THE RELATIONSHIP BETWEEN PREVENTIVE MAINTENANCE CHARACTERISTICS AND THE MAINTENANCE PERFORMANCE OF HIGH-RISE OFFICE BUILDINGS IN MALAYSIA

AU YONG CHEONG PENG

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Name of Candidate: Au Yong Cheong Peng (I.C. No: 870404-23-5033)
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ABSTRAK

Salah satu matlamat utama dalam industri pembinaan adalah mengekalkan kemapanan bangunan. Untuk mencapai matlamat tersebut, penyenggaraan bangunan serta kemudahan-kemudahannya menjadi satu kriteria yang penting. Ia termasuk perancangan, pelaksanaan, dan hasil aktiviti penyenggaraan. Namun begitu, kos penyenggaraan bangunan semakin meningkat akibat penyenggaraan yang kurang berkesan. Oleh yang demikian, penyelesaian segera harus dicadangkan untuk mengurangkan kos penyenggaraan dan pada masa yang sama meningkatkan prestasi penyenggaraan. Ianya merupakan satu strategi jangka panjang untuk menguruskan isu prestasi penyenggaraan. Kajian mengenai strategi penyenggaraan ini adalah bertujuan untuk meningkatkan prestasi penyenggaraan. Untuk mencapai matlamat kajian, tesis ini akan mengenalpasti ciri-ciri penting penyenggaraan berjadual dan penyenggaraan berasas-keadaan. Kajian ini juga akan mengkaji hubungan antara ciri-ciri tersebut dan prestasi penyenggaraan, serta membangunkan model regresi untuk perancangan dan ramalan penyenggaraan. Malahan, penyelidikan ini memperkenalkan mekanisme penyertaan sebagai langkah untuk meningkatkan prestasi.

Kajian ini menggunakan pendekatan triangulasi yang merangkumi kaedah kuantitatif dan kualitatif. Pertama, kertas soal selidik diedarkan kepada responden yang berkaitan daripada populasi penyelidikan sebanyak 398 untuk mengumpul data fakta mengenai ciri-ciri penyenggaraan berjadual dan berasas-keadaan, prestasi penyenggaraan, serta pendapat mengenai mekanisme penyertaan. Penyelidikan ini mengenalpasti tahap kepentingan pembolehubah melalui analisis kedudukan. Kemudian, analisis korelasi dilakukan untuk menguji hubungan antara pembolehubah-pembolehubah tersebut dan prestasi penyenggaraan. Selain itu, kajian ini menghasilkan model regresi untuk membuat ramalan terhadap aktiviti penyenggaraan secara praktikal. Untuk mengesahkan keputusan soal selidik, temu bual separa-berstruktur dan dokumentasi arkib dilaksanakan. Ia bertujuan untuk mendapatkan maklumat lanjut mengenai ciri-ciri tersebut dan mekanisme penyertaan yang meningkatkan kecekapan strategi penyenggaraan. Lima belas (15) pengurus bangunan yang berpengalaman telah ditemuramah dan empat (4) bangunan pejabat telah dipilih untuk dokumentasi arkib.

Keputusan menunjukkan bahawa pembolehubah ciri-ciri penyenggaraan dan mekanisme penyertaan yang mempunyai hubungan penting terhadap prestasi

penyenggaraan adalah tahap kemahiran dan pengetahuan pekerja, peruntukan kewangan untuk alat dan bahan ganti, kawalan stok alat dan bahan ganti, kualiti alat dan bahan ganti, sela jadual yang ditetapkan serta tempoh gangguan akibat kegagalan penyenggaraan berjadual; tahap kemahiran dan pengetahuan pengurus, peruntukan kewangan untuk peralatan dan teknik; Penyediaan peralatan dan teknik, keupayaan untuk menggunakan peralatan dan teknik, peruntukan kewangan untuk pengumpulan maklumat penyenggaraan, ketepatan maklumat penyenggaraan, serta kekerapan pemantauan dan pemeriksaan bagi penyenggaraan berasas-keadaan; penyediaan platform untuk berkongsi pengetahuan dan berkomunikasi, penyediaan latihan, komitmen pemilik, serta kepuasan dan maklum balas pengguna bagi mekanisme penyertaan. Seterusnya, keputusan menghasilkan model regresi logistik untuk ciri-ciri penting penyenggaraan berjadual dan berasas-keadaan seperti berikut:

