AUTOMATING SUPERVISORY MANPOWER ALLOCATION FOR CONSTRUCTION SITES

Jieh-Haur Chen[1], Li-Ren Yang[2], W. H. Chen[3], and C. K. Chang[4]
[1] Assistant Professor, Institute of Construction Engineering and Management, National Central University, B413, 5th Engineering Hall, 300 Jhung-da Rd, Jhungli, Taoyuan 32001, Taiwan. E-mail: jhchen@ncu.edu.tw
[2] Assistant Professor, Department of Business Administration, Tamkang University, 151 Ying-chuan Rd, Tamsui, Taipei County 25137,Taiwan. E-mail: iry@mail.tku.edu.tw
[3] Graduate Student, Institute of Construction Engineering and Management, National Central University, A409 5th Engineering Hall, 300 Jhungda Rd., Jhungli, Taoyuan 32001, Taiwan. E-mail: 943205005@cc.ncu.edu.tw
[4] Graduate Student, Department of Civil Engineering, National Central University, E251 1st Engineering Hall, 300 Jhungda Rd., Jhungli, Taoyuan 32001, Taiwan. E-mail: rt005798@mail.ruentex.com.tw

Abstract

In the highly competitive construction industry, a slight inaccuracy of estimation can easily cause the loss of a project. Erroneous experience-based cost estimates or allocations of on-site supervisory manpower often offset the profit gained from the project and may jeopardize the management processes. To counter these types of problems, we develop a model using mathematical analysis and case-based reasoning to automate the allocation of on-site supervisory manpower and estimate construction site costs. The method is founded upon laborious data collection processes and analysis by matching statistical assumptions, and is applicable to construction projects. In the modeling the costs and allocation of on-site supervisory manpower are quantified for both owners and contractors before initiating or bidding on the projects. The findings confirm that the degree of variation of the model predictions has an accuracy rate at 88.47%. Single-site construction projects can be accurately predicted and the assignment of supervisory manpower feasibly automated.

Keywords: Allocation, Automation, Human resource management, CBR, Costs, On-site, Overhead, Supervisory manpower.

1. Introduction

For most construction projects especially relatively small- and medium-scaled projects, the traditional delivery method and the lump-sum type of contract is characteristic. Even though for most infrastructure projects the traditional contract methods are still being used, in some relatively large-scaled construction projects, the turnkey type of contract has been implemented. As shown in a previous study, medium-sized regional constructors have retrenched into particular markets, either by acting as subcontractors or merging with large firms. In other words there has been a trend towards the formation of either large- or small-sized construction companies [1]. These smaller companies seek to maximize profits and reduce competitive risk of by not allowing construction projects to turn out to be large and complex [2]. The result is that precise cost estimates for a project is a must.

In the highly competitive construction market, contractors awarded a construction project, whether it is a lump sum or turnkey type of contract, are faced with a huge challenge – a low profit margin – which narrows their allowable range of erroneous cost estimation down to a pinpoint.

For most construction projects in Taiwan, contractors perform well in relation to the estimation of direct costs and home office overhead. For example Maloney discusses cost controlling applied to indirect costs. The cost of on-site supervisory manpower however, which makes up a large proportion, over 3%, of the total project costs, has not often been discussed. The percentage varies, depending on the size of the construction projects, but is typically in the range of 1% to 10% of the total project costs. A comparison of the percentage with the average profit margin and estimation accuracy rates yields the fact that the accurate assessment of such costs and the allocation of on-site supervisory manpower are key to meeting a desired profit margin, irregardless of the size of the project.

In this research there are two major purposes for on-site supervisory manpower: to quantify the reasonable or statistical cost range; and to establish a model to predict the costs and allocation. The scope of this research mainly focuses on both residential and commercial construction projects. Assumptions and constraints are as follows: The construction project duration is defined as the project duration agreed to in the contract. Once legal processes and agreements are granted, the actual duration of the project is defined as the original duration plus or minus the duration approved by the changes in orders. However, any project that remains pending more than 6 months (due to contract administration problems or disputes) is not taken as consideration. The scope of the research in terms of project size is aimed at all-sized construction projects, to fit the industrial reality. In addition, over the last 2 decades, the impact of economic inflation has become a concern. All calculations regarding time-money relationship take this into account.

