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EVALUATING CRITICAL SUCCESS FACTORS FOR ACCURATE FIRST COST ESTIMATES OF LARGE-SCALE CONSTRUCTION PROJECTS

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ABSTRACT: The demands for large-scale construction projects such as Mega-projects are largely increasing due to the rapid growth of increasing populations as well as the need to replace existing buildings and infrastructure. Increasing costs of materials, supplies, and labors require the first cost estimates at the preliminary planning stage to be as accurate as possible. This paper presents the results obtained from the survey on evaluating nine critical success factors that influence the accurate first cost estimates for large-scale projects from practical experiences. It then examines the current cost structures of construction companies for large-scale projects, followed by the causes for cost and schedule overrun. Twenty completed surveys were collected and the Analytic Hierarchy Process was applied to analyze the data. The results indicate that technology issues, the contract type, and social and environmental impacts are the significant leading factors for accurate first cost estimates of large-scale construction projects.

Keywords: Project management; Cost estimating; Risk; Planning; Mega-project

1. INTRODUCTION

1.1 Research Background

The demands for large-scale construction projects such as Mega-projects are largely increasing due to the rapid growth of increasing populations as well as the need to replace existing buildings and infrastructure. Increasing costs of materials, supplies, and labors require the first cost estimates at the preliminary planning stage to be as accurate as possible. Thus, the accurate early estimate for construction projects plays an extremely important role of making decisions on project development for an organization. Flyvbjerg et al. presented an interesting research finding that public works projects such as rail, road, bridge, and tunnel projects have experienced cost underestimating [1]. Their findings based on 258 transportation infrastructure projects worth US $90 billion explain that cost estimates for large-scale construction projects are significantly unreliable. A study conducted by Kumaraswamy and Morris assessed the sustainability of BOT-type megaprojects in Asia regions [2]. They emphasized the need to search for critical success factors for prospective clients. Therefore, early project estimates increase the importance for the business decisions in a more complicated project environment as well as the basis for the project's ultimate funding.

1.2 Previous Studies

Several studies provide factors that affect the first cost estimate of large-scale construction projects, depending on the geographical locations of projects, different project types, and different historical periods. Merna and Smith classified two stage categories of risk factors [3]. The first factors are political, legal, commercial, and environmental factors, which are generally considered to be beyond control of the project parties. The second ones are construction, design, technology, operation, finance, and revenue risks that are placed in control of the project sponsor to some degree. Tiong identified six critical success factors for Build-Operate-Transfer (BOT) type projects such as entrepreneurship and leadership, right project identification, strength of the consortium, technical solution advantage, financial package differentiation, and differentiation in guarantees [4].

A survey conducted by Akintoye et al. revealed 26 assumed risk factors such as design, construction cost, environmental, and legal risk [5]. It then ranked the importance of these risks by the contractors, clients, and lenders. Tam and Leung evaluated risk management of BOT projects in Southeast Asian countries [6]. They found that political risks are the most difficult to handle, followed by financial and technical risks, respectively. Charoenpornpattana and Minato identified privatization-induced risks in transportation projects in Thailand based on political, economic, legal, transaction, and operation risks [7].

Oberlender and Trost developed an 11-factor model to predict accuracy of early cost estimates based on estimate quality. The eleven factors include formal estimating process, basic process design, bidding and labor climate, site requirement, team experience and cost information, money issues, technology issues, contingency and reviews, team alignment, time allowed to prepare the estimate, and owner's cost [8]. They identified and quantified the drivers of estimate accuracy for capital projects in the process industry, but they did not consider the construction projects in the building and infrastructure sectors. Capka identified major factors for the successful management of a mega-project. The factors include project size, technically complex undertakings, complex procurement contracting, controversy, impact of a protracted lifespan, scope creep, urban setting, human and environmental impacts, and risk and uncertainty [9].

