USING SIA AND DEMATEL TO IDENTIFY THE FACTORS AFFECTING DESIGN DELAYS

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Abstract

Design delays can adversely affect the total completion time of a construction project. Factors affecting the delays of design duration are complicated and interrelated. This study proposes a methodology to support identify key driving factors affecting design delays and sieve out the initiating delay factors for improvement. The core of the methodology is to integrate a “satisfied importance analysis” and a “decision making trial and evaluation laboratory technique”. A real-world design project in Taiwan is applied to examine the benefits of the methodology. In this case study, four first-level delay factors and 17 second-level delay sub-factors are defined. The “organization’s decision makings and budget constraints” is identified as the key driving factor causing design delays in this case project. Top management of the case project appreciates the application results.

KEYWORDS: design delays, satisfied importance analysis (SIA), decision making trial and evaluation laboratory technique (DEMATEL), influence-relations (IR) map

INTRODUCTION

The design of a facility includes conceptual design, schematic design and detailed design. During the conceptual and schematic design phases, a prime designer (architect / engineer or A/E) seeks to incorporate information from a wide range of disciplines; represent candidate solutions, and generate new states from the current ones based on the available information to meet the owner’s requirements. In the detailed design phase, the design deliverables must be met to prevent future construction work from being delayed.

However, numerous factors (such as clarity of user needs and timely decisions) can affect the duration performance of the abovementioned design phases. The design delays not only can postpone the completion time of a construction project, but also they result into a waste of project resources. Unfortunately, identifying the right delay factors may not be easy because these factors are interrelated with each other. Especially, in practice, when delays arise, project participants (such as facility users, decision-makers, project management, and designers) frequently blame with each other and the delays remain.

This research proposes a methodology to identify the key factors affecting design delays and trace the initiating factors which dominate the key factors. Taking corrective actions on those initiating factors should be much effectively in preventing design delays. A real-world facility design project located in northern Taiwan is used as a case study. The following paper is organized as follows: First, the literature on design management is reviewed. Second, the proposed methodology is presented. Third, the case project is described. Fourth, the details of each methodological step are demonstrated using the case project. Finally, the conclusions and future work are provided.

LITERATURE REVIEW ON DESIGN MANAGEMENT

The importance of efficient design management to ensuring the smooth running of a project is being increasingly appreciated (Luh et al., 1999; Austin et al., 2000; Wang et al., 2006). Much research has been undertaken to better control the design process, and thus increase the effectiveness of the management of design duration. For example, Sanvido and Norton (1994) proposed a building design process model and identified the flow of information and knowledge that supports the development of the design. Some researchers have addressed the design process problems in a collaborative environment, including for example, miscommunication among designers and incompatibility of design data caused by changes to the design (Peng 1994, Hegazy et al 2001). So far, little research is related to identifying the key factors causing design delays.

PROPOSED METHODOLOGY

This work proposes a methodology to identify the delay factors and sub-factors for a design project. The steps of this methodology are as follows: (1) Step 1: defining the factors and sub-factors that may affect the performance of design duration. (2) Step 2: using the "satisfied importance analysis (SIA)" to assess the importance degree and satisfaction degree of each factor. A factor results into a delay when it is considered to perform unsatisfactorily. (3) Step 3: applying the "decision making trial and evaluation laboratory technique (DEMATEL)" to construct a cause-effect influence-relations (IR) map between factors. (4) Step 4: Integrating the evaluation results using the SIA and DEMATEL methods. That is, the

SIA indicates the key factors that are highly important and highly unsatisfactory to design delays. Then, DEMATEL traces initiating factors dominating those key factors. (5) Step 5: Further investigating the problematic sub-factors under the initiating factors. (6) Step 6: Improving the identified delay factors and sub-factors.

DESCRIPTION OF CASE PROJECT

The case project is the construction of a high-tech facility located in northern Taiwan. Total floor area is about 53,000 m^2. The construction budget is approximately \$84.2 million US dollars. The project client established a task force to manage the project throughout the project phases. The research team of this paper has worked closely with this task force. Currently, the project is in the construction phase. Construction duration is 950 calendar days.

FACTORS AFFECTING DESIGN DELAYS

By interviewing with three project engineers and one project manager who are involved in the case project, four first-level delay factors and 17 second-level sub-factors are defined corresponding to four project participants (namely, users, decision-makers, project management, and designers). See Table 1.

