tables 4 and 5 show the elements, along with their reachability sets, antecedent sets, and intersection sets and levels for the first two iterations.

In Table 4, elements 1 (instability of the US dollar), 2 (poor cost estimation), 3 (changes in governmental regulations) and 13 (poor communication among project stakeholders) are found at level I. Therefore, they are placed at the bottom level of the hierarchy in the ISM model.

After discarding elements 1, 2, 3, and 13 from Table 4 of the first iteration, element 5 (delays in material delivery) and element 10 (high staff turnover) are found at level II in the next iteration as shown in Table 5. Thus, they will be positioned at the second to bottom level of the hierarchy of the ISM model. The iteration process is repeated until the last (top) level is reached (level VII), which contains element 14 (project cost overruns) as shown in Table 6.

2.5 Formation of the ISM Diagram

Once the hierarchical levels of all factors and both direct and indirect interrelationships as determined from the reachability matrix and after including transitivity links are known, a preliminary model called a diagram is developed. The indirect links between the factors are removed to obtain the interpretive structural model.

3. Discussion

The aforementioned steps of ISM were applied to the cost overruns problem. A portrayal of the final ISM model is shown in Fig. 3, where the 13 factors are segregated in a hierarchy structure showing the sequence of cause and effect relationships among them. Clearly, the ISM model appears to be cohesive and easy to interpret, and proves that the project cost overrun is not a result of individual factors; rather, it is the net result of many interacting factors occurring in sequence or parallel.

The bottom level factors of the hierarchy (instability of the US dollar, poor cost estimation, changes in governmental regulations, and poor communication among project stakeholders) are the immediate causes of the problems of high staff turnover and delays in material delivery in the second highest level of the hierarchy structure. Subsequent factors in level II are causing the factors in level II and so on. As such, the factors at the bottom (level I) are the root cause of the cost overruns. By directing corrective measures at the root causes, the risk of problem recurrence is more likely to be minimized.

The result of the current study was compared with the findings of research in other developing countries as reported in the literature. The

Table 4. Iteration 1.

Element	Reachability Set	Antecedent Set	Interaction Set	Level
1	1,4,6,7,8, 10, 11,14	1	1	I
2	2,14	2	2	I
3	3,4,5,7,11,12	3	3	I
4	4,14	1,3,4,9,12,13	4	
5	5,11,14	3,5	5	
6	6,8, 11	1,6, 10	6	
7	7,14	1,3,7,9,12,13	7	
8	8,9,11,12	1,6,8,10	8	
9	4,7,9,11,12,14	8,9,10,13	9	
10	6, 8,9,10,11,12,14	1, 10	10	
11	11,14	1,3,5,6,8,9,10,11,12,13	11	
12	4,5, 7,11,12,14	3,8,9,10,12,13	12	
13	4,7,9,11,12,13,14	13	13	I
14	14	1,2,4,5,7,9,10,11,12,13,14	14	

Table 5. Iteration 2.

Element	Reachability Set	Antecedent Set	Interaction Set	Level
4	4,14	4,9,12	4	
5	5,11,14	5	5	II
6	6,8, 11	6, 10	6	
7	7,14	7,9,12	7	
8	8,9,11,12	6,8,10	8	
9	4, 5, 7,9,11,12,14	8,9,10	9	
10	6, 8,9,10,11,12,14	10	10	II
11	11,14	5,6,8,9,10,11,12	11	
12	4,7,11,12,14	8,9,10,12	12	
14	14	4,5,7,9,10,11,12,14	14	

Table 6. Iteration 8.

Element	Reachability set	Antecedent set	Interaction set	Level
14	14	14	14	VII

thirteen identified factors that cause cost escalations in construction projects in Oman are typical of similar projects in the UAE, Kuwait, Malaysia, Vietnam, Ghana, and others. Of note is that "Inflation and sudden change in prices" has been ranked the number one risk factor in Emirati construction projects (El-Sayegh 2008). In contrast, "Coordination with subcontractors" and "Quality of work" were among the highest risk factors in the Kuwaiti construction industry (Kartam and Kartam 2001). The findings of a major cost overrun risk study in China (Wang and Yuan 2011) ranked the "Crude cost estimation" to be number six among a group of 13 factors leading to cost overruns. Similarly, "Inaccurate estimation" was the most important risk factor in construction projects in Vietnam (Long *et al*. 2004). Furthermore, "Poor contract management" and "Inflation" were ranked number 2 and 4, respectively ,in studying cost overruns in construction of groundwater projects in developing countries (Frimpong *et al* 2003). "Information and communication" was ranked the second most severe contributor of cost overrun in construction in Malaysia (Abdul Azis 2013). In this study, the four factors found as the root causes of the cost overruns were in good agreement with previous studies which were conducted in similar developing countries.