Different studies use different factors, depending on different project types, different geographical regions, and even different historical periods. For this reason, researchers consequently disagree with regard to the reliability of cost estimates. Although decision makers can not consider all of these situations, they still need a systematic way to trust the first cost estimate for large-scale construction projects in deciding whether or not to build them.

1.3 Research Objective and Methodology

Predicting the accurate first cost estimate requires an extensive data analysis from the actual construction projects. Although having a large number of project data is the best way, interviews or surveys are also good alternatives to collect meaningful data. The fundamental problems of inaccurate cost estimating on large-scale projects can be caused by a variety of reasons. In order to address this challenge, this paper attempts to propose a way to identify and assess the critical success factors for the accuracy of early estimates. The main objective of this research is to identify and evaluate critical success factors (CSFs) that influence the accurate first cost estimates of large-scale projects at the preliminary planning phase to discover current cost estimating practices. Three tasks are as follows:

1. To identify and create the CSFs for the success of large-scale construction projects from literature reviews,
2. To evaluate nine CSFs by determining the order of relative importance based on data using Analytical Hierarchy Process (AHP) technique, and
3. To examine the cost structures of construction companies for large-scale projects, followed by the causes for cost and schedule overrun.

To achieve the objectives of this research, a structured survey form was developed. Figure 1 shows one of the pair-wise comparison questionnaires.

Relative importance between two factors			← Factor 1 is more important				equal	Factor 2 is more → important			
Factor 1		Factor 2									
A. Project size and type	vs.	B. Contract type	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	C. Community/Political controversy	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	D. Economic impacts	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	E. Social/Environmental impacts	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	F. Financial risks and funding	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	G. Technology issues	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	H. Management organization	4	3	2	1	0	1	2	3	4
A. Project size and type	vs.	I. Project schedule	4	3	2	1	0	1	2	3	4

Figure 1. Example of pair-wise comparison questionnaire

Data were collected on the final version of the survey form to compare the relative importance of nine CSFs. The structured survey form was designed for data analysis using AHP. The form also enables us to acquire the knowledge and experiences of the experts on the first cost estimates for large-scale construction projects.

A structured survey form consists of two sections. In Section I, the respondents are asked to mark "X" to the appropriate number by comparing relative importance between two factors for 36 pair-wise comparisons. Section II has five questions: (1) respondents are asked to assign main categories by % for the prediction of a first cost estimate, ranging from inception to funding approval of a mega-project; (2) they are asked to compare the first cost estimate to total cost at completion to see how close the two figures were; (3) what were the major causes affecting the cost overrun (+) and/or underrun (-)?; (4) in the case of Question 2, how much did you have schedule overrun (+) and/or underrun (-)?; and (5) what were the major causes affecting the schedule overrun and/or underrun?

The research team conducted a survey using a structured questionnaire on CSFs for large-scale construction projects, including megaprojects, with professional experts. 50 Department of Transportations and "Engineering News Record; the top 50 companies" from each of Design/Build, Construction Management for Fee, and Construction Management at Risk companies in the U.S. are selected for data collection. These companies are big enough to implement large-scale projects, even though collecting a required number of survey responses is highly difficult. We then analyzed data to rank the order of relative importance using the AHP technique.

This paper begins with the definitions of both Mega-projects and first cost estimates, followed by the data analysis section that contains the demographics of respondents and the implementation of AHP technique. The paper then presents the analysis of results and summarizes the conclusions and limitations, followed by the future study.

2. FACTORS FOR FIRST COST ESTIMATES OF LARGE-SCALE PROJECTS

2.1 Mega-projects and First Cost Estimates

The Federal Highway Administration (FHWA) defined megaprojects as “major infrastructure projects that cost more than $1 billion, or projects of a significant cost that attract a high level of public attention or political interest because of substantial direct and indirect impacts on the community, environment, and State budgets [9].” Mega-project can also be defined as a major project, which is complex technically, logistically, and politically in nature, having total installed costs in excess of $1 billion dollars [10].

