IT-BASED APPROACH FOR EFFECTIVE MANAGEMENT OF PROJECT CHANGES: A CHANGE MANAGEMENT SYSTEM (CMS)

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ABSTRACT: In a perfect world, changes will be confined to the planning stages. However, late changes often occur during construction, and frequently cause serious disruption to the project. The need to make changes in a construction project is a matter of practical reality. Even the most thoughtfully planned project may necessitate changes due to various factors. The fundamental idea of any variation management system in a building project is to anticipate, recognize, evaluate, resolve, control, document, and learn from past variations in ways that support the overall viability of the project. Learning from past variations is imperative because the professionals can then improve and apply their experience in the future. Primarily, the study proposes six principles of change management. Based on these principles, a theoretical model for change management system (CMS) is developed. The theoretical model consists of six fundamental stages linked to two main components, i.e., a knowledge-base and a controls selection shell for making more informed decisions for effective management of variations. This paper argues that the information technology can be effectively used for providing an excellent opportunity for the professionals to learn from similar past projects and to better control project variations. Finally, the study briefly presents a knowledge-based decision support system (KBDSS) for the management of variations in educational building projects in Singapore. The KBDSS consists of two main components, i.e., a knowledge-base and a controls selection shell for selecting appropriate controls. The KBDSS is able to assist project managers by providing accurate and timely information for decision making, and a user-friendly system for analyzing and selecting the controls for variation orders for educational buildings. The CMS will enable the project team to take advantage of beneficial variations when the opportunity arises without an inordinate fear of the negative impacts. By having a systematic way to manage variations, the efficiency of project work and the likelihood of project success should increase. The study would assist building professionals in developing an effective variation management system. The system would be helpful for them to take proactive measures for reducing variation orders. Furthermore, with further generic enhancement and modification, the KBDSS will also be useful for the management of variations in other types of building projects, thus helping to raise the overall level of productivity in the construction industry. Hence, the system developed and the findings from this study would also be valuable for all building professionals in general.

KEYWORDS: CMS, information technology, KBDSS, changes, management.

1 INTRODUCTION

In a perfect world, changes will be confined to the planning stages. However, late changes often occur during construction, and frequently cause serious disruption to the project (Cameron, et al., 2004). Great concern has been expressed in recent years regarding the adverse impact of variations to the construction projects. The need to make changes in a construction project is a matter of practical reality. Even the most thoughtfully planned project may necessitate changes due to various factors (Ibbs, et al., 2001). Developments in the education sector and the new modes of teaching and learning fostered the need for renovation or extension of existing academic institutions. The change of space in academic institutions is required to cater for the new technology used. The construction of an educational building also poses risks as in the construction of any other large projects. Variations during the design and construction processes are to be expected. Arain and Low (2005a) identified the design phase as the most likely area on which to focus to reduce the variations in future educational projects. If one were to seriously consider ways to reduce problems on site, an obvious place to begin with is to focus on what the project team can do to eliminate these problems at the design phase (Arain, 2005a; Arain and Low, 2005b).

Considering the hectic working environment of construction projects, decisions are being made under pressure and cost and time invariably dominate the decision making process (O'Brien, 1998). Most forms of contract for construction projects allow a process for variations (Arain and Low, 2005b). Even though there may be a process in place to deal with these late changes, cost and time invariably dominate the decision making process. If the change affects the design, it will impact on the construction process and, quite possibly, operation and maintenance as well (Cameron, *et al.*, 2004). To overcome the problems associated with changes to a project, the project team must be able to effectively analyze the variation and its immediate and downstream effects (CII, 1994; Arain and Low, 2007a). To manage a variation means being able to anticipate its effects and to control, or at least monitor the associated cost and schedule impact (Hester, *et al.*, 1991). An effective analysis of variations and variation orders requires a comprehensive understanding of the root causes of variations and their potential downstream effects.

In project management, variations in projects can cause substantial adjustments to the contract duration time, total direct and indirect cost, or both (Ibbs, *et al.*, 1998; Gray and Hughes, 2001; Ibbs, *et al.*, 2001). Every building project involves a multi-player environment and represents a collaborative effort among specialists from various independent disciplines (Arain, *et al.*, 2004). Because variations are common in projects, it is critical for project managers to confront, embrace, adapt and use variations to impact positively the situations they face and to recognize variations as such (Ibbs, 1997). The variations and variation orders can be minimized when the problem is studied collectively as early as possible, since the problems can be identified and beneficial variations can be made (CII, 1994; Arain and Low, 2007a). The variations and variation orders can be deleterious in any project, if not considered collectively by all participants. From the outset, project controls should take advantage of lessons learned from past similar projects (Ibbs, *et al.*, 2001).

The integration of construction knowledge and experience at the early design phase provides the best opportunity to improve overall project performance in the construction industry (Arain, *et al.*, 2004). To realize this integration, it is not only essential to provide a structured and systematic way to aid the transfer and utilization of construction knowledge and experience during the early design decision making process, but also to organize these knowledge and experience in a manageable format so that they can be inputted effectively and efficiently into the process.

Decision making is a significant characteristic that occur in each phase of a project. In almost every stage, decision making is necessary. Often, these decisions will, or can affect the other tasks that will take place. To achieve an effective decision making process, project managers and the other personnel of one project need to have a general understanding of other related or similar past projects (CII, 1994a). This underscores the importance of having a good communication and documentation system for better and prompt decision making during various project phases. If professionals have a knowledge-base established on past similar projects, it would assist the professional team to plan effectively before starting a project, during the design phase as well as during the construction phase to minimize and control variations and their effects. The current technological progress does not allow the complete computerization of all the managerial functions or the creation of a tool capable of carrying out automatically all the required management decisions. To insure the success of this important management function, it is believed that human involvement in this process remains essential. Thus the Decision Support System (DSS) approach for this kind of application seems to be the most natural idea (Miresco and Pomerol, 1995).

Information technology has become strongly established as a supporting tool for many professional tasks in recent years (Arain and Low, 2005c). Computerized decision support systems can be used by project participants to help make more informed decisions regarding the management of variations in projects by providing access to useful, organized and timely information (Miresco and Pomerol, 1995; Mokhtar, *et al.,* 2000). As mentioned earlier, project strategies and philosophies should take advantage of lessons learned from past similar projects from the inception. It signifies the importance of an organized knowledge-base of similar past projects. The importance of a knowledge-base for better project control was recommended by many researchers (Miresco and Pomerol, 1995; Mokhtar, *et al*., 2000; Gray and Hughes, 2001; Ibbs, *et al*., 2001; Arain and Low, 2005c).

A knowledge-based decision support system is a system that can undertake intelligent tasks in a specific domain that is normally performed by highly skilled people (Miresco and Pomerol, 1995). Typically, the success of such a system relies on the ability to represent the knowledge for a particular subject. Computerized decision support systems can be used by project participants to help make more informed decisions regarding the management of variation orders in projects by providing access to useful, organized and timely information. The objective of this study is therefore to develop a theoretical model for CMS for better management of variations in educational building projects in Singapore. The system would assist the professionals in learning from past projects for reducing potential variations in the educational building projects.