On the other hand, factors were analysed according to their driving power and dependence level as shown in Table 3, where any entry of 1 along the rows indicates that that factor has a driving power in causing other factors while any entry of 1 along the columns indicates a dependence on other factors. Subsequently, a diagram for the driving power-dependence level was constructed (Fig. 4). Based on the values in Table 3, one can observe that factor 1 has a driving power of 8 and a dependence level of 1. Therefore, in Fig. 4, the value is positioned in a location corresponding to a driving power of 8 and dependence level of 1. As such, these elements are classified into four clusters according to the levels of driving power and dependence (Fig. 4). The first cluster (I) consists of autonomous factors, which have both a weak driving power and dependence level. These factors are relatively disconnected from the system, and have only a few links that may be considered strong. The second cluster (II) consists of the dependent factors that have weak driving power but a strong dependence level. The third cluster (III) has linkage factors with both a strong driving power and dependence level. These factors are unstable because any actions taken on them will affect others. The fourth cluster (IV) includes independent factors that have strong driving power (an ability to influence other elements), but a weak dependence level (slightly influenced by other elements). A factor with a very strong driving power is called the key element, and falls into the category of independent or linkage factors. Factor 1, instability of the US dollar; factor 3, changes in governmental regulations; factor 9, design changes during the construction phase; factor 10, high staff turnover, and factor 13, poor coordination among the project parties, fall into the independent category, requiring greater intervention to minimize their effect.

4. Conclusions

In assessment of effective solutions for the cost overrun problem, it is necessary to identify the root causes. This can be achieved by identifying and modeling the complex relations among the causal factors. For this purpose, the current study proposes to use ISM, which is characterized by its ability to simplify a complex set of interrelated variables into a simple structural model. The ISM was applied to develop a model for factors that caused costs to escalate for construction projects carried out in Oman. Thirteen factors causing project cost overruns and their interrelationships were determined using an expert opinion approach. Then, interactions among these factors were organized by the ISM procedure into a simple yet very easy to interpret hierarchy structure consisting of seven levels. The bottom level factors—two external and two internal factors—were the root causes of the cost overrun problem in the current study. The two external factors are the instability of the US dollar and changes in governmental regulations. The two internal factors are faulty cost estimation and poor coordination among the project parties. To better control future projects' costs, remedies for these causes should be the first focus of attention.

The conclusion drawn from the ISM model provided several important implications for project managers and can be used in case studies to deal with similar problems in future projects. Specifically,

- Managers can better deal with the instability of the US dollar—an external factor —by adopting a hedging policy that mitigates risks in foreign currency exchanges when multiple currencies are used in procurement and budgeting.
- The effects of changes in governmental regulations can be minimized by setting aside contingency funds during the planning stage. These funds should be retained to pay for mandatory and optional modifications initiated by the owner or the contractor after the contract has been awarded.
  A more accurate cost estimate process could be achieved by using an analogy approach in combination with cost estimate techniques such as parametric methods (Bashir 2008).
- Coordination between parties could be enhanced by adopting quality function deployment (QFD) procedures during the planning phase, a common approach in the manufacturing industry that has also found its way into the construction industry (Dissanayaka *et al*. 2007).
- Careful attention should be given to developing a transparent and mutually-beneficial relationship between the owner and the contractor that enables the scope of

