DEMATEL-based model to improve the performance in a matrix organization

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ABSTRACT

Carrying out a design project for a high-tech facility requires a large amount of special knowledge in order to deal with the specific requirements from the client. Often the client forms a matrix organization, structured with several interrelated functional and project divisions to dictate the various requirements and needs. However, an ill-defined matrix organization is likely to result in late and inadequate decisions. This in turn may result in a poorly performing design. Identifying those divisions within the organization that perform poorly in the way they provide information for the project is critical. Therefore, this study proposes an innovative model to identify those divisions that may be responsible for the poor performance of the design project. The proposed model integrates the satisfied importance analysis (SIA) and the decision making trial and evaluation laboratory technique (DEMATEL). The SIA evaluates the performance of each division, while the DEMATEL captures the causal relationships among divisions to generate an influence-relations map. The proposed model is applied to a real-world high-tech facility design project in Taiwan to demonstrate the strengths of the model.

1. Introduction

Carrying out a design project for a high-tech facility requires a large amount of special knowledge in order to deal with the specific requirements from the client. Thus, the client must allocate the necessary staff to review all the specification requirements and user needs so that the project architect/engineer can design the project.

Many researchers as well as project managers/engineers/architects have long recognized that the way a construction project is organized will have a significant impact on the successful completion of the project (Thomas, Keating, & Bluedorn, 1983). Prior to the design and construction of semiconductor facility projects, the assigned staff members are often organized in a project task forces, or core teams, guiding the project from the design stage to start-up (Allen, 2000). Sometimes, a project client may form a matrix organization structured with several interrelated functional and project divisions to support the project when its complexity is high and the size of the project is large in scope. However, a matrix organization structured with ill-defined authorities/responsibilities for the various managers is very likely to result in late and inadequate decisions. As a result, the design is unlikely to be completed in time or in accordance with the required specifications.

Efficient design management in ensuring the smooth running of a project is being increasingly appreciated (Austin, Baldwin, Li, & Waskett, 2000; Bogus, Molenaar, & Diekmann, 2005; Chua, Tyagi, Ling, & Bok, 2003; Karniel & Reich, 2009; Luh, Liu, & Moser, 1999; Sanvido & Norton, 1994; Senthilkumar, Varghese, & Chandran, 2010; Wang & Dzeng, 2005; Wang, Liu, & Liao, 2006). Those divisions within a company that are responsible for the poor client input into the project (such as late and ambiguous decisions regarding requirements/needs) must be identified. This will allow the client to rectify the situation so that delays can be eliminated or, at least be minimized. Nevertheless, identifying the cause-effect relationships among many divisions and sections is difficult since their relationships are interrelated.

This study proposes an innovative model to identify the divisions responsible for the poor performance of the design project. The core of the model combines the satisfied importance analysis (SIA) with the decision making trial and evaluation laboratory technique (DEMATEL). This DEMATEL-based model is then applied to the real-world design project of a high-tech facility in Taiwan.

The remainder of this paper is organized as follows. Section 2 reviews the latest related studies. Section 3 introduces the steps in the proposed model, while Section 4 elucidates the background of the case project. Section 5 presents the details of the proposed model with reference to a case study. Section 6 discusses the application results. Finally, in Section 7 we draw our conclusions, and offer recommendations for future research.

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2. Literature review

The client in the design and the construction of a new facility, often must make two types of decisions related to organizational structure. The first one is to determine which type of contractors (e.g., architect/engineer, consultants, project management, civil/structure/architect contractor, and mechanical/electrical/plumbing contractor) should be involved in the project and the contractual relationships between these participants. The organization structure is usually decided based on the project management approach adopted, such as the traditional design/bid/build, professional construction management, or turnkey operations (Hendrickson & Au, 2003). In the first type of decision, for example, Cheng, Su, and You (2003) applied a model to investigate various alternative ways of coordination among the participants in a construction project. They defined a total resistance index to evaluate the coordination efficiencies of each alternative organization in order to identify the optimal structure for the project.

The second type of decision is to determine whom or what group of people from the client should oversee the project. That is, should a functional, a matrix, or a project-oriented organization be applied? For instance, in a functional organization, the project is fully controlled by various functional divisions of the organization. In a project-oriented organization, the project manager takes full control and responsibility of the project. There are many variations of management style between these three organizational forms, depending on the objectives of the client's organization and the nature of the project (Thomas et al., 1983).

A few researchers have discussed the second type of decision. For example, Thomas et al. (1983) described different organizational forms of project management and outlined the principles to guide the organization in establishing their authority and responsibility. They suggested guidelines to improve the chances for success in the matrix organization. Different goals and situations result in unique organizational requirements for each project. Thus, Tatum and Fawcett (1986) outlined a logical process for structuring an organization by presenting seven criteria that managers can use to evaluate their organizational requirements for the engineering and construction of a project. Tatum (1986) applied his expanded view of organizational structure to arrive at a systematic design for the organizational structure for a specific project.

The present study is more related to the second type of decision, which is focused on the organizational structure of the project client itself. To date however, there is scant literature available on identifying the key divisions of a client's organization as an efficient strategy for improving a design.

3. Proposed model

Fig. 1 presents the steps of the proposed model to identify the divisions and sub-divisions of a client's organization that are responsible for the poor performance in a design project. The steps in the model are as follows.

