Modeling and Analyzing of Delay Factors in Public R&D Projects Using an Integrated ISM-Fuzzy MICMAC Approach

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Abstract

Numerous studies have investigated factors causing delays in projects of different types. However, there is a lack of studies investigating this issue in the context of public research and development (R&D) projects. To fill this gap, this study utilized an approach that integrates interpretive structural modelling (ISM) and fuzzy cross-impact matrix multiplication (MICMAC) analysis to model and analyze factors causing delay in public R&D projects in the context of the United Arab Emirates (UAE). In addition to modeling 17 identified interrelated delay factors by a simple hierarchical graphical model, hidden work activities, low experience/qualification project manager, new technology development, scope underestimation, poor cost estimation, technological complexity, and change orders have been identified as the key factors causing delays in public R&D projects. The findings of this study could be of value to project managers in public organizations that are carrying out R&D projects in the UAE and other nations with similar environments, such as the Gulf Cooperation Council countries.

Keywords
R&D, interrelated activities, project delay, interpretive structural modeling and Fuzzy MICMAC.

1. Introduction
Ensuring the success of their projects is vital for project-oriented organizations to enhance their competitiveness. This need is also applicable to public R&D organizations due to the large amount of public money invested in the projects. Because of its importance, the success of a project is among the most frequently discussed topics in the project management literature. Despite their limitations in measuring the success of complex projects with multiple different objectives such as public R&D projects (Bashir et al. 2019; Ojiako et al. 2019; Toor and Ogunlana 2010), the three most common essential criteria for assessing the success of any project are the completion time relative to a predetermined schedule, the cost incurred relative to an allocated budget, and the quality of the outcome. However, the literature has reported that project delay is a common problem of all types of projects. For instance, Faridi and El-Sayegh (2006) revealed that half of the construction projects in the United Arab Emirates (UAE) suffer from delays. Calvo et al. (2016) indicated that between 2011 and 2016, forty-two percent of public projects in the United States were behind schedule, amounting to 17,325 years in delay time—or over-budgeted—adding $7.55 billion in cost overruns. Because of the nature of R&D projects that require mental activity and the absence of easily identifiable items to measure, the problem of delays in research and development projects (R&D) is more severe compared to those of other types of projects (Bashir 2000). For instance, Kumar and Thakkar (2017) reported that a public R&D project in India, which was initially planned for 7 years, took 12 years to complete. An R&D project is defined by OECD (2015) as "the sum of actions deliberately undertaken by R&D performers in order to generate new knowledge."

Several studies have reported on the significant consequences of project delays. For instance, Sambasivan and Soon (2007) found that failure to achieve completion within the estimated time resulted in a variety of unexpected negative effects on the projects, such as cost overruns. Haseeb et al. (2011) pointed out that for an owner, a delay meant a loss of income and the unavailability of facilities. For a contractor, a delay meant a financial loss as a result of extra expenses for materials and equipment, as well as labor costs and a loss of time. Kikwasi (2012) identified the effects of construction project delays as being disputes, idling resources, overruns in cost and time, and negative social impacts James et al. (2014) studied the causes and effects of delay on project delivery time. They found that delays may result in the spending of more money, which could lead to an increase in final project costs, as well as to the wastage and underutilization of manpower and resources.

A literature review showed that there have been extensive studies investigating factors contributing to delays across different types of projects in different countries. In contrast, there have been only two studies that addressed this issue in the context of R&D projects; Tohumcu and Karasakal (2010) and Kumar and Thakkar (2017). Tohumcu and Karasakal (2010) investigated schedule deviation in public R&D institutes in Turkey. The results showed that the project delays mainly occurred due to handover of the final deliveries of the documents or prototypes, the low quality of subcontractors, rework and corrections, procurement of licenses, test failures and repetitions, and design immaturity. Kumar and Thakkar (2017) analyzed the impact of 10 economic and 11 technological factors on cost and schedule overruns in a public R&D project in India using an analytic network process and system dynamics. Accordingly, three technological factors (design changes, hidden activities, and the absence of expertise) and three economic factors (conflicts, project delays, and unforeseen incidents) were identified as the key factors.