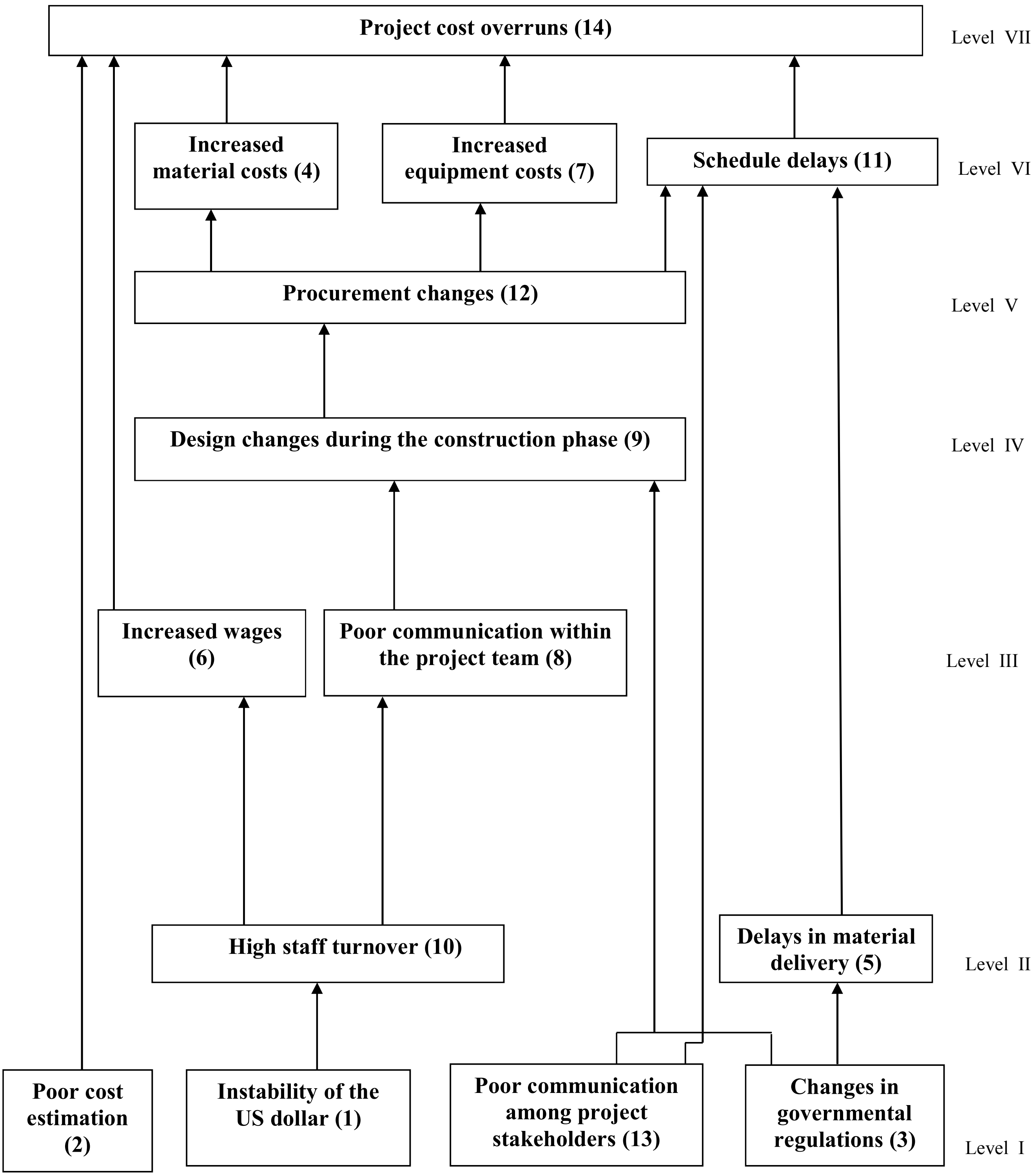

Figure 3. ISM-based model for the cost overrun problem.

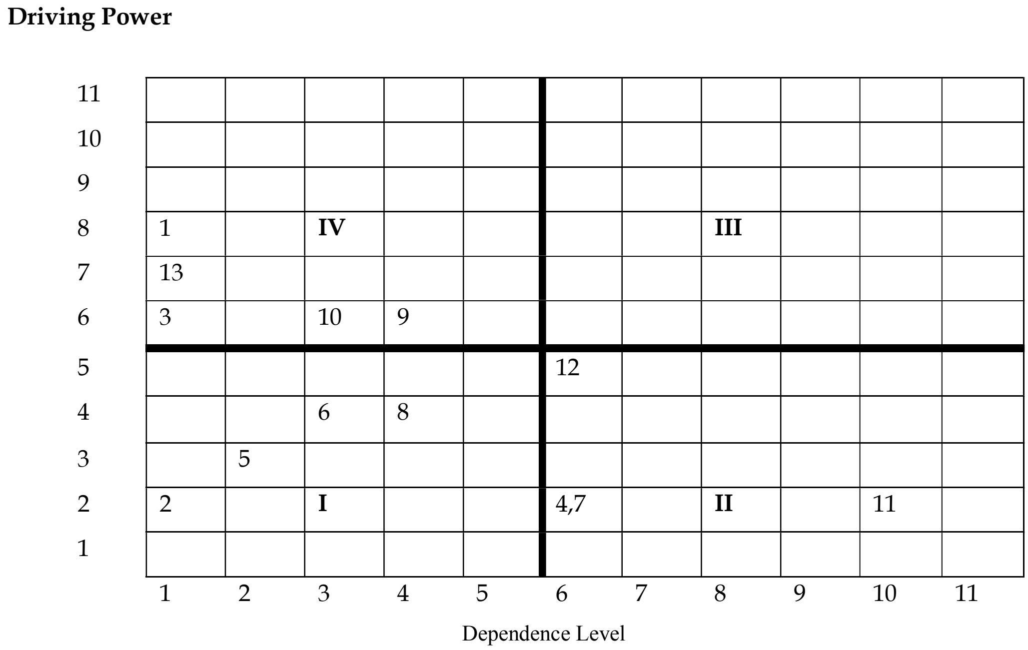

Figure 4. Driving power and dependence level diagram.

the work and plan execution to be successful. This would enable a high degree of cooperation and a team spirit to develop between project participants.