This is a timely study as the programme of rebuilding and improving existing educational buildings is currently under way in Singapore; it provides the best opportunity to address the contemporary issues relevant to the management of variation orders. The CMS framework would be helpful in developing a knowledge-based decision support system (KBDSS) that eventually would assist professionals in taking proactive measures for reducing potential variations in educational building projects. The knowledge-based system should present a comprehensive scenario of the causes of variations, their relevant effects and potential controls that would be helpful in decision making at the early stage of the variations occurring. The KBDSS would assist project management teams in responding to variations effectively in order to minimize their adverse impact to the project. Furthermore, the CMS will enable the project team to take advantage of beneficial variations when the opportunity arises without an inordinate fear of the negative impacts.

2 SCOPE OF RESEARCH

The government of Singapore initiated a major program of rebuilding and improving existing educational buildings to ensure that the new generation of Singaporeans would get the best opportunities to equip them with the information technology (IT) available. A total of about

290 educational buildings will be upgraded or rebuilt by a government agency over a period of seven years, at an estimated cost of S$4.46 billion from 1999 to 2005 (Note: at the time of writing, US$1 is about S$1.80). Developing a change management system will contribute towards the better control of variations through prompt and more informed decisions. Therefore, this research concentrated on the educational building projects under this major rebuilding and improvement programme in Singapore. The number of completed educational projects is 80. Furthermore, the interviews were restricted to the developers (governmental agency), the consultants and contractors who have carried out these educational projects.

3 BACKGROUND

The issue of managing variations has received much attention in the literature. Despite many articles and much discussion in practice and academic literature, the issue of learning from the past projects for making timely and more informed decisions for effective management of variation orders was not much explored in the literature. Many researchers have proposed theoretical models for managing variations. Krone (1991) presented a variation order process that promoted efficient administrative processing and addressed the daily demands of changes in the construction process. The contractual analysis technique (CAT) found that early notification and submission of proposals helped to maintain management control and avoided impact claims. The CAT laid the foundation for future contract variation clauses in construction management. The proposed process was limited to administrative processing and addressing the daily demands of variations in the construction process. Stocks and Singh (1999) presented the functional analysis concept design (FACD) methodology to reduce the number of variation orders in construction projects. They found that FACD was a viable method that could reduce construction costs overall. Harrington, *et al.* (2000) presented a theoretical model for the management of change (MOC) in the organizational context. The model presented a structured process consisting of seven phases, namely, clarify the project, announce the project, conduct the diagnosis, develop an implementation plan, execute the plan, monitor progress and problems, and evaluate the final results. They suggested that the MOC structure can be applied outside the organization to any project change management.

A theoretical model was proposed by Gray and Hughes (2001) for controlling and managing variations. The central idea of the proposed model was to recognize, evaluate, resolve and implement variations in a structured and effective way. CII (1994) and Ibbs, *et al.* (2001) proposed a project change management system (CMS) that was founded on five principles. The five principles included: promote a balance change culture, recognize change, evaluate change, implement change, and improve from lessons learned. The change management system was a two-level process model, with principles as the foundation, and management processes to implement those principles. The proposed system lacked the basic principle and process of implementing controls for future variations in the construction projects.

The basic principles of variation management that are presented in this paper were adapted from the research works by CII (1994) and Ibbs, *et al.* (2001).

4 BASIC PRINCIPLES OF VARIATION MANAGEMENT

The fundamental idea of any variation management system is to anticipate, recognize, evaluate, resolve, control, document, and learn from past variations in ways that support the overall viability of the project. Learning from the variations is imperative, because the professionals can improve and apply their experience in the future. This would help the professionals in taking proactive measures for reducing potential variations.

This study proposes six basic principles of variation management. As shown in Figure 1, the six basic principles include identify variation for promoting a balanced variation culture, recognize variation, diagnosis of variation, implement variation, implement controlling strategies, and learning from past experiences. Each of these principles works hand-in-hand with the others.

The decision-makers seek guidance from past decisions, like learning from the past experiences. The Adaption-Innovation Theory (AIT), proposed by Kirton (1976), defined and measured two styles of decision making: adaption and innovation. Kirton (1984) further explained that adaptors characteristically produced a sufficiency of ideas, based closely on, but stretching, existing agreed definitions of the problem and likely solutions. Kirton (1984) argued that the decisions made by adaptors were precise, timely, reliable and sound.

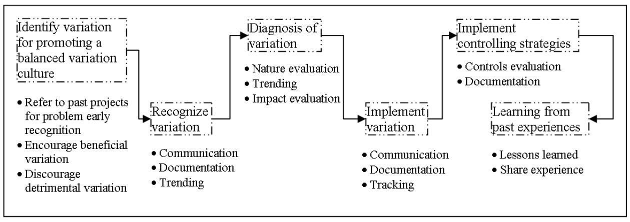

Figure 1. Fundamental principles of variation management.

The first principle of variation management is to identify variations. As shown in Figure 1, in this principle, referring to past projects for early recognition of a problem is very important, because it will assist in identifying the issue at the early stage. Furthermore, this will also assist in encouraging beneficial variations and discouraging detrimental variations. Beneficial variations are those that actually help to reduce cost, schedule, or degree of difficulty in the project. Detrimental variations are those that reduce owner value or have a negative impact on a project.

The second principle of variation management is to recognize variations. In this principle, communication, documentation and awareness about trending are very important, because these would assist in identifying variations prior to their actual occurrence. The third principle of variation management is to diagnose the variation. As shown in Figure 1, nature evaluation, trending, and impact evaluation are very important aspects. This is because these would assist in determining whether the management team should accept and implement the proposed variation.

Implementing variation is the fourth principle of variation management. After evaluating the variation, implementing variation is an important step. As shown in Figure 1, in this principle, communication, documentation and tracking are very important. This is because these would assist in implementing variation through communicating information between team members and developing database through documenting and tracking of the variation implemented. Implementing controls for variations is the fifth principle of effective variation management. It is a very important step, since this is the main reason to have the variation management system. As shown in Figure 1, evaluating and documenting controls are very important, because evaluating suggested controls would assist in selecting effective controls for variations, and documenting the controls would assist in learning lessons from the variation.

The sixth principle of variation management is to learn from past experiences. In this principle, learning lessons and sharing experiences are very important because the main idea is to evaluate mistakes made so that errors can be systematically corrected. Such analysis should be shared between team members so that everyone will have a chance to understand the root causes of the variations and to control problems in a proactive way.

5 THEORETICAL MODEL FOR CHANGE MANAGEMENT SYSTEM (CMS)

Based on these principles, a theoretical model for change management system (CMS) is developed. The model consists of six fundamental stages linked to two main components, i.e., a knowledge-base and a controls selection shell for making more informed decisions for effective management of variation orders. The database will be developed through collecting data from source documents of past projects, questionnaire survey, literature review and in-depth interview sessions with the professionals who were involved in the projects. The knowledge-base will be developed through initial sieving and organization of data from the database. The controls selection shell would provide decision support through a structured process consisting of building the hierarchy between the main criteria and the suggested controls, rating the controls, and analyzing the controls for selection through multiple analytical techniques.

