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REVIEW ARTICLE

Maintenance and Physical Asset Management Issues in Project Commissioning

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Abstract

This study describes the review on maintenance related issues during design and construction stage within construction industry. The paper highlights the causes and errors made during design and construction stage and their impact during the operation/production/occupancy stage as well as the maintenance costs associated with it. The study identifies the mistakes in the working processes within design and construction stage leading to the errors that affect the durability, performance, reliability, maintainability, availability and safety of the systems. The paper presents a comprehensive review of the published literatures, journals, technical papers in the related areas in the construction field. The review highlights the new approaches and decision framework which link the designers and construction personnel that could reduce the errors and defects in construction which then lead to maintenance issues and asset management. The factors of accessibility, materials, design and documentation standardization have been discussed thoroughly for better understanding in improving maintenance and physical asset management in project commissioning.

Keywords: Design and Maintenance in Construction; Design Faults; Construction Errors in Maintenance; Concurrent Engineering.

Introduction

The effectiveness of systems design/building in construction is not only being measured by its design/architecture values but how it would serve the required functions for reliable performance and considerable maintenance and asset management awareness. In actual practice the important links of the two elements are always neglected. Most of the construction projects have been designed, developed and built with very little attention being given on the aspects of maintenance and operation (El-Haram and Horner, 2002). The consideration of design factors on the construction performance after completion is almost neglected. The difficulties in maintaining the building after completion also have never been taken into account, especially at the time the building is proposed to be built.

Therefore, the cost to maintain the building increases as a result of frequent occurrence of maintenance activity, its life cycle declines and more structures and parts of the building easily deteriorate (Ahmad Ramly et al., 2006). While much emphasis has been placed upon constructability, relatively little attention has been given to maintenance aspect like availability, reliability and maintainability. This paper attempts to highlight the issues, bring awareness and consider some approaches for better maintenance awareness during design and construction.

Therefore the objectives of this paper are:

- To highlight the issues, bring awareness and consider some approaches for better design and construction towards better reliability, availability, maintainability.
- To examine some of the major factors contribute to design/construction errors and explore solutions towards the aim for construction project with maintenance and asset management awareness.
- To appreciate some of new techniques and developments as studied by researchers and industry leaders in engineering construction projects with consideration given to maintenance and asset management as a whole.

Maintenance Problems and Issues Related to Design and Construction

The construction industry has been under pressure to minimize the number of defects in projects and to increase the quality of service offered to public and clients. There have been so many cases and problems in maintenance that caused by construction errors/faults. The most effective and quality construction project will take into consideration the maintenance and asset management issues and awareness during the design and construction stage and it requires so much proper and professional coordination between all the parties involved in the construction include the design team, main contractor (construction), sub-contractors (construction), suppliers/vendors, external consultant, project management team etc. There are many issues and problems encountered during operation/production stage but just the critical problems will be discussed and highlighted in this topic in order to prioritize the problems and finding the optimum solution for those problems. Subjects that will be discussed and studied are the maintenance issues that occur as a result of faults/mistakes that originate from design/construction phase.

Accessibility

Maintenance accessibility related to the definition of how easy and well the maintenance personnel perform the maintenance in terms of area/space. It includes the aspect like, is there adequate space for technicians to perform maintenance activity, including space for hands, arms, tools etc. (Labib, 2006). There are numerous accessibility problems encountered during the production stage when for instance the preventive /predictive maintenance/turnaround management to be performed, the accessibility issue has been major factor in difficulty to execute the maintenance activity. Since the duration of the maintenance activity will be proportionally related to the increase of costing, therefore this issue must be taken into consideration when design and development phase is carried out. (Lenahan, 2006).

Reliability, Availability and Safety

There are many cases that involve the breakdown and malfunction of equipment as a result of errors performed by the main contractor in the equipment purchasing process, not as specification, suppliers and vendors mistakes in technical specifications errors etc. It is agreed that maintenance has a considerable impact on the performance and safety of a construction product and that maintenance related problems that occur during the lifetime of a building/construction project can be minimized by making the corresponding decisions

early in the design phase of the project, as long as these decisions are made in the context of a life-cycle cost analysis.

Materials

The defect of material related issue has also been at the very high priority in the operation and production stage since this problem could bring to catastrophic failure of equipment, structures, piping etc. and therefore will bring to the loss of production and business of a company. It focuses on various matters related to materials, including durability, sustainability, and clean ability of materials There have been quite number of cases associated with materials defect in the oil and gas industry for instance corrosion of piping and structures, and in the civil and building industry like cracking, corrosion, fixing failure etc. (Arai et al., 2006; Sadi Assaf et al., 1996; Chong and Low, 2006). Some of the examples of building defects are listed as follow:

- Sealant deterioration
- Peeling and flaking
- Yellowing
- Crating
- Staining
- Delamination
- Spalling
- Blistering
- Scratches abrasions
- Misalignment of joints
- Buckling and warping

Chong and Low (2005) studied the differences among the defects that occurred during construction and 2 to 6 years after initial occupancy. The defect data used for the study and research were from a total of 35 institutional, 4 hospitals, 13 residential, 11 commercial, and 11 other buildings. The findings of the research revealed that a total of 122 types of defects were found during construction and 135 types during occupancy, 96 defects found during occupancy were not found during construction, and 39 types were found at both stages. It was also found that material quality and poor design decisions were the roots of the defects. The results from their study are as shown in Table 1.