2. Supervisory manpower and related approaches in construction

The literature discussing the estimation and management of overhead costs is comprehensive. Generally speaking, company overhead costs can vary substantially, but they are generally in the range of 8 to 15% of the total construction volume [3]. Previous papers focusing on home office overhead are also numerous. For example, Adrian and Franks mentioned that the commonly used mechanism for the identification of a company's overhead is to summarize all company overhead costs for a fiscal year, then to scale them against the total direct costs for the same period [4],[5]. Cliensek in 1991 defined home office overhead as the cost needed to operate and manage a construction business [6]. However, few papers have discussed project supervision costs. Most studies mention them only briefly in passing [7],[8]. Costs of project supervision have most often been estimated based on educated guesses.

Discussion of personnel in a company or on construction projects, as "cost" or "asset", has risen since the 1980s [9]-[12]. Over the last two decades numerous research works on human resource management and profit margins have been published. It is now believed that human resources are essential aspects to an organization's or project's success [13]. In the mid-1980s scholars found that the people in a company are key to its competitive advantage [9],[10]. The importance of strategic planning in Human Resource Management (HRM) has also been emphasized. Studies have found that business strategy is now the

most important management issue and will remain so for years [14],[15]. A step-by-step algorithm for the optimization of human resource allocation for a fast food store has been discussed [16].
Approaches and algorithms based on similarity to simulations or modeling help to provide knowledge and reasoning functions. Artificial Intelligence (AI) has been a popular approach applied to industries. AI is generally divided into two major branches, symbolic and connectionist branches [17]-[19]. Both have been widely used in the construction industry. However, research shows that arguments inferred using neural networks are not useful, due to Artificial Neural Networks' (ANN) black-box like characteristics and case-based recording procedures in court [17], [18]. Case-Based Reasoning-oriented (CBR) inference processing exists in numerous studies related to construction. The main CBR algorithm simulates human thinking and logic process with the goal of yielding the most similar cases based on past experience. Even though there is no past experience in the database supporting the input, the CBR algorithm proceeds similarly, to calculate the best answer for the request [20].

3. Data collection and analysis

Model development and simulation always depend on well-defined data. In this study, data collection is based on a pilot investigation. In Taiwan in 2004 there were 16,710 construction companies, divided into 4 classes: A, B, C, and Subclass C. The 13,989 companies classified as Class C or Subclass C are small-sized construction companies. Each one has an annual maximum volume of $60 million NTD each [21]. Class A or B construction companies characteristically perform middle- to large-sized projects. The annual maximum volume of projects for a Class B company is $300 million NTD. No limitation plagues Class A companies. As a result, of all sized projects, only 16.3%, or 2,721, construction companies meet our criteria for further investigation.
According to statistical data sampling principles, the required sample size for random collection if 50 construction companies, satisfying the following assumptions: confidence level of 95%, limit of error of 10%, and proportion of 10-90%. From the public database sponsored by the Ministry of Interior, contact information is available for Class A and B construction firms. We randomly selected 100 construction companies with capital sizes varying from $20 million NTD to $5 billion NTD for in-person or phone interviews to gather related information regarding project costs and on-site supervisory manpower allocation. The essential project supervision costs included eight items: salary, hourly-wage, bonuses, overtime pay, room and board, retirement fund, insurance and other welfare expenses. The investigation range spread was primarily in urban areas of northern Taiwan. This was because most registered construction companies were centralized in northern urban areas. The investigation took a few months. Next we zoomed in on construction projects being built within the last 6 years, or from 2000 to 2005 a period when the inflation rate in Taiwan was relatively low and stable. The 20-year inflation rate is determined to be 2.02% [22]. 125 construction projects randomly selected from Class A or B companies were investigated. Due to integrity of data, conditions of data storage, and business confidentiality requirements, only 65 construction projects are shown. The acceptance rate was 52%. Therefore, statistical requirements are met, and we can have confidence in the collected data.
Fundamental statistical analysis is not used to explore the characteristics of these 65 sets of collected data. Each construction project is managed by on-site HRM in the range of 0~1

project managers, 1~5 senior engineers, and 1~10 engineers. In all collected projects, the total number of on-site supervisory personnel fell in the range between 2 and 16. On-site supervisory salaries vary based on experience and educational background: $37,000 ~ $50,000 NTD/month for an engineer, $45,000 ~ $80,000 NTD/month for a senior engineer, and $60,000 ~ $100,000 NTD/month for a project manager. The average monthly salary for an on-site project manager is approximately $80,000 NTD, while the average monthly salaries for a senior engineer or engineer are approximately $60,000 NTD and $42,000 NTD, respectively.