The knowledge-base should be capable of displaying variations and their relevant details, a variety of filtered knowledge, and various analyses of the knowledge available. This would eventually lead the decision makers to the suggested controls for variations and assist in selecting the most appropriate controls.

As shown in Figure 2, the need for a variation can originate from the client, user, design consultant, project manager and contractor. Considering the underlying principles of effective variation management and the theoretical framework discussed earlier, the first step of the theoretical model for management of variation orders is to identify variations for promoting a balanced variation culture. Once the variation is proposed, the proposal will be analyzed through a knowledge-base (level 1) for initial decision support to recognize the variation at an early stage for encouraging beneficial variations and preventing detrimental variations. If options are required for certain variations, then the request for a proposal will be made. However, the proposals will be analyzed generally through a knowledge-base that will assist in establishing the first principle of effective variation management.

The second step of the theoretical model for management of variation orders is to recognize the variation. Therefore, it is important that an environment be created that allows team members to openly communicate with one another. In this stage, team members are encouraged to discuss and to identify potential variations (Ibbs *et al.,* 2001; Arain and Low, 2006a). Identifying variations prior to their actual occurrence can help the team to manage variations better and earlier in the project life cycle. As shown in Figure2, the knowledge-base (level 2) provides structured information of past projects that would assist in effective communication between team members. The codes and categorized information relating to the effects on programme, cost implications, and frequency of occurrence of variations would eventually assist in recognizing variations at the early stage of their occurrence.

After the team recognizes the variation, the diagnosis of variation is carried out through the knowledge-base (updated). The knowledge-base (updated) contains information about the frequency of variations and variation orders in the present project, their root causes, and potential effects. This information assists the management team in evaluating the variation. The purpose of the evaluation is to determine whether the management team should accept and implement the proposed variation.

After the evaluation phase, the team selects the alternatives and communicates the details of the variation to all affected parties. Better team communication will allow for the timely implementation of the variation selected. Documentation of the variation implemented is an integral part of the implementation phase. The documentation contributes to the knowledge-base decision support system as shown in Figure 2.

After the implementation phase, selecting and implementing controls for variations are very important as shown in Figure 2. The knowledge-base eventually leads the decision makers to the suggested controls for variations and assists them in selecting the most appropriate controls. The controls selection shell would provide decision support through a structured process consisting of building the hierarchy between the main criteria and the suggested controls, rating the controls, and analyzing the controls for selection through multiple analytical techniques.

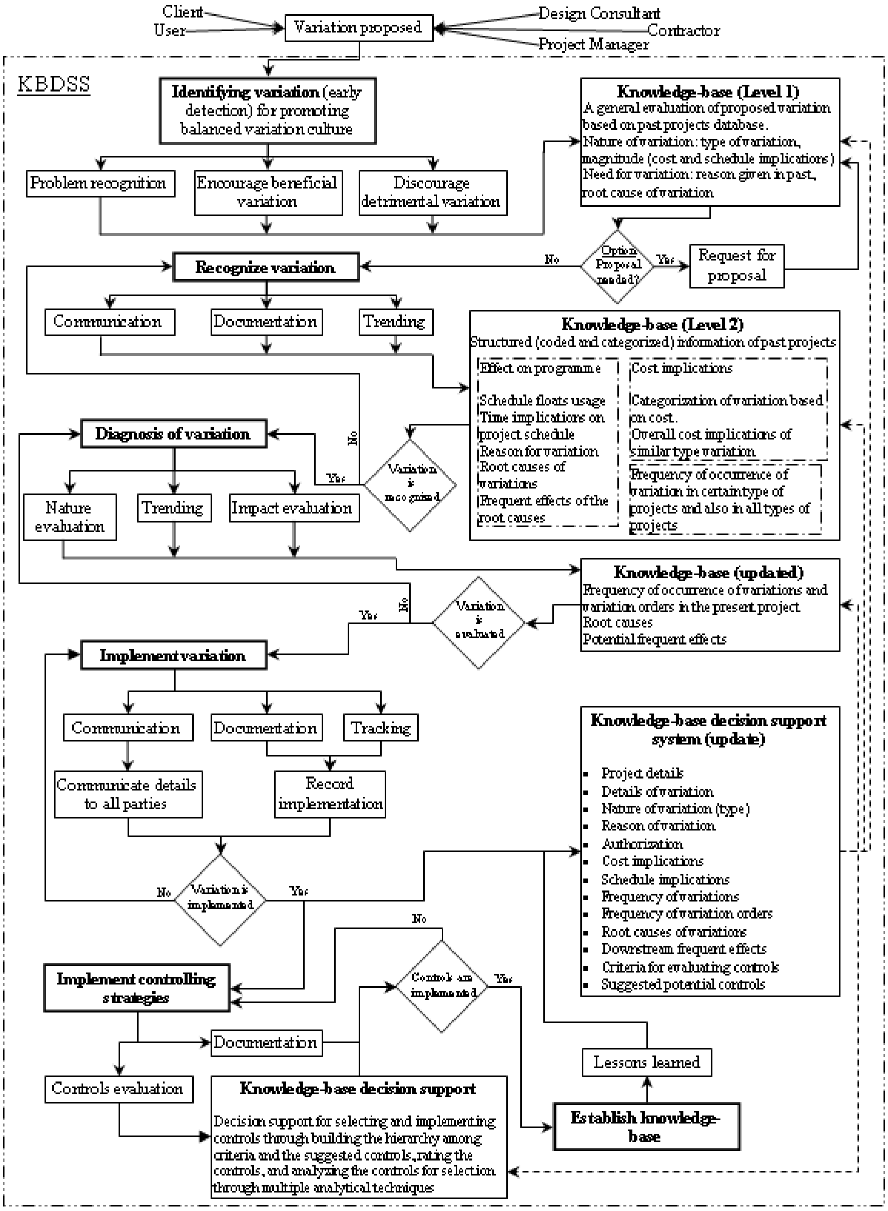

Figure 2. Change Management System (CMS) model.

After selecting and implementing the controls for variations, establishing and updating the knowledge-base is the last yet most important phase of the theoretical model for management of variation orders (Arain and Low 2006a). The knowledge-base will improve with every new building project, since the essence of the model is to provide timely and accurate information for the decision making process. The knowledge-base established may assist project managers by providing accurate and timely information for decision making, and a user-friendly system for analyzing and selecting the controls for variation orders.

6 KNOWLEDGE-BASED DECISION SUPPORT SYSTEM (KBDSS)

The fundamental idea of any strategic management system is to anticipate, recognize, evaluate, resolve, control, document, and learn from past experiences in ways that support the overall viability of the project (Ibbs, *et al.*, 2001; Arain, 2005b; Arain and Low, 2005c). The professionals can improve and apply their experience in the future projects hence learning from the variations is imperative. This would help the professionals in taking proactive measures for reducing potential variations.