In order to broadly search for critical success factors in both building and infrastructure sections, the first cost estimate for a large-scale project, including mega-project, is defined in this paper as a preliminary, planning-based number that may lead to unrealistic expectations, but not the engineer’s estimate. Megaprojects and/or large-scale construction projects can be defined as either a huge project worth more than $1 billion dollars, as originally defined by numerous entities, or a project to improve the nation’s social infrastructure, consisting of several smaller investments and being the aggregated value of more than $1 billion dollars.

The definitions of mega-projects and first cost estimates were clearly indicated in the survey in order not to confuse survey respondents. Due to the limited number of projects that go beyond $1 billion dollars over the survey period, the size of a large-scale project is refined for this survey as a project with a budget over $20 million dollars to improve the nation’s social infrastructure. Thus, a single large-scale project with a budget over $20 million can also be applied for the survey.

2.2 Factors Considered

Throughout the information gathering and generation of feasible alternatives from the existing studies mentioned in the previous section, the research team identified nine evaluation criteria associated with their support considerations, which may significantly affect the accuracy of the first cost estimates at the preliminary planning stage of large-scale construction projects. Table 1 summarizes nine critical success factors associated with their supporting considerations. The factors considered in this paper include project size and type (CSF-1), contract type (CSF-2), community or political controversy (CSF-3), economic impacts (CSF-4), social and environmental impact (CSF-5), financial risks and funding (CSF-6), technology issues (CSF-7), management organization (CSF-8), and project schedule (CSF-9).

Table 1. Critical Success Factors with Considerations

ID	Factors	Major supporting considerations
CSF 1	Project size and type	
		Understanding of scope and its creep
		Urban setting
		Right project identification
		Publicity
CSF 2	Contract type	
		Complex procurement contracting
		Allocation of risks
		Bidding climate
CSF 3	Community or Political controversy	
		Stakeholder and public support
		Projects on sensitive ground
		Two state governments involved
		Tax dollars spent
		Political violence
		Government instability
		Terrorist activity
		Risk of nationalization of assets
		Changes in public view as project increases
CSF 4	Economic impacts	
		Money factors
		Economic slowdown of trading partners
		Increase in world oil price and materials
		Currency fluctuation
		Changes in material, labor, equipment prices due to inflation
CSF 5	Social/Environmental impacts	
		Governmental requirements
		Displacement of existing communities
		Loss of livelihoods and jobs
		Changes in natural habitats
		Pollution of air

Table 1. Continued

ID	Factors	Major supporting considerations
CSF 6	Financial risks and funding	
		Owner's costs
		Taxes and insurances
		Funding availability and procurement
		Problem with budget balloon
		Last minute costs
		Changes in funding as project increases
CSF 7	Technology issues	
		Logistics for engineering and construction
		Innovative technologies
		Lack of in-country experience on construction
		Construction equipment
CSF 8	Management organization	
		Mega-management (multiple project participants)
		Work force
		Labor productivity
		Strength of the consortium
		Skill and experience level of management team
CSF 9	Project schedule	
		Longer time horizons
		Changes in supply of labor, material, and equipment
		Schedule conflicts among participants

3. DATA ANALYSIS

3.1 Demographics of Respondents

Twenty completed surveys were collected from professional experts on cost estimating practices of a large-scale project during June 25 – July 28, 2008. All pair-wise comparison data obtained from 20 participants were analyzed. Figure 2 gives a breakdown of the respondents by their experience. A majority of the respondents have above 26 years (73.68%) practical experience on cost estimating, followed by 16-20 years experience (15.79%).