Because factors that delay projects are not isolated events but are both directly and indirectly interrelated (Alzebdeh et al. 2015; Bashir et al. 2020a; Kumar and Thakkar 2017), this study utilized an approach that integrates interpretive structural modelling (ISM) with fuzzy cross-impact matrix multiplication (MICMAC) analysis to model and analyze factors causing delays in public R&D projects in the context of the UAE, an issue which has been scarcely addressed in the literature.

2. The Study

As shown in Figure 1, using the ISM-Fuzzy MICMAC approach involved two phases. Initially, ISM was utilized to obtain the hierarchal representation of the factors and their interrelationships. The second phase utilized fuzzy MICMAC analysis to categorize the factors in terms of their criticality based on their dependence power and driving power.

ISM is a technique that was widely used in the literature to transform a complex structure comprising interrelated variables into a simple hierarchical structure (Warfield 1974). The applications of this technique in the field of project management include modeling of interdependencies in project portfolios (Al Zaabi and Bashir 2019), modeling factors causing cost overruns in construction projects (Alzebdeh et al. 2015), and scheduling interrelated project activities (Bashir et al. 2020b). Duperrin and Godet (1937) developed cross-impact matrix multiplication (MICMAC) analysis (MICMAC) to classify variables in terms of their criticality based on their driving power and dependence power. The classical version of MICMAC analysis utilizes only a binary representation of an association. To overcome this limitation, several studies have applied, a fuzzy version of MICMAC with ISM or social networks in different research areas. For instance, in the field of project management, fuzzy MICMAC has been integrated with social networks to model and analyze factors affecting project delays (Bashir et al. 2020a) and to model and analyze interdependencies in project portfolios (Al Zaabi and Bashir 2000).

2.1 ISM

The primary purpose of this phase was to construct a hierarchical graphical model that represents the relationships among the factors. First, a panel of experts was formed, consisting of four R&D project managers in a governmental organization in the UAE. Utilizing the literature review and in consultation with the members of the expert panel in a brainstorming session, the following list of 17 delay factors was identified:

1. Poor communication skills
2. Design/scope changes
3. Hidden work activities
4. Low experience/qualification project manager
5. New technology development
6. Prerequisite availability
7. Rework
8. Scope underestimation
9. Work pressure
10. Poor cost estimation
11. Technological complexity
12. External risks
13. Change orders
14. Slow/poor decision making
15. Ineffective/poor planning and scheduling
16. Project complexity
17. Lack of room for creativity