A knowledge-based decision support system was a system that could undertake intelligent tasks in a specific domain that was normally performed by highly skilled people (Miresco and Pomerol, 1995). Typically, the success of such a system relied on the ability to represent the knowledge for a particular subject (Mokhtar, *et al.*, 2000). Computerized decision support systems can be used by project participants to help make more informed decisions regarding the management of variation orders in projects by providing access to useful, organized and timely information.

It is important to understand that the KBDSS for the management of project changes was not designed to make decisions for users, but rather it provided pertinent information in an efficient and easy-to-access format that allows users to make more informed decisions.

As mentioned earlier, the issue of managing variations has received much attention in the literature. In spite of many articles and much discussion in practice and academic literature, the issue of learning from the past projects for making timely and more informed decisions for effective management of variations was not much explored in the literature (Arain, 2005b; Arain and Low, 2006b). Many researchers have proposed principles and theoretical models for managing variations (Mokhtar, *et al*., 2000; Ibbs, *et al*., 2001; Arain and Low, 2005c). This study presents a change management system (CMS) containing a KBDSS for managing variations in educational projects in Singapore, which has not been studied and developed before. Hence, the study is a unique contribution to the body of knowledge about KBDSS towards the management of variations in construction. It is important to understand that the KBDSS for the management of variations is not designed to make decisions for users, but rather it provides pertinent information in an efficient and easy-to-access format that allows users to make more informed decisions.

The KBDSS consists of two main components, i.e., a knowledge-base and a controls selection shell for selecting appropriate controls (Arain and Low, 2007b). The database is developed by collecting data from the source documents of 80 educational building projects, questionnaire survey, literature review and in-depth interviews with the professionals who were involved in these projects. The knowledge-base was developed through initial sieving and organization of the data from the database. The knowledge-base was divided into three main segments, namely, macro layer, micro layer and effects/controls layer. The system contains one macro layer that consists of the major information gathered from source documents, and 80 micro layers that consist of detailed information pertinent to variations and variation orders for each project. Overall the system contains 155 layers of information. The segment that contained information pertinent to possible effects and controls of the causes of variation orders for educational buildings was integrated with the controls selection shell. The shell contains 53 layers based on each of the causes of variations and their most effective controls. The controls selection shell provided decision support through a structured process consisting of building the hierarchy between the main criteria and the suggested controls, rating the controls, and analyzing the controls for selection through multiple analytical techniques.

The KBDSS is developed in the MS Excel environment using numerous macros for developing the user-interface that carry out stipulated functions. These are incorporated within a controls selection shell. The graphical user interface (GUI) assists users in interacting with the system on every level of the KBDSS. In addition, the GUI and inference engine will maintain the compatibility between layers and the decision shell. The KBDSS provides an extremely fast response to the queries. The KBDSS is capable of displaying variations and their relevant in-depth details, a variety of filtered knowledge, and various analyses of the knowledge available. The KBDSS is able to assist project managers by providing accurate and timely information for decision making, and a user-friendly system for analyzing and selecting the controls for variation orders for educational buildings.

The detailed information that is available on various layers of the KBDSS is briefly discussed below. The information and various filters that can be applied to the knowledge-base developed may assist the professionals in learning from past projects for enhancing management of variations in educational building projects.

6.1 *Macro layer of the KBDSS*

As mentioned earlier, the macro layer is the first segment of the knowledge-base. It consists of the major information gathered from source documents of 80 educational projects and through interview sessions with the professionals. As shown in Figures 3a, 3b and 3c, the macro layer contains the major information about the educational projects completed, i.e., project name, program phase, work scope, educational level, date of commencement, project duration, date of completion, actual completion, schedule completion status, schedule difference, contract final sum, contingency sum percent, contingency sum, contingency sum used, total number of variation orders, total cost of variation orders, total time implication, total number of variations, frequency of variation orders, frequency of variations, main contractors and consultants.

A variety of filters are provided on the macro layer that assists in sieving information by certain rules. The user would be able to apply multiple filters for analyzing the information by certain rules, for instance, the user would be able to view the information about the educational projects that were completed behind schedule and among these projects, the projects with the highest frequency of variation orders, highest contingency sum used, highest number of variations, etc. This analysis assists the user in identifying the nature and frequency of variations in certain type of educational projects.

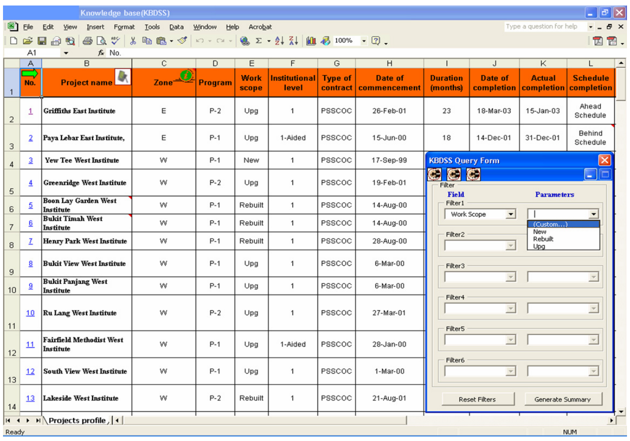

Figure 3a. Macro layer of the knowledge-base that consists of the major information regarding educational building projects.

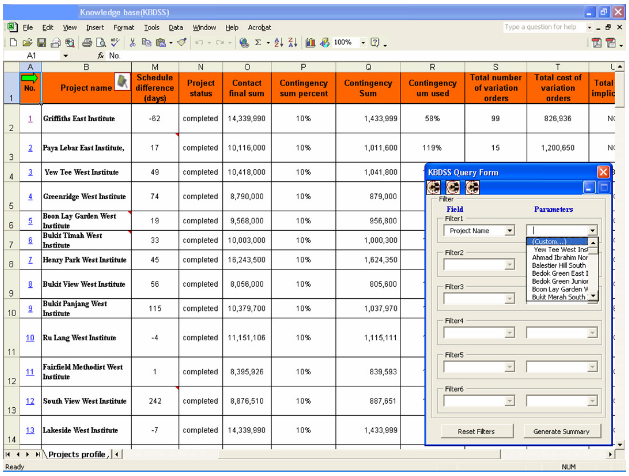

Figure 3b. Macro layer of the knowledge-base (cont'd).

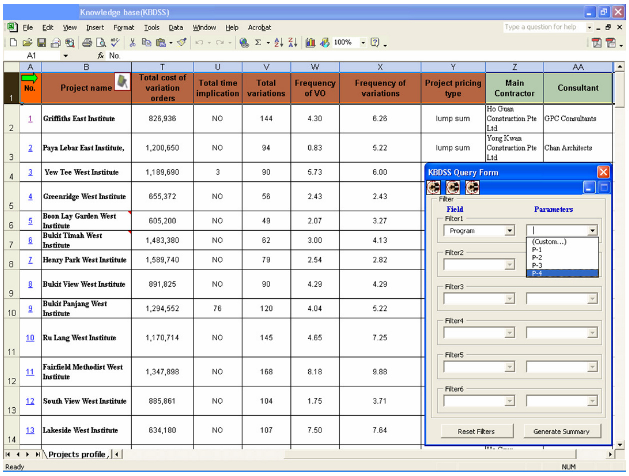

Figure 3c. Macro layer of the knowledge-base (cont'd).

