Development of a defect monitoring system (DMOSYS) for building maintenance at polytechnic

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Abstract

Purpose – The current maintenance management method has affected the efficiency of the building facility management at Polytechnics. Many issues such as poor service delivery, inadequate finance, poor maintenance planning and maintenance backlogs have emerged due to the usage of conventional method application (paper-based form and unsystematic database. The purpose of this paper is to review existing literature and case studies project of the technologies in maintenance management at Polytechnic, and subsequently to identify the challenge in improving the current maintenance management technologies.

Design/methodology/approach – The purpose of this paper is to review existing literature and case studies project of the technologies in maintenance management at Polytechnic, and subsequently to identify the challenges of information and communication technology (ICT) implementation for strategic defect diagnosis and decision-making in improving the current maintenance management technologies. Eight Polytechnics are selected on the basis of the major problems of using the conventional method in the comparison to investigate the maintenance management practices in each Polytechnic. There are around 32 Polytechnics in Malaysia and most are using conventional methods.

Findings – The findings reveal the need for a more sophisticated maintenance management system that provides guidelines for decision-making processes with the implementation of ICT. The interview results also reveal irregularities within the Malaysian Polytechnics' maintenance management database. The system architecture and the information system prototype are presented to integrate the information database and maintenance management processes in improving the building diagnosis approach and decision-making process for managing building maintenance.

Originality/value – This new system is expected to become the successful technology in assisting the maintenance contractors, clients and developer for effective management of maintenance defects at Polytechnic.

Keywords Conventional method, Information and communication technology, Building services, Maintenance management, Maintenance management system, Malaysian polytechnic

Paper type Technical paper

1. Introduction

Presently, most organisations are still implementing conventional method rather than modern computerised systems to manage the maintenance of building facilities and infrastructure (Supramani, 2005; Dukic *et al.*, 2013). The application of conventional method mentioned in the definition is recognised in this research as a paper-based report or unsystematic computational database for building facility management at Polytechnics. The conventional method is apparently not able to capture long-term business targets (Hassan, 2010). The problems emerged as a result of the need to manage critical and complex facilities; problems can include, for instance, a lack of defect diagnosis caused by an

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unsuitable system for assessing processes and excessive retrieval time in the recovery of maintenance on facility defects.

The preservation of Polytechnic is another issue in maintenance management. Polytechnic has a department to coordinate maintenance and repair of equipment, buildings, infrastructure and facilities-related work, including support services. However, the management system implemented by this department faced many problems of assessing the defect. All assessment reports regarding facilities defect must use "Assessment Form", where a few staffs are not knowledgeable to report the specific defects due to many technical term and expertise needed for that task. Moreover, the staffs have to assess the defects within the extended duration after inspection in case of uncertainty information and other related factor. They also have to take the risk condition for report mistaken before reaching the related department. As engineers, staff also have the difficulty in assessing and maintaining instantly, and this contributes to the negligent management. In addition, the teaching and learning process cannot be carried out smoothly and bother the lecture sessions because of this ineffective assessment system (Lazim and Samad, 2012).

Meanwhile, the existing computerised database is based on intensive paper-based form to record the annually defects. Sometimes, the maintenance management staff misplace and unhand many paper report. Therefore, it leads to the difficulty for staffs to determine the facility budget either in a month or in a year because there is no system to record the number of facilities defect accurately (Lazim and Samad, 2012). In addition, the application of computerised maintenance management system (CMMS) database turns to be limited in operation when handling complex data (Lecorche and Senecal, 2002). The staff also require extensive time to recover data and this potentially turn into devastated time. The poor accessibility of data collection affects the criticality to assign the problems on maintenance execution at Polytechnic.

The development of information and communication technology (ICT) offers possibilities of efficiently processing and communicating a large amount of information during the building maintenance. The ICT area facilitates new and innovative solutions in many disciplines, certainly in the area of sustainable construction. The recently developed modern computerised systems concept is an example of an ICT-dependent innovative solution that includes methods, systems and tools for corrective and preventive maintenance management (Hallberg, 2009). Essentially, maintenance management in the organisation consists of identification, assessment, planning and execution in the building facility development. The source of information is based on report defect from the customer, annual planning, preventive maintenance, *ad hoc* maintenance and others implemented by maintenance management staff.

The application of paper-based form and CMMS is practiced for the maintenance management processes till recently, where the emerging techniques and technologies using sophisticated information system are used to improve the maintenance operation, which is considered to have a higher impact as a result of the previous approaches to the maintenance process. The advancement of sophisticated information system adds to the understanding of today's computer applications for building maintenance management, which is crucial for every maintenance manager using or purchasing sophisticated information system (Kans, 2009). This application is also expected to assist in generating sustainable building facility and infrastructure besides reducing maintenance cost and erratic accident (Sooriyarachchi and Gayani, 2010).