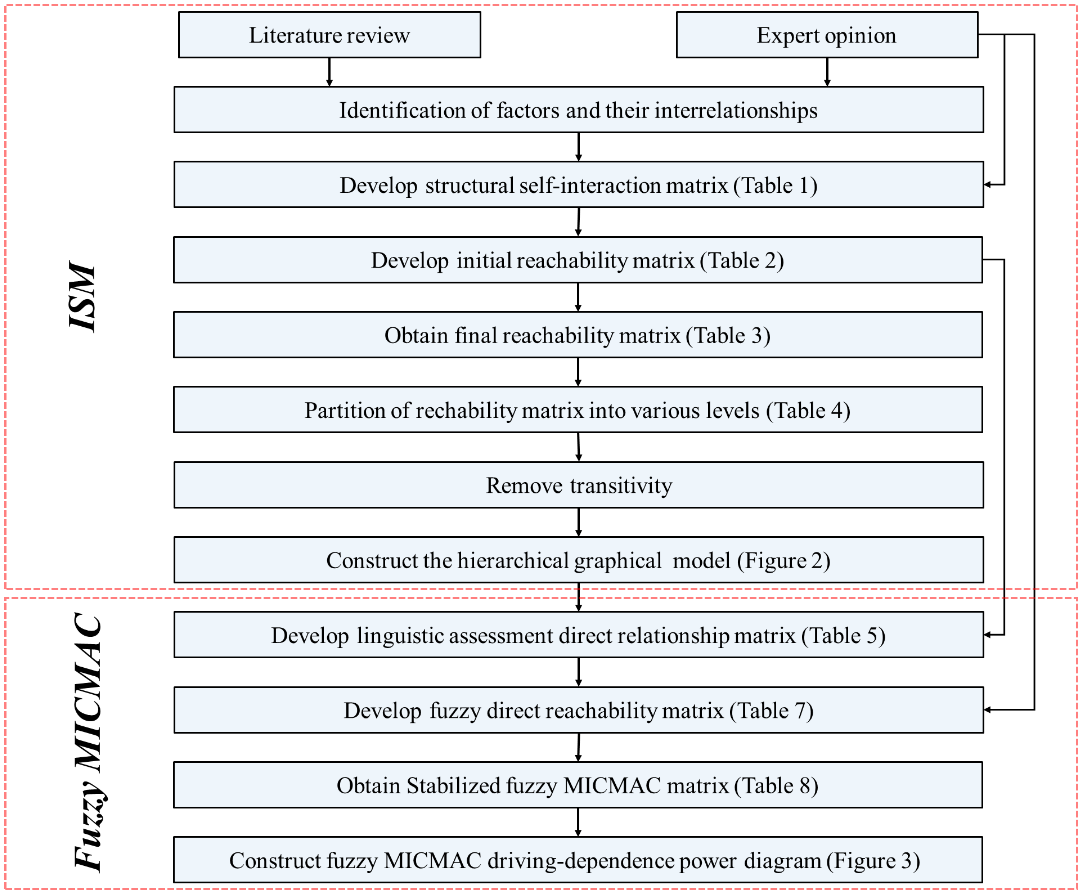

Figure 1. Flow chart of the integrated ISM-fuzzy MICMAC approach (Bhosale and Kant 2016)

The expert panel has conducted another brainstorming session in which a structural self-interaction matrix (SSIM) was created to identify the relationship among the identified factors. As shown in Table 1, this matrix uses four symbols to illustrate the associations between factors *i* and *j* (Jawad and Bashir 2015):

- "V means that factor *i* leads to factor *j* (a forward relationship).
- A means that factor *j* leads to factor *i* (a backward relationship).
- X means that factor *i* leads to factor *j*, and factor *j* leads to factor *i* (a mutual relationship).
- 0 means that factor i and factor j are unrelated (no relationship)."

After that, the initial reachability matrix (Table 2) was obtained by converting the SSIM to an $n \times n$ matrix, where n represents the number of delay factors identified "by substituting the four symbols (V, A, X, or O) with 1s and 0s". The rules for the substitution are the following:

- "If the (i, j) entry in the SSIM is V, 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 A, 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 X, then the (i, j) entry in the reachability matrix becomes 1, and the (j, i) entry becomes 1;
- If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0, and the (j, i) entry becomes 0" (Jawad and Bashir 2015).

The final reachability matrix shown in Table 3 was then created from the initial reachability matrix by utilizing the "transitivity" principle. The transitivity principle could be explained as follows: if factor *i* affects factor *j*, and factor *j* affects factor *k*, then factor *i* affects factor *k*. Incorporating transitivity was obtained by multiplying the initial reachability matrix by itself until it was stabilized (Kim 1982).

Table 1. Structural self-interaction matrix

Factor	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	O	O	O	V	O	O	O	O	A	O	O	O	O	O	O	O
2	O	O	O	O	A	O	O	A	O	O	V	O	O	O	O	
3	O	O	V	O	O	O	O	O	V	O	O	O	O	O		
4	O	O	O	V	O	O	A	O	O	V	O	O	O			
5	O	O	O	O	O	O	V	O	O	O	O	O				
6	O	O	A	O	O	O	O	O	O	O	O					
7	O	O	O	A	O	O	O	O	X	O						
8	O	O	O	O	O	O	O	V	O							
9	V	O	O	V	O	O	O	O								
10	O	O	O	O	V	A	A									
11	O	V	O	O	O	O										
12	O	O	O	O	O											
13	O	O	O	O												
14	O	O	O													
15	O	O														
16	O															