Table 1. Defects Statistics at Different Stages (Chong and Low, 2006)

Elements	Number of defects found at construction	Number of defects found and occupancy	Types of defects found at construction and occupancy	Total types of defects found	New defects found at occupancy
Floors	10	16	6	20	10
Internal Wall	10	12	5	17	7
Windows	12	14	5	21	9
External Wall	21	13	7	27	6
Mechanical and electrical	13	13	0	26	13
Doors	12	17	4	25	13
Ceilings	13	10	3	20	7
Plumbing and sanitary	12	28	5	35	23
Roofs	19	12	4	27	8
Overall	122	135	39	218	96

Some case studies in oil and gas industry reveal that some of the failure and breakdowns of equipment, structures, pipeline, etc. are caused by construction errors. A case study by Dey (2001) was on inspection and maintenance of cross-country petroleum pipeline. The case study and research had been carried out on a crude oil pipeline with length of 1500 km in the western part of India. Failure analysis revealed numbers of pre commissioning failures which relate to the quality of construction. Poor construction, combined with inadequate inspections and low quality materials, also contributed to pipeline failures. He then suggested some improvement means in design, construction and operational philosophy of pipelines. Here were some of his recommendations:

- Pipeline routes to be decided on the basis of a life-cycle costing approach, not on the basis of shortest route.
- Pipe thickness shall be decided on the basis of its maintenance characteristics throughout the life-cycle.
- Construction methodology of pipeline to be formulated and considered seriously during the feasibility stage of the project and this shall include design and operational philosophy of the pipeline on the overall.
- During the construction stage and construction methodology, high considerations should be emphasized on the availability of consultants, contractors and vendors, government regulations, and environmental factor.

Design Issue

Most of the issues are in the subjects related to complexity of the equipment or systems that make the maintainer difficult to perform the maintenance. The complexity of the design will make it difficult for maintenance people to make decision to perform the maintenance activities in addition of unclear specification and details on the diagram of the equipment, piping or instrumentation. The more complex and sophisticated the system is, the more longer it will be for the maintenance personnel and operation team to get back to the system operating mode and it is certainly will contribute to the more money wasted in offline and breakdown duration. The safety route designed for the use of emergency time, sometimes are used during the maintenance activity and this is not appropriate from the engineering and safety point of view. The safety route should be vacant and remain unaltered of its function as route for the safety path during emergency time. It could not be used even temporarily for material handling and maintenance activity. These are the examples of maintenance issues associated with the design complexity (Rafael et al, 2015).

Documentation

Operation and manual documentation although represent small part of the maintenance but very essential and crucial because with inadequacy of all those documentation, the end user personnel will face difficulty in understanding the equipment, systems, process etc. especially when the maintenance people want to perform maintenance activities. Maintenance people will need to understand how each machine operates, the control system that ties the machines together, know how to effectively troubleshoot the process and repair the individual machines, performing routine maintenance and performing changeovers. (Wheelhouse, 2006). For a company to be considered as reliable and supportive, it is essential to produce system/construction with documented and predictable quality, reliability, supportability, and maintainability. (Markeset et al., 2003).

Spares

As in the operation and production of a plant, the downtime of the breakdown should be minimized at all time to avoid loss to the company and one of the essential factors that could contribute to the long breakdown time is the inefficiency in managing spares. This problem

could be originally caused by so many reasons and factors and one of them is the poor quality of construction in terms of purchasing terms and agreement with suppliers/vendors. It is really frustrated when all the maintenance personnel feel when they cannot find the spare parts they need, or are faced with long lead times for getting replacements and senior management is breathing down their neck to get the plant operational as soon as possible. The problem that usually been linked with the spares are availability of the spares, long lead time for the spares to arrive, very hard to find the same and exact product and spares etc. (Lenahan, 2006).

Causes of Errors and Faults during Design and Construction Leading to Maintenance Issues

It is normally accepted that human are the major causes of errors resulting in maintenance issues in design, construction and operation/production. The construction process is influenced by unpredictable factors that could result from different sources. Design and construction defects are always the key concern of the construction industry since it will result to the maintenance and asset management problems in the later stage Dhillon et al., (2006), on his study stated that human errors in maintenance may be categorized into six classes:

- operating errors;
- assembly errors;
- design errors;
- inspection errors;
- installation errors; and
- maintenance errors

Errors during Design Phase

Design errors which are not rectified during the design phase will eventually appear in the construction phase where the impact can be more severe than in the design phase. Mendelsohn (1997) on his study had found that approximately 75% of the problems generated on site were originated at the design phase. The design flaws will surely create problem on site and construction team will face the issues that should be earlier if the errors eliminated at the design stage.

Ahmad Ramly et al., (2006) on their study also agreed on the causes of bad design resulted from insufficient data and information that can support design inputs, inexperienced designers or a lack of consulting /advisory expertise of design team. Design complexity requires the involvement of skilled professionals. Complexity affects the flow of construction activities, whereas simple and linear construction works are relatively easy to handle. Complex designs can lead to loss of productivity. Hence complexity may cause inconsistencies at project interfaces. In reliability study, the chain and link between the parts in the design will be affected as a result of change that occurs and this will also lead to the change in reliability integrity of the whole product. (Eckerta et al*.,* 2006).