The various functions in the sophisticated information system for maintenance management improve the current conventional processes practices. The maintenance management staff are contented to use for the building inspection, to gain the precise

information of the maintenance status of the building facility without delaying time and problems of inaccurate delivery of information. (Lateef *et al.*, 2010). In addition, the smoothness of maintenance management processes directly prevents budget badly behaved and maintenance backlogs in the organisation to reach higher levels of maintenance quality and overall building effectiveness (Marquez *et al.*, 2009).

This paper provides a brief summary of the practical implementation technologies and challenges of the maintenance management system in an effort to suggest a more effectively viable approach to future maintenance management system development at Polytechnic. Second, it presents the introduction to the components of maintenance management processes including "defect complaint", "defect diagnosis and assessment", "preventive maintenance" and "report protection". It then describes the key features of the process for maintenance management and discusses the development of the prototype system, "DMOSYS – defect monitoring system", which is based on the integration of maintenance management processes and information system. Next, it examines the choice of the system development environment, system architecture and the development process of the maintenance management system. Finally, this chapter demonstrates the operation of the prototype system and concludes by showing the discussion approach of the prototype system.

2. Information and communication technology implementation for building maintenance at polytechnic

According to Gabbar *et al.* (2003) and Sharma and Govindaraju (2010), in the context of global education industries such as Polytechnic, the developed maintenance strategies are commonly implemented and managed within the information system, which is usually separate from the effective operational system (e.g. diagnosis, assessing and decision-making). The classical information system is used to decide the maintenance strategies without having a comprehensive approach to optimise the maintenance management for the facility.

As an example, the maintenance management information system for "facilities work order system" is currently focused on improving maintenance assessment only as well as "e-Aduan"' is for managing complaint based on the defect identification of the building facility. Meanwhile, the "CMMS" at Rensselaer Polytechnic Institute (RPI) is mostly used for maintenance planning and execution with the limited of defect diagnosis and decision-making process. The selected information system for maintenance management is explained further as below.

The Southern Polytechnic State University in the USA has developed the facilities work order system application to assist the maintenance management staff in assessing the defects for building facility with the specific location information. The procedures for the maintenance assessment are classified into two, which are the *ad hoc* and preventive maintenance. The tabulated data from this system also provide the annual and monthly project planning to monitor the time preparing for the maintenance services. The *ad hoc* maintenance procedure is designed to prevent the insufficiency allocation of budget for maintenance management. Meanwhile, the critical maintenance, which involves the major costing, is performed in stages with expert database recorded in prioritising the work orders regarding facility defects risk (Southern Polytechnic State University, 2012). Presently, the information system application is executed at the Malaysian Polytechnic institutions for the maintenance management unit in charge of building facility and infrastructure. The scope of this unit is to implement the maintenance operation through monitoring of the defect

complaint from customers who are Polytechnic staff and students, including *ad hoc* and preventive maintenance (Ismail and Kasim, 2013; Jabatan Pengajian Politeknik, 2013).

"e-Aduan" is an information system application developed by Seberang Perai Polytechnic, Pulau Pinang, in managing complaints about building facility including student hostel at Polytechnic, which has quite similar activity and function to the "Aduan Online" application. The engineer from the Maintenance and Development Unit (UPP) evaluates the facility defects and instructs the work orders to the technician for maintenance execution. The status of complaints is notified to the customer such as student and Polytechnic staff. This system can be accessed from anywhere including facility location with the internet network rather than to attend at the maintenance management office. The late delivery complaints are also reduced for the timely manner in improving the maintenance efficiency (Politeknik Seberang Perai, 2009).

Because of the building collapsing incident in 2012, the RPI in the USA started using information system application to manage the maintenance planning and executing of building facility and infrastructures. This system provides the inventory, financial control and preventive maintenance in handling the complaints about the critical defects at Polytechnic. The complaints are prepared through email from a customer with the feedback to the maintenance status for building facility defects. The data collection in the information system generates the progression of work orders for maintenance repairs to the relevant maintenance management staff due to the specialised field requirement. This detailing data of work orders improve the timely manner for maintenance planning and ensure the sufficient resources and budgets in the building maintenance. In addition, the system is equipped with the procurement processes for direct materials purchase, which estimated the direct material inventory and quantity used in the construction (Rensselaer Polytechnic Institute, 2013).

Based on the research conducted on the implementation of the information system at Polytechnic, there are some major difficulties of the features system that affect the maintenance assessment, planning and execution to the respective organisations. The mentioned systems provide the building complaint and inspection functions to facilitate staff in completing the assessment report. However, the information access is not fully comprehensive diagnostics. The engineer and technician find it rather exhausting due to the lack of available information and they also feel less competent in handling critical facility defects. Generally, the maintenance management staff members find it difficult to collaborate with contractors and consultants in producing database knowledge of defect diagnosis. The building diagnosis has problems to identify the detailing data of symptoms, causes and reasons for the critical defects.

Furthermore, the system is not supported with the decision-making processes on defect assessment for the reference action. The uncertainty of maintenance planning and execution will emerge in prioritising the specific maintenance on both of *ad hoc* and preventive maintenance for building facility. Maintenance management staff members are unable to assess the design specification information, feature/type of construction materials and previous maintenance management recorded in case where specific facility defects are reported. This allows the repetition of defects to happen without realising the actual main causes and results in the unexpected losses to optimise the maintenance for most sophisticated building facilities at the Polytechnics.