Step 1: Define the organizational divisions and sections of a client that affect the performance of the design project.
Step 2: Use the "satisfied importance analysis (SIA)" to evaluate the degree of importance and the degree of satisfaction with each division. A division that results in poor performance is considered to be unsatisfactory.
Step 3: Apply the DEMATEL technique to construct a cause-effect impact-relations map (IRM) for the different divisions.
Step 4: Integrate the SIA and DEMATEL. The SIA specifies those divisions that are most responsible for the poor performance of the design project, and the DEMATEL traces these divisions.
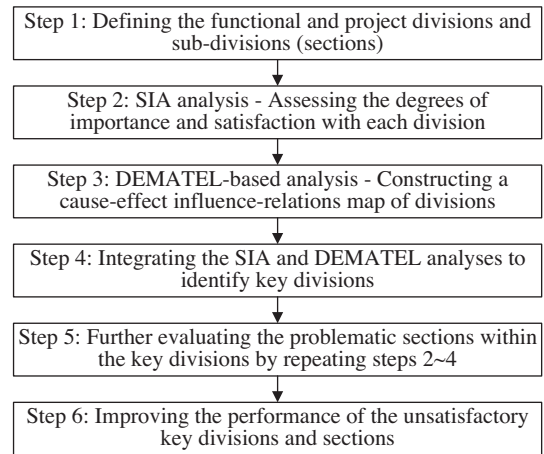

Fig. 1. Steps of the proposed model.

Step 5: Further evaluation of the problematic sections within these key divisions is carried out by repeating steps 2–4.
Step 6: Improve the performance of these unsatisfactory key divisions and sections.

4. Case project

This case project involves the design and construction of a high-tech facility for a national research center (i.e., the project client) located in northern Taiwan. The case project is comprised of three main components; (1) civil and building construction (Civil); (2) mechanical, electrical and plumbing (MEP) works; and (3) special equipment construction (SPE). Designing SPE requires particular domain knowledge, such as synchrotron accelerators and resistance against micro-vibrations. The total floor area of the facility is approximately 53,000 m^2. The total budget for both the design and construction was approximately USD 229.3 million.

At the beginning of the design phase of the project (called design project hereafter), the project client went through several discussions with several consultants on how to structure the organization of the group that to manage this design project. In the end, the client set up a matrix organization because the project size was too large (insufficient staff available to form a project-based organization) and the required expertise too diverse (involving too many functional divisions). Fig. 2 shows the client's matrix organization for managing this design project, including seven first-level divisions (three functional divisions and four project divisions) and 10 second-level sub-divisions (called "sections").

It should be noted that the design of the Civil and the MEP phases of this project was contracted out to an architect, and that the construction management (CM) division of the project client managed the architect. In addition, the aforementioned SPE was designed by both the acceleration design & operations (AD) and the acceleration engineering (AE) divisions.

Unfortunately, as the design project progressed, the design was significantly delayed and the design was unable to meet the needs of the user. One of the main reasons for this delay was due to the fact that the client made several decisions that came too late, and the fact that they made frequent changes. As a result, the relationship between the different divisions and sections of the client was very tense when it came to the question of responsibility. Since all these divisions and sections were interrelated it was hard for top management to determine the cause and effect relationships among them, making it nearly impossible to take the appropriate corrective action. It was at that time that we began to implement our proposed model to help identify the divisions/sections that
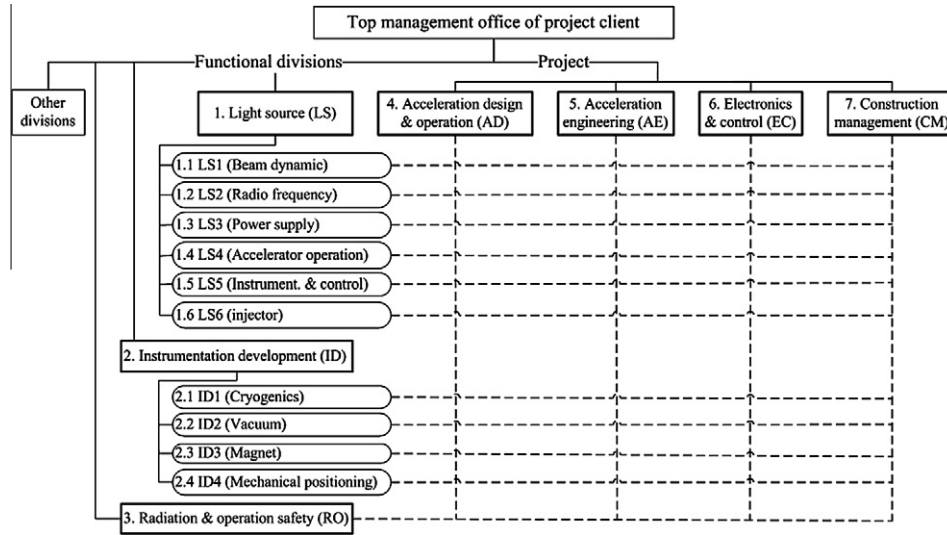
Fig. 2. The matrix organization of the client for managing the case project.

were problematic and to suggest guidelines that hopefully would prevent any further poor performance.

5. Applying the proposed model to the case project

This section will first present the required input data for conducting SIA and DEMATEL analyses, and then the analyses will be discussed in detail.