There are 8 categories of essential project information discussed: project type, owner type, structure type, project size (or contract price), floor area, structure height, construction location, and project duration. In the project type category, residential projects make up 62% of the total, as well as the largest proportion among all other projects. They mainly include villas and apartments. The remaining 38% of the projects is comprised of different types of commercial buildings and industrial facilities. 95% of the projects are private. Most structures are built of reinforced concrete (RC). The ratio of RC structures to total structures is 74%. Precast structures comprised 18% of the total. The other types are steel structures (SS) and steel reinforced concrete (SRC), only constituting 8% of the total. Figure 1 shows that the distribution of the project size based on contract price. 51% of the projects are classified as large-sized construction projects. The largest, approximately $1.99 billion NTD was equal to the size of the smallest one multiplied by 100. The floor area of the largest project was 142,000 m^2 compared to the smallest, 800 m^2. Building heights also varied based on project type. Residential projects are comprised of relatively higher structures. They are constrained by availability of land or limitations of location. The number of the high-rise buildings with heights exceeding 50 meters makes up 14% of the total. Low- and middle- structures less than 36 meters are prevalent at 70%. The final important feature of a construction project is its duration. Naturally complex projects are usually relatively longer in duration. In this research, all investigated projects had durations greater than 6 months. One quarter had durations of less than one year but greater than 6 months; the other three-quarters had durations varying from 1.5 to 2 years. The majority, 35%, ranged between one and 1.5 years.

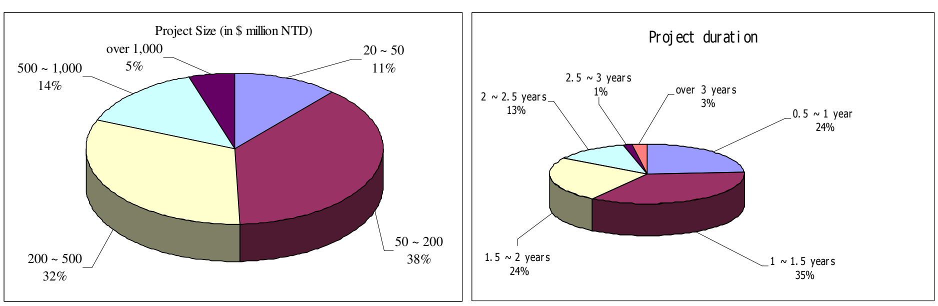

Figure 1: Project size and duration

A comparison of the average monthly productivity and project duration yielded from on-site supervisory costs divided by their actual project prices indicates that project duration is not a significant factor influencing average monthly productivity. An analysis of the average monthly productivity versus floor area and building height indicates that reduction in costs of on-site project supervision, reveal that human resource management enhances to average monthly productivity. The percentage of project completion associated with actual profit margin versus project supervision costs is consistent (Figure 2). The analysis indicates that the investigated construction companies performed well in terms of cost controlling and project management.

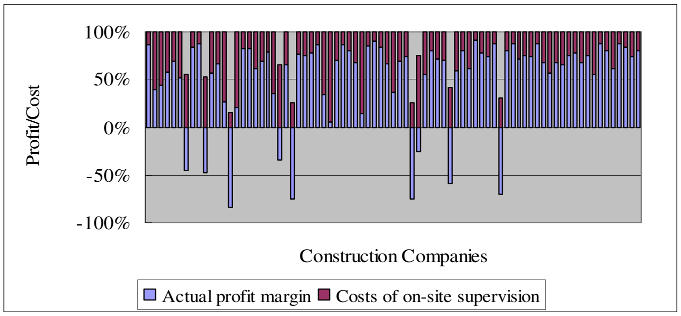

Figure 2: Actual profit margin versus on-site supervisory costs

After data analysis progressive examination is the next objective The standard deviation (σ) and mean value (Y) is calculated for the 65 investigated projects and the statistical boundaries found. Based on the normal distribution the boundaries can be calculated follows:

$$Bounders = Y \pm 2\sigma \qquad \text{Eqn. (1)}$$

where Y = 3.36% and σ= 1.37%.

Thus, the statistical upper and lower bounds of the on-site supervisory costs for $20 million to $2 billion NTD projects (at a 95% confidence interval) are 6.1% and 0.6%, respectively. Next, linear regression is applied to model the relationship between project contract price and on-site supervisory costs. The function of the on-site supervisory costs, Z, is:

$$Z = \$2064191 + \$0.0211X\ , \qquad \text{Eqn. (2)}$$

where X is the cost of on-site supervisory manpower and R^2 equal to 0.76.