3. Methodology

The case studies on the eight Polytechnics were undertaken to identify the maintenance management problems, the current approaches to addressing the problems and the ICT

implementation and the maintenance management system to obtain information relating to the maintenance identification, assessment, planning and execution processes. Those Polytechnics are selected based on major problems of using the conventional method in the comparison to investigate the maintenance management practices in each Polytechnic. There are around 32 Polytechnics in Malaysia and almost all are using conventional methods (Jabatan Pengajian Politeknik, 2013). The number is considered very big indicating that the use of modern ICT is still very limited compared to other institutions of higher learning (e.g. Universiti Sains Malaysia) in Malaysia.

The interviews consisted of three types of Polytechnic, namely, "New Polytechnic", "Old Polytechnic" and "Premier Polytechnic". The case study was based on eight cases (Case A-H) of Polytechnic in Malaysia. There were two case studies (Case A and B) on "Premier Polytechnic" under the transformation plan to become a University College by 2015 and three case studies (Cases C, D and E) on "Old Polytechnic" due to older establishment and operation such as in the Melaka Polytechnic, which was established in January 1999. In addition, three more case studies (Cases F, G and H) were classified as "New Polytechnic", which manages the maintenance operation with fully equipped new amenities and facilities.

The justifications for the selected case studies were according to the following main criteria:

- exposed to the conventional method used and major problems;
- attempted to implement computerised technology; and
- the willingness of staff to share their experiences in improving the maintenance management processes at the Polytechnic.

The different types of Polytechnics were to provide variations on the maintenance management practices classified as old, new and premier Polytechnic, respectively. The professional staff were interviewed which included engineer or assistant engineer and had the experiences in the maintenance management practices. The summary of the eight case studies and respondents is presented in Tables I and II, respectively.

The semi-structured interviews were conducted with the engineers or assistant engineers who were responsible for the maintenance management of the entire Polytechnic's building facility under the Facility Management and Development Unit (UPPF) and Maintenance and Development Unit (UPS). The interview sessions took around half an hour to accumulate the data on the maintenance processes including the demonstration of the current maintenance management system with the implementation of the ICT tools by the engineer and assistant

Case	Name of polytechnic	Type of polytechnic	Person interviewed	Maintenance management system
A	Ibrahim Sultan Polytechnic, Johor	Premier	Engineer	Conventional
B	Sultan Salahuddin Abdul Aziz Shah Polytechnic, Selangor	Premier	Assistant engineer	Conventional
C	Port Dickson Polytechnic, Negeri Sembilan	Old	Assistant engineer	Conventional
D	Melaka Polytechnic, Melaka	Old	Assistant engineer	Conventional
E	Merlimau Polytechnic, Melaka	Old	Engineer	Conventional
F	Mersing Polytechnic, Johor	New	Assistant engineer	Conventional
G	Banting Polytechnic, Selangor	New	Assistant engineer	Conventional
H	Nilai Polytechnic, Negeri Sembilan	New	Assistant engineer	Conventional

Table I.
List of case studies

Case	Name of polytechnic	Type of polytechnic	Person interviewed	Name of respondent
A	Ibrahim Sultan Polytechnic, Johor	Premier	Engineer	Mr Kamarudin Mazlan (Representative)
B	Sultan Salahuddin Abdul Aziz Shah Polytechnic, Selangor	Premier	Assistant engineer	Mr Mohd Nizal Yusof
C	Port Dickson Polytechnic, Negeri Sembilan	Old	Assistant engineer	Mr Mawardi Yusoff
D	Melaka Polytechnic, Malacca	Old	Assistant engineer	Mrs Teh Kamalia Hasan
E	Merlimau Polytechnic, Malacca	Old	Engineer	Mr Nasri Haji Marob
F	Mersing Polytechnic, Johor	New	Assistant engineer	Mrs Asiah Abdul Jalil (Representative)
G	Banting Polytechnic, Selangor	New	Assistant engineer	Mr Azhar Mohd Khairi
H	Nilai Polytechnic, Negeri Sembilan	New	Assistant engineer	Mrs Syahila Abdul Hafiz

Table II.
List of respondents

engineer. All the data from the interviews were recorded using a video camera and transcribed verbatim.

On the basis of the case studies, the Nilai Polytechnic recorded the highest major problems on the maintenance management processes and are summarised together with other elements of analysis in Table III.

4. Limitations of the current practices

The email and "E-Aduan" system were the technology used in managing the defects at the Polytechnic. However, both of these technologies were inadequate compared to the modern ICT tools to record the information related to the maintenance assessments into the database system.

The paper-based form mostly used at the Polytechnic provided not enough data and explanations such as design specification information, feature/type of construction materials and previous maintenance management in detail that could help the maintenance management staff to conduct an effective planning and repairs on the defect. The deficiency of information was also due to the lack of the knowledge of the technician/engineer about the technicality when addressing the defect problems at the site location.