5.1. Collection of the input data

The required input data for performing the SIA and DEMATEL were obtained using two questionnaires. Thirty-five experts (including engineers and division/section managers that were involved in this case project) were asked to fill out each questionnaire. Table 1 shows an example of the questionnaire for conducting the SIA. Table 1 also shows the degree of importance and the degree of satisfaction using a scale ranging from 10 (highest importance or satisfaction) to 0 (lowest importance or satisfaction).

Table 1
Example of questionnaire for executing the SIA.

Divisions/sections	Degree of importance	Degree of satisfaction
1. LS	7.7	5.2
1.1 LS1	10	8
1.2 LS2	8	6
1.3 LS3	7	4
1.4 LS4	2	1
1.5 LS5	9	7
1.6 LS6	10	5
2. ID	7.8	7.5
2.1 ID1	8	7
2.2 ID2	8	9
2.3 ID3	8	8
2.4 ID4	7	6
3. RO	10	8
4. AD	10	8
5. AE	9	7
6. EC	9	6
7. CM	9	7

Note: Degrees of importance and satisfaction range between 10 (highest importance or satisfaction) and 0 (lowest importance or satisfaction).

Table 2 presents an example of the questionnaire for conducting the DEMATEL. Each respondent was asked to evaluate the impact (i.e., the degree of controlling the decision-making process and the resource allocations) of a division on each of the other divisions using an integer scale (from 0 to 4). Table 2 shows that if division i (AE) has a weak direct influence on division j (LS), then a score of "1" is given to represent this weak influence. Conversely, if the AD division has a strong direct influence on the CM division, a score of "3" is assigned. A high score represents the belief that an improvement in the CM division depends strongly on an improvement in the AD division.

Cronbach's α (SAS, 2007) was applied to test the reliability of the data collected from the questionnaires in this case project. The test results revealed that the questionnaires used in the SIA and DEMATEL analyses are reliable (since α exceeds 0.7) (see Table 3).

5.2. Evaluation of the SIA

The SIA method is based on the importance-performance analysis proposed by Martilla and James (1977). In the SIA, the input data (degree of satisfaction and degree of importance of each division/section) collected from the questionnaires are normalized to a single measuring scale. Eqs. (1) and (2) yield the initial degree of satisfaction (IDS) and the standardized satisfaction value (SS). The number of respondents in the case study was 35

$$\text{IDS} = \frac{\text{Sum of the degrees of satisfaction from all respondents}}{\text{Number of respondents}},$$
(1)

$$\text{SS} = \frac{(\text{IDS-Average of the initial degrees of satisfaction in all divisions})}{\text{Standard deviation of the initial degrees of satisfaction in all divisions}}.$$
(2)

Eqs. (3) and (4) calculate the initial degree of importance (IDI) and the standardized importance value (SI)

$$\text{IDI} = \frac{\text{Sum of the degrees of importance from all respondents}}{\text{Number of respondents}},$$
(3)

$$\text{SI} = \frac{(\text{IDI-Average of the initial degrees of importance in all divisions})}{\text{Standard deviation of the initial degrees of importance in all divisions}}.$$
(4)

Table 2
Example of questionnaire for performing the DEMATEL.

Division j / Division i	1. LS	2. ID	3. RO	4. AD	5. AE	6. EC	7. CM
1. LS							
2. ID							
3. RO							
4. AD							3
5. AE	1						
6. EC							
7. CM							

Note: 0: no influence; 1: weak direct influence; 2: moderate direct influence; 3: strong direct influence; 4: very strong direct influence.

Note: 0: no influence; 1: weak direct influence; 2: moderate direct influence; 3: strong direct influence; 4: very strong direct influence.

Table 3
Reliability tests for the questionnaires.

Tests	Cronbach's alpha	Results
In SIA analysis:		
Data on the degree of importance	0.9225	High
Data on the degree of satisfaction	0.9520	High
In DEMATEL analysis:		
Data on first-level divisions	0.9838	High
Data on the second-level sections of the LS division	0.9843	High
Data on the second-level sections of the ID division	0.9584	High

Table 4 shows the evaluations made using SIA in the case study. The evaluations are classified under the following four categories (SS, SI):

(1) ○ (+,+): a division with high satisfaction and high importance. This category is labeled as "keep up the good work".
(2) • (+,−): a division with high satisfaction and low importance. A division in this category requires no further improvement. However, it is likely that the resources invested here may be better diverted elsewhere.
(3) ▼ (−,−): a division with low satisfaction and low importance. This category is labeled as "low priority".
(4) ×(−,+): a division with low satisfaction and high importance. This category is labeled as "concentrate here", indicating that the division requires urgent corrective actions.

In this case study, only the AE division (acceleration engineering) nearly falls in the fourth category. That is, the AE division is

Table 4
Degrees of satisfaction and importance of the first-level divisions.

Divisions	Degree of satisfaction		Degree of importance		(SS, SI)
	Initial value	SS	Initial value	SI	
1. LS	6.790	−1.218	8.200	−0.970	▼(−,−)
2. ID	7.179	0.243	8.200	−0.970	•(+,−)
3. RO	7.057	−0.214	8.286	−0.799	▼(−,−)
4. AD	7.571	1.722	9.514	1.654	○(+,+)
5. AE	7.114	0.001	9.029	0.685	○(+,+)
6. EC	7.257	0.539	8.943	0.513	○(+,+)
7. CM	6.829	−1.074	8.629	−0.114	▼(−,−)

considered to be highly important, but is providing a low degree of satisfaction. Therefore, the AE division should be improved immediately. Fig. 3 shows the results of the SIA evaluation. Divisions (including the LS, RO and CM divisions) that are in the third quadrant are easily identified as requiring improvement, but as having a low priority.