- Penyenggaraanberjadual, P [over-budget]: Z = 1.237 – 0.963 LSK + 0.728 LPM
- Penyenggaraan berasas-keadaan, P [downtime extension]: Z = 3.734 – 1.061 CAT

Kesimpulannya, perancangan dan pelaksanaan strategi penyenggaraan berjadual dan penyenggaran berasas-keadaan perlu mengambilkira ciri-ciri penting kedua-dua strategi penyenggaraan tersebut dan model regresi yang dihasilkan. Selain itu, pengenalan mekanisme penyertaan dalam pengurusan penyenggaraan adalah dicadangkan untuk meningkatkan prestasi penyenggaraan.

ABSTRACT

Sustainability of buildings is one of the main aims in the construction industry. In achieving sustainability, maintenance of building and its facilities which include planning, implementation and outcome of maintenance activities become an important criterion. However, building maintenance costs are continuously increasing as a result of poor maintenance. Consequently, there is an urgent need to develop solutions to reduce the maintenance costs while optimizing the maintenance performance. It is a long term strategy to manage the issue of maintenance performance. Thus, a study of the maintenance strategies is aimed to improve the maintenance performance. Taking into cognizance the aim of the study, this thesis seeks to identify significant characteristics of scheduled and condition-based maintenance. This study is also dedicated to examine the relationship between the characteristics and maintenance performance, as well as to develop the regression models for maintenance planning and prediction. Furthermore, the research introduces participative mechanisms as a measure to improve the performance.

The study adopts triangulation approach that includes quantitative and qualitative methods. Firstly, questionnaires were distributed to relevant respondents from research population of 398 to collect factual data regarding the characteristics of scheduled and condition-based maintenance, maintenance performance, as well as the opinion on participative mechanisms. The research identified the importance of the variables through ranking analysis. Then, correlation analysis was performed to test their relationship to the performance. Moreover, the study developed regression models for prediction purpose in practical. In order to validate the questionnaire results, semi-structured interview and archived documentation were executed to obtain further details about the characteristics and participative mechanisms in enhancing the efficiency of the maintenance strategies. Fifteen (15) experienced building managers were interviewed and four (4) high-rise office buildings were selected for archived documentation.

The findings highlight the variables of maintenance characteristics and participative mechanisms that are significantly correlated to the maintenance performance. They are level of labour skill and knowledge, budget allocation for spare part and material, level of spare part and material stock, quality of spare part and material, length of

predetermined maintenance interval, as well as amount of failure and maintenance downtime for scheduled maintenance; level of manager skill and knowledge, budget allocation for equipment and technique; availability of equipment and technique, capability to adopt equipment and technique, budget allocation for acquisition of maintenance data, reliability of maintenance data, frequency of monitoring and inspection as well as for condition-based maintenance; provision of knowledge-sharing and communication platform, provision of training, clients' commitment, as well as users' satisfaction and feedback for participative mechanisms. Then, the result produces most significant logistic regression models for characteristics of scheduled and condition-based maintenance respectively as below:

- Scheduled maintenance, P[over-budget]: Z = 1.237 – 0.963 LSK + 0.728 LPM
- Condition-based maintenance, P[downtime extension]: Z = 3.734 – 1.061 CAT

As a conclusion, the planning and application of scheduled and condition-based maintenance strategy should consider their significant characteristics and make reference to the resulting regression models. Meanwhile, the research recommends introduction of participative mechanisms in maintenance management to enhance the performance.

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Meanwhile, it is of paramount importance that a research project is accompanied by complete and accurate supplements. I take pride in mentioning that the supplements referred for this research project possess these qualities and much more. I appreciatively thank the providers and authors of all these supplements. It is worth completing the research by sacrificing a lot of time and energy.