Andi and Minato (2003) in their findings of research mentioned that inadequate information, unawareness, wrong assumptions, and lack of knowledge, alongside other organizational and motivational factors, contributed to defects at the design stage. Surther (1998) in his study on evaluation of the perception of design errors in the construction industry highlighted the causes that contribute to design errors could be classified into 3 categories:

1) Client response
    - poor site monitoring and documentation control
    - lack of coordination between parties
    - owner changing design criteria at the later stage
    - inexperienced design personnel

2) Designer/Consultant response
   - misunderstanding of the scope
   - inexperienced of drafting personnel
   - client create change in scope in the very late stage
   - lack of coordination
3) Construction Contractor response
   - lack of expertise and knowledge on construction among the designers
   - designers issue drawing before fully review and checking
   - time constraint for the designers

In another study by Shelton (1998), it was found that for both constructors and designers, the client feedback was the main measure to assess the effectiveness of maintainability consideration. Since the client feedback was not so active, the maintainability aspect was not considered as critical as other consideration like design aspect or constructability. In addition, it was also found that designers regarded operability during engineering and planning more than maintainability.

Errors during Construction Phase

Construction projects involve complex and time consuming design. The processes of construction involve unexpected circumstances and therefore, some of the errors during the construction could lead to the maintenance issue in the later stage. The causes of the errors have become the main concern in the construction industry. The role of human error in construction defects study by Atkinson (1999), a statistical study of 23 house-building sites and a further series of unstructured interviews revealed that, managerial influences underlie many errors leading to defects and defects appearing in finished work were caused by pressures of time, checking problems, and poor formal communications.

Soetanto et al., (2000) in their study purposely to assess the performance of construction contractors, as addressed by clients and architects in the UK, 39 clients and 31 architects concluded that contractors had to improve their performance. 51 per cent of clients and 54 per cent of architects were generally satisfied with the performance of their contractors. In terms of criteria in need of improvement, completion of defects was considered the priority by both clients and architects. This means that contractors should always have the awareness of the defect free and defects should be immediately detected and assessed during construction to prevent from delay until final stage of the project. False or unclear specifications always associated with the main problems with drawings. Construction contractor interprets specification on their own without approval and without discussing with consultants/designer and sometime they also use their own standard practice specifications (Santoso et al., 2003).

Ahmad Ramly et al., (2006) in their study stated that the design configuration and workmanship may have been sufficient if the proper materials had been used. The contractors sometimes disobey the technical specification of materials, in order to save time and money without taking into consideration the effect on the occupancy stage. If the vendors/suppliers of the systems and equipment do follow and comply with the design for manufacture guidelines like design for a minimum number of parts, developing a modular design, minimizing part variation, and other guidelines, the problem related to maintenance can be reduced (Labib, 2006). All of the causes combined with the lack of communication and coordination between professionals have led to the defects and errors during design and construction stage. The consequence of the defects is a construction failure that could lead to maintenance and asset management problem. Those serious defects could cost client/ end user a lot of financial impact and is considered not economical. Reducing the errors and number of design and construction defects will result in reduction of maintenance and asset management expenditure in the future. Such problems should be avoided in the modern construction industry and this requires constant monitoring and rectification of the

organization policy, structure, and management practice towards construction project with maintenance and asset management awareness in mind.

Working Practices In Construction/Design Affecting Maintenance

Studies in the construction industry indicate that some work processes are not properly defined, or have procedures, routines or checklists that are not followed or are not easy to follow. Even if many of the required procedures, routines and checklists are in place, time-pressure occasionally makes them difficult to follow. Procedures, routines, and checklists are used to coordinate and control the work process to ensure that the actual output meets the expectations (or according to specifications and quality).

During the construction stage, one important concern is to monitor the progress and quality of workmanship on site to ensure that the construction works comply with the design. It is really essential to monitor the specifications, drawings, bills of materials and installation works in order to prevent any defects on construction occur that could later result in serious maintenance problems during operation/occupancy phase (Rosaler, 1997).

Errors in work processes (design, analysis, construction, procurement, commissioning etc.) can cause physical flaws and typically include incorrect calculations, faulty assumptions, miscommunications, failure to follow established procedures and quality checking, review etc. Understanding the working practices in design and construction related to maintenance engineering and asset management issues is important for monitoring and control. Even though the construction project is very complex in nature and faults and errors during the working process are normal, the problems and issues in working process must be considered a core management competence of an organization. Using effective application and of the technique of work process review and quality assurance monitoring together with implementation of correct approach, work process improvement will result in huge reduction in maintenance and asset management problems during operation/occupancy stage thus optimizing the life cycle cost of the construction project (Perlman et al., 2014).

Drawings and Specifications

Drawings and specifications issues during design and construction stage have been one of the major problems that could lead to maintenance and asset management problems in the operation/occupancy stage. The greater the quality of drawings, the easier it is for the contractor to conform to the owners objectives' and requirements. The quality that include the aspect of reliability and maintainability will not be achieved successfully due to the fact that usually, as construction project is driven by cost or time and the quality element is always become minimal. Furthermore, the contractor has not been involved in the planning and concept of design, which normally discussed between client/owner and designer. The drawings and specification must be always be given high attention since they cover the aspect of design for reliability and maintainability. Contractors are willing to bid on jobs with poor scope definition so they could get the job. Therefore, it is the designer and client responsibility to ensure that the scopes are clearly defined to avoid any errors during construction that later could to bring asset management problems.