5.3. Evaluation of the DEMATEL

In the proposed model, the end product of the DEMATEL process is an influence-relations map (IRM) that is a visual representation of the interdependencies of the divisions within the organization. The Battelle Memorial Institute of Geneva developed the DEMATEL method for a Science and Human Affairs Program to solve complex and interrelated problems (Gabus & Fontela, 1973; Li, 2009; Lin & Tzeng, 2009). The DEMATEL method enables management to solve problems visually and to isolate the related variables (e.g., divisions or sections) into cause and effect groups in order to improve the understanding of the causal relationships among these variables (Li, 2009). This method has been employed in numerous fields, including the assessment of the structure of a software
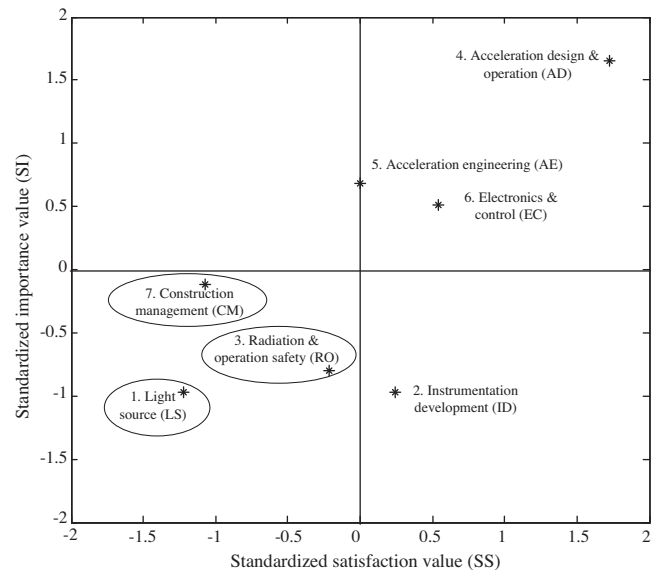

Fig. 3. SIA analysis of the first-level divisions.

system design for supervisory control systems (Hori & Shimizu, 1999), the reprioritization of failures in a system failure mode (Seyed-Hosseini, Safaei, & Asgharpour, 2006), the development of competencies of global managers (Wu & Lee, 2007), the evaluation of the performance of e-learning programs (Tzeng, Chiang, & Li, 2007), the reconfiguration of policy portfolios in the field of semiconductor intellectual property (Huang, Shyu, & Tzeng, 2007), the evaluation of airline safety (Liou, Tzeng, & Chang, 2007), the assessment of the interrelated ranking criteria in the ranking problem of a real estate agent service quality (Tseng, 2009), and the evaluation of value-creating industrial clusters in a science park (Lin & Tzeng, 2009).

The steps in the DEMATEL method are as follows (Lin & Tzeng, 2009); (1) Step D1 – find the average matrix, (2) step D2 – calculate the direct influence matrix, (3) step D3 – calculate the indirect influence matrix, (4) step D4 – derive the total influence matrix, and (5) step D5 – obtain the influence-relations map.

5.3.1. Step D1: Finding the average matrix

Suppose h experts are available to solve a complex problem with n organization divisions being considered. The scores assigned by each expert yield an $n \times n$ non-negative answer matrix X^k, with $1 \leqslant k \leqslant h$. Hence, $X^1, X^2, \ldots, X^h$ are the resulting matrices for each of the h experts, and each element of X^k is an integer, denoted as x_{ij}^k. The diagonal elements of each resulting matrix X^k are all set to zero. The $n \times n$ average matrix A can then be computed by averaging the h experts' value (or score) matrices. The (i,j) element of the average matrix A is denoted as a_{ij} (the average influence),

$$a_{ij} = \frac{1}{h} \sum_{k=1}^{h} x_{ij}^k. \tag{5}$$

Table 5 presents an initial average matrix A of the divisions in the case project. The value of h in Eq. (5) is 35 (35 respondents). For example, the initial average value of the effect of the AE division on the CM division (AE → CM) is calculated to be 2.086, indicating a medium direct influence (since 4.0 is the highest value).

5.3.2. Step D2: Calculating the direct influence matrix

A direct influence matrix D is obtained by normalizing the average matrix A. That is,

$$D = sA, \tag{6}$$

where s is a constant, which is calculated as follows (Tzeng et al., 2007);

$$s = Min \left[\frac{1}{\max_{1 \leqslant i \leqslant n} \sum_{j=1}^{n} |a_{ij}|}, \frac{1}{\max_{1 \leqslant j \leqslant n} \sum_{i=1}^{n} |a_{ij}|} \right], \quad i,j = 1, 2, \ldots, n. \tag{7}$$

In Table 5, the sum of the fourth row is the maximum value (11.943) of $\max_{1 \leqslant i \leqslant n} \sum_{j=1}^{n} |a_{ij}|$ and $\max_{1 \leqslant j \leqslant n} \sum_{i=1}^{n} |a_{ij}|$. Thus, the value of s equals $1/11.943$. Then, based on Eq. (6) and the values of the

Table 6
Direct influence matrix D of the divisions.