There was no dedicated system to improve the maintenance diagnosis for reducing the repetition of defect problems where the defect took more time to be investigated to identify the causal explanation. "mySPATA" and "mySPA" only supported the inventory management for the facilities. The maintenance assessment processes at the Polytechnic was lacking with ICT tools that can associate the diagnosis, quality control and preventive maintenance technology.

5. Synthesis of good practices

Table IV represents the suggested solutions from the case studies to improve the current practices on the maintenance management by implementing ICT at the Polytechnic. Cases A, C and H suggested improving the particular defect of information in the assessment by combining with the related software technology compared to other cases. In fact, the

Table III. Cross-case analysis

Element of analysis	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
Maintenance management problems	Nonspecific assessment Time gap of building repairs Limited budgets Less competent manpower Defects repetition	Less competent manpower Defects repetition Time gap of building repairs Limited budgets	Nonspecific assessment Time gap of building repairs Limited budgets Less competent manpower Defects repetition	Less competent manpower Defects repetition Time gap of building repairs	Limited budgets Defects repetition	Less competent manpower Defects repetition Time gap of building repairs Limited budgets	Nonspecific assessment Unsystematic database Defects repetition Less competent manpower Time gap of building repairs Limited budgets Poor quality contractor	Nonspecific assessment Delayed assessment delivery Limited budgets Time gap of building repairs Defects repetition Poor quality contractor
Approaches to address problems	Replacing existing material (e.g. timber) with the stronger material (e.g. heavy steel) Training courses for technician	Training courses for technician Replacing existing material (e.g. timber) with the stronger material (e.g. heavy steel)	Replacing existing material (e.g. timber) with the stronger material (e.g. heavy steel) Training courses for technician	Provide more frequent inspection and assessment in identifying the causes of defect Training courses for technician	Priority on maintenance repairs	Training courses for technician	Main contractor improved the maintenance assessment for building works Training courses for technician	Main contractor improved the maintenance assessment for building works

(*continued*)

Table III.

Element of analysis	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
ICT implementation	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture)	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture) Email System – for managing complaints	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture) Email System – for managing complaints	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture) E-Aduan System – for managing complaints	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture)	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture)	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture) Email System – for managing complaints	mySPATA-Data inventory for immobile facilities (e.g. building) mySPA-Data inventory for mobile facilities (e.g. furniture)
Maintenance management system	Conventional (e.g. paper-based form and unsystematic database)	Conventional (e.g. paper-based form and unsystematic database)	Conventional (e.g. paper-based form and unsystematic database)	Conventional (e.g. paper-based form and unsystematic database)	Conventional (e.g. paper-based form and unsystematic database)	Conventional (e.g. paper-based form and unsystematic database) and under DLP*	Conventional (e.g. paper-based form and unsystematic database) and under DLP*	Conventional (e.g. paper-based form and unsystematic database) and under DLP*

Note: *DLP: defect liability period

problem of unspecific information in the assessment delivery also does affect the other Polytechnics to some extent, but the significance of this factor is not that obvious. The customers will use the electronic form to report the defect complete with the data facilities and more detail of the defect explanation to gather accuracy of the inspection works. The other suggestion from the assistant engineer was to provide the information on the specific defective materials and the method used to diagnose the facility at the Polytechnic (Cases A, B, C, D, F and G). However, Cases E and H are not facing the impact of problems for the inspection information management, which is associated with the competent engineer for handling the defect of facilities with less critical and complex building and infrastructure facilities.

The assistant engineer also suggested in improving the maintenance assessment for the material and method used in the building facility and infrastructure in regard to the repetition of the defect at almost Polytechnics. The case studies (Cases A-H) recommended providing more sustainable facilities to control the budget expense for the entire facilities at the Polytechnic.

Cases A, B, C, E, F, G and H suggested on preventing the limited budgets through efficient maintenance planning on the *ad hoc* maintenance. Case D is a special case as it is composed of small, modified shop lots building with the area of fewer than 100 acres. The maintenance budget for this Polytechnic also is sustained because of reducing demands from students and Polytechnic staff for better living environments. Commonly, there were many departments and units considered for the maintenance management processes at the Polytechnic. The mishandling of defect report had caused inadequate budget in maintaining the facilities. Therefore, the systematic database with the current ICT technology and decision-making process should be developed to improve the building facility and infrastructure performance by conducting regularly time schedule on the maintenance repairs.

6. Requirements for integrating maintenance management system

There were many problems related to the conventional method at the Polytechnic, such as nonspecific assessment through paper-based form, limited budgets and a time gap of maintenance repairs. The paper-based form wasted a lot of time, effort and materials. The number of students and the long-life span of services required an efficient management to maintain the building facility at the Polytechnic (Yusof, 2010). Therefore, the transformation of the conventional process into the new system is important to improve the maintenance management in the works of inspection and to reduce the budget that was allocated for maintenance repairs especially on the *ad hoc* and preventive maintenance (Dukic *et al.*, 2013).