Procurement

Successful construction project from maintenance and asset management point of view is a project that should result in the required performance and most economical in terms of life cycle cost which relates to the costs comprising its acquisition, operational and running costs. The contracts must be awarded on the basis of most economical tender which comprising the element of cost and quality rather than on the basis of lowest cost. It must be stressed that evaluation process may require strict quality criteria (technical specification) rather than initial costing. The cost of operating, maintaining, and repairing, of the facility/platform will be affected by the decisions made during the requirements assessments,

conceptual planning, and design phase. Suppliers and subcontractors should be fully involved in the design team for which reason they should be procured in early stages, thus facilitating their involvement in value engineering and innovation exercises (Khalfan and McDermott, 2006). Always buying the cheapest equipment and systems is a big mistake since company will have to pay increased operating and maintenance costs every year of its lifecycle. Some major companies in oil and gas industry, have already revised their procurement policy to ensure that life cycle costs influence the purchasing decisions (Wheelhouse, 2006). Figure 1 shows commitment diagram for a project where it is clearly shows that maintenance views must be sought at a very early stage in the detailed design. Figure 2 shows the relationship between reliability and cost where it could be concluded that in order to achieve the lowest life cycle cost, it does not mean that highest reliability equipment has to be purchased, the optimum reliability equipment which meets the requirements is the right one to be purchased (Wheelhouse, 2006).

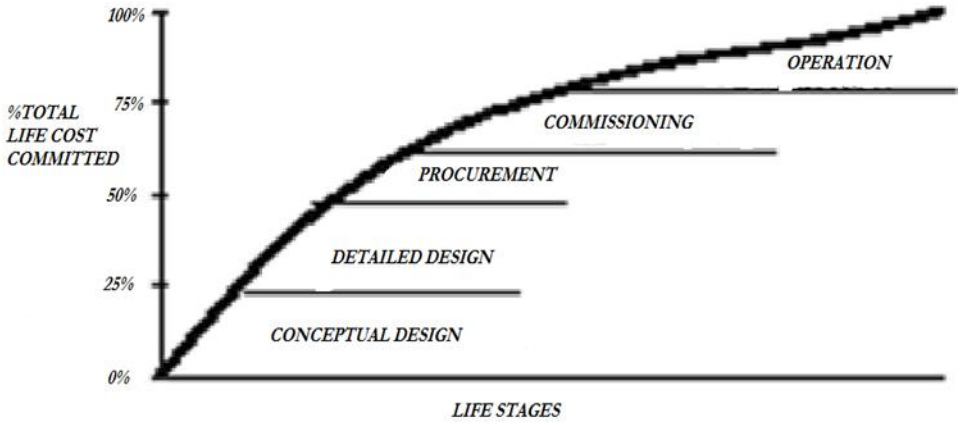

Figure 1. Percentage (%) of Total Life Cost Committed against Life Stages (Wheelhouse, 2006).

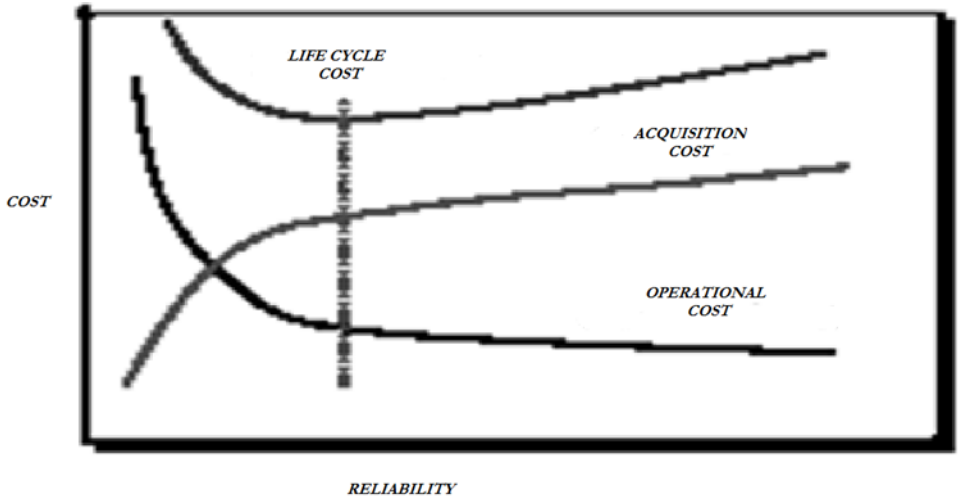

Figure 2. Life Cycle Cost and Reliability Relationship (Wheelhouse, 2006).

Life Cycle Cost Analysis

To achieve total maintainability of construction project life cycle approach is essential in order to achieve minimum costing in maintenance expenditure in the long term. In the early phase of any construction project, the client must decide the amount of money they will spend and length of life required for the facilities/plant/building. The effects of the decisions made during

design stage would affect the future building maintainability (Briffett, 1990). Life cycle costing attempts to identify all costs related to the facility including feasibility study and development, design, construction, operation and maintenance costs. It is suggested that 60 to 75 per cent of major equipment or systems lifecycle costs are associated with the maintenance and support costs (Dhillon, 1999). El-Haram and Agapiou (2002) in his study of the life cycle cost approach in building construction stated that it is hard to benchmark the building life cycle cost since there are no standards that support information exchange and sharing on the subject of building life cycle.

The Building Research Establishment (BRE) of United Kingdom (2000) emphasizes the implementation of LCC at various stages of the decision making process helps save construction cost, as it takes into consideration initial capital costs, future costs, life expectancy of building component, and factors affecting investment appraisal such as discount rates and inflation, disruption to building operations, failure analysis, taxation allowance, and energy efficiency (BRE, 2000). It is recommended that the whole organization in the project team must use whole life cycle analysis and other related techniques such as durability, maintainability, availability, failure mode and effect analysis, RCM etc. to assist in the design of cost-effective buildings in terms of value capital as well as cost to maintain and operate. Life Cycle Costing is obviously a method and approach that has the impact on economic construction works since in Life Cycle Costing, all costs that arise after the investment decision being made are the reflect to the decision that everybody have already anticipated in the decision making stage (BRE, 2000).