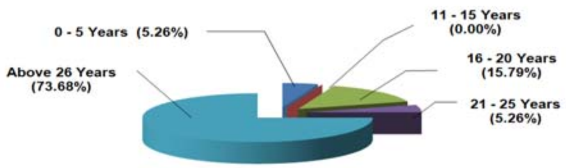

Figure 2. Distribution of Respondent by Experience

Figure 3 shows the distribution of responses by project type. 70 percent of respondents are involved in infrastructure projects such as roads, bridges, ports, toll building gantry, airports, railways, and power, while the rest of respondents take part in building projects such as hospitals, healthcare, hotels, education, laboratories, casino, Disney, warehouse, heavy construction, processing plants and manufacturing facilities, and other industry facility.

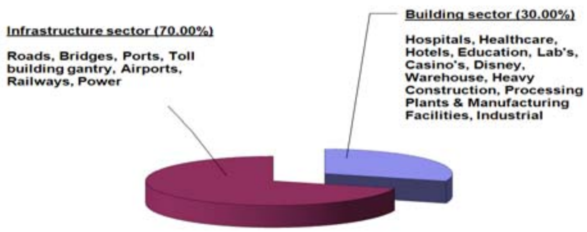

Figure 3. Distribution of Responses by Project Type

Figure 4 shows the distribution of projects by contract type. Most of the projects surveyed in this paper were delivered with Design-Bid-Build contract type (44.44%), followed by Design-Build (18.52%), CM for Fee (7.41%), CM at Risk (7.41%), and other delivery methods. Other delivery methods include General Contractor Cost Plus with Guaranteed Maximum Price, Turnkey, Design-Bid-Build-Finance, Design-Build-Operate, Design-Build-Finance-Operate-Maintain, and Design-Build-Operate-Maintain.

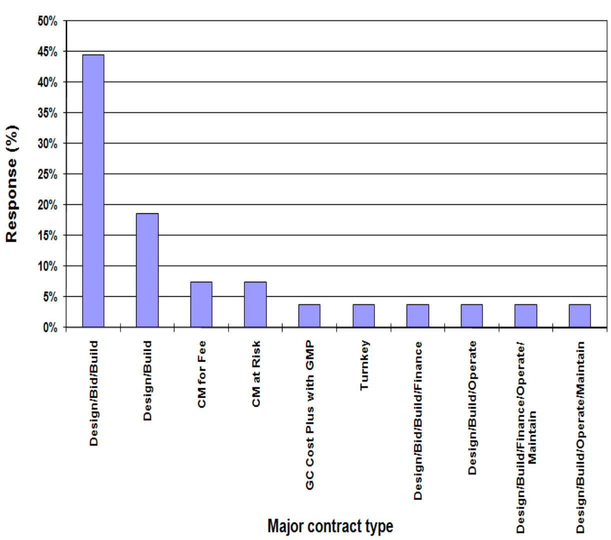

Figure 4. Distribution of Responses by Contract Type

3.2 Analytic Hierarchy Process

The analytic hierarchy process (AHP), which is one of Multi Criteria decision making methods that was originally developed by Satty [11], was used to analyze the data throughout six steps [12]. Figure 5 shows an example of model implementation for pair-wise comparison of the attributes.

Step 1: Hierarchy Construction

As the first phase of the AHP-based criteria evaluation, the research team determined nine major criteria (Level 1) for identifying critical success factor for the accurate first cost estimate of large-scale construction projects, which is the highest level (Level 0). Associated with each criterion, three or more attributes were decided to only support the criterion immediately above them, which constitutes the common basis for the pair-wise comparisons.

Step 2: Pair-wise Comparisons

Relative weights of the attributes were determined by comparing them in pairs using the interrelationships between attributes. Figure 5(a) shows one of total 20 numbers of reciprocal matrices, where data obtained from Section I of the survey form were input. Twenty matrices were developed to compute the relative importance.

Step 3: Relative-Weight Calculation

The average of normalized columns (ANC) method was applied to compute the eigenvector of the decision matrix [11]. Figure 5(b) illustrates the ANC calculation process in detail for pair-wise comparisons of Level 1. Note that three or more attributes (Level 2) that support each factor in Level 1 are not included in this paper.

