Built Environment Project and Asset Management

Simulation techniques for cost management and performance in construction projects in Malaysia

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Abstract

Purpose: Simulation techniques for cost management are useful for modeling uncertainties, making decisions, and improving the accuracy of cost estimation. Despite their usefulness, the application of these techniques in construction projects seems to be uncommon in the construction sector in Malaysia. The purpose of this paper is to determine the application of simulation techniques for cost estimation and control and to assess their influence on project cost performance.

Design/methodology/approach: A survey questionnaire was used to collect data from 83 government agencies, consultant firms, and contractor firms in Kuala Lumpur, Malaysia.

Findings: The findings revealed that knowledge of respondents and usage of cost simulation techniques in the Malaysian construction industry is low. In addition, main barriers of implementing cost simulation techniques are identified. Cost performance of construction projects in Malaysia is satisfactory; however, there is no association between this performance and the application of simulation techniques.

Originality/value: This paper contributes to construction management field by highlighting the main simulation techniques for cost management and drawing the attention of construction professionals and contractors to implement these techniques in construction projects.

Keywords: 4D simulation; BIM; Cost Estimates; Contingency Planning; Monte Carlo Simulation; Performance.

Manuscript Type: Research Paper

Introduction

Cost is one of the most important elements throughout the project life cycle, which can determine the success or failure of a project. High accuracy of cost estimation and control is important to prevent cost overrun at the end of the project (Ali and Kamaruzzaman, 2010). The advancement of computer programs has facilitated the usage of simulation techniques to perform complex mathematical and statistical analyses (Ashworth, 2004). Simulation techniques are used to analyze and assess uncertainties causing issues to project budget. The accuracy of cost estimation can be improved through high level of work definition and risk analysis (Potts and Ankrah, 2014). By using simulation techniques, cost estimator has a better understanding of factors causing cost variance, which enable him/her to make better decision and produce accurate estimation.

The detailed cost estimation is converted to a project budget for controlling and monitoring purpose. Project budget or cost baseline is estimated by aggregating the cost of project activities and the cost of contingencies (Norman *et al.*, 2010). Contingencies are included in the budget to respond to anticipated (known) risks at the activities level (Cernauskas and Kumiega, 2008) and to unanticipated (unknown) risks at the project level (Adafin *et al.*, 2014). Project managers and consultants rely on conventional methods to estimate contingencies such as self-experience, intuition, and judgment (Adafin *et al.*, 2014). The usage of traditional techniques of cost estimation may result in over-budgeted or under-budgeted projects. Non-traditional methods such as Monte Carlo simulation, case-based reasoning, neural networks, and multiple regression analysis can be used to forecast cost using probability distribution and improve the accuracy of the estimation (Aram *et al.*, 2014; Kim *et al.*, 2004). However, there is a low uptake of simulation techniques for cost estimation and control in the construction industry (Chou, 2011). Probabilistic estimation is more scientific approach to estimate contingencies but it is seldom used in the construction industry (Uher, 1996). In addition, Akintoye and Fitzgerald (2000) find that complex statistical formula and range estimation (probabilistic technique) are among the least techniques used by contractors for cost estimation in the UK.

Previous studies on cost simulation in construction focused on developing a Monte Carlo simulation procedure for road projects (Chou, 2011) and quantifying cost resulted from project delay (Cernauskas and Kumiega, 2008). There is a need to conduct more studies to explore the application of simulation techniques for cost management in construction projects. The purpose of this paper is to provide an insight into the application and limitations of cost simulation techniques and their influence on the performance of construction projects in Malaysia.

The next section provides a review of the literature on cost estimation using simulation techniques followed by two sections about the advantages and limitations of simulation techniques. The section after that outlines the research method used in this study using questionnaire survey. The section after that provides a discussion of the results. The last section concludes the study and provides study's contributions and future research.