Value Engineering

Another popular and widely used program by the designers and construction firms is Value Engineering. Value engineering is a process of functional analysis that provides the least expensive solution to meet the functional requirements (Merritt and Ricketts, 2000). Value Engineering is defined as an organized effort towards assessing the functions of systems, equipment, facilities, and services in order to achieve the required functions at the lowest life cycle cost together with the required performance, reliability, quality and safety. Primary aim is on attaining maximum life cycle value within project funding. Value Engineering could be implemented in various ways which include improved function, maintainability or reducing life cycle cost (LCC). Figure 3 depicts the importance of value engineering implementation which covers not just during the conceptual planning stage but also during design and construction.

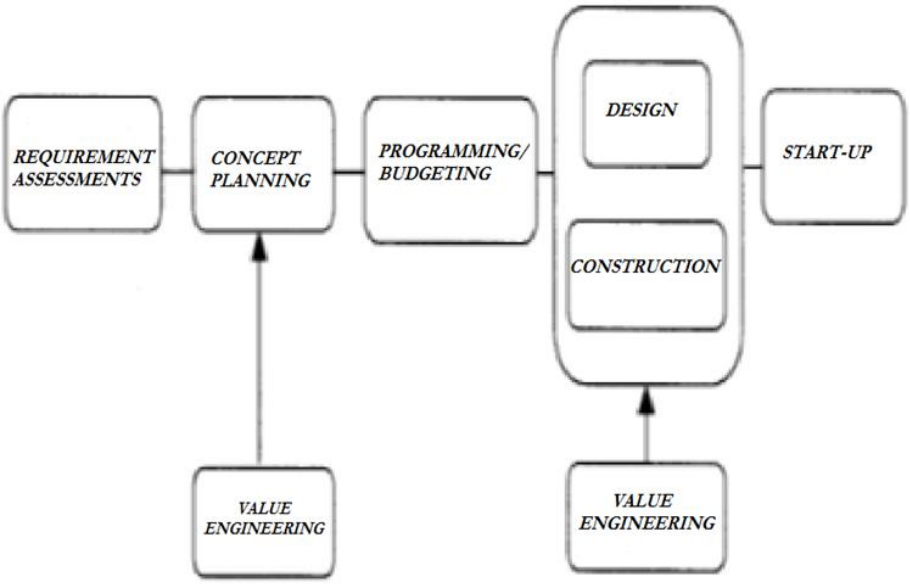

Figure 3. Framework of Value Engineering in Facilities Acquisition Process (The Federal Facilities Council Ad Hoc Task Group, 2001).

Change Management

In the construction and design stage which always come parallel and together with each other, it is not possible to avoid completely the changes in the specification, documentation, installation, etc. For instance, the sources of change that occur during the construction stage include:

- Clarification of work is not clear
- Additional work/modification have to be performed by contractors/subcontractors/vendors
- Lacking clearness or uncertain specifications
- Design errors
- Delays in retrieving drawings, documentation, specification.
- Change in scope for vendor/suppliers/subcontractors
- Lack of knowledge among the staffs of the construction team
- Mandatory changes by the regulations/testing/client
- Owner caused delays in the coordination/review job

The project may be modified to accommodate unexpected developments at the site or in the owner's requirement. Most concern for project accomplishment is speed. On the other hand, the designer prefers more time to finish drawings and to coordinate with other disciplines for the final documentation and validation/checking. The quality of the documents created by the designers establishes the quality the contractor will demonstrate on the job site (Federal Facilities Council, 2001; Eckert CM et al., 2006).

All design development should be recorded so that, at a later date, reports of progress can be created to assist in tracking changes. Controlling and communicating changes to project data is essential to successful project execution. The data changes should be highlighted and automatically track by some means and maintaining full data history.

Quality Assurance Role in Reducing Maintenance Problems

The construction industry has experienced various quality issues for many years including errors and defects that finally result in the poor construction quality and increasing the costing for maintenance expenditure in the later stage. The life cycle cost of the construction project could be reduced significantly if the industry were to adopt the concept of quality assurance to ensure quality of the construction and eliminating errors and defects that could later bring to the maintenance and asset management issues. According to one study pilot made by Performance Validation Inc., US (2005), a nationwide leader in validation, commissioning and construction services, approximately 50 % of the contractors did not have Quality Manuals and most of construction contractors did not know what was expected in a quality program. (Harrison J, 2005). ISO 9000 part 4 emphasizes on the importance of quality assurance and checking on the reliability, maintainability and availability of the input resources for the process involve in production/construction and delivery service. If this aspect is taken highly consideration by the integrated team in the construction stage, the possibility or errors and mistakes that could lead to the problems during the operation stage can possibly be eliminated (Harris et al., 2006; Pheng and Shiua, 2000).

It emphasizes on the aspects like:

- Instructions must be clearly provided, calculations must be accurate and working documents must be clear in their interpretation.
- Formalized systems implemented by all people for the checking and recording of communications would solve many of the problems.
- Quality Assurance requires that formal records are kept throughout the period of design and construction as well as being retrieved during the completion stage.

Quality Assurance is a systematic and documented program which allow the construction project run efficiently and would therefore reducing the errors and faults that could contribute to maintenance and asset management problems. The strategic approach is needed to improve construction working processes within the organization and encourage the focus towards producing quality construction project that will also result in the improved life cycle of the assets. For the cultural shift towards improving working process towards asset management awareness, all the parties involved in the construction project must have the same interests towards that aim.