No.	Suggested solutions	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
1	Improve the specific defect information in assessment	/		/					/
2	Provide more specific information on repair materials and method	/	/	/	/		/	/	
3	Decrease defect repetition through assessment for material and method used	/	/	/	/	/	/	/	/
4	Control the budget allocated for maintenance planning	/	/	/		/	/	/	/

Table IV.
Suggested solutions from case studies

In the case studies, the engineers and assistant engineers revealed a number of shortcomings in the conventional method. The building defect information was insufficient to facilitate the maintenance management staff to handle the defect analysis and track the previous assessment history. The data were also inaccurate to assess the size of work done and other decision-making information.

The repetition of the defect was frequent at Polytechnic (Yusof, 2010). The maintenance diagnosis was not able to address the building defect causes and reasons at the particular location due to less competent engineer. Furthermore, the maintenance backlogs management caused the budget to be expanded to prevent the deterioration of the building facility.

In this research, the development of the system was intended to improve the maintenance management problems and processes at the Polytechnic. The processes consisted of defect assessment, defect diagnosis, preventive maintenance and report protection. The explanation of the maintenance management processes in this system is as follows:

- *Defect assessment*: In the assessment form, the technician can choose the data from the list of the design specification information, feature/type of construction materials and previous maintenance management in details. The status of the assessment can be ranked as "not risked" and "risked" in the system through defect risk index.
- *Defect diagnosis*: The database for the building defect diagnosis are categorised into four types, namely, "schedule of condition", "expert witness", "defect production index" and "not economical to repair". The building performance also can be measured through the analysis of failure classification, such as good and moderate at the Polytechnic.
- *Preventive maintenance*: The system is equipped with the decision-making process to present the calculation of alert levels for reliability when the particular equipment is near to the date of services.
- *Report protection*: All information of the maintenance management database has a restricted access for the personal files and documentation at the Polytechnic.

7. The development of a prototype system of DMOSYS

In this research, the development of the system was intended to improve the maintenance management problems and processes at the Polytechnic. Figure 1 shows the components of a maintenance management system, which comprises defect assessment, defect diagnosis, preventive maintenance and report protection.

The components of the maintenance management processes are briefly described as follows:

7.1 Defect assessment

The user will provide the password to log into the complaint form (VB.Net). The password is confidential to provide a restricted access from the hackers. In the assessment form, the user can choose data from the list of the design specification information, feature/type of construction materials and previous maintenance management in details. The database system (MS Access) facilitates the customer to register defect complaint with complete information in the assessment form. The status of the assessment can be checked by using the same password and the status is classified into "not risked" and "risked" in the system through defect risk index.

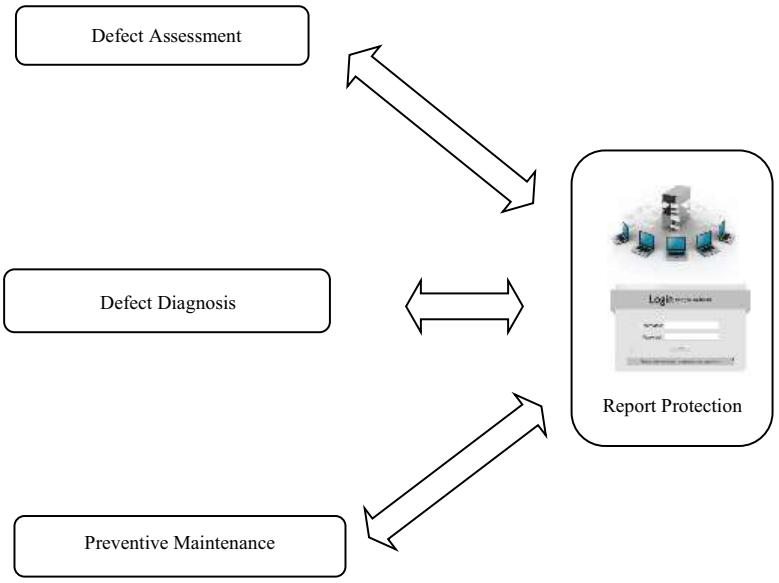

Figure 1.
Components of maintenance management system

7.2 Defect diagnosis

The staff (technician/engineer) will monitor the received assessment from the user. The inspection form (VB.Net) is used to update the particular data on the defect inspection including the diagnosis that will be categorised into four types: schedule of condition, expert witness, defect production index and not economical to repair. The data collection for the highest type of building defects is to assist the maintenance staff in inspecting the actual defect precisely at the site location. Besides, the total numbers of *ad hoc* maintenance can be analysed statistically to estimate the required budget and facility performance through the analysis of failure classification, frequency of repair and long-life span of services at Polytechnic.

7.3 Preventive maintenance

At this stage, the staff examines the required information based on the schedule of preventive maintenance for the building facility. The system is equipped with the decision-making process to present the calculation of alert levels for reliability in the form (VB.Net) when the particular facility is close to the date of services. The alert signs are sorted into two colours. The yellow colour indicates the uncritical date of service, whereas the red colour specifies the critical date of services that needs immediate action to execute the maintenance repairs.