Simulation Techniques for Cost Management

Simulation is a computer-based math-logical modeling technique which involves deterministic and stochastic variables and represents graphically the activities occurring in the construction operation process (Castro and Dawood, 2004). The main function of simulation is to determine and analyze the behavior of a construction system (Castro and Dawood, 2004). Therefore, simulation can be used in scheduling, quantitative risk analysis, forecasting, planning, process engineering, resource allocation, strategy, and organizational design (Jahangirian *et al.*, 2010; Kwak and Ingall, 2007; Schwalbe, 2013). There are different computer programs that can perform simulation such as Crystal Ball for modeling uncertainties and making decisions (Loizou and French, 2012). Innovaya and ConstructSim (Bentley) can be used for cost estimation and simulation. The most common approaches of simulation mentioned in the literature are Monte Carlo simulation and virtual simulation or four-dimensional (4D) construction simulation, which can be used for cost estimation and control.

Monte Carlo simulation is one of the earliest simulation method (Jahangirian *et al.*, 2010), which is a probabilistic technique that can be applied for cost estimation and decision making (Chou, 2011). This approach uses a large number of simulated trials and sampling technique to approximate a solution to a problem (Ashworth, 2004; Grinstead and Snell, 2012), such as developing realistic cost estimate (Khedr, 2006). The application of Monte Carlo simulation includes a stochastic technique that calculates values fall within a specified probability distribution (Potts and Ankrah, 2014). The distributions of project variables are used to generate random value for each variable and repeated hundreds or thousands times to calculate the overall distribution of the project (Kwak and Ingall, 2007; PMI, 2013). With the advances of computer technology, the repetitiveness of the process and the handling of huge amount of numerical information is no longer a barrier in implementing Monte Carlo simulation (Bennett and Ormerod, 1984). Monte Carlo became an alternative for the program evaluation and review technique (PERT) for cost estimation (Balcombe and Smith, 1999; Khedr, 2006; Moselhi, 1997). Furthermore, this approach can be used to determine final budget at project completion and contingencies estimation, which can be calculated based on the probability distribution of the final budget (Kwak and Ingall, 2007). The general processes of simulation include data collection, random number generation, formulation of the model, data analysis, and visual presentation (Chou, 2011).

On the other hand, virtual simulation or 4D visualizes project information such as the schedule prior to the construction phase (Heesom and Mahdjoubi, 2004). The concept is to link time information with the traditional 3D model and display the construction schedule to simulate construction activities (Wang and Messner, 2007; Wang *et al.*, 2004). 4D simulation is not used directly in cost simulation but it can be used to optimize project cost by eliminating idle cost, ensuring the project runs smoothly without delays, and controlling cost by anticipating risks.

Building Information Modeling (BIM) provides a platform to visualize construction process and identify clashes of design. Autodesk, Bentley, Vico, Nemetschek, Cost-X are some examples of BIM programs (Latiffi *et al.*, 2013). In order to create 4D simulation in BIM model, Autodesk Navisworks can be used as a platform to create a multidiscipline model to simulate the planned construction process (Latiffi *et al.*, 2013).

Benefits of Simulation Techniques

There are many benefits of applying simulation techniques in construction projects. Simulation aids in cost estimation, project planning, change control of the project, risk analysis, review constructability, and scenario-based planning such as what-if analysis (AbouRizk, 2010; Balcombe and Smith, 1999; Wood, 2002). Specifically, Monte Carlo simulation helps project managers to quantify and justify project reserves based on the identified risk (Kwak and Ingall, 2007). By using 4D simulation, the construction team can discuss together and provide suggestions on which design and construction method is most suitable, cost effective, and less time consuming (Latiffi et al., 2013). 4D simulation can be used to visualize and conceptualize construction process and progress and this makes project stakeholders understand the project plan evolved quickly and thoroughly, improves construction management, and aids in decision making (Heesom and Mahdjoubi, 2004). Koo and Fischer (2000) report that simulation model can improve communication between project participants and safety by anticipating hazard in the construction site. Other benefits of simulation relevant to project cost include better understanding of construction system (e.g. constructability), which reduces cost of rework; automatic takeoff of quantities, better risk response and mitigation through accurate contingency allocation; better resource management including cost; and more accuracy of cost-related works such as estimation, budgeting, and controlling (Ashworth, 2004; Bennett and Ormerod, 1984; Cernauskas and Kumiega, 2008; Heesom and Mahdjoubi, 2004; Koo and Fischer, 2000; Loizou and French, 2012; Mahalingam *et al.*, 2010; Nemuth, 2008; Ng *et al.*, 2009; Staub *et al.*, 1998; Wang *et al.*, 2004).