As current research has found ISM to be effective in identifying and modeling the complex interrelationships among factors causing project cost overruns, the methodology should be extended to other industries. However, the ISM methodology may have some limitations, even though it has demonstrated itself to be highly reliable and practical. One drawback is that it relies on experts' opinions, limiting the use of sensitivity analysis. Moreover, implementing the ISM manually tends to be rather time consuming. This could be addressed by putting the entire system into a computer application.

References

Abdul Azis A, Memon A, Abdul Rahman I, Karim A (2013), Controlling cost overrun factor in construction projects in Malaysia. Research Journal of Applied Sciences and Technology 5(8), 2621–2629.

Ali AS, Kamaruzzaman SN (2010), Cost performance for building construction projects in Klang Valley. Journal of Building Performance 1(1), 110–118.

Al-Khalil MI, Al-Ghafly MA (1999), Delay in public utility projects in Saudi Arabia. International Journal of Project Management. 17(2), 101–106.

Ansari M, Kharb RK, Luthra S, Shimmi SL, Chatterji S (2013), Analysis of barriers to implement solar power installations using interpretive structural modelling technique. Renewable and Sustainable Energy Reviews 27:163–174.

Arditi D, Akan GT, Gurdamar S (1985), Reasons for delays in public projects in Turkey. Construction Management and Economics 3(2):171–181.

Assaf SA, Al-Hejji S (2006), Causes of delay in large construction projects. International Journal of Project Management 24:349–357.

Azhar N, Farooqui RU, Ahmed SM (2008), Cost overrun factors in construction industry of Pakistan, in Proceedings of the First International Conference on Construction in Developing Countries. Karachi, Pakistan, August 4–5.

Bashir HA (2008), Modelling of development time for hydroelectric generators using factor and multiple regression analyses. International Journal of Project Management 26(4):457–464.

Bashir HA (2010), Removal of redundant relationships in an AON project network for evaluating schedule complexity. Journal of Construction Engineering and Management 136(7):787–793.

Bashir HA, Thomson V (1999), Metrics for design projects: A review. Design Studies 20(3):263–277.

Bolanos R, Fontela E, Nenclares A, Paster P (2005), Using interpretive structural modeling in strategic decision making groups. Management Decision 43:877–895.

Brand Jr. DH, Irwin DM, Kawamura K (1976), Implementation of interpretive structural modelling in a state-level planning context, in Proceedings of the Seventh Annual Conference on Modelling and Simulation, Pittsburgh, Pennsylvania, USA, April 26–27.

Creedy GD. (2006), Risk factors leading to cost overrun in highway construction projects, in Sidwell, A.C. (ed) Proceedings of Queensland University of Technology Research Week International Conference, Brisbane, Australia. Unpublished doctoral dissertation, Queensland University of Technology, Australia, July 4–8.

Dissanayaka SM, Delgado-Hernandez DJ, Bampton KE, Anspinwall E (2007), Quality function deployment in construction. Construction Management and Economics 25(6):597–609.

El-Sayegh S (2008), Risk assessment and allocation in the UAE construction industry. International Journal of Project Management 26(4):431–438.

Enshassi A, Al-Najjar J, Kumaraswamy M (2009), Delays and cost overruns in the construction projects in the Gaza Strip. Journal of Financial Management of Property and Construction 14(2):126–151.

Fairdi A, El-Sayegh SM (2006), Significant factors causing delay in the UAE construction industry. Contraction Management and Economics 24(11):1167–1176.

Farooquie P, Khan J (2007), An interpretive structural model for project planning and success, in IEEE International Conference on Industrial Engineering and Engineering Management, Singapore, December 2–5, 1022–1026.

Flyvbjerg B, Skamris Holm MK, Buhl SL (2004), What causes cost overrun in transport infrastructure projects? Transport Reviews 24(1):3–18.

Flyvbjerg B, Skamris Holm, MK, Buhl SL (2003), How common and how large are cost overruns in transport infrastructure projects? Transport Reviews 23(1):71–88.

Frimpong Y, Oluwoye J, Crawford L (2003), Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. International Journal of Project Management 21(5):321–326.

