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Yusuf Latif,
Civil Engineering Department, Faculty of Engineering, University of Indonesia
(email: latief73@eng.ui.ac.id)
Ismeth Abidin,
Civil Engineering Department, Faculty of Engineering, University of Indonesia
(email: CPI_abidin@yahoo.com)
Bambang Trigunarsyah,
School of Urban Development, Queensland University of Technology
(email: bambang.trigunarsyah@qut.edu.au)

Abstract

Poor project monitoring and control process has been identified as one of the main reasons for construction projects not achieving project cost objectives. Other factors contribute to this condition include: lack of documentation on project lessons learned, not optimum in adopting information technology, and a long process in making decisions. Documentation of lessons learned corrective actions can help project team in identifying various project risks. It is an important feedback in the effort to achieve better project performances, to prevent occurrences of specific risks or to prepare responses to such risks. This paper discusses the development of knowledge-based corrective actions related to controlling project material cost, which includes identifying the impacts, the causes and corrective actions. A survey on various high rise building projects was selected as the research method, and structured interviews with experts on such projects was used as data collecting method. Probability matrix, statistic and simulation were used to analyse the data, and expert system was used to develop decision support system based on cost control theory and practices. The results of the research show that there are four cost performance indicators, fifty eight impacts with fifty seven causes of risks for developing knowledge based lessons learned corrective action which provides about one hundred and fourteen corrective actions

Keywords: Knowledge base, cost control, lessons learned

1. Introduction

Construction industry is highly competitive industry. To win a construction projects, many construction companies have to work with small profit margin. Many construction companies fail to get profit from their projects because of their lack of capability in developing strategy that based on effective management system [1]. This condition typically caused by limited capabilities of project personnel, which resulted in ineffective project control. For that reason, the focus of project control in most developing countries is in project cost rather than time and...
quality [2]. In developing countries such as Indonesia, construction project failures are caused by [3]:

- Poor monitoring and control
- Lack of documentation on project lessons learned
- Not adaptive to information technology development
- Delayed and mistakes in decision making

There are also constraints that are faced by construction companies which are caused by internal as well as external factors. These factors are considered as sources of risk that potentially resulted in cost overrun [4]. Cost overrun in construction projects in Indonesia is typically caused by poor weather condition forecast, increased material cost due to inflation, increased labour cost, and lack or project experience [5]. A good coordination among project stakeholders using a good control system tool is needed in order to achieve required project performances [6].

There are several variables that need to be controlled in order to control project cost, which include: labours, materials, equipment, subcontract and field overhead [7, 8]. Sufficient data, particularly in material costs, is required to have effective monitoring and evaluation process. To support this, a good control system tools is needed.

Improvement in construction process is required in order to have a better quality performance management. This improvement should consider factors that directly influence the quality of construction process, particularly those that are related to documenting lessons learned, management techniques and technology used [9]. Many cost control techniques using software project management system have been developed and used to support project cost control process. However, is yet to provide optimum solution, in particular to support anticipating cost overrun. Therefore, a development of a decision support system tools using an expert system approach for corrective action in controlling project cost would be very beneficial, which in the end could improve quality performance management.

Base on the above problems description, the purpose of this paper is to discuss the development of a decision support system for project material cost control based on expert system approach as well as cost control theory and practices. To develop such system, it starts with identification of source of risks that cause cost overrun, then continued with the identification of appropriate lessons learned corrective actions.

2. Research method

To achieve the research aim, the following approach has been adopted:
Secondary data collection was based on completed project report. Primary data was collected using questionnaire surveys and structured interview to different experts and experience project personnel.

Data was analysed using Delphi method, risk assessment techniques, and statistical analyses. These analyses have provided various knowledge that were stored in knowledge based system. Risk analysis was used to assess related risk level for specified source of risks. Correlation analysis was used to identify various sources of risks, which have been assessed to have negative correlation with project cost performance. The Delphi method was used to select recommended corrective actions based on the specific source of risks. Regression analysis was then used to perform simulation which assessed the relation between the selected corrective actions and project cost performance. This process has resulted in preliminary conclusions which were used as input for the succeeding steps.

Using an inference engine, a knowledge structure was then developed and converted into computer language.

The knowledge based system was further developed using a scenario decision flow diagram, which considered various conditions that are related to decision making process. This scenario was used as the basis for developing subsequent decision flow diagrams. Dependency diagram and logic diagram were used in developing the knowledge structure.

The validation of expert system application was done to compare the results with the opinion of experts.

### 3. Research results

#### 3.1 Relationship between costs overrun indicators with events and causes in project cost control

Knowledgebase for project cost control process are based on relationships between cost overrun indicators with events and causes. In the initial stage of the research, these relationships were grouped into related project cost components. Table 1 shows the number of knowledgebase indicators as well as their related events and causes.