Limitations of Simulation Techniques

Regardless of the several benefits of simulation, there are some limitations of the application of this concept in construction. The usage of simulation techniques requires a certain level of skills to run the models effectively and accurately (Sutrisna *et al.*, 2015). According to Mahalingam *et al.* (2010), many construction professionals have heard about simulation but they do not have the skills to use it. Simulation model usage is sophisticated as users need to know probability distributions for each variable and correlation between them (Loizou and French, 2012; Touran and Wiser, 1992). The selection of wrong probability distributions may cause inaccurate cost estimation. Besides, the application of simulation is time-consuming due to the repetition of trials and the levels of details required to build up the models that address the needs of different parties involved (Bennett and Ormerod, 1984; Loizou and French, 2012; Mahalingam *et al.*, 2010; Moselhi, 1997). Furthermore, the generated data requires considerable time and efforts to convert it to strategic information and act upon it. Kwak and Ingall (2007) mention high amount of time and resources required, lack of user-friendly software, and difficulty to incorporate management action in the simulation. In Malaysia, the application of simulation techniques is seen as an expensive technology to be adopted in construction projects (Latiffi *et al.*, 2013).

Research Method

Questionnaire survey structure

This research is conducted to determine the application of simulation techniques in construction projects in Malaysia and assess the influence of their usage on cost performance. To achieve these objectives, a structured questionnaire survey was used. Questionnaire surveys are among the most popular methods of data collection (Kothari, 2004) as they permit collecting large amount of data from respondents who are dispersed in a wide geographical area. In addition, questionnaire surveys can be used to sampling a large population with lower cost and efforts and when the purpose is to generalize the finding (Naoum, 2012).

In this study, the questionnaire was divided into five parts. Part 1 included questions about the demographic information of the respondents. Part 2 comprised 7 questions to assess the practice of contingency estimation and the application of cost simulation techniques in general. The first question in this section asked about the method used for calculating contingency cost. The second and third questions attempted to measure respondents' understanding of simulation techniques and programs used for cost estimation and control. Fourth, fifth and sixth questions asked about the respondents' understanding and opinions on the usage of simulation techniques. The last question asked whether companies provide training for staff to use simulation. Part 3 aimed to assess the usage of simulation techniques for cost estimation and control in the following applications: perform what-if analysis, identify risk, measure effect of risk, compute chances of the project being completed within budget, aid decision making throughout the project, develop cost estimate, estimate contingency cost, calculate resource usage, increase accuracy of cost estimating, control cost throughout the project, eliminate waste cost, and prevent cost overrun. A 5-point Likert scale was provided for rating the usage of these techniques, in which 1=Not applied at all, 2=Applied in very few projects, 3=Do not know or Neutral, 4=Applied in most projects, and 5=Applied in all projects. Part 4 aimed to identify the barriers of applying cost simulation techniques, which highlighted in the previous section. A 5-point Likert scale was provided for rating the agreement of participants with the barriers (ranged from 1=Totally Disagree to 5=Totally Agree). Lastly, part 5 provided a multi-choice measurement of cost performance based on the experience and perspective of the respondents. Using this measurement facilitated the assessment of project cost performance from different aspects including the overall cost performance, percentage of projects experienced cost overrun, extent of cost variance if project experienced cost overrun, and difference between estimated contingency cost and the actual contingency cost.