7.4 Report protection

All information for the maintenance management is sent to the database system (MS Access) with restricted access to the personal files and documentation of the members of senior management at the Polytechnic. The security database helps to avoid any security risks from hackers and competitors that may impact the building facility and business applications.

8. Processes

There are four key components in the maintenance management processes as described below.

8.1 Defect assessment process

The users such as staff at the Polytechnic have to report the defect, especially on the building facility and infrastructure through the online maintenance management system. The list of the design specification information and feature/type of construction materials detail are the main attributes to record the facility defect into the electronic form of the database system. This system can be used in mobile device applications and report can be lodged anywhere to ease complainer for submitting the defect identification immediately by utilising paperless office. However, for the critical defect such as exploded cable or leaking pipe is undertaken via a phone application. In the electronic form, the status of defect complaint is updated concurrently when the report is reviewed for defect diagnosis activities by the technician. In addition, the complainers do not have to explain further about the facilities defect in the form where the database of defect facilities at the Polytechnic is provided for their references. Figure 2 illustrates the defect assessment process as follow:

(1) Defect identification: The defect is examined through observation and reflection in services on the building facility and infrastructure determined by three major areas of civil engineering, electrical engineering and mechanical engineering reported by the complainer. The defect is divided into two types of facilities, which are the mobile and immobile facilities, whereas the report of the defect is limited to the uncritical defect for the entire facilities at the Polytechnic, which includes the old and newly developed ones.

(2) Submit the report of defect identification: The system can be logged in through the verified password using the electronic form for reporting the defect facilities. In the electronic form, the particular database with the detailing data of the list of the design specification information, feature/type of construction materials and previous maintenance management, provide precise information to facilitate the task of a technician in inspecting the defect facilities at the site location. The defect that has risked or not risked in the specified duration is updated in the defect status of the system for complainer's reference. The defect form information will be saved into the database, which includes:

- name of complainer;
- department;
- phone No.;
- email;
- inventory No.;
- list of the design specification information;
- feature of construction materials;

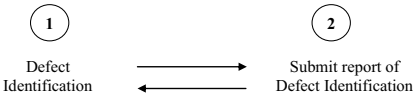

Figure 2.
Defect assessment process

- type of construction materials; and
- note on defect.

8.2 Defect diagnosis process

The defect diagnosis process refers to the inspection for the defect at the site location that is classified into four major types of repairs, namely, schedule of condition, expert witness, defect production index and not economical to repair. The competence technician is hired to investigate the facility performance to prevent serious defect and decrease defect repetition for certain facilities. The defect that has been inspected and diagnosed in the particular duration is recorded for the maintenance planning action. The planning of defect consisted of the corrective and preventive maintenance. The corrective maintenance is due to the unpredictable defect of the facility, whereas the regular repair acts as the preventive maintenance. The defect level of the facilities is measured precisely to plan the priority maintenance especially when it involves the corrective maintenance for severe facilities. The defect diagnosis scenarios are illustrated in Figure 3:

- *Defect diagnosis*: Defect diagnosis is to identify and analyse the real defect that took place at the facility location based on the report received from the complainer. This report information also can be captured through the regular technician's inspection done twice every month at the particular location.
- *Defect analysis*: The findings data such as the design specification information, feature/type of construction materials and previous maintenance management are recorded into the inspection form in the system to assess the cause – effect for the defect sequence on the building facility and infrastructure at the certain duration. Besides, the classifying of a defect using defect production index is appraised which is grounded by the current performance of the facilities. The feedback for the maintenance status is updated automatically by the technician to conclude the defect solution before this form is submitted to the engineer for validating the required action.
- *Maintenance planning*: The budget expense and the objective of the facility repair are among the concerned factors in the maintenance planning. Commonly, the corrective maintenance is associated with the total highest rates of defects compared to the preventive maintenance. Therefore, the analysis of failure classification for the defect repair in the system is to facilitate the technician's job to determine the maintenance priorities for the complicated defect facilities

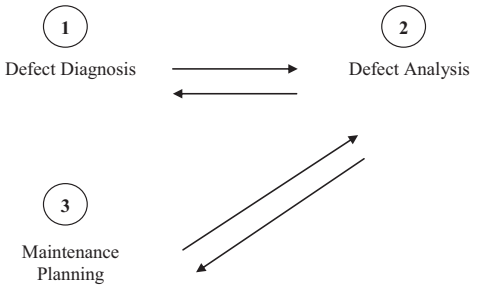

Figure 3.
Defect diagnosis process

and are arranged based on the facility conditions, which are the "critical", "moderate" and "good" level for the next step of the maintenance execution.