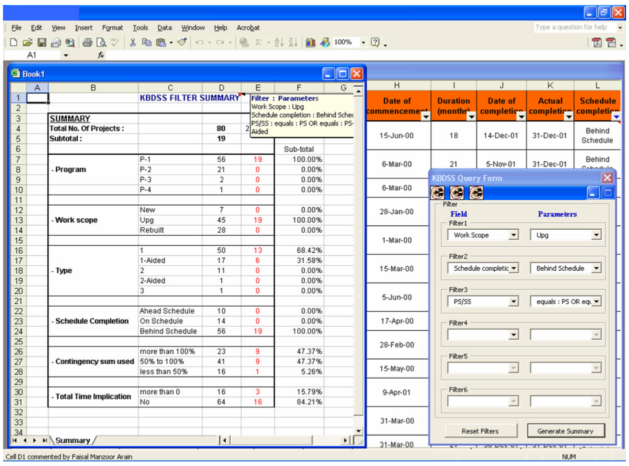

Figure 4. Summary section displaying the results of the filters applied on the macro layer.

The inference engine provides a comprehensive summary of the information available on the macro layer as shown in Figure 4. Furthermore, the inference engine also computes the percentages for each category displayed in Figure 4. This assists the user in analyzing and identifying the nature and frequency of variation orders in certain type of educational projects. The information available on the macro layer would assist the professionals in identifying the potential tendency of encountering more variations in certain type of educational projects. By applying multiple filters that are provided on the macro layer, the professionals would be able to evaluate the overall project variance performance. These analyses at the design stage would assist the professionals in developing better designs with due diligence.

6.2 *Micro layer of the KBDSS*

The micro layer is the second segment of the knowledge-base that contains 80 sub-layers based on the 80 educational projects respectively. As shown in Figures 5a and 5b, the micro layer contains the detailed information regarding variations and variation orders for the educational project. The detailed information includes the variation order code that assists in sieving information, detailed description of particular variation collected from source documents, reason for carrying out the particular variation provided by the consultant, root cause of variation, type of variation, cost implication, time implication, approving authority, and endorsing authority. Here, the information regarding the description of particular variation, reason, type of variation, cost implication, time implication, approving authority, and endorsing authority were obtained from the source documents of the 80 educational projects. The root causes were determined based on the description of variations, reasons given by the consultants, and the project source documents and were verified later through the in-depth interview sessions with the professionals who were involved in these projects.

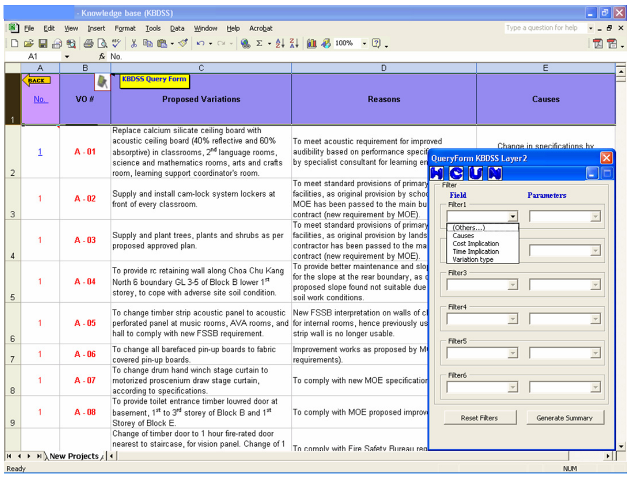

Figure 5a. Micro layer of the knowledge-base that contains the detailed information regarding variation orders for the educational project.

In addition to computing the abovementioned information, the inference engine also computes and enumerates the number of variations according to various types of variations as shown in Figure 6. The inference engine also assists in computing the actual contingency sum by deducting the cost of variations requested and funded by the institution or other sources. This may assist in identifying the actual usage of contingency sum based on the project cost.

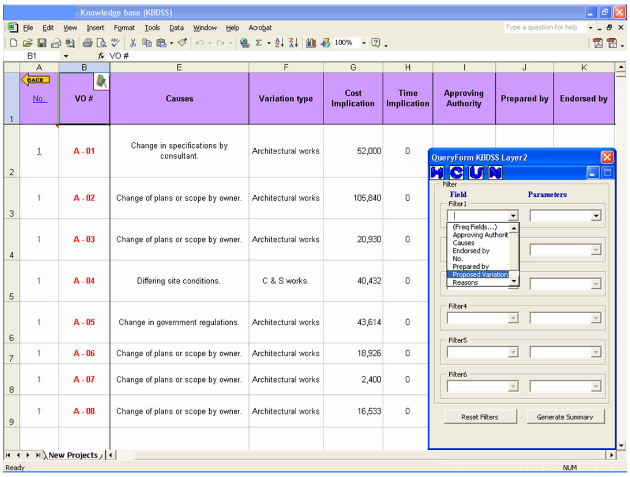

Figure 5b. Micro layer of the knowledge-base that contains the detailed information regarding variation orders for the educational project.

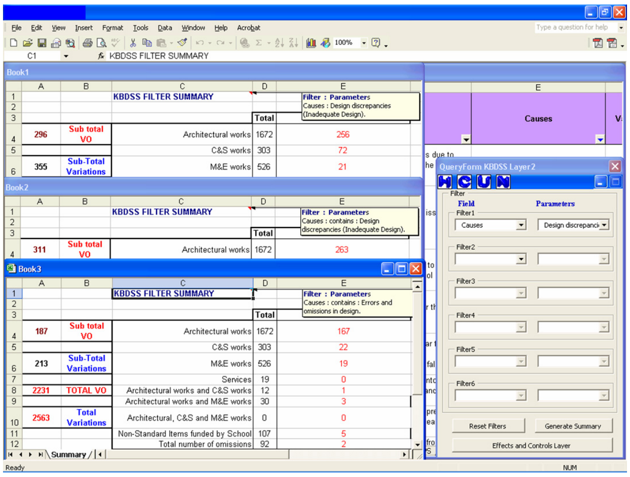

Figure 6. Multiple summary sections displaying the results of the filters applied on the micro layer, and the KBDSS query form showing the effects and controls layer tab that connects the micro layer with the effect and controls layer of the knowledge-base.

The information can be sieved by certain rules through a variety of filters provided in the micro layer. The professionals would be able to apply multiple filters for finding out the most frequent causes of variations, most frequent types of variations, and variations with most significant cost implication and time implication. The multiple summaries that can be generated by apply filters and using the query form is presented in Figure 6. The professionals would be able to analyze the most potential variations in educational building projects. The information available on the micro layers would assist in pinpointing the root causes of variations in the past educational projects.