Divisions	1. LS	2. ID	3. RO	4. AD	5. AE	6. EC	7. CM	Sum
1. LS	0	0.139	0.103	0.196	0.141	0.191	0.100	0.871
2. ID	0.129	0	0.096	0.141	0.215	0.132	0.127	0.840
3. RO	0.124	0.115	0	0.132	0.132	0.124	0.151	0.778
4. AD	0.191	0.175	0.129	0	0.179	0.177	0.148	<u>1.000</u>
5. AE	0.141	0.222	0.105	0.153	0	0.139	<u>0.175</u>	0.935
6. EC	0.165	0.136	0.110	0.151	0.139	0	0.079	0.780
7. CM	0.077	0.120	0.115	0.098	0.148	0.089	0	0.646
Sum	0.828	0.907	0.658	0.871	0.955	0.852	0.780	

average matrix A (Table 5), a direct influence matrix D is obtained and presented in Table 6. For example, the value of the direct influence AE → CM is calculated to be approximately 0.175(=2.086/11.946).

Let us suppose that the (i,j) element of matrix D (denoted as d_{ij}) is the direct influence by division i on division j. Then, $\lim_{n \to \infty} D^m = [0]_{n \times n}$, where $D = [d_{ij}]_{n \times n}$ (Goodman, 1988). In addition, $0 < \sum_{j=1}^{n} d_{ij}, \sum_{i=1}^{n} d_{ij} \leqslant 1$, and the sum of only one row or column equals one.

5.3.3. Step D3: Calculating the indirect influence matrix

The indirect influence of division i on division j declines as the power of the matrix increases, as in $D^2, D^3, \ldots, D^\infty$ (Lin & Tzeng, 2009). This fact guarantees convergent solutions to the matrix inversion, similar to an absorbing Markov chain matrix. The indirect influence matrix ID can be obtained from the values in the direct influence matrix D. That is,

$$ID = D^2 + D^3 + \cdots = \sum_{i=2}^{\infty} D^i = D^2(I - D)^{-1}, \tag{8}$$

where I is the identity matrix. Table 7 shows the calculated indirect influence matrix ID of the divisions in the case project, using the calculation functions from MATLAB (2009).

5.3.4. Step D4: Deriving the total influence matrix

The total influence matrix T is also an $n \times n$ matrix, and is given by Li (2009),

$$T = D + ID = D + D^2 + D^3 + \cdots = \sum_{i=1}^{\infty} D^i = D(I - D)^{-1}. \tag{9}$$

Let t_{ij} be the (i,j) element of matrix T; the sum of the ith row and the sum of the jth column, d_i and r_j, respectively, are obtained as follows:

$$d_i = \sum_{i=1}^{n} t_{ij} \quad (i = 1, 2, 3 \ldots, n), \tag{10}$$

$$r_j = \sum_{j=1}^{n} t_{ij} \quad (j = 1, 2, 3 \ldots, n). \tag{11}$$

Table 5
Initial average matrix A of the divisions.

Divisions	1. LS	2. ID	3. RO	4. AD	5. AE	6. EC	7. CM	Sum
1. LS	0	1.657	1.229	2.343	1.686	2.286	1.200	10.400
2. ID	1.543	0	1.143	1.686	2.571	1.571	1.514	10.029
3. RO	1.486	1.371	0	1.571	1.571	1.486	1.800	9.286
4. AD	2.286	2.086	1.543	0	2.143	2.114	1.771	<u>11.943</u>
5. AE	1.686	2.657	1.257	1.829	0	1.657	<u>2.086</u>	11.171
6. EC	1.971	1.629	1.314	1.800	1.657	0	0.943	9.314
7. CM	0.914	1.429	1.371	1.171	1.771	1.057	0	7.714
Sum	9.886	10.829	7.857	10.400	11.400	10.171	9.314	11.943

Table 7
Indirect influence matrix **ID** of the divisions.

Divisions	1. LS	2. ID	3. RO	4. AD	5. AE	6. EC	7. CM	Sum
1. LS	0.678	0.721	0.535	0.674	0.746	0.664	0.625	4.643
2. ID	0.636	0.715	0.518	0.662	0.703	0.652	0.602	4.487
3. RO	0.584	0.642	0.484	0.609	0.663	0.598	0.546	4.126
4. AD	0.723	0.797	0.592	0.787	0.826	0.746	0.689	5.158
5. AE	0.687	0.734	0.560	0.715	0.804	0.705	0.641	4.846
6. EC	0.593	0.654	0.484	0.623	0.678	0.631	0.573	4.237
7. CM	0.506	0.547	0.401	0.523	0.560	0.515	0.484	3.534
Sum	4.407	4.810	3.574	4.592	4.979	4.511	4.159	

Table 8
Total influence matrix **T** of the divisions.

