

Strategic Management of Variation Orders for Institutional Buildings: Leveraging on information technology*

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Abstract

This study identifies the major findings from the data collected from the source documents of 79 institutional building projects and how these would have implications for future policy implications. Finally, the study presents a Knowledge-Based Decision Support System (KBDSS) developed based on the data collected from these 79 institutional buildings, for making timely and more informed decisions for management of variations. To achieve the study objectives, an in-depth study of source documents and questionnaire survey was carried out for data collection. In-depth interviews with 62 professionals, who were involved in these projects, were analyzed. The results indicate that the total number of variations in upgrading projects were almost twice the total number of variations in new projects. The root causes of variations were grouped under five categories. The highest number of variations and variation orders were contributed from the Owner Related Variations (ORV) and Contractor Related Variations (CRV) groups. Further analysis of these two groups revealed the most important and common root causes of variations from both these groups. Furthermore, the study revealed the most frequent effects and most effective controls for each of the most important causes of variations identified that assisted in developing the KBDSS. The KBDSS consists of two main components, i.e., a knowledge-base and a decision support shell for selecting appropriate controls. 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. This would eventually lead the decision maker to the suggested controls for specific variations and assist the decision maker in selecting the most appropriate controls for managing the variations timely. 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 institutional buildings. With further generic enhancement and modification, the KBDSS will also be useful for the management of variation orders in other types of building projects, thus helping to raise the overall level of productivity in the construction industry. The system developed and the findings from this study would also be valuable for all building professionals in general.

Introduction

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, Assaf, & Low, 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.

Variations are common in all types of construction projects (CII, 1994; Fisk, 1997; Ibbs, Wong, & Kwak, 2001). The nature and frequency of variations occurrence vary from one project to another depending on various factors (CII, 1986; Kaming, Olomloaiye, Holt & Harris, 1997). Arain and Low (2005a) identified the design phase as the most likely area on which to focus to reduce the variations in future institutional 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, 2005). Variations in construction projects can cause substantial adjustment to the contract duration, total direct and indirect cost, or both (Ibbs, 1997; Ibbs, Lee & Li, 1998). Therefore, project management teams must have the ability to respond to variations effectively in order to minimize their adverse impact to the project.

Information technology has become strongly established as a supporting tool for many professional tasks in recent years (Arain & Low, 2005b). 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 & Pomerol, 1995; Mokhtar, Bedard & Fazio, 2000). The objective of

this study is therefore to develop a knowledge-based system for linking information to support decision making for effective management of variations in institutional building projects in Singapore. The system would assist the professionals in learning from past projects for reducing potential variations in the institutional building projects

Scope of Research

The government of Singapore initiated a major program of rebuilding and improving existing institutional 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 institutional 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 knowledge-based decision support system for management of variations in institutional building projects will contribute towards the better control of variations through prompt and more informed decisions. Therefore, this research concentrated on the institutional building projects under this major rebuilding and improvement programme in Singapore. The number of completed institutional projects is 79. Furthermore, the interviews were restricted to the developers (governmental agency), the consultants, and contractors who have carried out these institutional projects.

Research Methodology

To achieve the study objectives, a case study approach and questionnaire survey was carried out. Information for the study was obtained from source documents of the institutional projects completed, questionnaire survey and through personal interviews and in-depth discussions with the professionals with a government agency responsible for the rebuilding and improvement programme, the consultants and the contractors who were involved in these projects.

The projects were documented and analyzed between February and September 2004. The purpose of the case study approach was to obtain data from the source documents of the completed projects. The source documents included the contract documents, variation orders documents, contract drawings, and as-built drawings. Through an extensive literature review, the 53 causes, their 16 potential effects, and 30 controls for variation orders were identified. The causes of variations were grouped under five categories: Owner related variations (ORV), consultant related variations (CRV), contractor related variations (CTRV), other variations (OV), and combination of causes (CC). These groups assisted in developing a comprehensive enumeration of potential root causes of variations.

In addition to collecting information from the source documents and sending out the questionnaires, 62 face-to-face interviews using the questionnaire and the collected data were also conducted to ensure that all questions were answered, to ensure that the information was accurate and the respondents have a chance to clarify any doubts with the research team. Interviews of 28 professionals with the government agency responsible for the rebuilding and improvement programme, 16 consultants and 18 contractors, who were involved in these institutional projects, were carried out. They included directors, senior managers, project managers, and project officers from the developer’s side, directors, principal architects, senior architects, and project architects from the consultant’s side, and directors, senior project managers, project managers, and construction managers from the contractor’s side.

Analysis of the Information Collected from the Source Documents

The profile of the projects investigated in this study is presented in Exhibit 1. The 79 institutional building projects were constructed between July 1999 and December 2003. There were two types of institutional projects, namely, level-1 institutions and level-2 institutions. Level-1 institutions were built for children between 6 to 12 years of age. Level-2 institutions were for students between 13 to 16 years of age. Both these institutional types consisted of similar facilities. However, the covered area for a level-1 institution was 17,500m² and a level-2 institution was 21,500m².

S/No.	Project types	Covered area	Work scope	No. of projects	Program phases			Total projects	Grand total
					P1	P2	P3		
1	Level-1 institutions	17,500m ²	Upgrading	42	24	16	2	67	79
			New	25	23	2	0		
2	Level-2 institutions	21,500m ²	Upgrading	3	2	1	0	12	
			New	9	7	2	0		

Exhibit 1: Profiles of the institutional projects investigated

S/No	Group name	Total number of variation orders	Total variations	Total omissions
1	Owner related variations (ORV)	2079	2502	172
		39.21%	39.00%	49.71%
2	Consultant related variations (CRV)	2896	3539	141
		54.63%	55.17%	40.75%
3	Contractor related variations (CTRV)	171	208	28
		3.22%	3.24%	8.09%
4	Other variations (OV)	42	51	5
		0.79%	0.79%	1.44%
5	Combination of causes (CC)	106	114	0
		1.99%	1.77%	0

Exhibit 2 Statistics of variation orders, variations and omissions in all institutional building projects

