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Analytic hierarchy process-based model for estimating probability of human error in design stage

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Abstract

The building information modeling (BIM) technique is used widely in construction. In general, BIM can prevent interference between different types of construction activities in advance, thereby reducing the cost of reconstruction. While it is clear that a decrease in the number of requests for information in the construction stage would have obvious benefits, there is a need to determine the effects of the investment from the planning stage. Therefore, in this study, a procedure for quantifying the design errors that occur at the design stage is proposed considering the probability of the human errors concept. To achieve this, factors for evaluating human errors can arise during the drawing stage. Based on these factors, an analytic-hierarchy-process-based human error probability estimation model is suggested. Based on the factors affecting the error in the design stage, we construct a hierarchy and calculate the relative importance based on the probability and assess the effectiveness of each risk control option. It is expected that if the model presented in this study is linked with the loss cost data for each factor, a loss estimation model at the design stage can be developed.

Keywords: analytic hierarchy process; building information modeling; return on investment; human error estimation

1. Introduction

Building information modeling (BIM) is being adopted in the field of construction on a wide scale. It has the advantages of BIM, which can be used to calculate the construction cost and the construction activities necessary based on the information inputted in advance, thus helping prevent conflicts between the construction stakeholders that can occur during the design stage. In addition, BIM makes it possible to reap economic and temporal benefits by reducing the number of requests for information (RFIs) that are generated at the construction stage; this is because it requires the collection and reviewing of all the design drawings to be exchanged between the architect, civil engineer, mechanical, electrical, and plumbing engineering personnel at the design stage.

However, despite the many advantages of BIM, it is not widely used in Korea. Although the Korean government encourages the use of BIM through policy incentives, construction companies are reluctant to preemptively invest in BIM because they are not sure of whether the initial-investment-to-profit ratio is effective or not. In other words, companies want to see proven return on investment(ROI)s before they invest in BIM.

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Most existing studies on the ROI of BIM [1-7] have focused on ROI after construction is completed. These studies show that it is advantageous to invest in BIM by calculating the financial profit and comparing it to the investment required based on analyses of cases where construction had been completed. While it is clear that there are obvious benefits to the decrease in the number of RFIs, there is a need to determine the effects of the investment from the planning stage if BIM is to be positioned as part of the overall process in the construction sector as well as a computer-aided design tool.

Therefore, in this study, a procedure for quantifying the design errors that occur at the design stage is proposed considering the probability of human errors.

2. Research method

This research is conducted as follows.

- Categorizing the evaluation factors - Categorize factors that could potentially lead to errors in the planning and design phases.
- Developing the hierarchy—A hierarchy for analytic hierarchy process (AHP)-based analysis is constructed with the goal of minimizing design errors.
- Determine the types of human errors—Determine the types of behaviors owing to which various types of errors may occur. In this study, only the skill-, rule-, and knowledge- approaches proposed by Rasmussen [8] were used.
- Determine the probability of occurrence of errors—Based on the probabilistic data presented in Step 3, determine the probability that a human error might occur while performing the task in question. Further, using this information, determine the probability of occurrence of the human error assigned.
- Determine the severity of occurrence—The severity of a human error should consider the consequences of the error on the design procedures. The severity is quantified by taking into account the delay and financial loss caused by the error.
- Determine the risk control options (RCOs)—Determine the administrative, institutional, and systematic measures that can be taken to minimize design errors.
- Final analysis—Use the proposed method to determine the optimal RCOs and their respective effects.

3. Model description

3.1. Categorizing the factors

In order to evaluate the proposed method, the behavioral errors that may have occurred at the design stage are set. The primary error categories and the related behavioral characteristics, as well as the probabilities of occurrence of these errors, were established based on the results of a previous study by Rasmussen [8]. In this study, the errors were categorized as mental, physical, knowledge-related, and environment-related errors. Detailed sub-factors are listed in Table 1.

Table 1. Descriptions of behavior factors and probabilities of occurrence of different types of errors

Category	Variance	Definition of sub-factors	Types of human error	Probability of occurrence
Mental	M1	Mistake (not intended)	Skill-based	5.00E-03

	M2	Attitude for doing work	Rule-based	5.00E-02
	M3	Personal concern	Skill-based	5.00E-03
	M4	Disagreement with team members	Knowledge-based	5.00E-01
Physical	P1	Lack of physical strength due to excessive work	Skill-based	5.00E-03
	P2	Unexpected health problem	Rule-based	5.00E-02
Knowledge	K1	Lack of relevant knowledge regarding design	Knowledge-based	5.00E-01
	K2	Lack of knowledge regarding collaboration	Rule-based	5.00E-02
	K3	Lack of ability to deal with graphics-related software	Knowledge-based	5.00E-01
	K4	Lack of ability to create design drawings	Knowledge-based	5.00E-01
	K5	Lack of skills to operate computer	Knowledge-based	5.00E-01
Environmental	E1	Low salary	Rule-based	5.00E-02
	E2	Related to working environment (human relations with team members)	Knowledge-based	5.00E-01
	E3	Excessive customer demands (frequent changes to design)	Skill-based	5.00E-03

3.2. Developing hierarchy

Based on the evaluation factors, a hierarchy of error is developed to minimize the human errors in the design phase.