6.3 *Effects and controls layer of the KBDSS*

The third layer of the KBDSS contains 53 sub-layers based on the potential causes of variations and 10 sub-layers of most important causes combined. The 53 causes can be modified in the event that new ones are discovered or emerged over time. The numerous filters provided in the macro, micro, and effects and controls layers will be updated automatically with every new project added. As shown in Figure 7, the graphical presentation of the 5 most important effects and 5 most effective controls for the cause of variations was presented. An understanding of the effects of variations would be helpful for the professionals in assessing variations. A clearer view of the impacts on the projects will enable the project team to take advantage of beneficial variations when the opportunity arises. Eventually, a clearer and comprehensive view of the potential effects of variations will result in informed decisions for effective strategic management of variations. It is suggested that variations can be reduced with due diligence during the design stages. Furthermore, the suggested controls would assist professionals in taking proactive measures for reducing variation orders for educational building projects. As mentioned earlier about the design stage, it is recommended that the controls be implemented as early as possible. As shown in Figure 7, the controls selection tab is provided in the CDP form. This feature assisted in linking the knowledge-base with the controls selection shell. This is required because the professionals may not be able to implement all the suggested controls. Therefore, the shell assists them in selecting the most appropriate controls based on their own criterions.

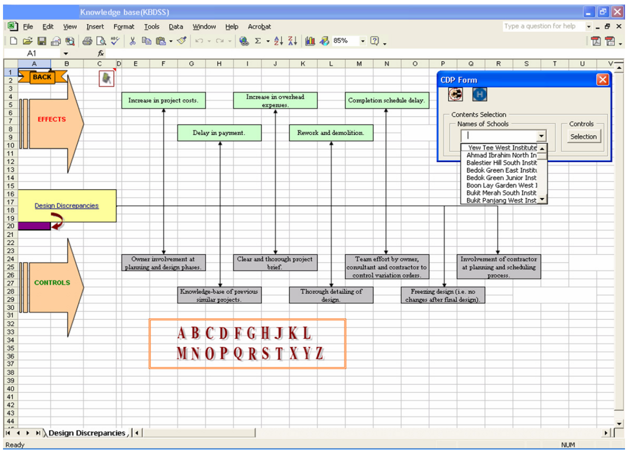

Figure 7. Effects and controls layer of the knowledge-base that pinpoints the most important effects and most effective controls for each cause of variations.

6.4 *Controls selection shell*

The controls selection shell is integrated with the knowledge-base to assist the user in selecting the appropriate controls of variations. As mentioned in the previous section, the 5 most effective controls for the cause of variations were presented on the effects and controls layer, and the layer was linked with the controls selection shell. The controls selection shell provides decision support through a structured process consisting of building the hierarchy among the main criterions and the suggested controls, rating the controls, and analyzing the controls for selection through multiple analytical techniques, for instance, the analytical hierarchy process, multi-attribute rating technique, and direct trade-offs. The controls selection shell contained four layers that were based on the structured process of decision making, namely, control selection criterions, building the hierarchy between criterions and controls, rating the controls, selecting the best controls based on the given criterions.

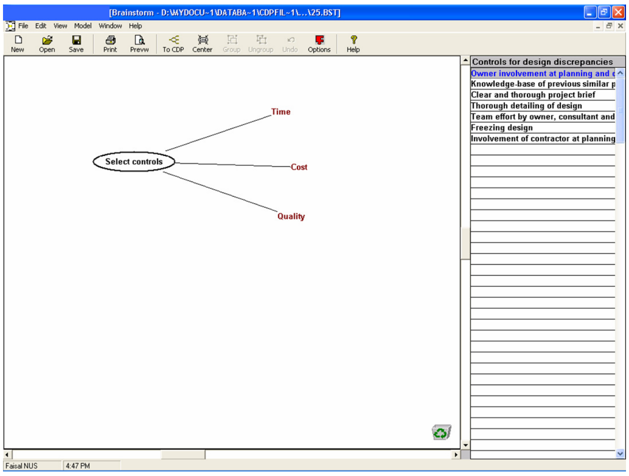

Figure 8. Main panel of controls selection shell that contains the goal, main criteria and the most effective controls for variations (focusing on Time, Cost and Quality).

As shown in Figure 8, this layer of the controls selection shell contains the suggested controls for the cause of variation selected in the controls and effects layer of the KBDSS. Hence, the controls selection shell contains 53 layers based on the each cause of variations and their most effective controls. Here the goal was to select the controlling strategies and the main criterions were time, cost and quality. In this layer, the professionals may add any suggested controls that are considered to be important. Furthermore, the professionals may specify their own contemporary criterions for selecting the controls. The provision of the facility for adding more controls and criterions would assist them in evaluating the suggested controls according to the project stages and needs. This may assist them in selecting and implementing the appropriate controls at appropriate time.

The main objective of this layer is to generate the hierarchy between the main criterions and the suggested controls for variations. The shell generates hierarchy among the goal, the criterions and the suggested controls as shown in Figure 9. The hierarchy assists in rating all the suggested controls.

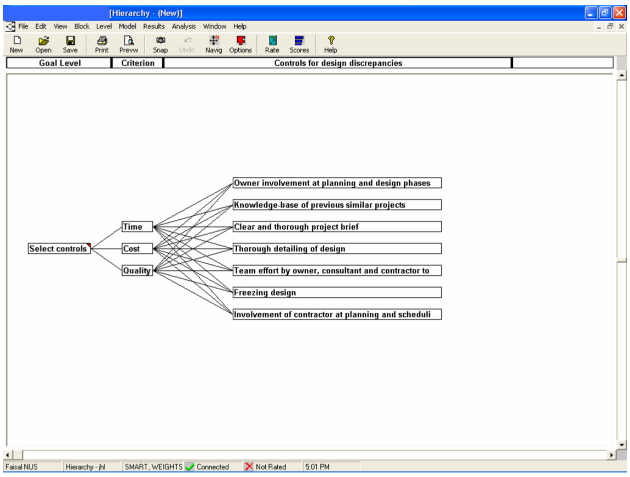

Figure 9. Building the hierarchy among the goal, main criteria and controls for variations.

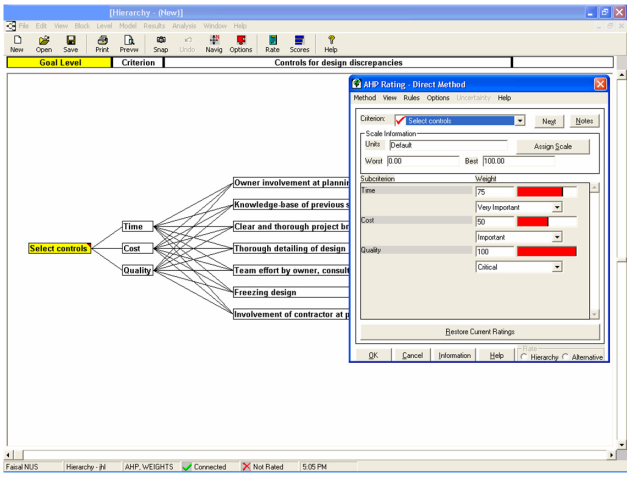

Figure 10. Rating the main criteria using the direct method, i.e. the default rating method provided in the KBDSS.