However, Equation (2) can be used to explain projects with a contract price close to $20 million or $2 billion NTD. Modification of Equation (2) using a quadratic equation is suggested as follows:

$$Z = \$517164 + \$0.0298X - \$6 \cdot 10^{-12} X^2 . \qquad \text{Eqn. (3)}$$

R^2 obtained from Equation (3) is equal to 0.79 which represents a strong correlation between project on-site supervisory costs and contract price. The function of on-site supervisory costs is explained well through plugging all the conditions described previously back into Equation (3). Thus, we adopt Equation (3) for the cost function of Z and the 2 bound values are 6.1% and 0.6%. We integrate CBR into the inference engine used to predict costs and allocation of on-site supervisory manpower.

4. Model construction

The use of 3-way cross validation with 3 randomly selected groups containing 22, 22, and 21 projects, respectively, is suggested as the validation method, where one out of 3 data groups is assigned to evaluate the model. From a summary of the analysis and basic constraints we can derive an outline of the inference engine. In addition, in the literature it is suggested that CBR is an approach that can effectively provide experience-oriented solutions. Thus we integrate the outline with CBR to develop the model (Figure 3). Given the constraints described above, the similarity calculation states that

$$Similarity\left(f^{I}, f_{i}^{R}\right) = 1 - \frac{\sum_{j=1}^{n} W_{j} \times \frac{| f_{j}^{I} - f_{ij}^{R} |}{f_{j}^{I}}}{\sum_{j=1}^{n} W_{j}}, \quad \text{Eqn. (4)}$$

where:
n: number of indices,
W_j: weight of each index,
f_j^I: the jth index of input cases,
f_{ij}^R: the jth index of previous cases in the litigation database.

Also, the constraints for the similarity calculation are based on the values from the 65 projects combined with Equation (3). They are:
Engineer's salary (S1): $37,000 ≤ S1 ≤ $50,000 NTD/month,
Senior engineer's salary (S2): $45,000 ≤ S2 ≤ $80,000 NTD/month,
Project manager's salary (S3): $60,000 ≤ S3 ≤ $100,000 NTD/month,
Number of engineer (C1): C1 ≥ 0 person/project,
Number of senior engineer (C2): C2 ≥ 1 person/project,
Number of project manager (C3): C3 = 0 or 1 person/project.
Function of on-site supervisory costs (Z): $Z = \$517164 + \$0.0298X - \$6 \cdot 10^{-12} X^2$ NTD/project.

With standardized data, programming is completed utilizing C^{++} language to construct the inference engine. The 24 items from database make up the inputs. With Equation (4), 3-way cross validation, and the constraints, we use the similarity calculation to perform a matrix calculation. We obtain a 130 by 24 matrix with an evaluation matrix of 65 by 24. 130 represents the number of any 2 data groups, multiplied by 3 in the database. The weight for every input is set to 1 as the default value. The optimal similarity value so as to yield the outputs is calculated. Statistics suggest that similarity matching in excess of the confidence interval at 95% (2σ) is significant; therefore any project that yields a similarity value greater than or equal to 95% is displayed. In addition, to prevent all calculated similarity values from being less than 95%, the top 5 most similar projects are displayed. The optimal range of on-site supervisory manpower allocation obtained is shown in Figure 4.