As shown in Exhibit 2, of the 5,301 variation orders for institutional projects, 39.21% were related to the ORV group, while a majority (54.63%) of variation orders was from the CRV group. Only 3.22% were related to the CTRV group. Very few variation orders were from the OV and CC groups. Of the 6,414 variations that occurred in both new and upgrading projects, 39.00% were related to the ORV group, and 55.17% of the variations were from the CRV group. The variations related to the CTRV group were only 3.24%. Very few variations were related to the OV and CC groups as shown in Exhibit 2. Of the 346 omissions that occurred in both new and upgrading projects, 49.71% were from the ORV group and 40.75% were from the CRV group. Omissions related to the CTRV and OV groups were 8.09% and 1.44% respectively. It was revealed through in-depth interviews with professional that the omissions were mainly carried out for reducing the project cost and not exceeding the contingency sum allocated for the project. The results suggested that the more number of variations encountered during the projects were also due to the timing of the projects implementation, as a majority of the projects were carried out during the early phases of the programme of rebuilding and improvement in Singapore. It was revealed through in-depth interviews with the professionals with the government agency that the objectives and specifications provided by the developers were not fully developed during the early phases of the programme. The time allocated for design development was not sufficient and the specifications and requirements were frequently revised by the developers, thus leading to numerous variations during the construction phase of the projects. As a majority of the institutional projects was completed during the initial phases of the programme of rebuilding and improvement, large numbers of variations were expected. The overall analysis suggests that the highest number of variation orders, variations and omissions that occurred in the upgrading and new projects were contributed from the ORV and CRV groups as shown in Exhibit 2. Hence, both these groups were further analyzed to determine the most important root causes of variations in both new and upgrading projects.

S No.	Causes	Group	TVO	TV	TO
1	Change of plans or scope by owner	ORV	984	1184	97
2	Change in specifications by owner	ORV	950	1145	65
3	Noncompliance design with govt. regulations	CRV	754	940	14
4	Design discrepancies (Inadequate Design)	CRV	580	697	1
5	Change in design by consultant	CRV	476	563	38

(Note: TVO= Total variation orders, TV= Total variations, TO= Total omissions)

Exhibit 3 Most important root causes of variations in institutional projects

The root causes of variations were determined based on the information available from the source documents of the 79 projects. Furthermore, the causes determined were also verified with the professionals during the in-depth interview sessions. The results suggest that the highest number of variation orders and variations were contributed from the ORV and CRV groups. As shown in Exhibit 3, further analysis of these two groups revealed that change of plans or scope by owner, change in specifications by owner from the ORV group and noncompliance design with government regulations, design discrepancies, change in design by consultant from the CRV group were considered as the top five most important and common root causes of variations in institutional building projects. The study suggests that the professionals should concentrate more on defining the scope of project, allocating sufficient time for design development and improving design detailings and compliance with government regulations that would assist in reducing variations related to the ORV and CRV groups.

The questionnaire responses were used for revealing the most frequent effects and effective controls for each of the 53 causes of variations in institutional building projects. Chan and Kumaraswamy (1993) used the relative importance index method. This method was also adopted to analyze the data collected from the questionnaire survey. The analysis was carried out for all three groups of respondents. Firstly, the questionnaire responses were used for carrying out cross-tabulation analyses between causes and effects, and between causes and controls. The cross-tabulation analyses assisted in identifying the important cores i.e., the causes and effects, and causes and controls that were considered important or very important by the respondents. The number of responses that rated the causes and effects as important or very important were extracted from the cross-tabulation analysis and used for developing the Relative Importance Index (RII). The RII method was adopted by many researchers (Kometa, et al., 1994) in earlier research studies. The analysis assisted in identifying the most frequent effects and effective controls for each cause of variation order for institutional building projects. Arising therefrom, a comprehensive tabulation of the 53 causes and their frequent effects and effective controls was also developed that assisted in developing the KBDSS for strategic management of variation orders for institutional buildings.

Knowledge-Based Decision Support System (KBDSS)

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 principles and theoretical models for managing variations (Mokhtar, et al., 2000; Ibbs, et al., 2001; Arain & Low, 2005b). This study presents a KBDSS for managing variations in institutional 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 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 & Low, 2005b). 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.

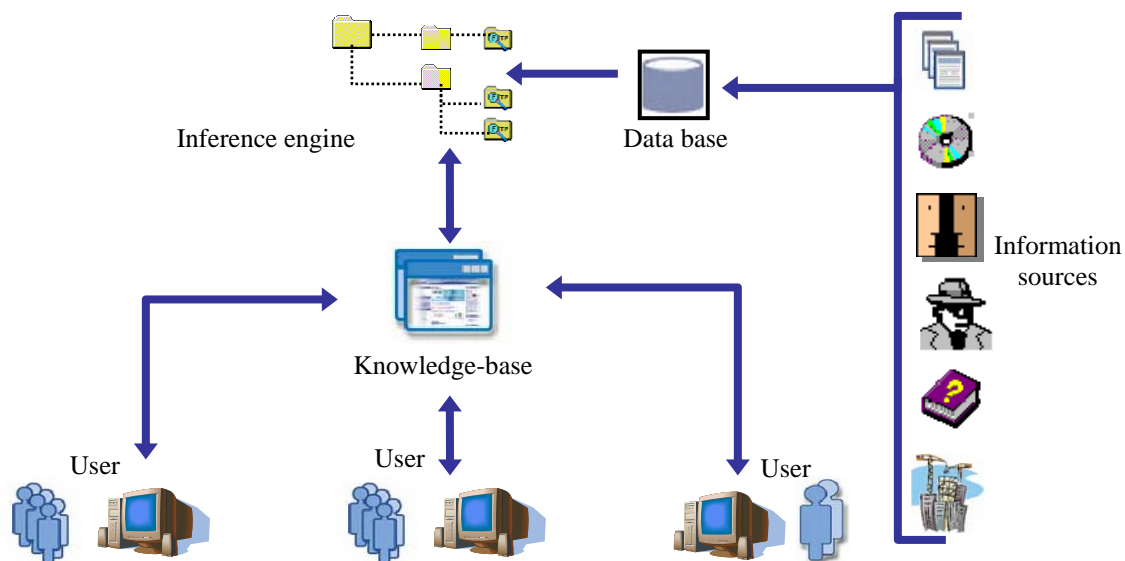


Exhibit 4: The main components of a knowledge-based decision support system (KBDSS)

The main components of the KBDSS are shown in Exhibit 4. As presented in Exhibit 4, the data was collected from various sources i.e., project documents, site data, interviews with experts, literature reviews, and variation

documents. This data was stored in a database. From the database, the data was sieved through an inference engine for developing the knowledge-base. Eventually, the knowledge-base provided decision support to the project teams for making more informed decisions for effective strategic management of variations.