Research context and participants

The population of this study included different sizes and types of construction companies in Malaysia such as government agencies, contractor, consultant, and developer firms. Since the population is very large, the research is narrowed down to Kuala Lumpur, which involves most active construction companies. Based on the information obtained from the official portal of Ministry of Works Malaysia, Real Estate Housing Developers Association Selangor (REHDA Selangor), Board of Quantity Surveyors Malaysia (BQSM), The Association of Consulting Engineers Malaysia (ACEM) and Construction Industry Development Board (CIDB), the total number of government agencies and registered active developer, consultant, and contractor firms in Kuala Lumpur was 8063. Among these firms, 5 are government agencies, 74 are developer firms, 145 are consultant firms, and 7839 are contractor firms. A random sample proportionated to the number of firms in each category was taken from this population. The formula used to calculate the sample size (s) from this population is (Krejcie and Morgan, 1970):

$$s = \frac{X^2 NP\,(1-P)}{d^2\,(N-1) + X^2 P\,(1-P)}$$

Where X^2 = table value of chi-square for 1 degree of freedom at the desired confidence level (1.96x1.96 = 3.841 for 95% confidence level); N = population size; P = population proportion (assumed to be 0.5 as this will provide the maximum sample size); and d = degree of accuracy expressed as a proportion (0.05).

Based on sample size calculation, 367 questionnaires were distributed randomly to the construction firms. Among these, 267 sets were sent out through email while 100 sets were delivered by hand. Project managers, quantity surveyors, and project engineers were the targeted group to answer the questionnaire survey.

Results and Discussion

Demographic information and reliability

In total, 83 questionnaire sets were satisfactorily completed and returned back, representing 23% response rate. The response rate using the email was about 14% and the response rate using the self-administered method was much better at 46%. Among the responses, 45 questionnaires were received from contractors, 21 sets from consultants, 12 sets from developers and 5 sets from government agencies. A limitation of this distribution is the difficulty to conduct comparative analysis to determine if there is a difference of using simulation techniques among these companies. However, targeting different types of companies can enhance the generalizability of findings. Most of the respondents were quantity surveyors, project managers, and project engineers. The respondents are well educated and have various years of working experience. Almost 70% of the respondents have more than 5 years of working experience. Table 1 shows the profile of companies and respondents. The reliability of the questionnaire was tested using Cronbach's Alpha, which scored 0.89 indicating reliable measurement instrument (Sekaran, 2006).

<Table 1 is about here>

Simulation techniques usage and understanding

The results in Table 2 show that contingency cost estimation is common in most construction projects (used by about 95% of construction companies). However, contingency cost is mostly calculated using traditional methods by adding a percentage (69.9%) or putting a lump sum (16.9%) to the base estimate. Few construction companies use simulation techniques to forecast contingency cost. Only 3.6% of the companies use Monte Carlo simulation and 6% of the companies use 4D simulation. This clearly shows that the adoption of simulation techniques in contingency cost estimation is still low.

Apart from simulation techniques, few companies use simulation programs for cost estimation and control such as Innovaya (1.2%), Bentley ConstructSim (2.4%), and Oracle Crystal Ball (6.0%). Under other simulation software, 9.6% of the respondents mentioned Buildsoft, Cost-X, BIM, Autodesk Navisworks, and SKALA. Buildsoft is a software developer of some related programs such as CUBIT and MudShark. These programs are useful for construction cost estimation and quantity takeoff but they cannot perform simulation functions such as running trials or providing approximation of solutions. While, Cost-X is a BIM-based estimating program (Latiffi *et al.*, 2013) and therefore can be considered a simulation tool. BIM, on the other hand, is part of 4D simulation whereas Autodesk Navisworks is considered a BIM tool platform. While, SKALA (*sistem kawal dan lapor* or report and control system) is developed by the Malaysian Public Works Department as project management system to track and monitor the progress of construction projects. Thus, SKALA is not a simulation tool rather a reporting and monitoring platform. This result indicates that some respondents lack a clear understanding of simulation techniques.

<Table 2 is about here>

In general, most of the respondents have fair (38.6%) and poor (28.9%) understanding level towards the usage of simulation techniques. Other respondents (9.6%) selected the answer "Not sure". Thus, most of the respondents have low understanding towards these techniques. The respondents also asked to rate the application level of cost simulation techniques in the Malaysian construction industry. Most of them rated poor and fair application levels. This result affirms that the usage of information technology in the Malaysian construction industry is low (Latiffi et al., 2013).