Design and Construction for Maintainability

Maintainability is the measure taken during the design phase to incorporate features that will increase the ease of maintenance and to ensure towards minimizing downtime and life-cycle costing (Labib, 2006). Design stage is the best period for the designers to design and develop systems/equipment incorporating maintainability aspect. During design phase, all the aspect of maintainability must be taken into consideration by the designers/consultant. A list of maintainability factors and consideration must be included and formed in the form of guidelines on maintainability. It is the responsibility of consultant/designer and the owner with the help and assistance of construction team in the concurrent engineering to form the guidelines for maintainability during the design stage and before the construction stage.

Maintainability Success Factor

Research conducted by the Construction Industry Institute (CII) Maintainability Research Team (Moua and Russell, 2001), based on surveys, interviews, and extensive case studies, the research team identified attributes that positively contribute to effective maintainability program. Attributes of Maintainability Program are classified into five main pillars: *(1) management commitment (2) program resources (3) maintainability planning (4) maintainability implementation and (5) program continuous review and checking.* As integrated and organized guidelines for maintainability projects are practised and awareness increases, a maintainability program will become successful program in producing construction project with maintenance friendly features. (Moua and Russell, 2001). Chew *et al* (2004) also pointed the same view in their study on building maintainability. They emphasized on the integration of maintainability concept in building construction with Life Cycle Costing and Total Quality approach. The study took the definition of building maintainability as attaining optimum building performance throughout the building life with minimum life cycle cost. The biggest difficulty to good maintainability practice during the design and construction is insufficient communication and coordination between design and operations groups in an organisation. Vendors and suppliers must also play their role in supporting the design for maintainability agenda led by client/owner. They have a significant impact in determining the final outcome of the program since they are responsible in the design, manufacture, testing, installation and commissioning of equipment and systems. Achievement of effective design for maintainability program requires cooperation and commitment of all the parties involved in construction project. It is important for the maintainability program to succeed, that all the personnel involved understand the concept and objectives as this will contribute to the increasing responsibility and awareness on the program. The importance of guidelines on how to achieve high maintainability must be agreed and followed by suppliers and construction contractors. In line with the aim to implement maintainability program during design and construction stage, the working practice of the organization in the construction industry must also be revised and improved so that successful application of maintainability design and construction principle could be achieved therefore reducing the maintenance and asset management issues in the later stage (Fuad, 2007).

Revolution of Maintenance Awareness in Design and Construction

In order to achieve the aim towards construction project incorporating maintenance and asset management awareness, some new techniques, new innovative technology, design and construction process must be looked to enhance the probability of attaining the aim. The design and construction process are really complex and vibrant therefore, traditional techniques and methods might not be capable enough to support the objective of reducing the maintenance and asset management related issues during design and construction stage.

Organization

It is important for an organization that embarks on the program towards design and construction for maintenance and asset management to recognize the cooperation and collaboration advantage in determining the success of the program. Birmingham et al*.,* (1997) suggested that design is now so complex that it usually requires a team of designers or the coordination of groups of designers to bring a project to a successful one.

Partnership and Collaboration

Partnering and collaboration seem to offer great advantages especially in creating win-win partnerships. Solid relationship must be formed between contractor's purchasing team and the vendors in order for the aspect of maintenance reliability to be delivered as promised. Coordination and expediting are essential and must be closely monitored by reliable and experienced experts to assure that delivery schedules would be met. In order to make the maintenance awareness program in design and construction stage for construction industry a success, the main party which is client is required to make decisions and commitment in emphasizing the objective and the policy of the program that would then drive the design and construction process towards that aim. Benchmarking tools could be used by the client to ensure that the maintainability objective will be achieved. In terms of implementation, to address the maintainability issues seriously during design and construction stage, the client should choose the tender/bidding based on life cycle costs which cover all the operation and maintenance consideration. (Silva et al*.*, 2004). In the construction industry today, some companies from consulting/design firm as well as IT solution/Technical Management Consultant have already play the role in exercising such program and one of the examples is partnership between Honeywell Process Solutions and Mustang Automation and Control. The Flexible Automation Solutions Team (FAST) Alliance formed by Honeywell Process Solutions and Mustang Automation and Control offer complete process automation solutions and services from conceptual design to long-term support and emphasizes flexibility in the execution of process automation solutions from initial contracting strategy through final long-term systems support. They can provide and deliver process automation solution, from design through construction and start-up. The advantage of utilising such service is that it will facilitate knowledge sharing and procedures that enable the transparent flow of data between organizations and projects.

Integrated Project Team Approach

An integrated project team approach from conceptual planning stage is important to implement the effective program incorporating maintenance issues during design/construction. The team should include the client/the owner, operation/production team, architects, engineers, planners, constructors, and facility managers who are responsible for operating and maintaining the system/platform/facilities. An integrated project team approach will ensure that contract documents are written to support design, construction, and performance objectives and facilitate a better understanding on how the

chosen materials and systems will affect the initial cost, life-cycle costs, operations and maintenance practices and the performance of a facility over its lifetime.