Project material cost has four indicators, which are purchasing cost, transportation cost, storage cost and excess (waste) material cost [10, 11, 12, 13]. Survey and interview with construction experts have identified 58 events that influence these cost overrun indicators. The four cost overrun indicators and their fifty eight events makeup 225 relationships. The numbers of events that influence each cost indicators are as follows:

- Purchasing cost: 57 events (98%)
- Transportation cost: 57 events (98%)
- Storage cost 54 events (93%)
- Excess (waste) material cost 57 events (98%)

<table>
<thead>
<tr>
<th>Table 1 Number of Knowledgebase Cost Overrun Indicators, Event and Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project cost component</strong></td>
</tr>
<tr>
<td>Equipment</td>
</tr>
<tr>
<td>Materials</td>
</tr>
<tr>
<td>Manpower</td>
</tr>
<tr>
<td>Subcontractor</td>
</tr>
<tr>
<td>Overhead</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

Literature survey and expert interviews have identified 57 causes of project material cost overrun, which can be grouped into ten as follows: planning & scheduling (12.3%); organization & key personnel (15.8%); purchasing (12.3%); transportation (7%); QA/QC (1.8%); storage (10.5%); usage (12.3%); change order (7%); monitoring & control (10.5%); and external factors (10.5%).

The 58 events and 57 causes make up complex relationships. The results of the analysis indicated that there are eleven events and their related causes which influence the cost overrun the most. Table 2 lists the eleven dominant events and their related causes.

<table>
<thead>
<tr>
<th>Table 2 - The dominant events and related causes in project material cost overrun indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Event</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>1. Delay in project completion</td>
</tr>
<tr>
<td>2. Material shortage during construction</td>
</tr>
<tr>
<td>3. increased material purchasing cost</td>
</tr>
<tr>
<td>4. reworks</td>
</tr>
<tr>
<td>5. excess materials</td>
</tr>
<tr>
<td>6. delay in procurement</td>
</tr>
</tbody>
</table>

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Further assessment using qualitative risk analysis has provided information on the complexity of the relationship between cost overrun indicators and events, as well as between events and their causes. Cost overrun on project materials which is caused by change order, for example, has 11 sources of risks.

The sources of risks that cause the most events on material cost overrun are purchasing and material usage. Eight events that have the most influence on material cost overrun, which are related to purchasing are:

- Project delay which is caused mostly by schedule variance and materials are purchased not in accordance to specifications & requirements,

- Increased material costs which is caused mostly by delay in purchasing and poor strategy in selecting sellers

- Change orders and excess materials which are mostly due to materials that are purchased not in accordance to specifications & requirements

- Delay in material procurement which is caused mostly by shortage in the market, change in materials sources that are related to project location, delay in payment, and delay in purchasing

- Delay in project works execution which is mostly due to shortage of materials in the market, change in materials sources that are related to project location, delay in payment, and delay in purchasing

- Increased procurement cost which is caused mostly by shortage of supply in the market

- Delay in delivery of materials to project site which is mostly due to poor strategy in selecting sellers

| 7. mistake in work execution | - organisation & key personnel | - change order |
| 8. delay in work | - purchasing related | - transportation related |
| | - QA/QC | - storage |
| | - usage | - change order |
| | - monitoring & control | - change order |
| 9. increased material procurement cost | - purchasing related | - transportation related |
| | - storage | - usage |
| | - change order | - change order |
| 10. delay in delivering material to site | - purchasing related | - transportation related |
| | - external factors | - change order |
| 11. increased damaged materials | - storage | - usage |
| | - change order | - external factors |
Seven events that have the most influence on material cost overrun which are related to material usage are:

- Delay in project completion which is mostly due to repairs or reworks
- Shortage of materials during construction which is caused mostly by excess materials onsite, reworks and inefficient works
- Reworks which are mostly caused by mistakes in material use
- Excess materials that are mostly caused by inefficient usage and materials movements of materials on site, poor understanding of site characteristics, insufficient equipment for mobilisation, and mistakes in materials usage.
- Delay in works execution which is due mostly to poor understanding of site characteristics and insufficient equipment for mobilisation
- Increase in procurement cost which is caused mostly by inefficient usage and materials movements of materials on site, reworks, mistakes in materials usage, poor understanding of site characteristics, insufficient equipment for mobilisation, and mistakes in materials usage.
- Increase in defective/damage materials which are caused by inefficient materials movements of materials on site, poor understanding of site characteristics, insufficient equipment for mobilisation, and mistakes in materials usage.

The cost overruns indicators that are influenced by the above events are purchasing costs, storage costs, and excess material cost.

The main objective of material cost control is to have required materials as scheduled. It is an important and integrated part of materials management. The important steps in implementing materials control are planning, executing, monitoring, analysing performance, evaluating variance and developing necessary corrective actions [14]. There is a need to plan the necessary corrective actions to anticipate the events that can cause material cost overruns.