3.3. Determining human error types

The definitions of the types of human errors [9] considered in this study are as follow:

Skill-based behaviors depend mostly on the operator's practice level while performing the task in question. These errors tend to be related to routine activities under familiar circumstances.

Rule-based behaviors are at work when the operator does not have adequate practice performing the required task, but has clear knowledge of what the procedures involves. Rule-based errors are related to the misapplication or inappropriate use of problem-solving rules.

Knowledge-based behaviors are related to instances where the operator needs to understand the situation, interpret information, or make a difficult decision. Also included in this category are cases where a procedure is not well defined. Knowledge-based errors are related to performance in new situations.

3.4. Determining probability of occurrence

3.4.1 Upper hierarchy

As suggested in Fig. 1, the probability of occurrence and severity make up the two elements of the matrix. These two elements are compared to determine the weighting vector for each element. Using the comparison scale given in Table 2, the importance of the two elements can be determined. In this study, it was assumed that the two elements have the same importance. The matrices can be written as follows:

Upper hierarchy = $\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$ and weighing vector =$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix}$

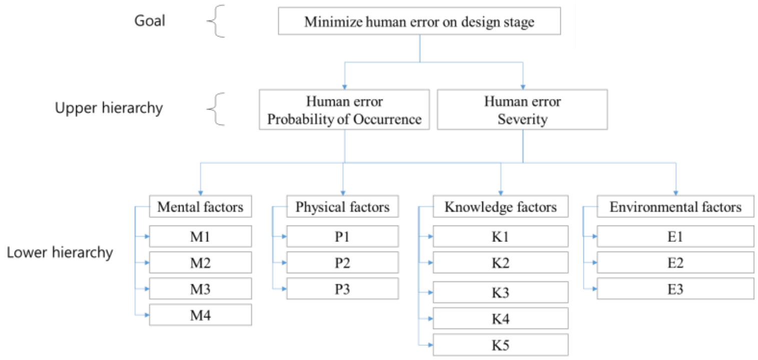

Figure 1. Hierarchy structure of the model

3.4.2. Evaluation of probability of human error

First, the importance of each factor (mental, physical, knowledge-, skill-, or environment-based) is determined. Using Table 1, the matrix shown below is obtained for the probability importance among factors.

$$\text{Probability} = \begin{bmatrix} 1.00 & 0.33 & 5.00 & 3.00 \\ 3.00 & 1.00 & 0.33 & 1.00 \\ 0.20 & 3.00 & 1.00 & 3.00 \\ 0.33 & 1.00 & 0.33 & 1.00 \end{bmatrix}$$

The weighting vector and normalized vector are determined by considering the weighting vector obtained in the matrix in section 3.4.1 and are as shown below:

$$\text{Weighting vector} = \begin{bmatrix} 0.3520 \\ 0.2561 \\ 0.2829 \\ 0.1090 \end{bmatrix} \text{ and Normalized vector} = \begin{bmatrix} 0.1760 \\ 0.1280 \\ 0.1415 \\ 0.0545 \end{bmatrix}$$

Table 2. Comparison scale

Determination value	Judgment Criteria	Determination value	Judgment Criteria
1	Both elements are of equal importance	1/3	Top weakly more important than left
3	Left weakly more important than top	1/5	Top moderately more important than left
5	Left moderately more important than top	1/7	Top strongly more important than left
7	Left strongly more important than top	1/9	Top absolutely more important than left
9	Left absolutely more important than top		

The matrices for the probability of occurrence of each sub-factor are determined as shown below:

$$\text{Mental} = \begin{bmatrix} 1.00 & 0.56 & 1.00 & 0.11 \\ 1.80 & 1.00 & 1.80 & 0.20 \\ 1.00 & 0.56 & 1.00 & 0.11 \\ 9.00 & 5.00 & 9.00 & 1.00 \end{bmatrix}, \quad \text{Weighting Vector} = \begin{bmatrix} 0.0781 \\ 0.1406 \\ 0.0781 \\ 0.7031 \end{bmatrix} \text{ and Normalized vector} = \begin{bmatrix} 0.0138 \\ 0.0248 \\ 0.0138 \\ 0.1238 \end{bmatrix}$$

The same procedure is repeated for the remaining sub-factors.

3.4.3. Evaluation of severity of human errors

The severity of the human errors related to the factors (mental, physical, knowledge-, skill-, and environment-based) is determined. The probabilities are compared based on the probability suggested in Table 1; however, the severity can be calculated through questionnaires filled by an expert group. In this study, it was selected according to the researchers' experience because it only explains the possibilities of the model. The remaining calculations are the same as those for determining the probability.