Table 2. Initial reachability matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0
4	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0
5	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
9	1	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1
10	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
11	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
13	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
14	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
15	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 3. Final reachability matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
2	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
3	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**
4	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**
5	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**
6	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
7	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
8	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**
9	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
10	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**
11	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**
12	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**1**
13	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**
14	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**
15	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**
16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
17	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**

The next step was to determine each factor's level in the hierarchical model as follows: the "reachability set" and "antecedent set" for each factor were attained from the final reachability matrix. The reachability set of factor *i* is the set of factors reachable from factor *i*, while the antecedent set of factor *i* is the set of factors that reaches factor *i*. After that, the intersection between the reachability set and the antecedent set was derived for all factors. For a factor in which the antecedent set and intersection set are the same, that factor was considered the bottom or the lowest level in the ISM hierarchy. When all the bottom-level factors were determined, they were excluded from the next iteration of the process. The same procedure was used to find the next level factors. This process was continued until reaching the top-level in the ISM hierarchy. The identified level of each of the 14 factors is shown in Table 4. Accordingly, and after removing transitivity, the hierarchical graphical model which provides visualization to the interactions among the delay factors was constructed, as illustrated in Figure 2. As shown in this figure, the constructed ISM model consists of nine levels. The lowest level of the model comprises hidden work activities, new technology development, and external risks. In contrast, the highest level comprises only one factor, namely the lack of room for creativity. It is essential to point out that the constructed ISM model confirms that the problem project delays is not a result of solitary effects. Instead, it is an accumulative result of many actions taking place in parallel or sequence. Accordingly, for any improvements desired in minimalizing the risk of project delays, a comprehensive plan needs to be implemented considering both the direct and indirect associations among the delay factors.

Table 4. Level partition of the final reachability matrix

Factor	Reachability set	Antecedent set	Level
1	1, 7 ,9 , 14, 17	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14	**8**
2	1, 2, 7, 9, 14, 17	2, 4, 5, 8, 10, 11, 12, 13, 14	**7**
3	1, 3, 6, 7, 9, 14, 17	3	**1**
4	1, 2, 4, 7, 8, 9, 10, 13, 14, 17	4, 5, 11	**3**
5	1, 2, 4, 5, 7, 8, 9, 10, 11, 13, 14, 16, 17	5	**1**
6	6	3, 6, 15	**3**
7	1, 7, 9, 14, 17	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14	**8**
8	1, 2, 7, 8, 9, 10, 13, 14, 17	4, 5, 8, 11	**4**
9	1, 7, 9, 14, 17	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14	**8**
10	1, 2, 7, 9, 10, 13, 14, 17	4, 5, 8, 10, 11, 12	**5**
11	1, 2, 4, 7, 8, 9, 10, 11, 13, 14, 16, 17	5, 11	**2**
12	1, 2, 7, 9, 10, 12, 13, 14, 17	12	**1**
13	1, 2, 7, 9, 13, 14, 17	4, 5, 8, 10, 11, 12, 13	**6**
14	1, 7, 9, 14, 17	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14	**8**
15	6, 15	3, 15	**2**
16	16	5, 11, 16	**3**
17	17	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 17	**9**

2.2 Fuzzy MICMAC

In this phase, the linguistic assessment of the direct relationships among the factors was carried out by the expert panel in another brainstorming session using the following linguistic variables: very low influence (VL), Low influence (L), medium influence (M), high influence (H), and very high influence (VH). Accordingly, the linguistic assessment direct reachability matrix was obtained (Table 5). The scales of these linguistic variables are given in Table 6. After the linguistic assessment was carried out, defuzzification of the fuzzy numbers of the triangle membership function "$\mu_{\bar{A}}(x)$" (Bhosale and Kant 2016), defined by equation (1), was implemented to develop the fuzzy direct relationship matrix that Table 7 shows. The defuzzified value of a fuzzy number that is termed the best non-fuzzy performance (BNP) was obtained using equation (2).