Step 4: Aggregation of Relative Weights

The overall scores of each alternative, indicating the preference of one alternative over another, were obtained, in addition to the scores for the pair-wise comparisons at Level 1.

Step 5: Consistency Ratio

The consistency ratio (CR) measures, the last element of the AHP, were computed for each reciprocal matrix. Figure 5(c) shows how to check the consistency of data. The CR, which must be less than or equal to 0.10, controls the consistency of pair-wise comparisons.

Step 6: Determination of Ranking Criteria and Attributes

Nine criteria were ranked by allocating the weights of nine to one for the first rank and the ninth rank and then averaged all scores to determine the overall rank for nine criteria.

RECIPROCAL MATRIX (36 pairwise comparisons are needed)

Choice	CSF-1	CSF-2	CSF-3	CSF-4	CSF-5	CSF-6	CSF-7	CSF-8	CSF-9
CSF-1	1.00	1.00	0.20	1.00	0.20	0.33	3.00	1.00	1.00
CSF-2	1.00	1.00	0.33	1.00	0.20	1.00	5.00	3.00	1.00
CSF-3	5.00	3.00	1.00	1.00	1.00	3.00	5.00	5.00	3.00
CSF-4	1.00	1.00	1.00	1.00	0.33	1.00	7.00	3.00	1.00
CSF-5	5.00	5.00	1.00	3.00	1.00	1.00	7.00	5.00	5.00
CSF-6	3.00	1.00	0.33	1.00	0.14	1.00	5.00	7.00	5.00
CSF-7	0.33	0.20	0.20	0.14	0.14	0.20	1.00	1.00	0.20
CSF-8	1.00	0.33	0.20	0.33	0.20	0.14	1.00	1.00	0.20
CSF-9	1.00	1.00	0.33	1.00	0.20	0.20	5.00	5.00	1.00
Column Sum	18.33	13.53	4.60	9.48	3.42	7.88	39.00	31.00	17.40

(a) Reciprocal Matrix

NORMALIZED MATRIX

Choice	CSF-1	CSF-2	CSF-3	CSF-4	CSF-5	CSF-6	CSF-7	CSF-8	CSF-9	Row sum	Priority vector
CSF-1	0.055	0.074	0.043	0.106	0.058	0.042	0.077	0.032	0.057	0.545	0.06
CSF-2	0.055	0.074	0.072	0.106	0.058	0.127	0.128	0.097	0.057	0.774	0.09
CSF-3	0.273	0.222	0.217	0.106	0.292	0.381	0.128	0.161	0.172	1.953	0.22
CSF-4	0.055	0.074	0.217	0.106	0.097	0.127	0.179	0.097	0.057	1.010	0.11
CSF-5	0.273	0.369	0.217	0.317	0.292	0.127	0.179	0.161	0.287	2.224	0.25
CSF-6	0.164	0.074	0.072	0.106	0.042	0.127	0.128	0.226	0.287	1.226	0.14
CSF-7	0.018	0.015	0.043	0.015	0.042	0.025	0.026	0.032	0.011	0.228	0.03
CSF-8	0.055	0.025	0.043	0.035	0.058	0.018	0.026	0.032	0.011	0.304	0.03
CSF-9	0.055	0.074	0.072	0.106	0.058	0.025	0.128	0.161	0.057	0.737	0.08
Column Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	9.000	1.000

(b) Normalized Matrix

lambda max (Eigenvalue) =	9.71		
Consistency Index (CI) =	0.09	n =	9
Random Consistency Index (RI) =	1.45 Obtained from Satty's table when n=9		
Consistency Ratio (CR) =	0.06		

Inconsistency is acceptable since CR <= 0.10.

(c) Consistency Ratio

Figure 5. Model Implementation: Pair-wise comparison

4. ANALYSIS OF RESULTS

This section presents analysis of results, which include (1) relative importance of CSFs; (2) cost structure for building projects; and (3) cost structure for infrastructure projects. It then discusses lessens learned from practical experience with regard to the causes that affects the cost overrun and/or underrun, followed by the schedule overrun and/or underrun.