Divisions	1. LS	2. ID	3. RO	4. AD	5. AE	6. EC	7. CM	Sum (d)
1. LS	0.678	0.859	0.638	0.870	0.888	0.855	0.725	5.514
2. ID	0.765	0.715	0.613	0.803	0.918	0.783	0.728	5.327
3. RO	0.708	0.757	0.484	0.740	0.795	0.723	0.697	4.904
4. AD	0.914	0.972	0.721	0.787	1.005	0.923	0.837	6.158
5. AE	0.828	0.957	0.665	0.868	0.804	0.844	0.816	5.781
6. EC	0.758	0.791	0.594	0.774	0.817	0.631	0.652	5.017
7. CM	0.582	0.666	0.515	0.621	0.708	0.604	0.484	4.180
Sum (r)	5.234	5.717	4.232	5.463	5.934	5.363	4.939	

Here d_i represents the sum of the direct and indirect influences of division i on the other divisions, and r_j denotes the sum of the direct and indirect influences on division j by the other divisions. Table 8 presents the total influence matrix obtained using Eq. (9). The table also provides the values of d_i and r_j.

When $j = i$, $d_i + r_i$ is an index of the strength of the influences by and on a division, and is a measure of the importance of that division. The term $d_i - r_i$ (also called "Relation") disaggregates the divisions into a "cause group" and an "affected group". If $d_i - r_i$ is positive, then division i influences other divisions more than it is influenced by them, and thus it belongs to the cause group. Conversely, if $d_i - r_i$ is negative, then division i is influenced by more divisions than it influences and thus it belongs to the affected group (Liou et al., 2007; Tzeng et al., 2007). Table 9 shows the values of $d_i + r_i$ and $d_i - r_i$ for each division. The results demonstrate that the values of $d_i - r_i$ are positive for the LS, RO and AD divisions, which therefore fall into the cause group. In general, if management wishes to improve the divisions that belong to the affected group, then they must take great care to also control the cause group divisions.

5.3.5. Step D5: Obtaining the influence-relations map (IRM)

To visualize the complex causal relationships among divisions using a visible structural model, one can develop an IRM from the values of $d + r$ and $d - r$, represented on the x-axis and the y-axis, respectively (Lin & Tzeng, 2009). Fig. 4 presents the IRM of the first-level divisions in the case project. Using this map, management can visualize the difference between the cause divisions

Table 9
Degree of total influence of the divisions.

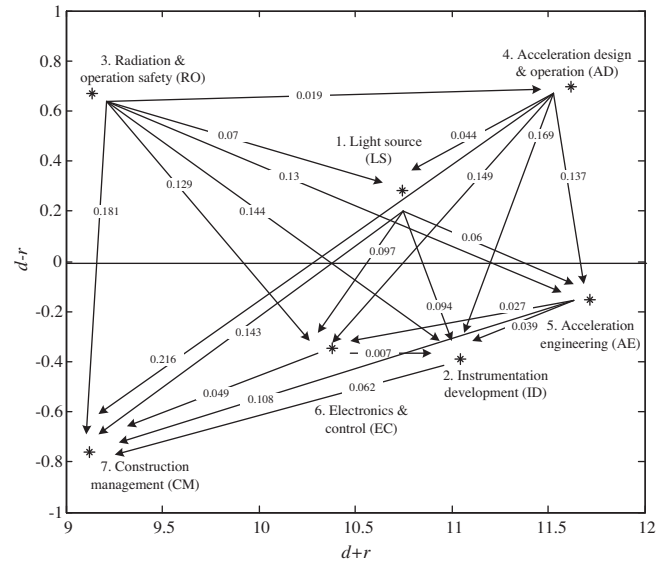| Divisions	d	r	$d + r$	$d - r$	Group
1. LS	5.514	5.234	10.748	0.280	Cause
2. ID	5.327	5.717	11.043	−0.390	Affected
3. RO	4.904	4.232	9.135	0.672	Cause
4. AD	6.158	5.463	11.622	0.695	Cause
5. AE	5.781	5.934	11.715	−0.153	Affected
6. EC	5.017	5.363	10.380	−0.345	Affected
7. CM	4.180	4.939	9.119	−0.759	Affected

Fig. 4. Influence-relations map of the first-level divisions.

Table 10
Net influence matrix **N** of the divisions.

Divisions	1. LS	2. ID	3. RO	4. AD	5. AE	6. EC	7. CM
1. LS							
2. ID	−0.094						
3. RO	0.070	0.144					
4. AD	0.044	0.169	−0.019				
5. AE	−0.060	0.039	−0.130	−0.137			
6. EC	−0.097	0.007	−0.129	−0.149	−0.027		
7. CM	−0.143	−0.062	−0.181	−0.216	−0.108	−0.049	

Table 11
Suggested strategies for improving the performance of the divisions.

Divisions	SIA			DEMATEL			Strategies
	SS	SI	(SS, SI)	$d + r$	$d - r$	Group	
1. LS	−1.218	−0.970	▼(−,−)	10.748	0.280	Cause	E
2. ID	0.243	−0.970	●(+,−)	11.043	−0.390	Affected	B
3. RO	−0.214	−0.799	▼(−,−)	9.135	0.672	Cause	E
4. AD	1.722	1.654	○(+,+)	11.622	0.695	Cause	A
5. AE	0.001	0.685	○(+,+)	11.715	−0.153	Affected	A
6. EC	0.539	0.513	○(+,+)	10.380	−0.345	Affected	A
7. CM	−1.074	−0.114	▼(−,−)	9.119	−0.759	Affected	F

(LS, RO and AD) and the affected divisions (ID, AE, EC, and CM). Furthermore, the following net influence matrix **N** can be used to evaluate the strength of the effect of one division on another:

$$\mathbf{N} = Net_{ij} = t_{ij} - t_{ji}. \tag{12}$$

Table 10 shows the net influence matrix of the divisions in the case project. For example, the net influence of the CM division on the AE division is −0.108(=0.708−0.816; Table 8).