$$\mu_{\bar{A}}(x) = \begin{bmatrix} 0 & x < l \\ \frac{x-l}{m-l} & l \le x \le m \\ \frac{r-x}{r-m} & m \le x \le r \\ 0 & x > r \end{bmatrix} \tag{1}$$

Where $l < m < r$, and $l, m \; and \; r$ denote the x coordinates of $\mu_{\bar{A}}(x)$.

$$BNP_{ij} = \frac{[(r-l)+(m-l)]}{3} + l \tag{2}$$

Where ij indicates the crisp rating of the relationship strength between factors i and j.

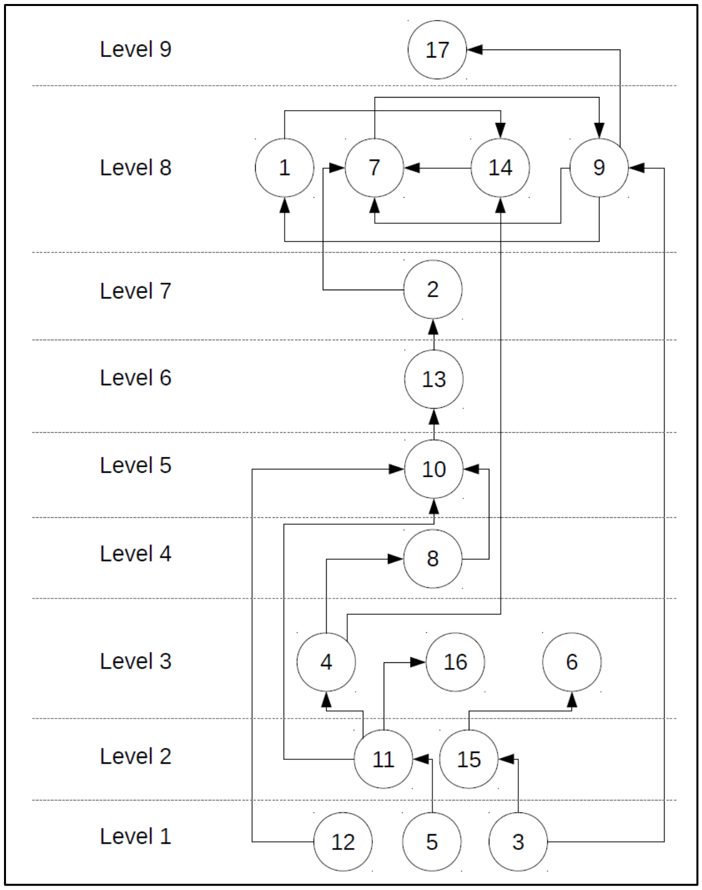

Figure 2. ISM hierarchical graphical model

Table 5. Linguistic assessment direct reachability matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	0	0	0	0	0	0	0	0	0	0	0	0	M	0	0	0
2	0	0	0	0	0	0	M	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	M	0	0	0	0	0	H	0	0
4	0	0	0	0	0	0	0	H	0	0	0	0	0	H	0	0	0
5	0	0	0	0	0	0	0	0	0	0	M	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	H	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	H	0	0	0	0	0	0	0
9	L	0	0	0	0	0	L	0	0	0	0	0	0	M	0	0	H
10	0	M	0	0	0	0	0	0	0	0	0	0	M	0	0	0	0
11	0	0	0	L	0	0	0	0	0	M	0	0	0	0	0	M	0
12	0	0	0	0	0	0	0	0	0	L	0	0	0	0	0	0	0
13	0	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	H	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	M	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. Fuzzy linguistic scale

Linguistic variable	Triangular fuzzy number
Very low influence (VL)	(0, 0.1, 0.3)
Low influence (L)	(0.1, 0.3, 0.5)
Medium influence (M)	(0.3, 0.5, 0.7)
High influence (H)	(0.5, 0.7, 0.9)
Very high influence (VH)	(0.7, 0.9, 1)