Application of the AHP methodology, which includes (1) constructing hierarchies; (2) establishing priorities; and (3) verifying logical consistency, brought meaningful results. Data collected from this research were only used to present the results. Figure 6 shows the final rating of the nine CSFs in Level 1. The result indicates that technology issues (CSF-7), contract type (CSF-2), and social/environmental impacts (CSF-5) represent 13.51%, 12.98%, and 12.57%, respectively. This means that they are likely to be the leading criteria among nine factors, followed by economic impacts (CSF-4, 11.93%), community or political controversy (CSF-3, 11.64%), management organization (CSF-8, 11.29%), and project size and type (CSF-1, 10.29%). Both project schedule (CSF-9, 8.65%) and financial risks and funding (CSF-6, 7.13%) are found to be the least significant factors.

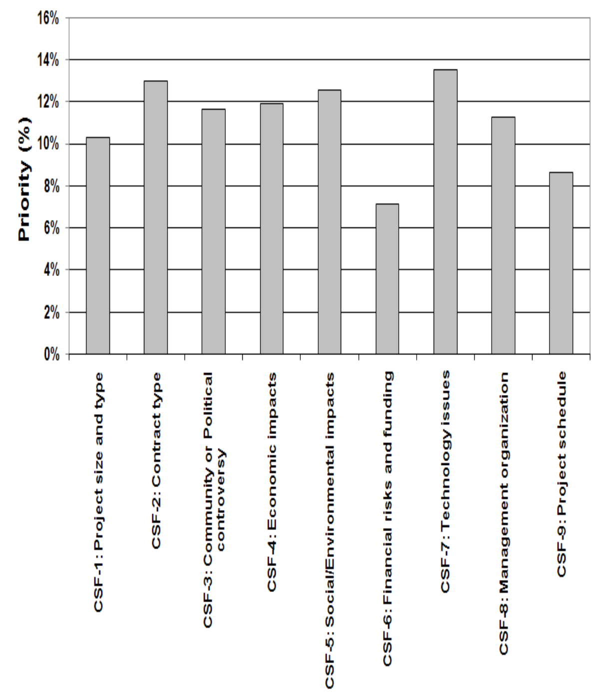

Figure 6. Final ratings of CSFs

Cost structure for building projects consist of three categories such as hard cost, soft cost, and financing cost. Cost items under hard cost include procurement and contracting requirements, general requirements, facility construction, facility service, site and infrastructure, process equipment, occupancy, inspections, testing, and balancing, and others. Cost items under soft cost are owner responsibility, professional services fees, escalation and currency, owner's contingency, owner specific equipment and furnishings, technology (Computers, phones, etc.), land costs and development fees, environmental impact costs, and others. Cost items under financing cost include planning phase, construction phase, permanent mortgage, and others. Figure 7 shows the proportion of cost structure for building projects. The proportions for hard cost, soft cost, and financing cost in the building sector represent on average 48.75%, 36.25%, and 15.00%, respectively.