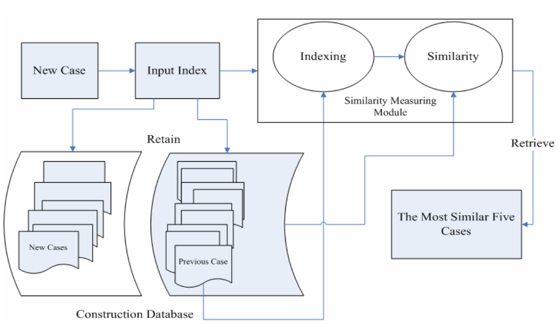

Figure. 3. Model interface

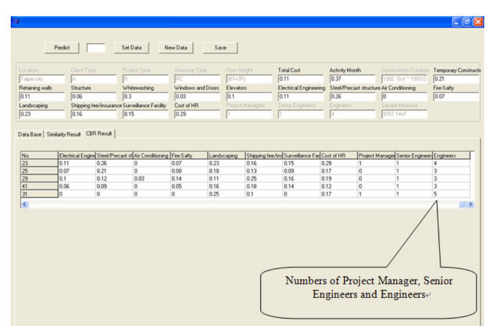

Figure. 4. Optimal allocation range of on-site supervisory manpower

4.1 Model implementation and evaluation

The design and development of the inference engine utilizes only generally available software to assure a user-friendly interface. The database is built using Microsoft Excel and easily provides the administrator with fast maintenance, modification, and operational capability. To execute the inference engine, the user keys in 24 values that follow the format and items in the user interface based on a new contract. The values are the contract price or estimated price at the beginning stage of the new project. By simply clicking the "Predict" button, the results will be displayed immediately. The inference engine is also equipped with a function to save the input data instead of modifying the database file. This not only saves the administrator from wasting data key-in time but expands the database.
Model evaluation is performed according to 3-way cross validation. The 65 evaluation results indicate that the CBR prediction model has high accuracy, as shown in Table 1. The average degree of maximum similarity reaches 95.11%. The average deviations for on-site supervisory allocation are 0.11, 0.08, and 1.08, respectively, resulting in an average deviation of on-site supervisory costs of around $58,900 NTD per month yielded from the sum of each average deviation multiplied by its average salary. By comparing the values obtained for all durations, project contract amounts, and then using Equation (3), the average on-site supervisory costs can be found, approximately $767,000 NTD per project. Thus, the variation of degree of prediction by the model is ±11.53% with and 88.47% accuracy rate. Likewise, this represents ±0.21% of the project contract price. By comparing to ±1% estimation error of the total contract piece for medium-sized projects or above, the model is deemed acceptable.

Table 1: Results of model evaluation

	Actual data (person)		
	PM	S. Engr.	Engr.
Average	0.59	1.45	6.36
Max. value	1	4	26
Min. value	0	1	0

	Evaluation results (person)			
	PM	S. Engr.	Engr.	Similarity (%)
Average	0.48	1.38	5.29	95.11
Max. value	1	3	25	99.40
Min. value	0	1	0	80.38
Average deviation	0.11	0.08	1.08	

5. Discussion

To solve the construction problems described in the introduction, the quadratic regression equation of Z with two statistical bounds and the proposed model are developed. Users can utilize these two bounds and Equation Z to assess supervisory costs. The suggested lower bound is 0.6% of the total construction fee, so any construction project with an on-site supervisory budget less than the lower bound may not be feasible. It can be easily jeopardized by insufficient supervisory manpower, if the contract price is between $20 million and $2 billion NTD. On the other hand, over-budgeting of the supervisory fee causes unnecessary waste. In the collected project data, the minimal contract amount was approximately $20 million NTD with 6 month duration under only one senior engineer who served as the project director. The on-site supervisory fee was 1.80% the contract price.

The project with the largest variation as calculated by Equation Z was a $593 million NTD project that budgeted $30.77 million NTD for the on-site supervisory fee or 5.19% of its contract price. No project with a cost overrun was present in the database.

The proposed model predicts costs and the allocation of on-site supervisory manpower with an accuracy rate of 88.47%. However, it is found that crashing schedules and floor plan construction complexity influence the predicted results significantly. In this research, 5 projects have crashing schedules. A crashing schedule is applied to meet the owner's anticipated deadline. Costs of on-site supervisory manpower increase significantly and the profit is offset. The actual versus predicted manpower allocations under crashing schedules for these 5 projects are presented itself in Table 2. They all faced various degrees of cashing schedule as well as project acceleration. Project acceleration is a major factor leading to increasing on-site supervisory expense; this is why this factor is treated precisely in the proposed model. These 5 projects had an obvious and common feature - relatively low similarity to the others. Prediction variation by the proposed model intensifies when assessing those projects with relatively serious crashing schedules. Few historical projects can match them based on the CBR algorithm and Equation (3). Projects 24, 27, and 50 illustrate this phenomenon here. It is suggested that more data are desirable. Apart from shortage of data for the provision of appropriate inferred estimation, a construction project with a considerable crashing schedule needs to assign more field engineers for supervision. The proposed model prediction results demonstrate weak assessment. This also suggests that the weights need to be adjusted instead of using equal weights among the factors.