The KBDSS consists of two main components, i.e., a knowledge-base and a decision support shell for selecting appropriate controls. The database is developed by collecting data from the source documents of 79 institutional 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 79 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 institutional buildings was integrated with the decision support shell. The shell contains 53 layers based on each of the causes of variations and their most effective controls. The decision support 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 decision support 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 institutional 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 institutional building projects.

Major Information available on the Macro Layer

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 79 institutional projects and through interview sessions with the professionals. As shown in Exhibits 5a, 5b and 5c, the macro layer contains the major information about the institutional projects completed, i.e., project name, program phase, work scope, institutional 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 institutional 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 institutional projects.

No.	Project name	Zone	Program	Work scope	Institutional level	Type of contract	Date of commencement	Duration (months)	Date of completion	Actual completion	Schedule completion
1	Griffiths East Institute	E	P-2	Upg	1	PSSCOC	26-Feb-01	23	18-Mar-03	15-Jan-03	Ahead Schedule
2	Paya Lebar East Institute,	E	P-1	Upg	1-Aided	PSSCOC	15-Jun-00	18	14-Dec-01	31-Dec-01	Behind Schedule
3	Yew Tee West Institute	W	P-1	New	1	PSSCOC	17-Sep-99				
4	Greenridge West Institute	W	P-2	Upg	1	PSSCOC	19-Feb-01				
5	Boon Lay Garden West Institute	W	P-1	Rebuilt	1	PSSCOC	14-Aug-00				
6	Bukit Timah West Institute	W	P-1	Rebuilt	1	PSSCOC	14-Aug-00				
7	Henry Park West Institute	W	P-1	Rebuilt	1	PSSCOC	28-Aug-00				
8	Bukit View West Institute	W	P-1	Upg	1	PSSCOC	6-Mar-00				
9	Bukit Panjang West Institute	W	P-1	Upg	1	PSSCOC	6-Mar-00				
10	Ru Lang West Institute	W	P-2	Upg	1	PSSCOC	27-Mar-01				
11	Fairfield Methodist West Institute	W	P-1	Upg	1-Aided	PSSCOC	28-Jan-00				
12	South View West Institute	W	P-1	Upg	1	PSSCOC	1-Mar-00				
13	Lakeside West Institute	W	P-2	Rebuilt	1	PSSCOC	21-Aug-01				

Exhibit 5a: Macro layer of the knowledge-base that consists of the major information regarding institutional building projects

No.	Project name	Schedule difference (days)	Project status	Contact final sum	Contingency sum percent	Contingency Sum	Contingency um used	Total number of variation orders	Total cost of variation orders	Total implic
1	Griffiths East Institute	-62	completed	14,339,990	10%	1,433,999	58%	99	826,936	Nc
2	Paya Lebar East Institute,	17	completed	10,116,000	10%	1,011,600	119%	15	1,200,650	Nc
3	Yew Tee West Institute	49	completed	10,418,000	10%	1,041,800				
4	Greenridge West Institute	74	completed	8,790,000	10%	879,000				
5	Boon Lay Garden West Institute	19	completed	9,568,000	10%	956,800				
6	Bukit Timah West Institute	33	completed	10,003,000	10%	1,000,300				
7	Henry Park West Institute	45	completed	16,243,500	10%	1,624,350				
8	Bukit View West Institute	56	completed	8,056,000	10%	805,600				
9	Bukit Panjang West Institute	115	completed	10,379,700	10%	1,037,970				
10	Ru Lang West Institute	-4	completed	11,151,106	10%	1,115,111				
11	Fairfield Methodist West Institute	1	completed	8,395,926	10%	839,593				
12	South View West Institute	242	completed	8,876,510	10%	887,651				
13	Lakeside West Institute	-7	completed	14,339,990	10%	1,433,999				

Exhibit 5b: Macro layer of the knowledge-base (cont'd)

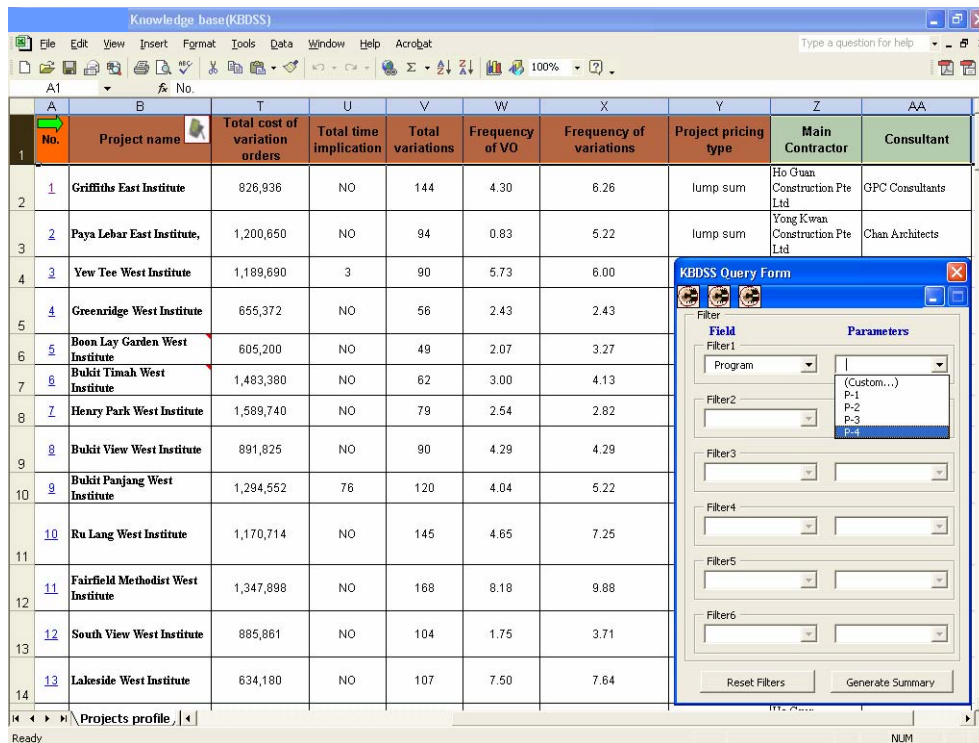


Figure 5c: Macro layer of the knowledge-base (cont'd)