Table 1: Factors and sub-factors affecting design delays

First-level factors / second-level sub-factors	Description
1. User needs and specification requirements (US)	
1.1 Eagerness of user needs (US1)	Facility users are eager to certain user needs?
1.2 Clarity of user needs (US2)	Users define their needs clearly?
1.3 Rigorousness of user needs (US3)	The user needs are too rigorous or difficult to meet?
1.4 Limitation of regulations (US4)	Governmental regulations may be restricted to meet user needs.
1.5 Limitation of specifications (US5)	Technical specifications may not be rigorous enough.
2. Organization's decision makings and budget constraints (OB)	
2.1 DM's decision makings (OB1)	Decisions made by the organization are timely and definitely?
2.2 DM's supervision ability (OB2)	DM's supervision methods are efficient?
2.3 Budget availability (OB3)	Project budgets are tight so that DM must prioritize the user needs.
2.4 DM's resource allocation (OB4)	DM's resource allocation ability is efficient?
3. Project control and review management (PM)	
3.1 PM's management model (PM1)	Project control methods are efficient?
3.2 PM's experience (PM2)	PM's experience and profession are sufficient?
3.3 PM's communications (PM3)	PM's communications with other parties are efficient?
3.4 PM's reviews (PM4)	PM's reviews and control of design deliverables are efficient.
4. Design execution and interface management (DM)	
4.1 Design ability (DM1)	A/E's experience and design ability are sufficient to efficiently deliver the user needs?
4.2 Designer's estimations (DM2)	A/E's cost estimation experience and ability is good?
4.3 Subcontractor management (DM3)	A/E manages the interfaces of design subcontractors effectively?
4.4 A/E's resource allocation (DM4)	A/E allocates sufficient design people to the jobs?

APPLYING SIA AND DEMATEL TO THE CASE PROJECT

Collection of input data

The data required to execute the SIA and DEMATEL are a set of questionnaires. 36 experts (engineers, section managers or managers who are involved in this case project) are asked to fill out each questionnaire. Table 2 presents an example of the questionnaire of SIA. Table 3 shows an example of questionnaire for executing DEMATEL. A respondent is asked to indicate the direct influence (or dominance) that he believes a factor exerts on each of the other factors based on an integer scale (ranging from 0 to 4). A high score indicates a belief that improvement in factor *i* is required to improve factor *j*. In Table 3, for example, suppose factor *i* (PCM) has little direct influence on factor *j* (US), then a score of “1” is given. Additionally, Cronbach’s α is used to test the reliability of the data collected from the questionnaires. The test results show that these data are reliable.

Table 2: An example of questionnaire for executing SIA

Factors and sub-factors	Importance degree	Satisfaction degree
1. User needs and specification requirements (US)		
1.1 Eagerness of user needs (US1)	8	5
1.2 Clarity of user needs (US2)	8	5
1.3 Rigorousness of user needs (US3)	7	5
1.4 Limitation of regulations (US4)	9	4
1.5 Limitation of specifications (US5)	8	8
2. Organization’s decision makings and budget constraints (OB)		
2.1 DM’s decision makings (OB1)	8	5
2.2 DM’s supervision ability (OB2)	7	5
2.3 Budget availability (OB3)	7	6
2.4 DM’s resource allocation (OB4)	7	6
3. Project control and review management (PM)		
3.1 PM’s management model (PM1)	9	7
3.2 PM’s experience (PM2)	8	8
3.3 PM’s communications (PM3)	8	8
3.4 PM’s reviews (PM4)	7	8
4. Design execution and interface management (DM)		
4.1 Design ability (DM1)	8	7
4.2 Designer’s estimations (DM2)	8	7
4.3 Subcontractor management (DM3)	8	7
4.4 A/E’s resource allocation (DM4)	7	6

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

Table 3: An example of questionnaire for executing DEMATEL

Factor *i* / Factor *j*	1. US	2. OB	3. PM	4. DM
1. US			3	
2. OB				
3. PM	1			
4. DM				

Note: 0: no influence; 1: little influence; 2: moderate influence; 3: high influence; 4: extremely high influence.

Evaluation of SIA

The input data (i.e., the satisfaction degree and importance degree of each factor and sub-factor) collected from the questionnaires will be normalized into the same measuring scales. The results classify the factors into four categories: (1) ○ (+,+) indicates a factor with high satisfaction and high importance, (2) ● (+,-) indicates a factor with high satisfaction and low importance, (3) △ (-,-) indicates a factor with low satisfaction and low importance, and (4) X (-,+) indicates a factor with low satisfaction and high importance. The fourth category, X (-,+), should receive the highest attention. Table 4 presents the evaluation results of SIA for the case study. Additionally, the OB factor falls into the fourth category (high importance, low satisfaction). Hence, the OB factor deserves for improvement immediately. Figure 1 graphically presents the SIA evaluation results.