5.4. Integration of SIA and DEMATEL

Integrating the SIA and DEMATEL generates various management strategies to improve the performance of the divisions. These strategies are as follows:

(1) Strategy A (SS > 0 and SI > 0): the division requires no further improvement;

(2) Strategy B (SS > 0 and SI < 0): the division requires no further improvement, but its resources may be better used elsewhere;
(3) Strategy C (SS < 0, SI > 0 and $d - r > 0$): the division must be improved directly, and with top priority;
(4) Strategy D (SS < 0, SI > 0 and $d - r < 0$): the division must be improved indirectly, and with top priority;
(5) Strategy E (SS < 0, SI < 0 and $d - r > 0$): the division must be improved directly, and has a low priority;
(6) Strategy F (SS < 0, SI < 0 and $d - r < 0$): the division must be improved indirectly, and has a low priority.

Table 11 presents the evaluation obtained using the SIA and DEMATEL methods. In the SIA analysis, the LS, RO, and CM divisions have an unfavorable performance (SS < 0) and must be improved. In addition, the DEMATEL analysis indicates that the LS and RO divisions are in the cause group, while the CM division is in the affected group. Thus, the LS and RO divisions should be improved directly, but with low priority based on strategy E (SS < 0, SI < 0 and $d - r > 0$) while the CM division should be improved indirectly with low priority according to strategy F (SS < 0, SI < 0 and $d - r < 0$). The AE division may be improved indirectly with top priority (strategy D: SS < 0, SI > 0 and $d - r < 0$) because its SS value is almost negative.

Fig. 5 shows the evaluation. The left of the figure presents the SIA analysis, whereas the right shows the DEMATEL analysis. It shows that the RO division affects all other divisions. Thus, determining the specifications/needs of the radiation and operation safety (RO) in a timely and positive manner is critical to the design management.

5.5. Identifying the second-level sections

Improving the LS division also depends on improving those sub-divisions (sections) that are responsible for the poor performance. The input data collected from the aforementioned questionnaires and the same modeling steps that are used in applying the SIA and DEMATEL methods yield the following results.

- The performance of the following three sections, LS3, LS4, and LS6 is not satisfactory.
- LS3 (power supply) and LS4 (accelerator operation) must be improved indirectly and with low priority as suggested by strategy F (SS < 0, SI < 0 and $d - r < 0$).
- The LS6 (injector) section must be improved indirectly with top priority based on strategy D (SS < 0, SI > 0 and $d - r < 0$).

Table 12 shows the suggested strategies for improving the second-level sections in the LS division. Fig. 6 shows the evaluation results of the SIA and IRM analyses of these sections.

6. Discussion

The above evaluation results were presented to two top managers of the project client. Their main feedback was as follows.

- The modeling results are useful in systematically identifying the key divisions/sections that perform poorly.
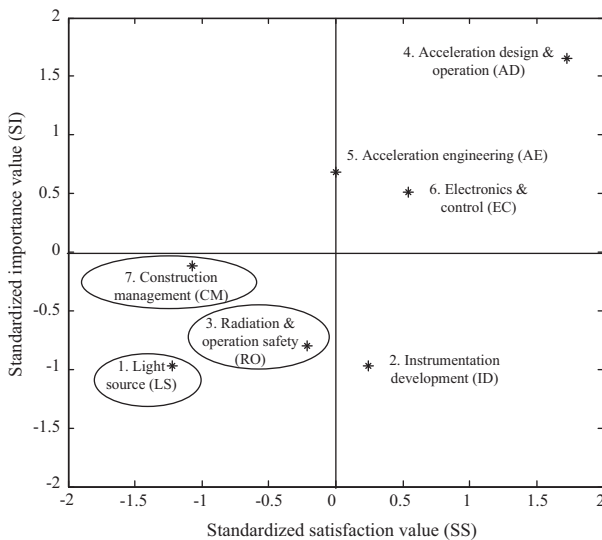

Fig. 5. Integration of the SIA and the DEMATEL for the first-level divisions.

Table 12
Strategies for improving the performance of the sections of the LS division.