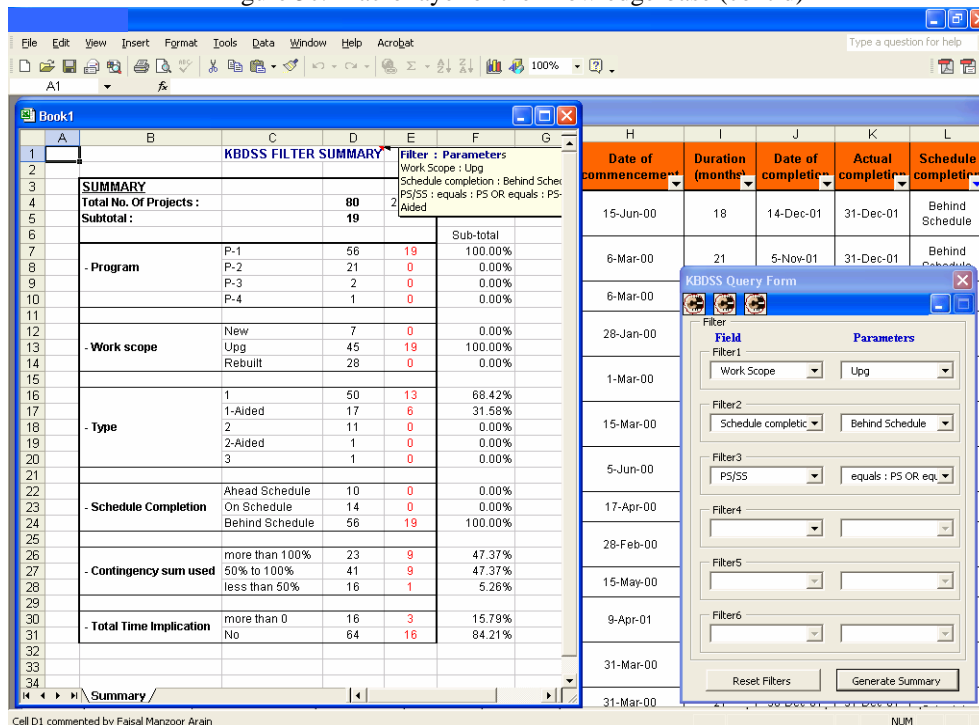


Exhibit 6: Summary section displaying the results of the filters applied on the macro layer

The inference engine provides a comprehensive summary of the information available on the macro layer as shown in Exhibit 6. Furthermore, the inference engine also computes the percentages for each category displayed in Exhibit 6. This assists the user in analyzing and identifying the nature and frequency of variation orders in certain type of institutional 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 institutional 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.

Major Information available on the Micro Layer

The micro layer is the second segment of the knowledge-base that contains 79 sub-layers based on the 79 institutional projects respectively. As shown in Exhibit 7a and 7b, the micro layer contains the detailed information regarding variations and variation orders for the institutional 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 79 institutional 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.

No.	VO #	Proposed Variations	Reasons	Causes
1	A - 01	Replace calcium silicate ceiling board with acoustic ceiling board (40% reflective and 60% absorptive) in classrooms, 2 nd language rooms, science and mathematics rooms, arts and crafts room, learning support coordinator's room.	To meet acoustic requirement for improved audibility based on performance specified by specialist consultant for learning environment.	Change in specifications by
2	A - 02	Supply and install cam-lock system lockers at front of every classroom.	To meet standard provisions of primary facilities, as original provision by school MOE has been passed to the main building contract (new requirement by MOE).	
3	A - 03	Supply and plant trees, plants and shrubs as per proposed approved plan.	To meet standard provisions of primary facilities, as original provision by lands contractor has been passed to the main building contract (new requirement by MOE).	
4	A - 04	To provide rc retaining wall along Choa Chu Kang North 6 boundary GL 3-5 of Block B lower 1 st storey, to cope with adverse site soil condition.	To provide better maintenance and slope for the slope at the rear boundary, as proposed slope found not suitable due to soil work conditions.	
5	A - 05	To change timber strip acoustic panel to acoustic perforated panel at music rooms, AVA rooms, and hall to comply with new FSSB requirement.	New FSSB interpretation on walls of corridors for internal rooms, hence previously used strip wall is no longer usable.	
6	A - 06	To change all barefaced pin-up boards to fabric covered pin-up boards.	Improvement works as proposed by MOE requirements).	
7	A - 07	To change drum hand winch stage curtain to motorized proscenium draw stage curtain, according to specifications.	To comply with new MOE specification	
8	A - 08	To provide toilet entrance timber louvred door at basement, 1 st to 3 rd storey of Block B and 1 st Storey of Block E.	To comply with MOE proposed improvement	
9		Change of timber door to 1 hour fire-rated door nearest to staircase, for vision panel. Change of 1	To comply with Fire Safety Bureau requirement	

Exhibit 7a Micro layer of the knowledge-base that contains the detailed information regarding variation orders for the institutional project