Table 4: Satisfaction and importance degrees of factors

Factors	Satisfaction: Initial value	Satisfaction: SS	Importance: Initial value	Importance: SI	(SS, SI)
1. User needs and spec. requirements (US)	6.233	0.217	7.772	-1.209	● (+,-)
2. Org. dec. makings and budget const. (OB)	5.583	-1.415	8.153	1.128	X (-,+)
3. Proj. control and review management (PM)	6.521	0.939	8.035	0.403	○ (+,+)
4. Design exe. and interface management (DM)	6.250	0.259	7.917	-0.322	● (+,-)

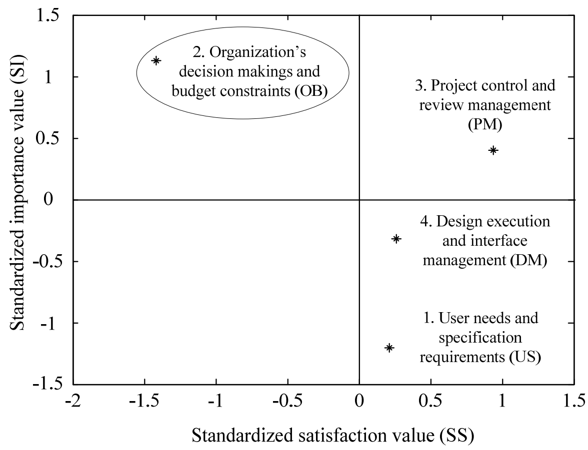

Figure 1: SIA analysis of the factors

Evaluation of DEMATEL

The DEMATEL method was developed for a Science and Human Affairs Program by the Battelle Memorial Institute of Geneva to solve complex and interrelated problems (Gabus and Fontela, 1973; Tzeng et al., 2007; Wu and Lee, 2007; Li, 2009; Lin and Tzeng, 2009). The steps to execute the DEMATEL are (Li 2009; Lin and Tzeng, 2009): (1) finding the average matrix,

(2) calculating the direct influence matrix, (3) calculating the indirect influence matrix, (4) deriving the total influence matrix, and (5) obtaining the influence-relations map.

Step D1: Finding the average matrix

Suppose there are *h* experts available to solve a complex problem and there are *n* factors to be considered. The scores given by each expert give a $n \times n$ non-negative answer matrix $\boldsymbol{X}^k$, with $1 \leq k \leq h$. Thus $\boldsymbol{X}^1$, $\boldsymbol{X}^2$ … $\boldsymbol{X}^h$ are the answer matrices for each of the *h* experts, and each element of $\boldsymbol{X}^k$ is an integer denoted by x_{ij}^k. The diagonal elements of each answer matrix $\boldsymbol{X}^k$ are all set to zero. We can then compute the $n \times n$ average matrix ***A*** by averaging the *h* experts' score matrices. The (i, j) element of average matrix ***A*** is denoted by a_{ij},

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

Table 5 displays an average matrix (average matrix ***A***) of the factors.

Table 5: Average matrix ***A*** of the factors

Factors	US	OB	PM	DM	Sum
1. User needs and spec. requirements (US)	0	3.111	2.972	2.861	8.944
2. Org. dec. makings and budget const. (OB)	3.167	0	3.056	2.750	8.973
3. Proj. control and review management (PM)	2.500	2.361	0	2.861	7.722
4. Design exe. and interface management (DM)	2.583	2.361	2.778	0	7.722
Sum	8.250	7.833	8.806	8.472	

Step D2: Calculating the direct influence matrix

A direct influence matrix ***D*** is obtained by normalizing the average matrix ***A***. That is, ***D*** = *s* ***A***, where

$$s = Min\left[\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}\right|}, \frac{1}{\max\limits_{1\le j\le n}\sum_{i=1}^{n}\left|a_{ij}\right|}\right] \tag{2}$$

Table 6 shows the direct influence matrix ***D*** for the factors.