Govindan K, Palaniappan M, Zhu Q, Kannan D (2012), Analysis of third party reverse logistics provider using interpretive structural modelling. International Journal of Production Economics 140:204–211.

Hasan MA, Shankar R, Sarkis J (2007), A study of barriers to agile manufacturing International. Journal of Agile Systems and Management 2:1–22.

Hawthorne RW, Sage AP (1975), On applications of interpretive structural modelling to higher education program planning. Socio-Economic Planning Sciences 9(1)31–43.

Iyer K, Sagheer M (2010), Hierarchical structuring of PPP risks using interpretative structural modeling. Journal of Construction Engineering and Management 136(2):151–159.

Kaliba C, Muya M, Mumba K (2009), Cost escalation and schedule delays in road construction projects in Zambia. International Journal of Project Management 27(5):522–531.

Kaming P, Olomolaiye P, Holt G, Harris F (1997), Factors influencing construction time and cost overruns on high-rise projects in Indonesia. Construction Management and Economics 15(1):83–94.

Kartam N, Kartam S (2001), Risk and its managements in the Kuwaiti construction industry: a contractors' perspective. International Journal of Project Management 19(6):325–335.

Kawamura K, Christakis AN (1976), The role of structural modelling in technology assessment, in Proceedings of the Second International Congress on Technology Assessment, Ann Arbour, USA, October.

Koushki PA, Al-Rashid, K, Kartam N (2005), Delays and cost increases in the construction of private residential projects in Kuwait. Construction Management and Economics 23(3):285–294.

Le-Hoai LY, Lee, D, Lee JY (2008), Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. KSCE Journal of Civil Engineering 12(6):367–377.

Long ND, Ogunlana SO, Quang T, Lam KC (2004), Large construction projects in developing countries: A case study from Vietnam. International Journal of Project Management 22(7):553–561.

Mandal A, Deshmukh SG (1994), Vender selection using interpretive structural modelling. International Journal of Operations & Production Management 14(6): 52–60.

Mansfield NR, Ugwa OO, Doran T (1994), Causes of delay and cost overrun in Nigerian construction projects International Journal of Project Management 12(4):254–260.

Mathiyazhagan K, Govindan K, Noorul Haq A, Geng Y (2013), An ISM approach for the barrier analysis in implementing green supply chain management. Journal of Cleaner Production 47(2):283–297.

Ogunlana S, Promkuntong K, Jearkjirm V (1996), Construction delays in a fast growing economy: Comparing Thailand with other economies. International Journal of Project Management 14(1):37–45.

Ravi V, Shankar R (2005), Analysis of interactions among the barriers of reverse logistics. Technological Forecasting and Social Change 72(9):1011–1029.

Rawlinson JG (1986), Creative thinking and brainstorming. Surrey, United Kingdom: Ashgate.

Sage AP (1979), Methodology for Large-scale Systems. New York: McGraw-Hill.

Sahney S, Banwet DK, Karunes S (2010), Quality framework in education through application of interpretive structural modeling: An administrative staff perspective in the Indian context. The TQM Journal 22: 56–71.

Sambasivan M, Soon YW (2007), Causes and effects of delays in Malaysian construction industry. International Journal of Project Management 25(5):517–526.

Schlesinger LA, Heskett J (1991), Breaking the cycle of failure in services. MIT Sloan Management Review 33(3):17–28.

Shankar C, Transue M, Felder FA (2011), Analysis of barriers to development in landfill communities using interpretive structural modelling. Habitat International 35:246–253.

Sharma HD, Gupta AD, Sushil PV (1995), The objectives of waste management in India: A future inquiry. Technological Forecasting and Social Change 48(3):285–309.

Singh MD, Shankar R, Narain R, Agarwal A (2003), An interpretive structural modelling of knowledge management in engineering industries. Journal of Advanced Research in Management 1(1):28–40.

Sweis G, Sweis R, Abu Hammad A, Shboul A (2008), Delays in construction projects: The case of Jordan. International Journal of Project Management 26(6):665–674.

Talib F, Rahman Z, Qureshi MN (2011), Analysis of interaction among the barriers to total quality management implementation using interpretive structural modeling approach. Benchmarking: An International Journal 18:563–587.

Wang G, Wang Y, Zhao T (2008), Analysis of interactions among the barriers to energy saving in China. Energy Policy 36(6):1879–1889.

Wang JY, Yuan HP (2011), Major cost-overrun risks in construction projects in China. International Journal of Project Organization and Management 3(4):226–242.

Warfield JW (1974), Developing interconnected matrices in structural modelling. IEEE Transactions on Systems, Man, and Cybernetics 4(1):51–81.