No.	VO #	Causes	Variation type	Cost Implication	Time Implication	Approving Authority	Prepared by	Endorsed by
1	A - 01	Change in specifications by consultant.	Architectural works	52,000	0			
2	A - 02	Change of plans or scope by owner.	Architectural works	105,840	0			
3	A - 03	Change of plans or scope by owner.	Architectural works	20,930	0			
4	A - 04	Differing site conditions.	C & S works.	40,432	0			
5	A - 05	Change in government regulations.	Architectural works	43,614	0			
6	A - 06	Change of plans or scope by owner.	Architectural works	18,926	0			
7	A - 07	Change of plans or scope by owner.	Architectural works	2,400	0			
8	A - 08	Change of plans or scope by owner.	Architectural works	16,533	0			

Exhibit 7b Micro layer of the knowledge-base that contains the detailed information regarding variation orders for the institutional project

			Total	Filter : Parameters
296	Sub total VO	Architectural works	1672	Causes : Design discrepancies (Inadequate Design).
355	Sub-Total Variations	C&S works	303	
		M&E works	526	

			Total	Filter : Parameters
311	Sub total VO	Architectural works	1672	Causes : contains : Design discrepancies (Inadequate Design).

			Total	Filter : Parameters
187	Sub total VO	Architectural works	1672	Causes : contains : Errors and omissions in design.
213	Sub-Total Variations	C&S works	303	
		M&E works	526	
		Services	19	
2231	TOTAL VO	Architectural works and C&S works	12	
		Architectural works and M&E works	30	
2563	Total Variations	Architectural, C&S and M&E works	0	
		Non-Standard Items funded by School	107	
		Total number of omissions	92	

Exhibit 8: 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

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 Exhibit 8. 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.

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 Exhibit 8. The professionals would be able to analyze the most potential variations in institutional building projects. The information available on the micro layers would assist in pinpointing the root causes of variations in the past institutional projects.

Effects and Controls for Potential Cause of Variations

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 Exhibit 9, 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 institutional 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 6, the controls selection tab is provided in the CDP form. This feature assisted in linking the knowledge-base with the decision support 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.

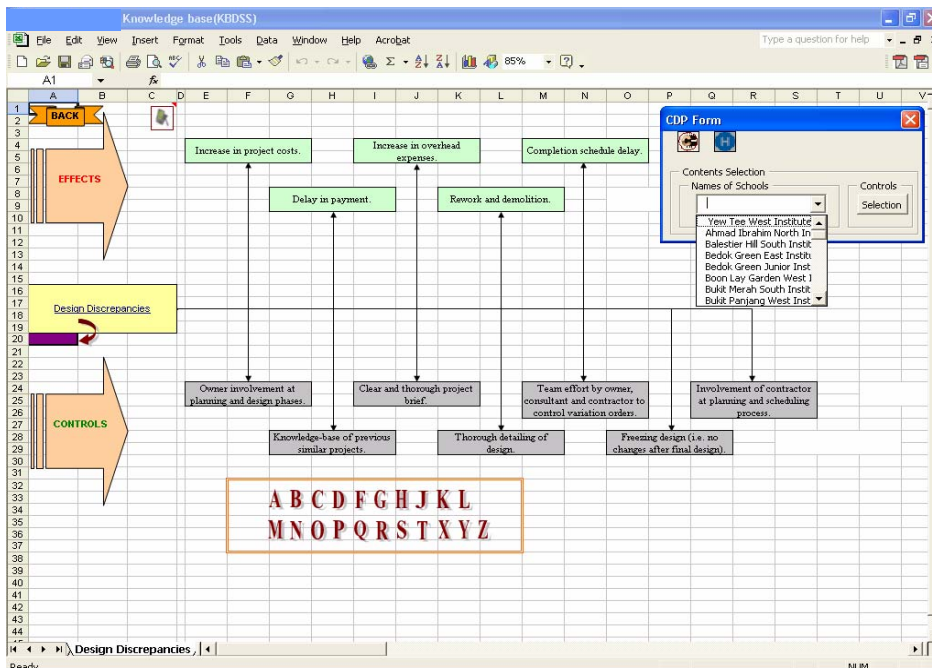


Exhibit 9: Effects and controls layer of the knowledge-base that pinpoints the most important effects and most effective controls for each cause of variations

Structured Process for Selecting Suggested Controls through Decision Support Shell

The decision support 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 decision support shell provides decision support through a structured process consisting of building the hierarchy among the main criteria 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 decision support shell contained four layers that were based on the structured process of decision making, namely, control selection criteria, building the hierarchy between criteria and controls, rating the controls, selecting the best controls based on the given criteria.

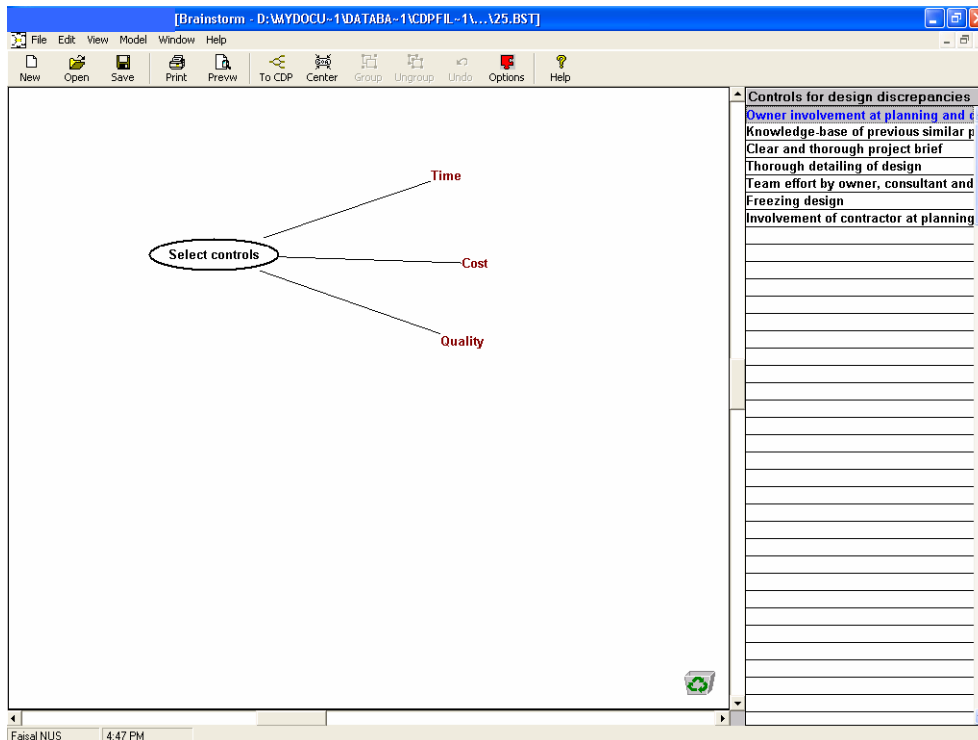


Exhibit 10: Main panel of decision support shell that contains the goal, main criteria and the most effective controls for variations (focusing on Time, Cost and Quality)