8.3 Preventive maintenance process

The facility services that require regular repair are recorded into a certain database system to ease the preventive maintenance implementation. The current condition of the defect facilities is investigated through the report from the complainer and technician's survey to decide whether the maintenance planning needs an external contractor or supplier in managing the maintenance repairs. The life cycle services for both the uncritical and critical facility in a distinct duration is highlighted for the prompt repairs to ensure the sustainability of the existing facility especially when it involves the inheritance building and infrastructure at the Polytechnic. The component of these facilities comprises the mechanical and electrical equipment as major maintenance, and is followed by the civil equipment such as the oxidation pond and fire extinguisher. Figure 4 is the description of the process:

(1) *Facilities list*: The preventive maintenance database with the explanation of the task for each of the facility details provided for the technician's inspection and defect diagnosis requirement. Meanwhile, the fixed date of maintenance is determined by the facility history and condition data for that facility. The facility table is to enable the tracking data for the number and type of the comparable facilities for reference. The information can be updated at any time when the maintenance repair is completed for the certain facility. Preventive maintenance information that should be stored in the process and saved to the database includes the following:

- facility equipment;
- location;
- building level;
- building room;
- daily;
- monthly;
- yearly;
- alert levels for reliability; and
- explanation of task.

(2) *Maintenance planning*: The maintenance planning processes is similar to the corrective maintenance as mentioned earlier in the defect diagnosis.

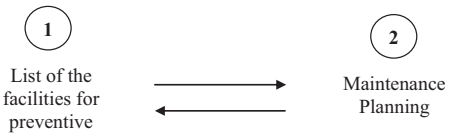

Figure 4.
Preventive maintenance process

8.4 Report protection process

The database system is equipped with a restricted access by using an encrypted password for information safety in managing the maintenance processes. The reason for using this report protection is to prevent the important data such as the number of inventory facility and the maintenance progress for the particular facility from being stolen and used by the third party. In addition, precise information can be controlled without negligent in providing the maintenance efficiency at Polytechnic. Figure 5 illustrates the report protection process to describe the application of the encrypted password to access the primary database in the maintenance management system.

- *Database login*: The particular staff is given the encrypted password to enter the database system. The data of maintenance management processes in the database system is used purposely to plan the future planning in managing maintenance on building facility and infrastructure at the Polytechnic.
- *Database control centre*: All data are sent into the main database associated with the particular network for facilitating staff in taking the recorded statistic of maintenance management processes. The range of networks is limited to the main office of Maintenance Management Unit in locating the entire information related to the facilities.

9. System architecture

The system architecture focuses on the collection of the facility defect information and assessment as well as maintenance planning and analyses the data for the execution reference. The mobile devices such as notebook enable staff to compare and adapt the data at any facility location with the customer's complaint recorded in the prototype system user-interface (MS Visual Basic.NET). The staff will be able to capture the evidence of the facility defect, update about the detailing defect and record the relevant aspect of the defect attribution into the inspection form of the prototype system. This information is stored in a computer database central (MS Access) at the office for further process. The information about the defect is analysed for the maintenance planning and execution using the defect diagnosis and decision-making process. The workflow is illustrated in Figure 6.

10. Operation of the prototype system

This section describes the interactive portion of the system including input data validation and updates of system database in the information system prototype. The prototype system has four main functions and graphical user interfaces:

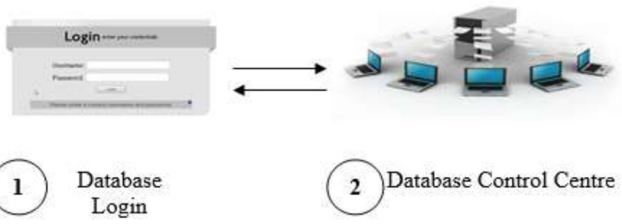

Figure 5.
Report protection process

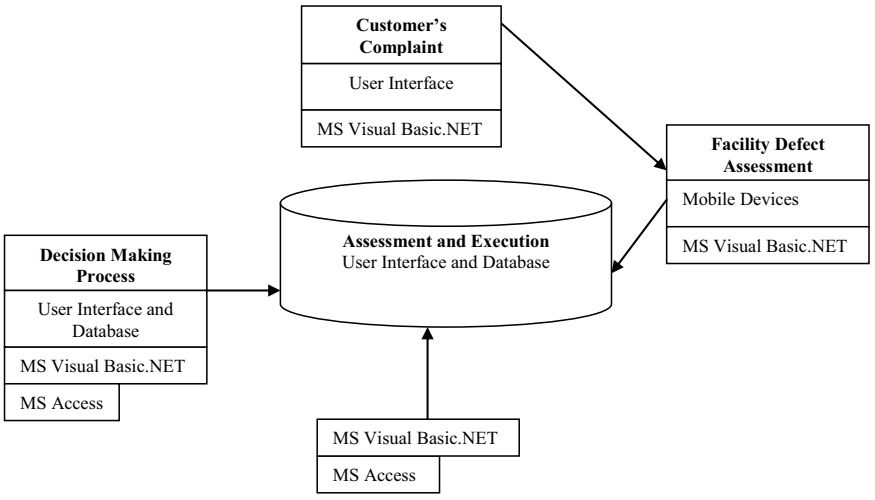

Figure 6.
System architecture of the maintenance management system (MMS) prototype

(1) System login;
(2) Defect assessment and status;
(3) Defect diagnosis; and
(4) Preventive maintenance.