Regardless of the low level of understanding and application of cost simulation techniques, majority of the respondents believe that these techniques can be useful and can ease their work. None of them chose "Not useful" rating. However, majority of construction companies (about 64%) do not provide any training for staffs about simulation techniques of cost management. This shows that there is less support from construction companies in applying these techniques. Training is imperative to increase awareness and provide technical knowledge about the application of simulation.

Application areas and barriers

Construction management style was described as traditional with lack of simulation and visualization process in managing projects (Shah *et al.*, 2009). Figure 1 shows the percentage of respondents' answer to the application areas of simulation techniques and the mean values of each of these areas. About 40% of the respondents have never applied simulation in their projects and answered "Not applied at all" for all of the listed application areas. This result indicates clearly that simulation application for cost management in construction projects in Malaysia is still low. If used widely, simulation techniques can have different applications. Accurate cost estimation can increase the chance of completing projects within budget. Improving decision-making process contributes to better project planning, controlling of cost, and preventing cost overrun. All of these application areas are linked with each other to perform full cost management cycle from estimation and planning to control.

<Figure 1 is about here>

The low level simulation techniques application is related to some barriers highlighted by the respondents. Price of software, lack of awareness, lack of skills, sophistication, appropriate software for particular purpose, and time consuming are the barriers of implementing simulation (mean values are 3.87, 3.80, 3.63, 3.63, 3.59, and 3.48 respectively). Previous studies highlighted similar barriers in construction projects including traditional barriers such as lack of awareness, time consuming, price, lack of simulation programs, lack of skills, and sophistication of simulation process (Bennett and Ormerod, 1984; Campbell *et al.*, 1997; Latiffi *et al.*, 2013; Mahalingam *et al.*, 2010). Overcoming these barriers can enhance the application and usage of simulation techniques. The performing companies (e.g. owner's organization), external organizations (e.g. such as the Construction Industry Development Board, Malaysia), and associations have to exert more efforts to promote simulation techniques implementation and increase the awareness about their usefulness among contractors and consultants. Training is necessary to enhance the skill level of project managers and estimators so they can use simulation techniques easily and accurately. Lastly, there is a need to develop more user-friendly and cheaper software programs that perform complex mathematical modeling and simulation runs easily.

Project cost performance

As shown in Table 3, more than half of the respondents (57.8%) emphasized that construction projects are completed according to the targeted cost. While, 26.5% of the projects are completed over the cost target (cost overrun) and 6% of the projects are completed with a cost that is lower than the target. In addition, 59% of the respondents specified that only few projects (20% or less) experienced cost overrun. Moreover, the cost variance is not very high if projects experienced cost overrun. Majority of respondents (about 61%) believed that cost overrun did not exceed 20% of target cost. Lastly, about 48% of the projects completed with a small variance (i.e. less than 20%) between estimated contingency and actual contingency. Thus, based on these results, the overall cost performance of construction projects in Malaysia is satisfactory.

<Table 3 is about here>

As shown in the previous results, the usage of simulation techniques in construction projects was low while cost performance was satisfactory. To check if there is an association between cost performance and simulation techniques application, Pearson correlation test was performed. Table 4 presents the result of correlations between cost performance and simulation techniques usage and barriers. The results show no association between simulation techniques implementation and all the indicators of cost performance including general cost performance, difference between estimated and final costs, and difference between estimated and actual contingency costs. Project cost performance may be attributed by 'non-technical' factors other than simulation techniques. Financial resource management, project management and contract administration, contractor's site management, material and machinery resources, labor resource, and external factors are the main factors contributing to cost performance (Memon *et al.*, 2012). Perhaps, the influence of simulation techniques on cost management can only be observed when simulation is applied widely in construction projects.

<Table 4 is about here>

Conclusion

This paper presents the results of the implementation and barriers of cost simulation techniques based on the perception of professionals working in construction projects in Malaysia. The associations between project cost performance and simulation techniques implementation, usage, and barriers are presented in this paper. The level of understanding and usage of simulation techniques in Malaysia is still low. These techniques have not been widely applied in cost management activities such as what-if analysis, cost estimation accuracy, risk analysis, and contingency cost estimation. The low uptake of these techniques can be related to some identified barriers including the high price of simulation techniques, lack of awareness, lack of skills, and sophistication of simulation process.