As shown in Exhibit 10, this layer of the decision support shell contains the suggested controls for the cause of variation selected in the controls and effects layer of the KBDSS. Hence, the decision support 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 criteria 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 criteria for selecting the controls. The provision of the facility for adding more controls and criteria 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 criteria and the suggested controls for variations. The shell generates hierarchy among the goal, the criteria and the suggested controls as shown in Exhibit 11. The hierarchy assists in rating all the suggested controls.

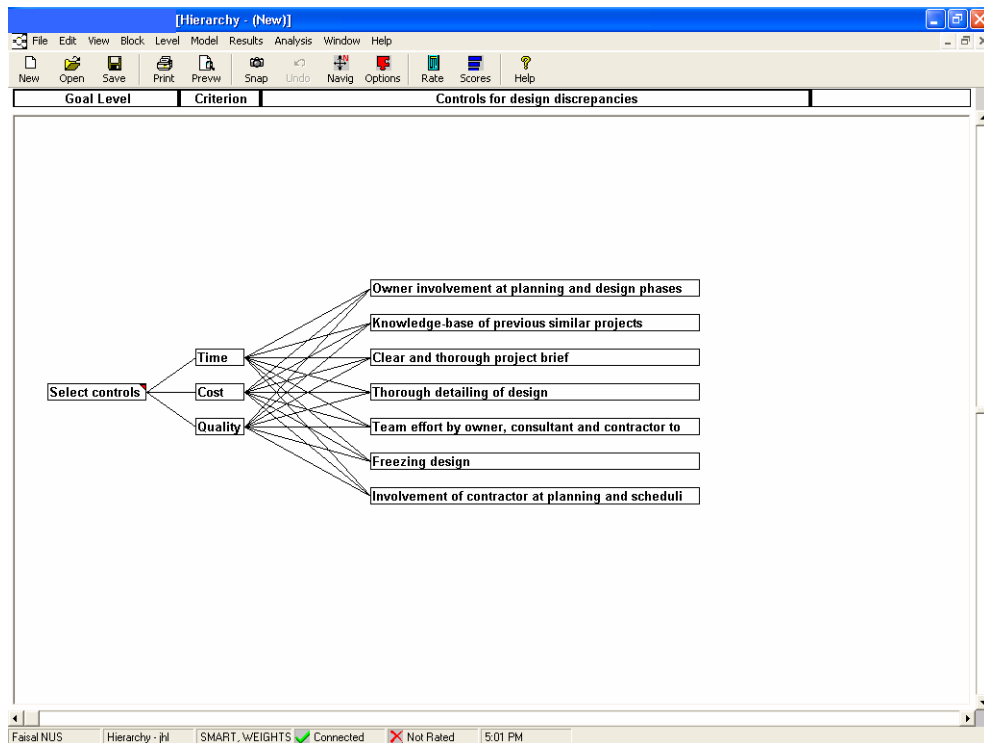


Exhibit 11: Building the hierarchy among the goal, main criteria and controls for variations

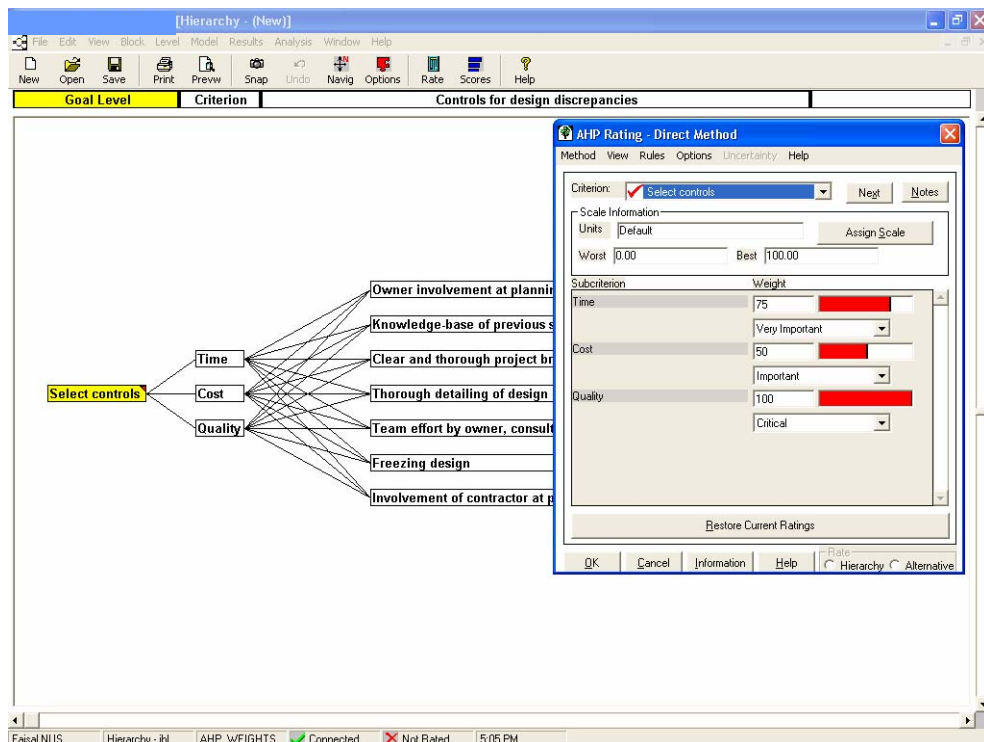


Exhibit 12: Rating the main criteria using the direct method, i.e. the default rating method provided in the KBDSS

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 Exhibit 12, the first step for rating the controls was to assign weight to the criteria, 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 Exhibit 13. The rating priority is based on hierarchy of the main criteria 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 Exhibit 14. 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 Exhibit 15. 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.