Advanced Techniques Incorporating Maintenance Awareness in Construction

Some techniques and tools in design and construction especially in detecting defects on construction sites are gaining acceptance in the construction industry. These techniques could also give an impact for the construction industry in terms of enhancing the design and construction towards maintenance and asset management awareness. Nowadays, the technologies, computer and information technologies have changed the techniques and process during design and construction. Dessouky and Bayer (2002) has proposed a methodology appropriate to be applied in the building construction industry which is the maintenance process model in providing justification of costs to integrate design for maintainability by considering the budget for design and construction to the operation and maintenance budget. The research highlights the focus on determining the maintenance policy to be used and then predicting the cost optimization and maximising availability. It takes into consideration the allocation of operation and maintenance funds at the design and construction stages. This approach could be implemented by designer and consultant in parallel with the Whole Life Cycle approach which aim for the reducing the life cycle costing of the construction project at all stages and minimizing the maintenance problems that could increase the costing (Dessouky and Bayer, 2002). Approach of maintenance awareness during the design and construction stage in the construction industry could also apply the concept adopted from other industry for example aerospace which is well known of having more complex, highly cost, and high risk associated with safety. Altavilla and Garbellini (2002), in their study of Risk Assessment methodologies implemented by Alenia Spazio, the second largest hardware provider for the International Space Station. It was a study and research on the Risk Assessment Method implemented and used by Alenia in the space system especially on the manned space transportation where the safety being the highest priority.

Modelling and Simulation

Modelling and Simulation is an effective technique to determine a level of reliability, or range of reliability in construction design. Simulation makes use of computer automation to achieve/simulate various solutions until an optimized solution is achieved. Reliability requirements should be developed within the context of the overall requirements for the system and program constraints. Vantage PDMS by AVEVA Ltd is an example of software used (as shown in Figure 4) in the application of design of plant/facilities from design stage to construction and it is really helpful in the aspect of maintenance study especially when performing the maintenance handling review for the plant/facilities to be constructed.

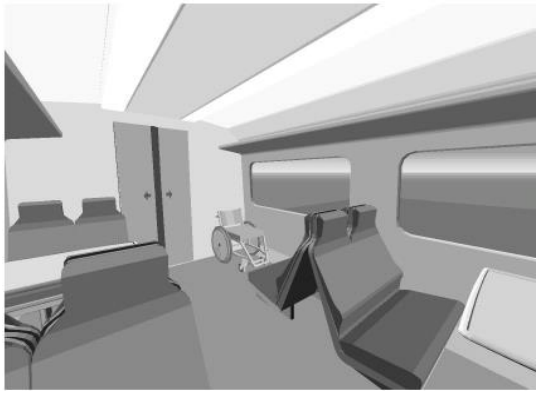

Figure 4. Clearance checking view of a virtual wheelchair railcar, Virtual Reality Application (Rooks Brian, 1999)

Advanced Information Technology

The application of the IT solution should be fully optimized and used by the personnel and staffs who involve in the design and construction which include the email, computer aided design, computer aided facilities management, CAD standards, shared database etc. (Johnson and Clayton, 1998). The advantage of using all those tools will not just bring best solution for the construction project management but will result in the smooth implementation of the maintenance friendly design construction practice. An automated approach to gathering and analysing information across the entire the life cycle stages could yield cost effective outcome for the facility owner/client. This is an example of Automation and Integration in Construction that features some vital applications that could ease major activities in planning and maintenance forecasting in construction towards better outcome of the construction.

Yabuki et al*.,* (2005) in his study recommended the methodology of virtual reality in construction and design in a very integrated and effective way. It focuses on the cooperative system environment for design, construction and maintenance of bridges as shown in Figure 5. The system is an integration of seven supporting tools which are product models, visualization system, distributed networking system, task systems and agents, data collection and database, linkage between data system and bridges, and data reuse. This tool should improve the communication among the stakeholders to accommodate design change or other problems in design, construction or maintenance so that everybody is informed with the latest information. Linkage between data and structures are achieved with the use of radio frequency identification (RFID) technology as shown in Figure 6 that links the two worlds smoothly. Sensor networks are used to provide data regarding the actual structures and help the user connecting the two worlds. Visualization System is performed with the virtual reality CAD system, utilising OpenGL program, GL4Java, and liquid crystal shutter glasses. It is concluded that inspection support system developed with RFID, PDA and database has improved the efficiency of the inspection task, reducing the number of errors and improves the expertise transfer and information sharing among the personnel.

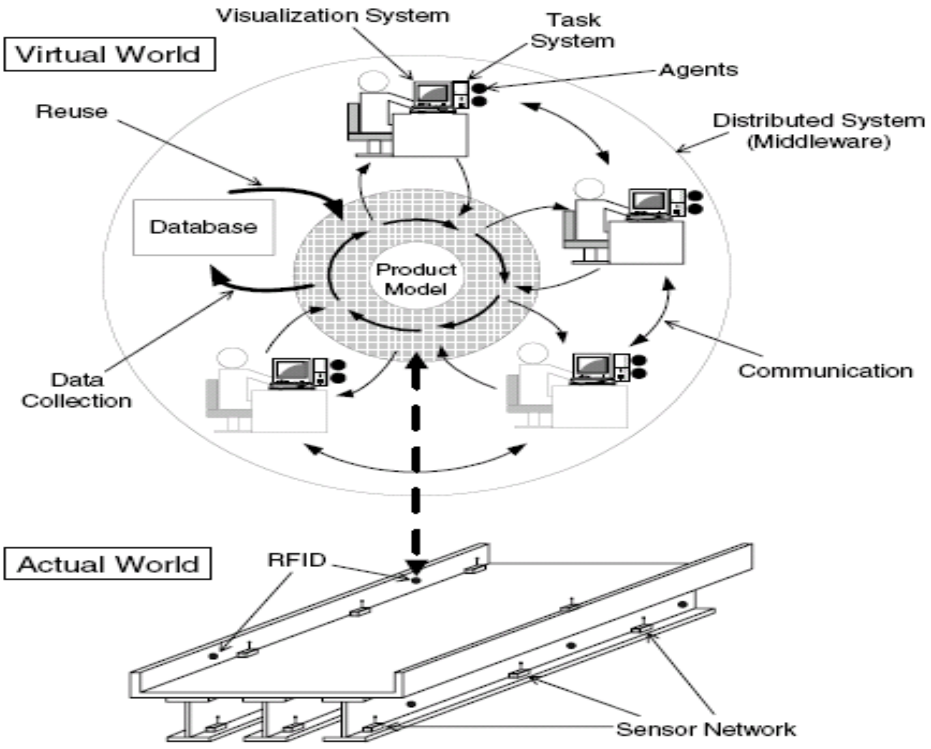

Figure 5. Conceptual view of integrated systems in network environment of design, constructions and maintenance (Yabuki et al., 2005).