The rating process includes four main activities i.e., choosing a rating method, selecting rating scale views, assigning rating scales and entering weights or scores. This layer provides analytical hierarchy process (AHP) as a rating technique. This is because the decision will be based on purely qualitative assessments of the suggested controls. There are three rating methods available, i.e., direct comparison, full pair-wise comparison, and abbreviated pair-wise comparison. The direct method is the default rating method and is used for entering weights for this decision process. As shown in Figure 10, the first step for rating the controls was to assign weight to the criterions, i.e., time, cost and quality. The professionals should rate each criterion based on the project phases. This is because during the early stages of the construction projects, normally the implementation cost of suggested controls is not significant. More emphasis should be given on the available resources at the present stage of the construction projects.

The second step was to rate the suggested controls with respect to quality. This was because quality was rated critical as shown in Figure 11. The rating priority is based on hierarchy of the main criterions rated earlier in the first step. Here the professionals should assign more weight to the controls that may enhance the project quality. The third step was to rate the suggested controls with respect to time. Here the professional should rate the controls, which may require less time for implementation, as high. The user rated all the suggested controls and assigned weights to each alternative (control) as shown in Figure 12. Lastly, the fourth step was to rate the suggested controls with respect to cost. Here the professionals should select more weights for the controls that are not costly. The user rated all the suggested controls and assigned weights to each alternative (control) as shown in Figure 13. Overall, the rating of the suggested controls may vary according to the project phases. For instance, the controls may be implemented only in the design phase or in the construction phase of the construction projects. Hence, the KBDSS would assist the professionals in selecting the appropriate controls for variations according to the present stage of the building project.

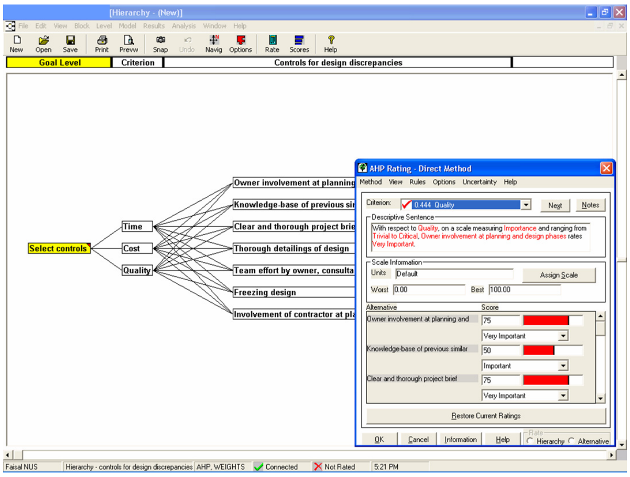

Figure 11. Rating the controls for variations with respect to quality.

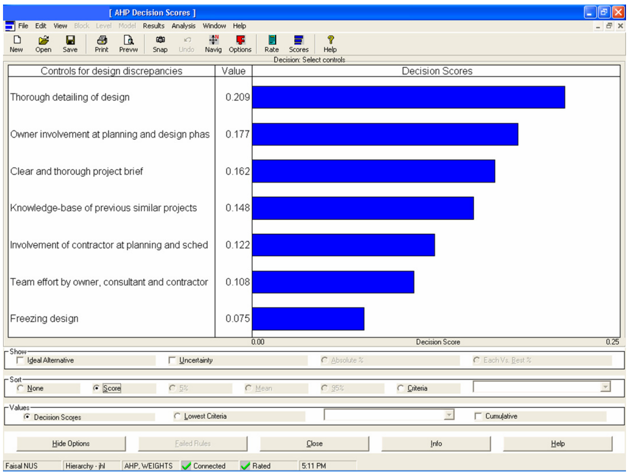

Figure 14. The controls for variations sorted according to the decision scores.

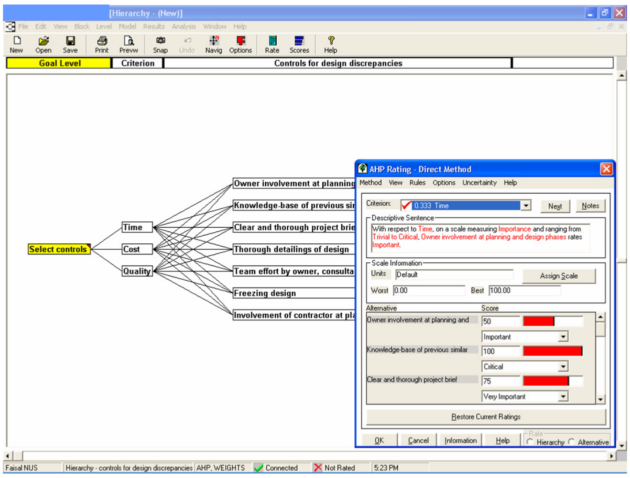

Figure 12. Rating the controls for variations with respect to time.

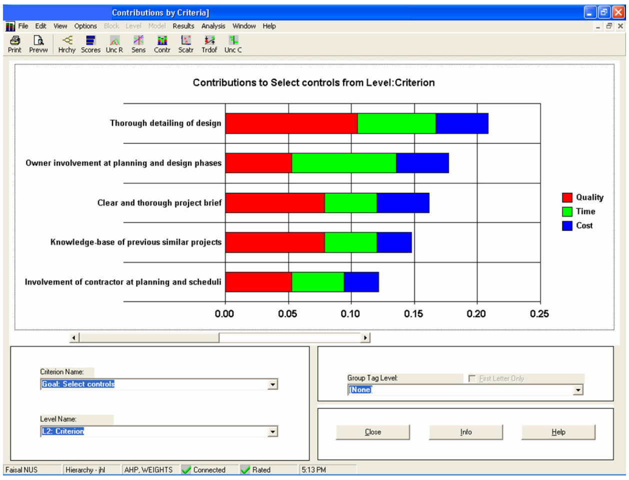

Figure 15. The suggested controls sorted according to contributions by criteria.

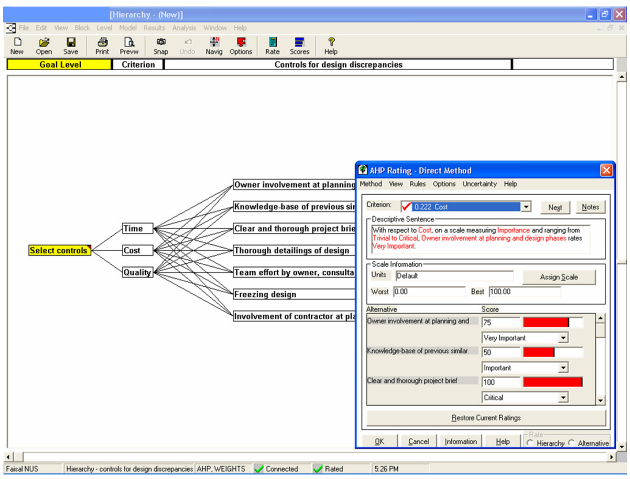

Figure 13. Rating the controls for variations with respect to cost.