3.5. Risk control options (RCOs)

In this study, several RCOs are proposed for reducing the design errors arising from human errors. This is done based on the AHP. These RCOs were evaluated against the lower hierarchy. For example, an arbitrary scale (1–10) was used to compare each RCO, with 1 meaning not effective and 10 meaning most effective. In order to evaluate these effects, we considered multiple factors such as cost, applicability, and efficiency. The RCOs used for evaluation were as follows:

- RCO1 – Introduction of a systematic management system for revised drawings
- RCO2 – Introduction of a cross-checking procedure for drawings
- RCO3 – Introduction of systematic work instructions (manual)
- RCO4 – Increasing the capacity through regular training
- RCO5 – Providing assistance with new computing technology

The matrices for the effectiveness of each RCO were calculated as below.

The behaviors are placed in the left column, the RCOs are placed in the top row, and the effects of the RCOs are evaluated based on the criteria listed in Table 2. For example, the effectiveness of the RCOs in the case of mental errors can be evaluated as shown in Table 3.

Table 3. Example of evaluation of effectiveness of RCOs

	RCO1	RCO2	RCO3	RCO4	RCO5
Mental1	8	9	5	8	7
Mental2	3	7	6	8	2
Mental3	1	1	2	3	5
Mental4	3	1	8	1	5

Next, we multiply the matrix of the evaluation results with the previously computed normalized matrix. The probability and severity of occurrence are listed in Table 4.

Table 4. Normalized results of effectiveness of RCOs

Factors	Probability					Severity				
	RCO1	RCO2	RCO3	RCO4	RCO5	RCO1	RCO2	RCO3	RCO4	RCO5
Mental1	0.0030	0.0033	0.0019	0.0030	0.0026	0.0030	0.0033	0.0018	0.0030	0.0026
Mental2	0.0029	0.0067	0.0057	0.0076	0.0019	0.0021	0.0049	0.0042	0.0056	0.0014
Mental3	0.0011	0.0011	0.0023	0.0034	0.0057	0.0021	0.0021	0.0042	0.0063	0.0105
Mental4	0.0206	0.0069	0.0550	0.0069	0.0344	0.0198	0.0066	0.0529	0.0066	0.0330
Physical1	0.0020	0.0080	0.0159	0.0040	0.0159	0.0014	0.0056	0.0111	0.0028	0.0111
Physical2	0.0107	0.0179	0.0286	0.0036	0.0214	0.0125	0.0209	0.0334	0.0042	0.0250
Knowledge1	0.0056	0.0067	0.0079	0.0090	0.0045	0.0082	0.0082	0.0082	0.0082	0.0082
Knowledge2	0.0011	0.0013	0.0013	0.0017	0.0013	0.0673	0.0673	0.0673	0.0673	0.0673
Knowledge3	0.0052	0.0026	0.0052	0.0130	0.0078	0.0237	0.0237	0.0237	0.0237	0.0237
Knowledge4	0.0061	0.0031	0.0046	0.0107	0.0092	0.0261	0.0261	0.0261	0.0261	0.0261
Knowledge5	0.0026	0.0026	0.0052	0.0155	0.0078	0.0162	0.0162	0.0162	0.0162	0.0162
Environmental1	0.0006	0.0006	0.0026	0.0038	0.0006	0.0003	0.0003	0.0012	0.0019	0.0003
Environmental2	0.0052	0.0052	0.0156	0.0130	0.0026	0.0044	0.0044	0.0132	0.0110	0.0022
Environmental3	0.0010	0.0013	0.0010	0.0002	0.0010	0.0035	0.0042	0.0035	0.0007	0.0035

Table 5 lists the degrees of effectiveness of the RCOs based on the summation of each calculated value for a particular factor. For example, the effect of achieving goals related to management activity through RCO1 is 13.91% while that for RCO2 is 13.27%. This can also be interpreted as meaning that the effectiveness when the "mental" factor is managed using the suggested RCOs is 35.20%.

Table 5. Results of evaluation of RCOs

Evaluation factors	RCO1	RCO2	RCO3	RCO4	RCO5	Sum
Mental	5.46%	3.50%	12.80%	4.24%	9.21%	35.20%
Physical	2.66%	5.23%	8.91%	1.45%	7.36%	25.61%
Knowledge	4.28%	3.64%	4.88%	9.38%	6.10%	28.29%
Environmental	1.51%	1.60%	3.71%	3.06%	1.03%	10.90%
Sum	13.91%	13.97%	30.29%	18.12%	23.70%	100.0%

4. Conclusions and future work

In this study, a method is proposed for calculating the effects of the final decision-making on the errors that can occur during construction activities and the methods used to manage them. This is done by introducing the concept of probability to the existing AHP method. The probabilities used are the three types of probabilities proposed by Rasmussen [8]. However, more accurate calculations are possible using the results reported by Dhillon [10] or the calculated probability values. In addition, if a clear RCO is set, the analysis of the effects will be more accurate. It is expected that if the model presented in this study is linked with the loss cost data for each factor, a loss estimation model at the design stage can be developed.

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