Table 7. Fuzzy direct relationship matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0
2	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.7	0	0
4	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0.7	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0
9	0.3	0	0	0	0	0	0.3	0	0	0	0	0	0	0.5	0	0	0.7
10	0	0.5	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0
11	0	0	0	0.3	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0
12	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0
13	0	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

After that, the fuzzy direct relationship matrix was multiplied by itself repeatedly until the matrix stabilized, and hence, to obtain the stabilized fuzzy MICMAC matrix, as illustrated in Table 8. Then, the driving power and the dependence power for each factor was calculated from this matrix. The driving power of a factor was computed by the summation of all the values of the row of the factor in the matrix. In contrast, the dependence power was calculated by the summation of all the values of the column of the factor in the matrix. A driving-dependence power diagram was then constructed to categorize the factors in terms of their criticality. As shown in Figure 3, this diagram classifies the factors into four groups:

I. Autonomous factors which have low dependence power and low driving power;
II. Dependent factors which have high dependence power but low driving power;
III. Linkage factors which have high driving power and high dependence power; and
IV. Independent or driver factors which have low dependence power but high driving power.

Autonomous factors are the least critical factors, whereas independent or driver factors are the most critical ones (key delay factors). According to Figure 3, the key factors causing delays in public R&D projects are hidden work activities, low experience/qualification of project managers, new technology development, scope underestimation, technological complexity, and change orders. Notably, these factors, namely hidden work activities, low experience/qualification of project managers, and change orders, were also identified by Kumar and Thakkar (2017) as key factors.

- Hidden work activities: the sudden appearance of such activities can disturb the entire project schedule, which leads to demand resources that would be allocated for other planned activities, and hence, contributes massively to the delay of the project (Kumar and Thakkar 2017).
- Low experience/qualification of project managers: the inherent nature of R&D projects, especially the dynamic scope of work, the continuous need for modification, and the resulting complexity controlling it needs an experienced and qualified project manager (Pillai and Rao 1996).
- New technology development: the time needed to develop new technologies usually expands in an increasing, non-linear pattern. Not addressing this risk properly will increase the project delay (Larson and Gray 2018).
- Scope underestimation: this is a typical delay factor in projects in general. For instance, Gobeli and Larson (1990) conducted a study that included more than 1400 project managers. The results suggested that around half of the planning problems are related to unclear definitions and underestimation of the project scope.
- Poor cost estimation: the poor cost estimation could be understood as a poor judgment of how much budget a project might cost or could be related to budget constraints, and hence, delays occurred to rectify on those initial estimations (Unger et al. 2004).
- Technological complexity: the risk associated with R&D projects that require developing advanced technologies is high, and the higher management usually are not in total control of those risks (Arbogast and Womer 1988).
- Change orders: the change order process, and especially their approval process, takes long time by the management of public R&D projects.

Table 8. Stabilized fuzzy MICMAC matrix

Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Driving power
1	0	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0.5	0	0	0.5	2
2	0.3	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0.5	0	0	0.5	2.3
3	0.3	0	0	0	0	0.5	0.5	0	0.5	0	0	0	0	0.5	0.7	0	0.5	3.5
4	0.3	0.5	0	0	0	0	0.7	0.7	0.7	0.7	0	0	0.5	0.7	0	0	0.7	5.5
5	0.3	0.5	0	0.3	0	0	0.5	0.3	0.5	0.5	0.5	0	0.5	0.5	0	0.5	0.5	5.4
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.3	0	0	0	0	0	0	0	0.7	0	0	0	0	0.5	0	0	0.7	2.2
8	0.3	0.5	0	0	0	0	0.5	0	0.5	0.7	0	0	0.5	0.5	0	0	0.5	4
9	0.3	0	0	0	0	0	0.5	0	0	0	0	0	0	0.5	0	0	0.7	2
10	0.3	0.5	0	0	0	0	0.5	0	0.5	0	0	0	0.5	0.5	0	0	0.5	3.3
11	0.3	0.5	0	0.3	0	0	0.5	0.3	0.5	0.5	0	0	0.5	0.5	0	0.5	0.5	4.9
12	0.3	0.3	0	0	0	0	0.3	0	0.3	0.3	0	0	0.3	0.3	0	0	0.3	2.4
13	0.3	0.7	0	0	0	0	0.5	0	0.5	0	0	0	0	0.5	0	0	0.5	3
14	0.3	0	0	0	0	0	0.7	0	0.7	0	0	0	0	0	0	0	0.7	2.4
15	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0.5
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dep. Power	3.6	3.5	0	0.6	0	1	6.2	1.3	6.4	2.7	0.5	0	2.8	6	0.7	1	7.1	