The controls selection shell calculates the decision scores based on the rating process and displays a graphical presentation of the results as shown in Figure 14. The decision scores can be sorted according to ascending or descending orders, which assist in viewing the comprehensive scenario. The professionals can easily select the best controls based on the decision scores. Furthermore, the results can be analyzed according to various contributions by criterions as shown in Figure 15. The graphical presentation of the results in radar form (web) is shown in Figure 16. The graphical presentations enhance the user-friendly interface that assist in analyzing the issues conveniently. The professionals may analyze the suggested controls by selecting any one of the criterions. For further analysis, various analysis modes are also provided, i.e., sensitivity by weights, data scatter plots, and trade-offs of lowest criterions. All these modes assist in analyzing and presenting the decision. Furthermore, the shell also presents various other options for displaying the results, i.e., decision score sheet, pie charts, stacked bars, stacked horizontal bars, and trend. The graphical presentations of the results not only assist in selecting the most appropriate controls but also help in presenting the results to the project participants.

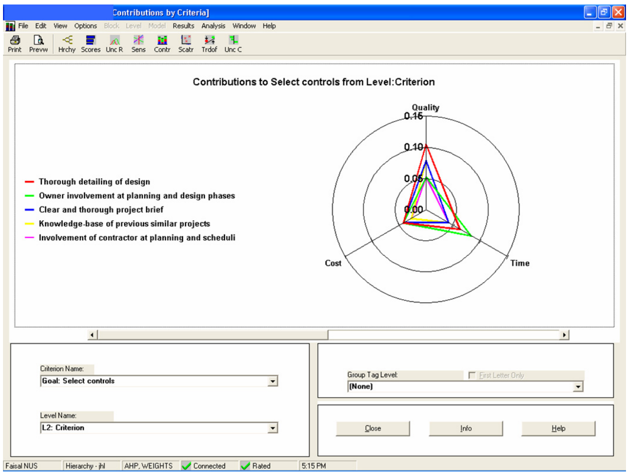

Figure 16. The results according to the contribution by criteria in radar form (web).

7 CONCLUSION

Construction projects are complex because they involve many human and non-human factors and variables. They usually have long duration, various uncertainties, and complex relationships among the participants. Primarily, the study proposed six principles of change management. Based on these principles, a theoretical model for change management system (CMS) was developed. This paper argued that the information technology could be effectively used for providing an excellent opportunity for the professionals to learn from similar past projects and to better control project variations. Finally, the study briefly presented a knowledge-based decision support system (KBDSS) for the management of variations in educational building projects in Singapore.

Although every construction project has its own specific condition, professionals can still obtain certain useful information from past experience. This information will enable building professionals to better ensure that their project goes smoothly without making unwarranted mistakes, and it should be helpful to improving the performance of the project. Furthermore, it is imperative to realize which variations will produce significantly more cost variation effect for a construction project. The CMS model consisted of six fundamental stages linked to two main components, i.e., a knowledge-base and a controls selection shell for making more informed decisions for effective management of variation orders. The database was developed through collecting data from source documents of past projects, questionnaire survey, literature review and in-depth interview sessions with the professionals who were involved in the projects. The knowledge-base was developed through initial sieving and organization of data from the database. The controls selection shell would provide decision support through a structured process.

The CMS model presented a structured format for management of variation orders. The CMS model would enable the project team to take advantage of beneficial variations when the opportunity arises without an inordinate fear of the negative impacts. By having a systematic way to manage variations, the efficiency of project work and the likelihood of project success should increase. The model emphasized on sharing the lessons learned from existing projects with project teams of future projects. The lessons learned should be identified throughout the project life cycle and communicated to current and future project participants.

The KBDSS provides an excellent opportunity to the professionals to learn from past experiences (Arain, 2005b). It is important to note that this system for the management of variations is not designed to make decisions for users, but rather it provides pertinent information in an efficient and easy-to-access format that allows users to make more informed decisions and judgments. Although this system does not try to take over the role of the human experts or force them to accept the output of the system, it provides more relevant evidence and facts to facilitate the human experts in making well-informed final decisions (Arain, 2005b). The KBDSS should be applied in the early stages (design stages) of the construction projects.

The KBDSS is a unique system developed specially for the effective strategic management of variations in educational building projects under the rebuilding and improvement programme for the first time (Arain, 2005b). This is a timely study as the programme of rebuilding and improving existing educational buildings is currently underway in Singapore; it provides the best opportunity to address the contemporary issues relevant to the management of variations. The KBDSS would assist professionals in analyzing variations and selecting the most appropriate controls for minimizing variations in educational building projects. The study is valuable for all the professionals involved with developing the educational projects. The initial use of the system for management of project changes resulted in reducing variations by 30 – 35% in educational building projects in Singapore. Presently, the system is being utilized by the governmental organization (the developer) for developing educational building projects in Singapore.

Knowledge acquisition was the major component for developing this system. The KBDSS is developed based on the data collected from the 80 educational buildings. The KBDSS consists of two main components, i.e., a knowledge-base and a controls selection shell for selecting appropriate controls. The database is developed by collecting data from the source documents of these 80 educational building projects, questionnaire survey, literature review and in-depth interviews with the professionals who were involved in these projects. The KBDSS provides a fast response to queries relating to the causes, effects and controls for variations. The KBDSS is capable of displaying variations and their relevant in-depth details, a variety of filtered knowledge, and various analyses of the knowledge available (Arain, 2005b). This would eventually lead the decision maker to the suggested controls for specific variations and assist the decision maker to select the most appropriate controls for managing the variations timely.

In CMS, the knowledge consolidation process of the past experience will allow such knowledge to reside within an organization rather than residing within individual staff that may leave over time. The KBDSS systematically consolidates all the decisions that have been made for numerous projects over time so that individuals, especially new staff, would be able to learn from the collective experience and knowledge of everyone. Hence, the system should be used during the early stages of construction projects to achieve optimal results. The professionals will be able to explore the details of all previous actions and decisions taken by other staff involved with the educational projects. This would assist them in learning from the past decisions and making more informed decisions for enhancing the management of variations.

The CMS through its KBDSS will help to enhance productivity and cost savings in that: (1) timely information is available for decision makers/project managers to make more informed decisions; (2) the undesirable effects (such as delays and disputes) of variations may be avoided as the decision makers/project managers would be prompted to guard against these effects; (3) the knowledge base and pertinent information displayed by the KBDSS will provide useful lessons for decision makers/project managers to exercise more informed judgments in deciding where cost savings may be achieved in future educational building projects; and (4) the KBDSS provides a useful tool for training new staff members (new professionals) whose work scope include educational building projects.

The study would assist building professionals in developing an effective variation management system. The system would be helpful for them to take proactive measures for reducing variations. The system efficiently assists the professionals in learning from past experiences. It is recommended that the system should ideally be used during the design stages of construction projects. Furthermore, with further generic enhancement and modification, the KBDSS will also be useful for the management of variations in other types of building projects, thus helping to raise the overall level of productivity in the construction industry. Hence, this study would also be valuable for all building professionals in general.

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