Table 2: Actual vs. predicted manpower allocation under a crashing schedule for construction sites

Proj. No.	Contract Price ($ million NTD)	Duration (months)	Similarity (%)	Actual Allocation (person)			Predicted Allocation (person)		
				PM	S. Engr	Engr	PM	S. Engr	Engr
3	611	9	94.21	1	4	26	1	3	18
11	593	11	89.91	1	2	14	0	1	1
24	882	17	90.60	1	3	19	1	1	5
27	1079	16	90.37	1	3	25	1	2	8
50	1759	24	84.89	1	4	26	1	2	16

Table 3: Actual vs. predicted manpower allocation for the most inaccurate prediction

Proj. No.	Contract Price ($ million NTD)	Floor Area (m^2)	Similarity (%)	Actual Allocation (person)			Predicted Allocation (person)		
				PM	S. Engr	Engr	PM	S. Engr	Engr
3	611	50,568	94.21	1	4	26	1	3	18
10	863	43,061	87.19	1	2	8	1	2	16
11	593	19,071	89.91	1	2	14	0	1	1
13	864	49,939	90.16	1	2	8	1	3	25
18	486	37,876	93.23	1	2	8	1	3	18
19	382	39,147	95.67	0	1	3	1	2	14
24	882	61,272	90.60	1	3	19	1	1	5
27	1079	57,376	90.37	1	3	25	1	2	8
40	882	67,191	93.44	1	2	13	1	1	4
50	1759	87,280	84.89	1	4	26	1	2	16
62	664	45,742	89.01	1	2	7	1	3	19

Floor area reflects construction complexity, especially in residential projects. Table 3 exhibits the projects with inaccurate predictions. Except for the construction projects with crashing schedule, Table 4 contains 7 projects whose floor areas are in the top 8; Project 57 is the most complex one with the largest floor area but is excluded here. The predictions for

Project 57 meet the actual on-site supervisory allocation with only slight variations, due to well-fitting explanations by Equation Z and its features. On average, the variation caused by the factor of floor area is slightly less than that caused by the factor of scheduling. The floor area factor still has a significant influence on the predicted results. For example, Project 24 has a relatively large floor area and more scattered construction site that increases difficulty of supervision so more supervisory manpower is assigned. Except for Project 24, 10 other projects also experience inaccurate predictions for the number of field engineers. All these are high-rise buildings. Construction complexity related to floor area and height explains this finding. Therefore, a weighted CBR algorithm and more historical data for the proposed system are recommended.

6. Conclusion

In this study we present a model with which to predict costs and the allocation of on-site supervisory manpower. It is based on the function of on-site supervisory costs regressed from the collected construction project data, and should subsequently provide a useful tool to help project stakeholders to arrange on-site supervisory human resources. An accuracy rate of 88.47% can be obtained for predicting on-site supervisory costs and allocations, which lies in the acceptable range and should have little influence on the profit margin. Nevertheless, it is always desirable to improve the accuracy of a model. It is suggested that plentiful data be included with the CBR inference engine. The construction project data collected so far is relatively insufficient; however, it is difficult to go further on the short-term due to most Taiwan construction companies having poor archive systems. Even though a few have launched fully electronic archive systems, project data are often stored separately in numerous locations or in a disordered way in the same department. This increases the difficulty of data collection. Vigorous and user-friendly archive systems are needed in the construction industry. In future the model can be modified by the use of weighting factors to more closely approach reality. Two significant factors - schedules and floor complexity - dominate the outputs of the model. Statistical methods may be conducted to determine the weights of the factors.

The main contribution of the research is that (1) the tendency of on-site supervisory costs (with R-squares at 0.79) brings the benefit that budget estimates of on-site supervisory costs can be easily obtained once the contract price of a construction project is available; (2) the statistical upper and lower bounds of on-site supervisory costs prevent over- or under-budgeting of on-site supervisory manpower in the initiating or planning phase; and (3) a model is developed to predict costs and allocation of on-site supervisory manpower so as to facilitate cost estimates. All of this will assist planners and project managers to establish appropriate budget and supervisory manpower allocations for project on-site management.

Future work related to this study could be developing a multi-functional resource allocation system based on the proposed model. The scope of this research could be expanded to include the allocation of resources other than human resources using the same methodology. Second, other approaches may be considered to increase the accuracy rate for example other AI approaches, data mining, optimal programming, etc. Finally, automatic archival systems can be built to squirrel away information about construction projects. In an experience-oriented industry such as the construction industry information about construction projects varies widely from case to case. System developers should have comprehensive knowledge about construction. In addition, an accessible platform connecting those construction companies willing to share information is necessary. Recently, the Taiwan government and private service-sector companies have initiated and integrated a similar idea to develop such a platform. An integration of the proposed model and the platform will enhance its practicability.

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