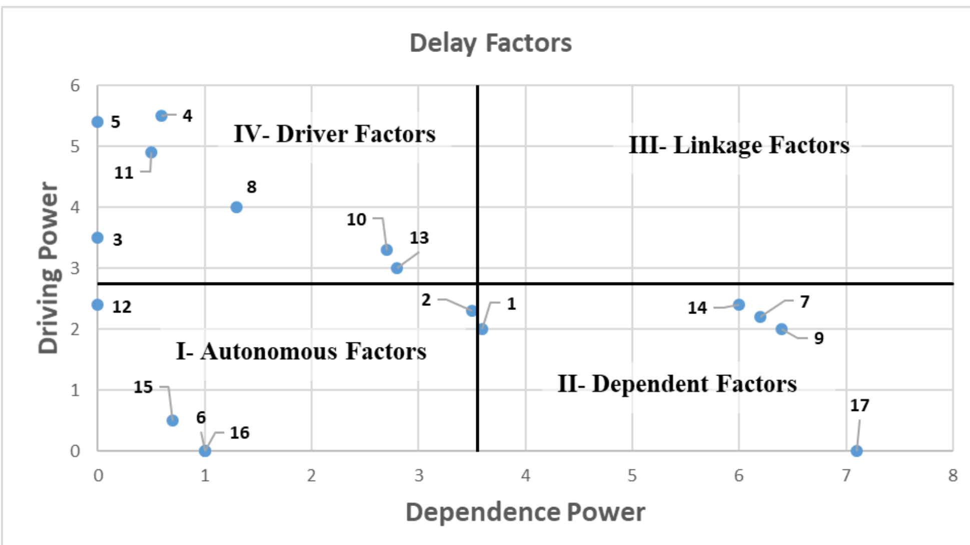

Figure 3. Fuzzy MICMAC driving-dependence power diagram

3. Conclusion

In this study, delay factors in public R&D projects were modeled and analyzed in the context of the UAE using an integrated ISM-Fuzzy MICMAC technique. The implementation of the approach comprised two phases. In the first phase, ISM was utilized in modelling 17 identified delay factors by a hierarchy consisting of nine levels. These factors were poor communication skills, design/scope changes, hidden work activities, low experience/qualification project manager, new technology development, prerequisite availability, rework, scope underestimation, work pressure, poor cost estimation, technological complexity, external risk, change orders (and their approvals), slow/poor decision making, ineffective/poor planning and scheduling, project complexity, lack of room for creativity. Because they are located at the bottom of the model, hidden work activities, new technology development, and external risks can be considered as the root causes of project delays. Therefore, any actions for mitigating risks for project delay without considering these three factors could be a futile effort. In the following phase, fuzzy MICMAC analysis was utilized to classify the factors in terms of their criticality. Accordingly, hidden work activities, low experience/qualification project manager, new technology development, scope underestimation, poor cost estimation, technological complexity, and change orders are the key delay factors. Because they are also located at the bottom of the ISM hierarchy, hidden work activities and new technology development should be given the highest intention to minimize the risk of project delays.

Finally, one main limitation of the findings of this study was that they were based on data collected from one organization. Therefore, future research might undertake a cross-organizational or cross-national study, taking into consideration that factors causing delays could vary considerably not only also across countries but also across organizations within the same country. Another possible future study is to conduct a comprison between delay factors in public versus private R&D projects.

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