10.1 System login
The login menu in the form is operated via ID and password input in allowing customer such as students and Polytechnic staff to enter the prototype system. The customers have to register their profile to report their complaint and check the status of the concerned building maintenance.

10.2 Defect assessment and status
In this application form, the customer is provided with two buttons, namely, complaint and report status to access other forms in the application in reporting defects for building facility.

10.3 Defect diagnosis
This form provides the additional data such as "maintenance status" option list of not repaired, being repaired and repaired as well as the "print" button for staff reference that is based on the standard paper report. Clicking the "defect production index" button is to fill the analysis and remedial measures information in the other application form relating to the actual defect at the site location. The defect diagnosis data added to this form are as follows:

- solar radiation;
- thermal expansion;
- durability;

- moisture emission;
- vapour permeability; and
- soil classification.

10.4 Preventive maintenance

This form provides the staff with the additional data on "Facility Registration" and "Inventory Registration" button. The red and white colour functions in the "preventive maintenance" forms allow the calculation of alert levels for reliability and needed duration for the maintenance services. The concerned facility is identified on the basis of the schedule set and the data only be extracted from the displayed red colour after clicking the "maintenance update" button at the row right-side of the table. Thus, the staff could ensure the real-time information on the services of maintenance facility, which is undertaken at the site location effectively.

11. Limitations of the research

The main limitations of this research are as follows:

- The prototype system was only limited to the maintenance activities on maintenance management at Polytechnic environment. It is not applicable in the complex and high-rise building construction.
- The prototype system has been tested at the Facility Management and Development Unit (UPPF) of Port Dickson Polytechnic and at the Building Works Branch of PWD. However, more testing is necessary for the real situations to achieve the efficacy point that meets user needs.
- The maintenance management system was not integrated with the emerging technology (such as radio-frequency identification [RFID], non-destructive testing [NDT] and sensor) to increase the impact on the usefulness of such system for maintenance management in the future.

12. Conclusion

This research was undertaken to overcome the problems of maintenance management using conventional methods such as paper-based form and unsystematic database at the Polytechnics. Based on this purpose, the improvement towards supporting the reliability of building facility was conducted through the development of the new information system for facilitating maintenance management processes equipped with the defect diagnosis and decision-making support system. The aim was accomplished through the following two specific objectives:

12.1 Integration of information database with building diagnosis

The new system development is able to integrate the related information with the building diagnosis data such as to provide the monitoring for the patent (ironmongery failure) and latent defects (underground pipe leakage) based on the data collection for the most recorded building defects to reduce the maintenance duration in order to provide better maintenance assessment for identifying symptoms, causes and reasons of building defects. Besides, the new system development could be used for facilitating appropriate inspection to the old building structure without depending on the

expensive instruments, for instance, non-destructive testing (NDT) and sensor technology.

12.2 The information database through integration with decision-making process

In the information database, the integration of database with the decision-making process using calculation of alert levels for reliability could support the maintenance efficiency in order to reduce the data inaccuracy in reporting and analysing defect at the actual site location. For instance, the customer reported that the door structure is broken. The new system clarifies the information of door structure from the database of what type of structure and type of defects occurred. The decision-making process in the prototype system provides the explanation that could be the ironmongery that has been damaged due to latches components. In addition, the time consumed for building inspection can be decreased because of the precise information flow plan based on the maintenance identification process.

The development of this prototype system offers the new approaches of information system technology to the construction industry and Polytechnic to take the advantage for managing maintenance identification, assessing, planning and execution of the building maintenance effectively in the site location. The industry practitioners could use this system to manage the complicated building maintenance process (such as building diagnosis) without using emerging technologies to achieve the best production of maintenance information. This prototype system able to produce the same results compared to other expensive tools (e.g. RFID, NDT and sensor) through the robust data collection of the highest type of building defects.

13. Test results and recommendations

The results and recommendations from the previous test include the following:

(1) Further improvement can be made to the prototype system with respect to:

- Generating distribution information from the defect diagnosis based on the expertise field of the maintenance management staff such as civil, mechanical and electrical engineering. Each of the received defect diagnosis analysis to the system is automatically divided into these fields to facilitate maintenance management staff on the maintenance activities for the particular building defects.
- Adding the selection guide of the design specification information, feature/type of construction materials and method of repair for the particular maintenance in the electronic inspection form for references action by engineer and assistant engineer as well as to keep the report in the systematic maintenance execution.
- Improvement of the electronic inspection forms by incorporating the approaches to addressing the defect problems for suggestive cost and planning duration of maintenance as needed.

(2) Integrating the prototype system with other sophisticated instruments (e.g. RFID, NDT and sensor) to improve the reliability of the maintenance management processes in the prototype system (Ahmad *et al.*, 2011). This integration will be able to increase the effectiveness of the system in solving building defect problems at Polytechnic for commercialisation strategy.

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