Table 6: Direct influence matrix ***D*** for the factors

Factors	US	OB	PM	DM	Sum
1. US	0.000	0.347	0.331	0.319	0.997
2. OB	0.353	0.000	0.341	0.307	1.000
3. PM	0.279	0.263	0.000	0.319	0.861
4. DM	0.288	0.263	0.310	0.000	0.861
Sum	0.920	0.873	0.982	0.945	

Step D3: Calculating the indirect influence matrix

A continuous decrease of the indirect effects of problems is along the powers of matrix, e.g., D^2, D^3 … D^∞. This guarantees convergent solutions to the matrix inversion. The indirect influence matrix ***ID*** can be obtained based on the values of direct influence matrix ***D***. That is,

$$\boldsymbol{ID} = \sum_{i=2}^{\infty} \boldsymbol{D}^i = \boldsymbol{D}^2(\boldsymbol{I}-\boldsymbol{D})^{-1} \tag{3}$$

where ***I*** is the identity matrix. Table 7 presents the indirect influence matrix ***ID*** for the factors.

Table 7: Indirect influence matrix ***ID*** for the factors

Factors	US	OB	PM	DM	Sum
1. US	3.196	2.984	3.283	3.195	12.658
2. OB	3.115	3.083	3.290	3.211	12.699
3. PM	2.783	2.680	2.995	2.836	11.294
4. DM	2.782	2.682	2.924	2.915	11.303
Sum	11.876	11.429	12.492	12.157	

Step D4: Deriving total influence matrix

The total influence matrix ***T*** is defined as follows:

$$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{ID} \tag{4}$$

$$\boldsymbol{T} = \sum_{i=1}^{\infty} \boldsymbol{D}^i = \boldsymbol{D}(\boldsymbol{I}-\boldsymbol{D})^{-1} \tag{5}$$

$$\boldsymbol{T} = [t_{ij}], \qquad i, j = 1, 2, ..., n \tag{6}$$

Table 8 presents the total influence matrix for the factors. Additionally, suppose d_i denotes the row sum of the *i*-th row of matrix ***T***. Then d_i can represent the sum of direct and indirect influences of factor *i* on the other factors. If r_j denotes the column sum of the *j*-th column of matrix ***T***, then r_j indicates the sum of direct and indirect influences that factor *j* has received from the other factors. Furthermore, when *j* = *i*, $d_i + r_i$ provides an index of the strength of influences given and received. If $d_i - r_i$ is positive, then factor *i* influences other factors more than it is influenced. Conversely, if $d_i - r_i$ is negative, then factor *i* is influenced by other factors (Tzeng et al., 2007). Table 9 shows the results of *d*+*r* and *d*-*r* for the factors.

Table 8: Total influence matrix ***T*** for the factors

Factors	US	OB	PM	DM	Sum
1. US	3.196	3.331	3.614	3.514	13.654
2. OB	3.468	3.083	3.631	3.518	13.700
3. PM	3.062	2.943	2.995	3.155	12.154
4. DM	3.070	2.945	3.234	2.915	12.164
Sum	12.795	12.302	13.474	13.101	

Table 9: Degree of total influence for the factors

Factors	Sum of columns (*d*)	Sum of rows (*r*)	Sum of (columns + rows) (*d+r*)	Sum of (columns – rows) (*d-r*)
1. US	13.654	12.795	26.449	0.859
2. OB	13.700	12.302	26.002	1.398
3. PM	12.154	13.474	25.627	-1.320
4. DM	12.164	13.101	25.266	-0.937

Step D5: Obtaining the influence-relations map

An influence-relations map can be developed using the values of *d*+*r* and *d*-*r* to be the *x* axis and y axis, respectively. Figure 2 presents the IR map for the case project. Additionally, a net influence matrix ***N*** can also be calculated as follows:

$$N = nt_{ij} = t_{ij} - t_{ji} \quad (7)$$

For example, based on the total influence matrix ***T*** for the factors (Table 8), the net influence of the OB factor on the US factor is calculated to be 0.137 (=3.468-3.331).