Figure 6. RFID and reader and a retrieving data activity by inspector from RFID by PDA (Yabuki et al., 2005)

Figure 7 shows the integrated information management system that could help the client to manage the facility during the operation/occupancy stage. The integrated information management will consist of information on the life cycle, construction data, operation and maintenance data etc. The availability of information from all the division and stage will assist the client to form a comprehensive and effective information management system and information sharing. The management of documentation during design and construction is crucial in determining the success of the program.

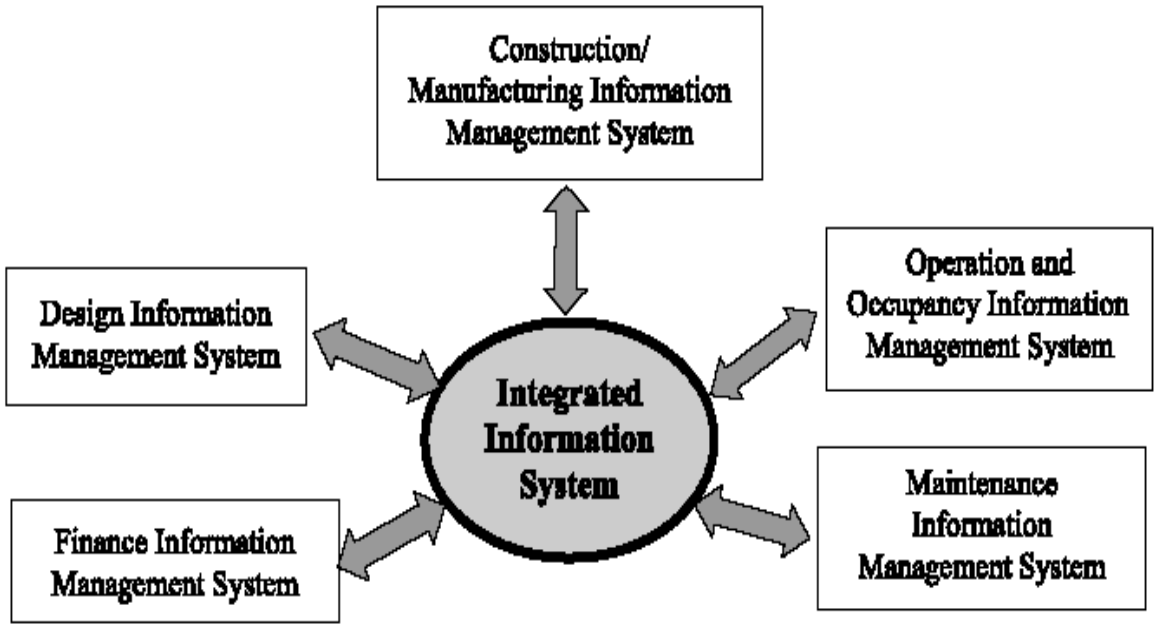

Figure 7. Integrated information management systems (El-Haram and Agapiou, 2002).

Web Portals

In many cases, the commissioning staff members responsible for reviewing the mechanical and electrical designs lack the time and skills to adequately examine those design documents during the review sessions. Thus, some design flaws that experienced tradesman or engineers would typically identify are not caught early in design and subsequently, resulting in the increase of maintenance costs after the plant/facility is built and operating. Internet portals will assist in solving the installation problem to facilitate mechanical and electrical design reviews. These portals would allow installations to access expert reviewers of mechanical and electrical designs of construction projects quickly and inexpensively. This approach could improve the effectiveness of design reviews in the major design areas that relate to maintenance issues like mechanical, electrical, piping, instruments etc.

Limitation of Proposed Techniques and Tools

Some of the techniques will require quite high investment in the implementation cost. The construction industry involves complex organization and parties therefore it may restrict the execution of some proposed techniques in the construction project. Besides that, time factor is also an issue where some application and advanced system may need plenty of time in planning and execution stage that may oppose with the client's demand on speed completion of construction project. Therefore some trade-offs are really important in determining the chosen techniques and tools to be implemented thus yielding the result of quality construction project incorporating maintenance awareness (Fernández and Márquez, 2012).

Conclusions

Design and construction defects and faults are always the main concern of the construction industry as they contribute to maintenance and asset management problems in the later stage. As many construction and design firms are striving for successful maintainability construction projects, a maintainability program will become a best practice towards design and construction incorporating maintenance and asset management. The concept of design for maintainability must be embraced by all parties especially client as the end user and the principle of design for maintainability must be followed throughout the project from design to the commissioning stage so that construction project will meet the aim of high maintainability construction project. There are many advance and effective methods and approaches that could be used, in order to provide efficient process of design and construction process such as innovative information technology, modelling and simulation, database sharing, integrated virtual environment, organization partnership and collaboration approach that would be the driving force behind the successful implementation of design and construction incorporating maintenance and asset management awareness.

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