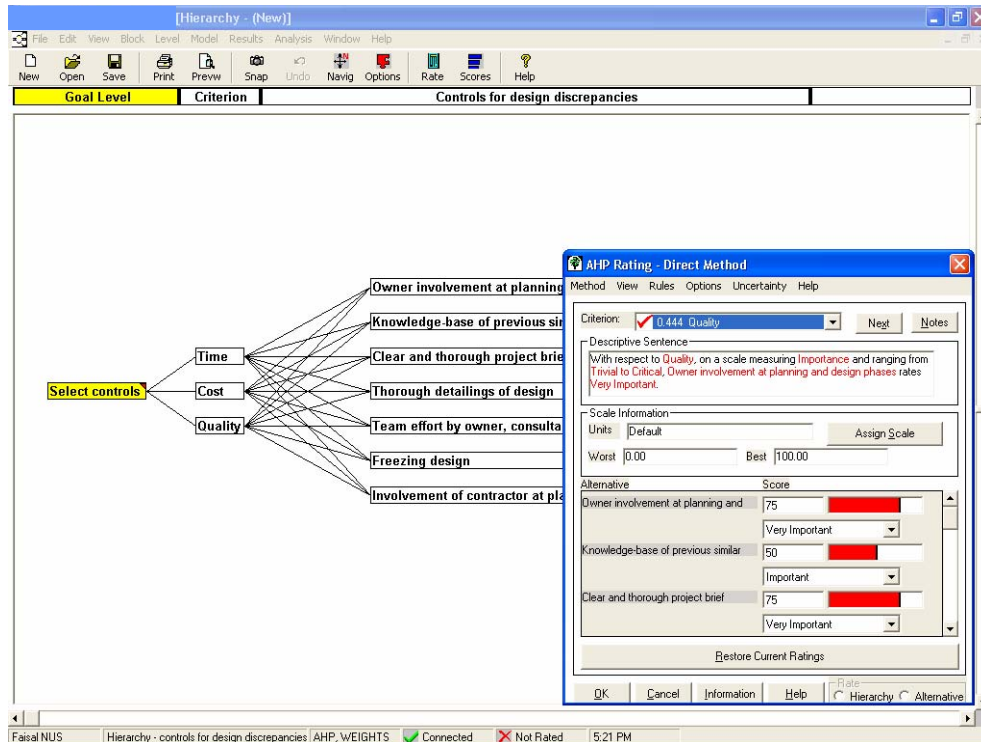


Figure 13: Rating the controls for variations with respect to quality

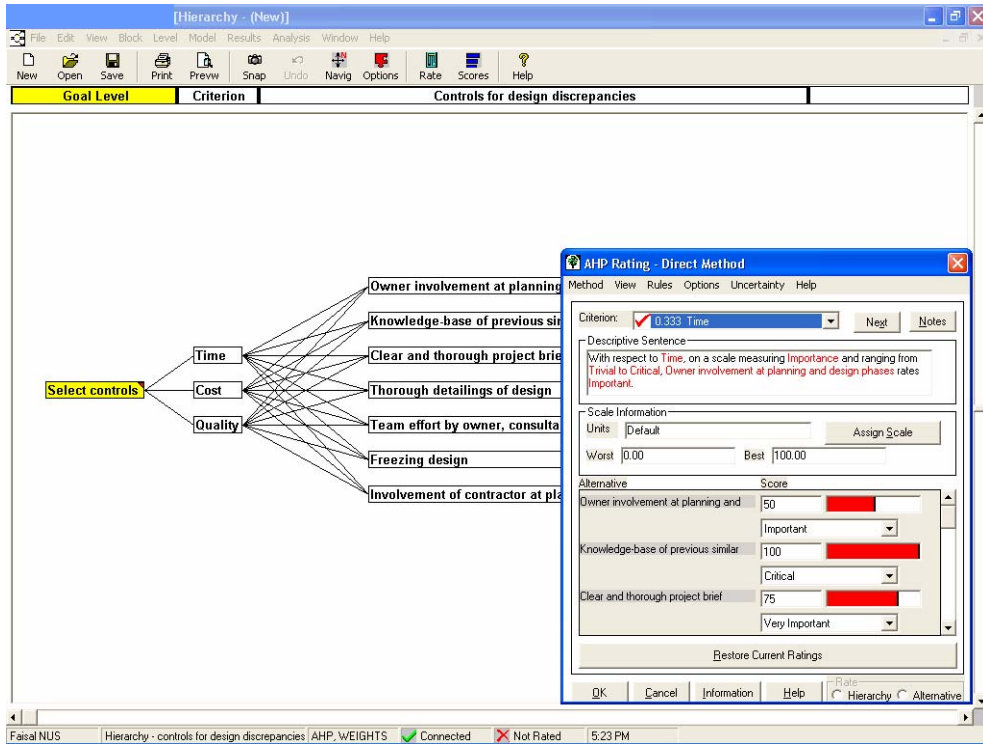


Exhibit 14: Rating the controls for variations with respect to time

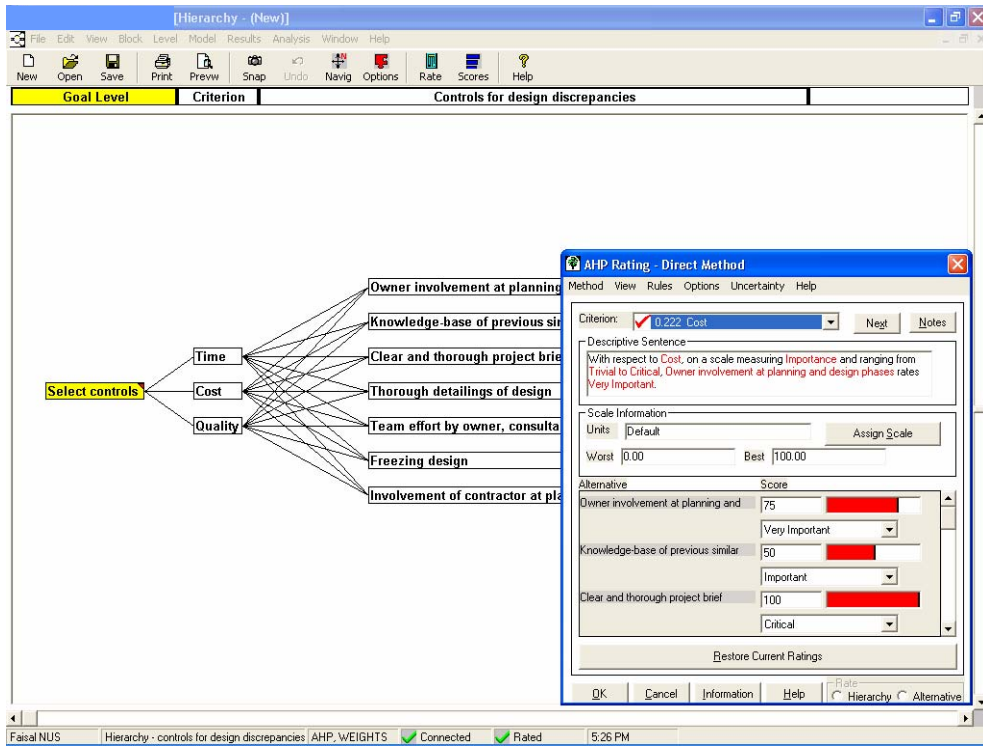


Exhibit 15: Rating the controls for variations with respect to cost

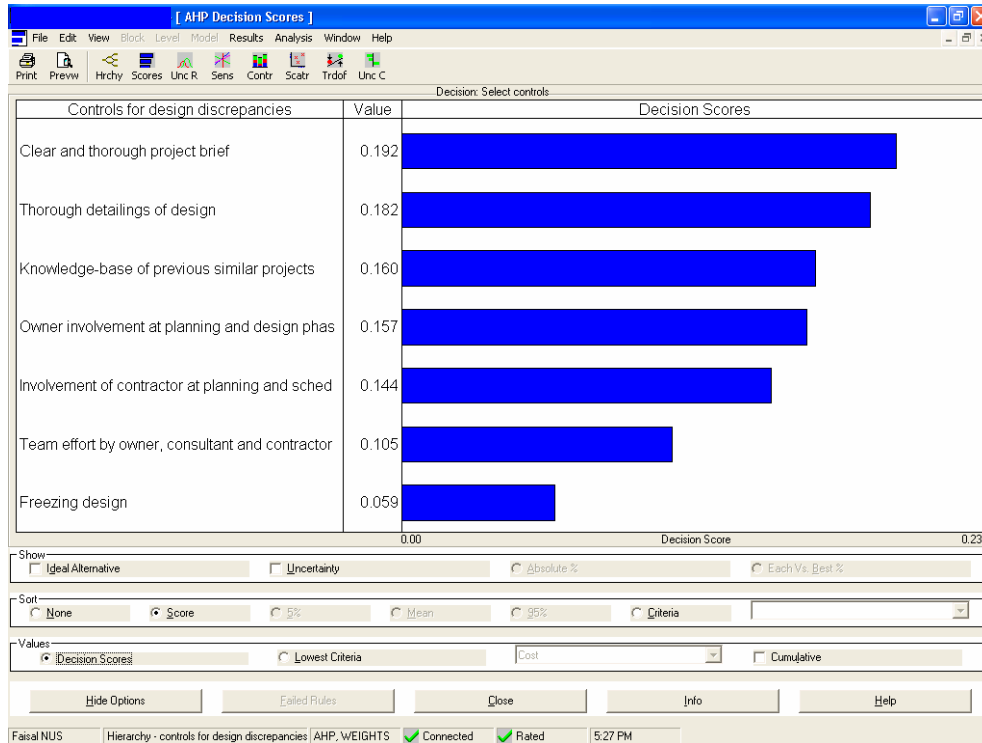


Exhibit 16: The controls for variations sorted according to the decision scores



Exhibit 17: The suggested controls sorted according to contributions by criteria

The decision support shell calculates the decision scores based on the rating process and displays a graphical presentation of the results as shown in Exhibit 16. 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 criteria as shown in Exhibit 17. The professionals may analyze the suggested controls by selecting any one of the criteria. For further analysis, various analysis modes are also provided, i.e., sensitivity by weights, data scatter plots, and trade-offs of lowest criteria. 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.

Conclusion

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 KBDSS provides an excellent opportunity to the professionals to learn from past experiences. 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. The KBDSS should be applied in the early stages (design stages) of the construction projects. In providing a systematic way to manage variations through the KBDSS, the efficiency of the building project and the likelihood of project success can be enhanced.

The KBDSS is a unique system developed specially for the effective strategic management of variations in institutional building projects under the rebuilding and improvement programme for the first time. This is a timely study as the programme of rebuilding and improving existing institutional 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 institutional building projects. The study is valuable for all the professionals involved with developing the institutional projects.

Knowledge acquisition was the major component for developing this system. The KBDSS was developed based on the data collected from the 79 institutional 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 79 institutional 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. 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.

The knowledge consolidation process of the past experience will allow such knowledge to reside within organization rather than residing within individual staff that may leave over time. Furthermore, 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 KBDSS should be used during the early stages of the 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 institutional projects. This would assist them in learning from the past decisions and making more informed decisions for effective management of variations.

The 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 institutional building projects; and (4) the KBDSS provides a useful tool for training new staff members (new professionals) whose work scope include institutional building projects. The system developed and the findings from this study would also be valuable for all building professionals in general. With further generic enhancement, the KBDSS will also be useful for the strategic management of variations in other types of building projects, thus helping to raise the overall level of productivity in the construction industry.

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* Waiver for screenshots from the given words limit was obtained from PMI on date 8th July 2005.

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