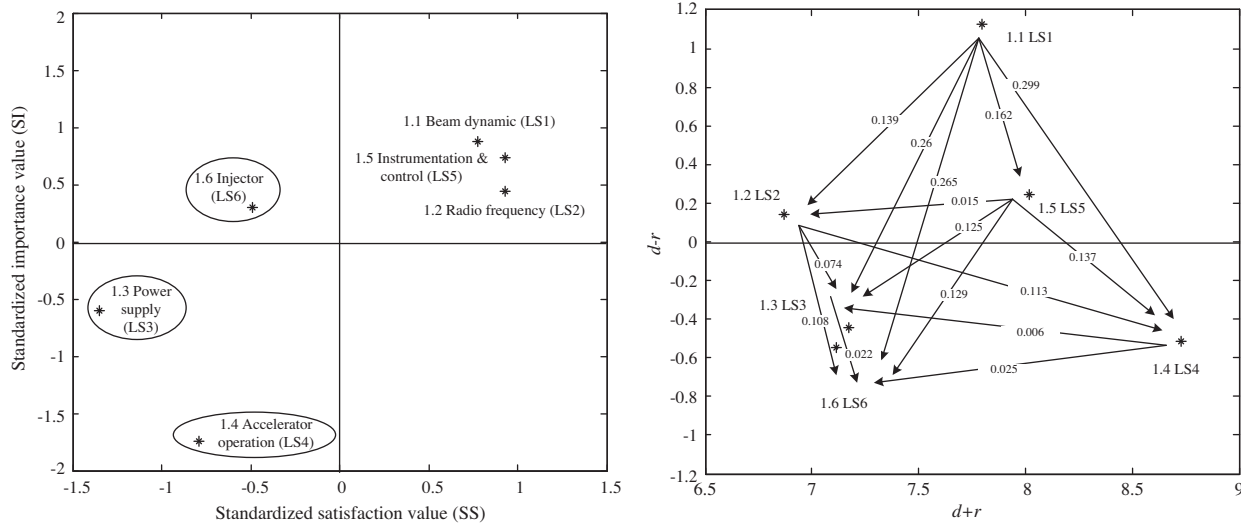| Sections	SIA			DEMATEL			Strategies
	SS	SI	(SS, SI)	$d + r$	$d - r$	Group	
1.1 LS1	0.775	0.873	○(+,+)	7.796	1.125	Cause	A
1.2 LS2	0.927	0.436	○(+,+)	6.871	0.140	Cause	A
1.3 LS3	−1.348	−0.604	▼(−,−)	7.171	−0.443	Affected	F
1.4 LS4	−0.792	−1.745	▼(−,−)	8.730	−0.517	Affected	F
1.5 LS5	0.927	0.738	○(+,+)	8.019	0.244	Cause	A
1.6 LS6	−0.489	0.302	X(−,+)	7.117	−0.549	Affected	D

Fig. 6. Integration of the SIA and the DEMATEL for the sections of the LS division.

- A visual diagram (Figs. 5 and 6) is useful for visualizing and clearly communicating the cause-effect relationships among the divisions/sections.
- The top managers appreciated the evaluation results and admitted that many of their late decisions as well as the inefficiencies in supervision were caused by an ineffective organizational structure and an excess of conflicting user opinions raised by different divisions or sections.
- The relatively poor performance caused by the LS division might be due to the fact that this division needs to assign a much larger number of staff members to be highly involved in this design project. Hence, some of the staff in the ID division may have to be transferred to support the LS division.
- The top managers considered taking the following three actions to improve the performance of the above mentioned key divisions/sections. First, they agreed to clearly define the authorities and responsibilities of each division/section manager. The project client actually had no previous experience with a matrix organization. A few division managers had difficulties in working cooperatively with each other. Second, the project client decided that the final decision-maker for the research center must direct and monitor the matrix effort in a firm and decisive manner. That is, he should take full control of the project until the various staff members are familiar with their duties and responsibilities within the matrix organization, and until the project is on the right track. Third, they would recruit additional engineers to alleviate the manpower shortage in some of the key divisions/sections.
- Finally, regular updating of the evaluation of the model is preferred. That is, any additional information obtained by management should be fed into the model as soon as possible to enable corrections to be made in a timely fashion.

7. Conclusion

A matrix-based organization consisting of many divisions/sections is often used for managing a design/construction project. In a large-scale design project, these divisions/sections are complex and interrelated. Controlling the key divisions that perform poorly is a key to the efficient management of the project. This study proposed an innovative model that helps to assess the performance and the cause-effect relationships among the matrix-based divisions of a high-tech facility with their design project.
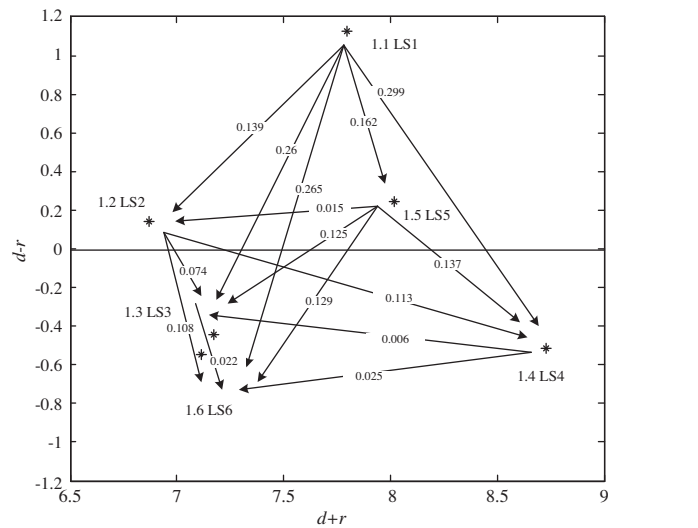
In the model, the SIA method was adopted to evaluate the performance of each division, while the DEMATEL analysis was employed to analyze the cause-effect interrelationships among the divisions. Then, the SIA and DEMATEL were combined to determine the key divisions that most strongly affected the design performance. Top management in the case study were pleased with the results of the presented model.

Future research will computerize the proposed model in order to expedite the evaluation steps, so that the appropriate actions can be taken sooner. In addition, the SIA and DEMATEL schemes may be applied to solve different decision-making problems, involving various interrelated divisions.

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