Although the study did not find an association between the implementation of simulation techniques and project cost performance, there is a need to promote the application of these techniques to attain the other benefits of cost management during project planning and control. The full potential and benefits of simulation techniques can only be realized when these techniques are applied widely in construction projects. Construction key players including the government, construction associations, and performing organizations should have a role to play in increasing the awareness of simulation tools implementation and benefits. Consequently, more accurate cost estimation and control can be attained, which contribute to better project cost performance. The identified techniques and factors in this study can be used as a guideline for construction companies to increase simulation awareness, usage, and implementation. Future research can be conducted about trend analysis of technology usage and its association with cost performance over a period of time so the role of simulation can be understood better.

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Table 1: Profile of the respondents

Characteristics	Frequency	Percentage (%)
1. *Type of organization*		
- Contractor	45	54.2
- Consultant	21	25.3
- Developer	12	14.5
- Government agency	5	6.0
2. *Type of projects that respondents' companies have conducted*		
- Mixed development	32	38.6
- Infrastructure	15	18.1
- Residential building	15	18.1
- Non-residential building	15	18.1
- Social amenities	5	6.0
- Others	1	1.2
3. *Company's size*		
- Large	41	49.4
- Medium	27	32.5
- Small	15	18.1
4. *Working position*		
- Quantity surveyor	45	54.2
- Project engineer	16	19.3
- Project manager	14	16.9
- Others	8	9.6
5. *Education level*		
- Degree	61	73.5
- Masters	12	14.5
- Diploma	8	9.6
- Certificate	1	1.2
- PhD	1	1.2
6. *Working experience*		
- 5-10 years	28	33.7
- Less than 5 years	22	26.5
- More than 15 years	22	26.5
- 10-15 years	11	13.3

Table 2: Results of general understanding of cost simulation techniques

Questions	Frequency	Percentage (%)
1. *How contingency cost is being calculated in your company?*		
☐ By adding percentage on the base estimate	58	69.9
☐ By putting lump sum based on intuition or experience	14	16.9
☐ By using simulation techniques to develop predictive model to forecast contingency	7	8.4
☐ Do not calculate contingency cost	1	1.2
☐ Not sure	3	3.6
2. *Which of the following simulation techniques for cost management are used in your company?*		
☐ Monte Carlo simulation	3	3.6
☐ Virtual simulation (4D simulation)	5	6.0
☐ None of the above	59	71.1
☐ Not sure	8	9.6
☐ Others (please specify....)	8	9.6
3. *Which of the following simulation software are used in your company for cost estimation and control?*		
☐ Innovaya	1	1.2
☐ Bentley ConstructSim	2	2.4
☐ Oracle Crystal Ball	5	6.0
☐ None of the above	64	77.1
☐ Not sure	4	4.8
☐ Others (please specify....)	7	8.4
4. *How would you rate the level of your understanding of the cost simulation techniques?*		
☐ Poor	24	28.9
☐ Fair	32	38.6
☐ Good	17	20.5
☐ Excellent	2	2.4
☐ Not sure	8	9.6
5. *In your opinion, how would you rate the application of simulation techniques in the Malaysian construction industry?*		
☐ Poor	29	34.9
☐ Fair	22	26.5
☐ Good	20	24.1
☐ Excellent	4	4.8
☐ Not sure	8	9.6
6. *In your opinion, how would you rate the usefulness of simulation techniques for cost estimation and control?*		
☐ Not useful	0	0
☐ Less useful	15	18.1
☐ Useful	42	50.6
☐ Very useful	12	14.5
☐ Not sure	14	16.9
7. *Does your company provide any training to conduct cost simulation techniques?*		
☐ Yes	30	36.1
☐ No	53	63.9