### 3.2 Relationship between cost overrun indicators with event, causes and corrective actions in project cost control

The second stage of the research is aimed to identify appropriate lessons-learned corrective actions related to sources and events of the cost overrun as discussed in the previous section. This part of the research provides relationship patterns for: indicators-event; event-causes; and causes-corrective actions. Table 3 shows the grouping of these relationships.
Table 3 Number of knowledge base groups for Project Cost Control

<table>
<thead>
<tr>
<th>Project cost Component</th>
<th>#indicators</th>
<th>#events</th>
<th>#causes</th>
<th>#corrective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>5</td>
<td>67</td>
<td>52</td>
<td>104</td>
</tr>
<tr>
<td>Materials</td>
<td>4</td>
<td>58</td>
<td>57</td>
<td>114</td>
</tr>
<tr>
<td>Manpower</td>
<td>4</td>
<td>48</td>
<td>70</td>
<td>149</td>
</tr>
<tr>
<td>Subcontractor</td>
<td>4</td>
<td>31</td>
<td>48</td>
<td>94</td>
</tr>
<tr>
<td>Overhead</td>
<td>4</td>
<td>52</td>
<td>43</td>
<td>120</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>256</td>
<td>270</td>
<td>581</td>
</tr>
</tbody>
</table>

For project cost materials overruns, there are 114 recommended corrective actions that are related to the 58 events and their 57 causes. Good understanding and experiences are needed to provide recommended corrective actions that are appropriate for a particular cause of cost overrun.

The relationship of indicator-event, event-causes, and causes-corrective actions can be summarised as shown in Figure 1. It is a complex network which requires a decision making tools that can identify the most appropriate corrective action for any cost overrun problem.

Figure 1 shows the integration of the relationships between indicator-event, event-causes and causes-corrective actions. The first level, which is the highest level of the network, is the four cost overrun indicators: purchasing cost, transportation cost, storage cost, and excess (waste) material cost. The second level is the events, the third level is the causes, and the fourth, which is the lowest level of the network, is the corrective actions.

An example of the relationship as follows: there is a cost overrun on purchasing cost (I1) as a result of the event number three (E3). This event is caused by the causes number twenty one (C21). To rectify this problem, the corrective actions number two and five (CA2 & CA5) are recommended to be performed. The interesting thing here is that by performing CA2 & CA5, they do not only solve the I1 problem but may also solve, for example, I2 (transportation cost) and I3 (storage cost). This is possible because, for example, C21 is also related to I2 and I3. These relationships make a complex network which requires a computer application to provide effective problem identification and decision making in selecting appropriate corrective actions.
Figure 1  Relationship pattern indicators-event-causes-corrective action in Project Material cost control

From the 114 recommended corrective actions for project materials cost control, almost 90% of them tend to be preventive in nature. They are more likely lessons-learned corrective actions as they are used to prevent the similar events from happening. As an illustration, in planning & scheduling related events, materials are purchased way before they are needed which is caused by inaccuracy in materials scheduling. The recommended corrective action is for supervisor to review planning document before works execution. Another example: delay in decision (organisation & key personnel related events), which is caused by lack of support from head office, the recommended corrective action is to apply appropriate procedure.

3.3 Decision Support System Program

The use of decision support system (DSS) in selecting corrective actions can improve the effectiveness and efficiency in getting recommended corrective actions that lead to better project cost performances. The DSS developed in this research follows the algorithm as shown in Figure 2.

The program starts with an introduction that explains what the program is all about and instructions to use the program. The second sub-model defines the project information, such as project type, contract type and contract value. The third sub-model consists of two modes of process, i.e. lessons learned mode and DSS mode. The fourth sub-model provides report of the process results. C++ has been used in developing the program.
The validation of the program was done by conducting several trials to construction experts. These experts were asked to assess the program and the results it provides. The assessment used in the validation include: completeness of knowledgebase system, speed, user friendliness, accuracy of the results, and level of application. Most of the experts involved in the validation gave good assessments for the program. They also suggested that an improvement in design can make the program more attractive.

4. Conclusions

The paper discusses the development of a decision support system for project material cost control based on expert system approach, cost control theory and practices. In the first step of the development four cost overrun indicators have been identified. Those indicators are purchasing, transportation, storage and excess material costs. The four cost-overrun indicators have fifty eight events and fifty seven causes. To rectify these costs overrun, one hundred and fourteen corrective actions have been recommended by high-rise building construction project experts.

Relationships between cost overruns-events and events-causes are complex. The combinations of these relationships require effective and efficient corrective actions that can lead to improve project cost performances. It is very significant to document those relationships as part of project cost control system. Those relationships make up a basis for a good knowledgebase to select corrective actions The use of DSS program can support the selection of effective and efficient corrective actions.

References