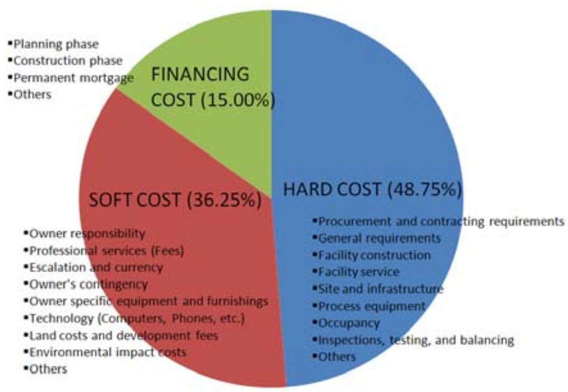

Figure 7. Proportion of cost structure in building sector

Cost structure for infrastructure projects consist of three categories such as project capital cost, development cost, and operations and maintenance (O&M) cost. Cost items under project capital cost include overhead, construction, equipment, engineering, and design, capital cost escalation, capital cost risk, and others. Cost items under development cost are proposal, financial close, development close, development overhead, development escalation, development risk, and others. Cost items under operations and maintenance cost include operations, maintenance, transfer, O&M escalation, O&M risk, and others. Figure 8 shows the proportion of cost structure for infrastructure projects. The proportions for project capital cost, development cost, and O&M cost represent on average 67.64%, 16.91%, and 15.45%, respectively.

The research findings on cost structures indicate that the proportions of cost categories showed different pattern so the accurate cost estimates based on cost structures need to be predicted separately for building and infrastructure sectors.

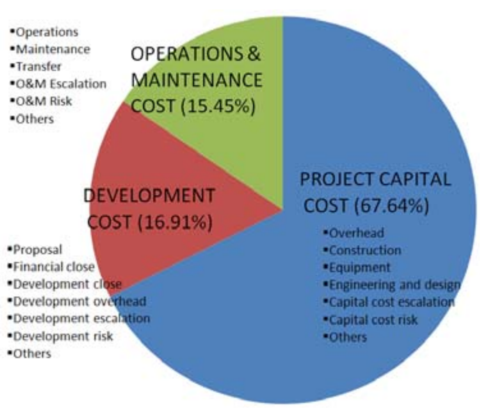

Figure 8. Proportion of cost structure in infrastructure sector

Cost overrun, which is also known as cost escalation, is an international convention and it measures the inaccuracy of cost estimates. Cost overrun can be calculated from actual costs minus estimated costs in percent of estimated costs [1]. Lessens learned from practical experience with regard to the causes that affects the cost overrun and/or underrun are found to be scope change and rough initial estimate. Understanding of scope definition is also needed for all team members. Other possible causes include project management structure contributed to organization's ability to control costs and to complete the project under the given budget, increasing costs of materials, supplies, and labors due to their escalation, increase in construction cost escalation, environmental regulation changes, inflation, development delays over 10 years, insufficient detail engineering quantities that are not available earlier in the process, and bad schedules.

Lessens learned from practical experience with regard to the causes that affects the schedule overrun and/or underrun are found to be right-of-way acquisition, equipment and material procurement (Delay in major equipment delivers, especially, long lead items), environmental problems. Other reasonable causes include the ability to manage multiple critical paths and change schedule logic allowed the project to complete on time, condition change and dispute resolution, lack of good management and team work for early project completion, control of vendor/shop schedules, approvals, local issues, and funding, widely optimistic initial schedule, political support for funding project, availability of construction funds because sometimes overall schedule exceeds initial schedule by more than 200%, and unforeseen issues.

5. CONCLUSIONS AND LIMITATIONS

This paper presented the evaluation of nine critical success factors for accurate first cost estimates of large-scale construction projects. Technology issues, contract type, and social and environmental impacts are the leading factors among nine factors. Both project schedule and financial risks and funding are found to be the least significant factors. The research findings on cost structures indicate that the proportions of cost categories showed different pattern so the accurate cost estimates based on cost structures need to be predicted separately for building and infrastructure sectors. Scope change and rough initial estimate are found to be the significant causes that affect cost overrun/underrun, while right-of-way acquisition, equipment and material procurement, environmental problems are found to be the most common causes for schedule overrun/underrun.

Modification and redistribution of the current survey form is required because some of data showed that the consistent ratio (CR) is not acceptable due to either the lack of the thorough understanding and knowledge for the AHP survey of respondents or the lack of the sufficient materials for decision makers, even though AHP allows some small inconsistency in human judgment.

In the future study, data collected will be separated between building and infrastructure sectors. For each sector, the relationships between contract type and factors for the first cost estimates need to be examined using more data, which will improve the consistency and accuracy of the survey results.

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