Table 3: Results of construction cost performance based on respondents' view

Questions	**Frequency**	**Percentage (%)**
1. *Generally, how is the cost performance of construction project conducted by your company?*		
☐ Under cost target	5	6.0
☐ On cost target	48	57.8
☐ Over cost target	22	26.5
☐ Not sure	8	9.6
2. *Based on all projects in your company, what is percentage of the total projects that experienced cost overrun?*		
☐ 0-20%	49	59.0
☐ 20-40%	18	21.7
☐ More than 50%	4	4.8
☐ Not sure	12	14.5
3. *What is the difference in terms of percentage between the estimated cost and final cost if the project experience cost overrun?*		
☐ 0-20%	51	61.4
☐ 20-40%	15	18.1
☐ More than 50%	4	4.8
☐ Not sure	13	15.7
4. *What is the difference between estimated contingency cost and the actual contingency cost?*		
☐ 0-20%	40	48.2
☐ 20-40%	17	20.5
☐ More than 50%	5	6.0
☐ Not sure	21	25.3

Table 4: Correlations among project cost performance, simulation usage, and barriers.

	CP1	CP2	CP3	CP4	STUsage	STBarr
CP1	1					
CP2	0.79**	1				
CP3	0.76**	0.86**	1			
CP4	0.46**	0.47**	0.51**	1		
STUsage	0.06	0.04	0.00	0.01	1	
STBarr	0.05	-0.06	-0.12	-0.09	0.06	1

** Significant at 0.01 level (2-tailed).
CP1: General cost performance of projects
CP2: Cost performance based on percentages of the total projects experienced cost overrun.
CP3: Cost performance based on the difference of percentages between the estimated cost and final cost if the project experience cost overrun
CP4: Cost performance based on difference between cost of actual and estimated contingencies
STUsage: Simulation techniques usage
STBarr: Barriers of simulation techniques application

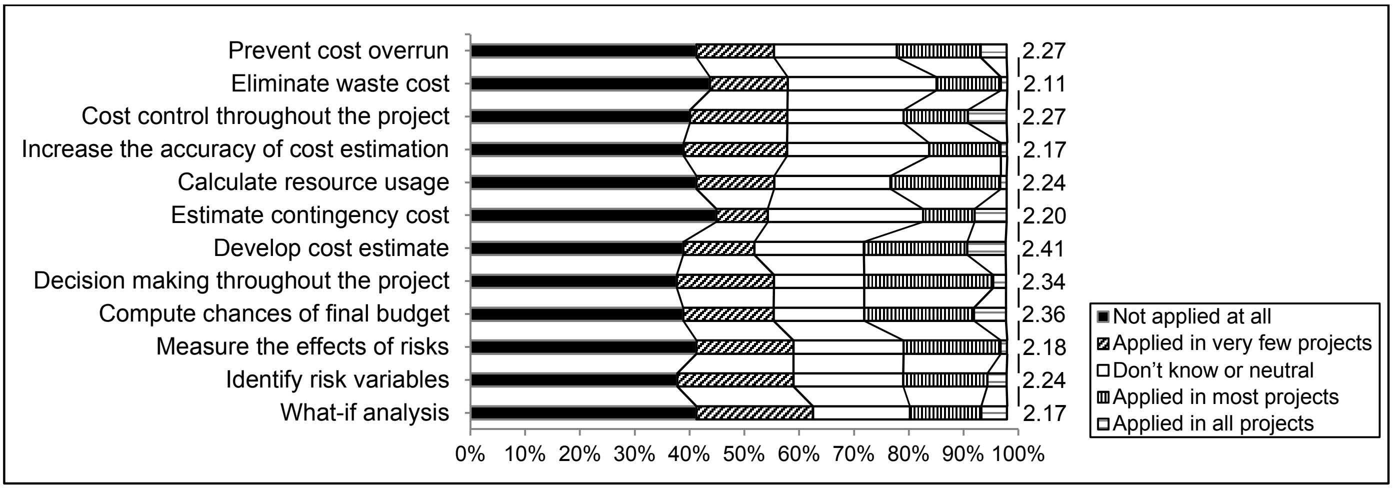

Figure 1: Application areas of cost simulation techniques