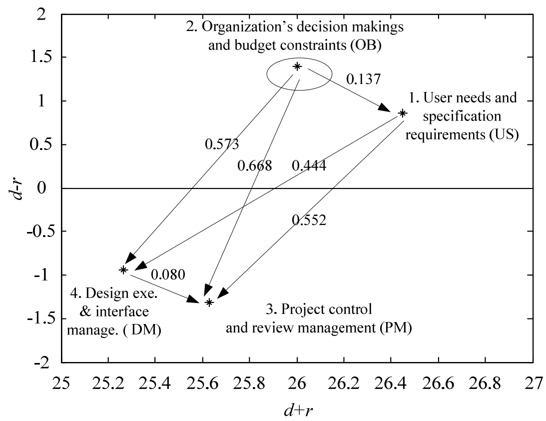

Figure 2: Influence-relations map of the factors

Integration of SIA and DEMATEL

Figure 3 integrates the evaluation results of applying the SIA and DEMATEL methods. The left of the figure (SIA) shows that the "organization's decision makings and budget constraints (OB)" factor has a positive value of importance (i.e., a high influence on the performance of design duration) and a negative value of satisfaction (i.e., unfavorable performance of design duration). That is, the performance of the OB factor requires to be improved immediately. Management then should trace which factor dominates the OB factor from the right of the figure (DEMATEL). The DEMATAL suggests that improving the performance of the OB factor must improve itself because the performance of the OB factor is only dominated by itself.

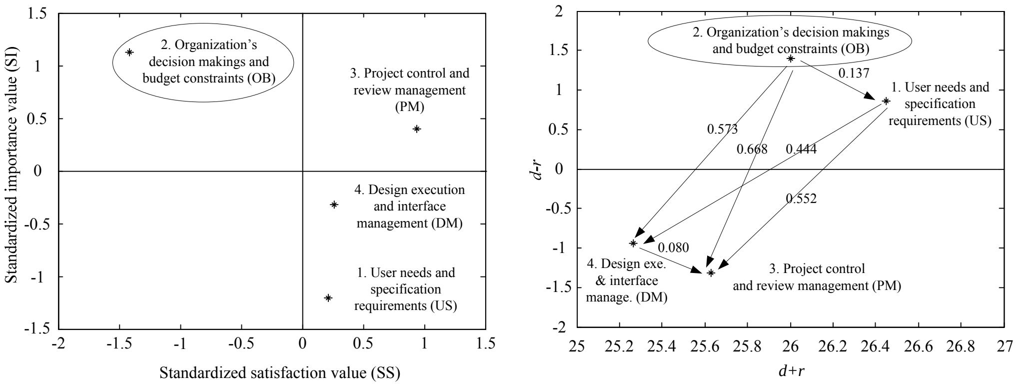

Figure 3: Integration of SIA and DEMATEL for the factors

Tracing to the second-level sub-factors

The next step is to further find out which sub-factors under the OB factor are the most influential factors that cause the design delays. Using the similar steps of SIA and DEMATEL methods, the results found that sub-factors OB1 (DM's decision makings) and OB2 (DM's supervision ability) need to be improved immediately under the OB factor. Figure 4 displays the IR map for the sub-factors under the OB factor.

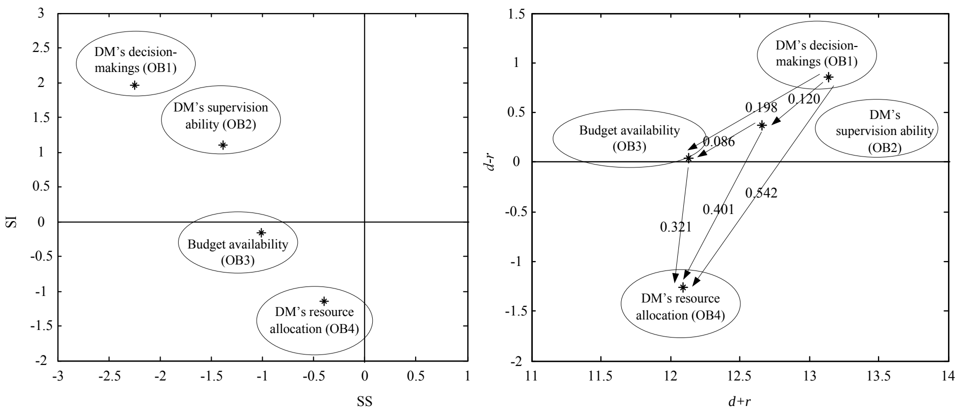

Figure 4: IR map for the sub-factors under the OB factor

CONCLUSIONS

Based on a real design project, this work proposes a methodology to support analyze and solve design delay problems. In the case study, the SIA analysis indicates that the OB factor is the key delay factor. Additionally, suggested by the DEMATEL analysis, improving the performance of the OB factor is to improve itself. Next, using the similar steps of SIA and DEMATEL, the results found that the OB1 and OB2 sub-factors of the OB1 factor must be improved immediately. Top management of the case project appreciates the application results. Future research is to computerize the proposed methodology for expediting the evaluations such that proper actions can be taken in time for supporting design duration management.

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