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LIST OF ABBREVIATIONS

AET	Availability of monitoring equipment and technique
AMD	Amount of failure and maintenance downtime
BAS	Building automation system
BDA	Budget allocation for maintenance data acquisition
BET	Budget allocation for monitoring equipment and technique
BS	British Standard
CAT	Capability to adopt monitoring equipment and technique
CCTV	Closed-circuit television
FMI	Frequency of monitoring and inspection
HVAC	Heating, ventilating and air conditioning
ISO	International Organisation for Standardisation
LCC	Life cycle cost
LCCA	Life cycle cost analysis
LCCM	Life cycle cost management
LCCP	Life cycle cost planning
LPM	Length of predetermined maintenance interval
LSK	Level of labour skill and knowledge
MSK	Level of manager skill and knowledge
NAFAM	National Asset and Facility Management
NAPIC	National Property Information Centre
PMB	Budget allocation for spare parts and materials
PMQ	Quality of spare parts and materials
PMS	Level of spare parts and materials stock
RMD	Reliability of maintenance data
SPSS	Statistical Package for Social Sciences

CHAPTER 1

INTRODUCTION

1.1) Introduction

Maintenance as defined by Lee and Wordsworth (2001) and Flores-Colen et al. (2010) refers to a combination of any actions carried out to retain an item in, or restore it to, an acceptable condition under BS 3811:1984 and ISO 15686-1 (ISO, 2000). Then, Chanter and Swallow (1996) highlighted two key components from the definition:

- Action that relates to the physical execution of maintenance work, initiation, financing and organisation.
- The notion of acceptable standard, which implies an understanding of the requirements for the effective performance of the building and its elements.

Generally, building maintenance is divided into two main categories, which are planned maintenance and unplanned maintenance under BS3811 (Seeley, 1987). Planned maintenance is the predetermined tasks that are well organised and performed in advance. The maintenance actions reduce or prevent any failure or damage of the components or items. Commonly, planned maintenance controls and monitors the conditions of building systems in a predetermined plan. On the other hand, unplanned maintenance is carried out in the event of emergency or contingency maintenance without any predetermined plan. The maintenance actions are carried out after the failure or damage is detected.

Moreover, both categories of maintenance are required to retain the sustainability of a building. However, planned maintenance should be the major activity in building maintenance compared to unplanned maintenance. Otherwise, frequent breakdown or downtime will occur and high maintenance cost is required by unplanned maintenance for repair and replacement works (Chareonsuk et al., 1997). Thus, unplanned maintenance should be minimised to achieve optimal maintenance performance.

According to Lee and Scott (2009), there are 3 basic maintenance strategies in planned maintenance, which are scheduled maintenance, corrective maintenance and condition-based maintenance. Basically, scheduled maintenance is defined as the preventive maintenance carried out in accordance with predetermined interval of time, number of operations, mileage and others to ensure such components are performing in good condition (Seeley, 1987; Horner et al., 1997; Nilsson, 2007; Flores-Colen and de Brito, 2010). Previous researchers have defined corrective maintenance as the repair or replacement work implemented after failure has occurred and intended to restore such item to its required performance function. Meanwhile, condition-based maintenance is defined as the maintenance initiated as a result of knowledge of the condition or significant deterioration of an item or component through continuous monitoring and routine inspection to minimise the total cost of repairs (Kelly and Harris, 1978; Seeley, 1987; Horner et al., 1997; Ellis, 2008; Flores-Colen and de Brito, 2010).

Taking into consideration the availability of several strategic options and alternative decisions for maintaining a building in proper aspect as suggested by Horner et al. (1997), a comparative study of the maintenance strategies is necessary to control the maintenance performance. Preventive maintenance that includes scheduled maintenance and condition-based maintenance is highly recommended to enhance the maintenance performance, as its concept is to prevent failure with optimal resources. On the other hand, corrective maintenance is more likely to jeopardise the maintenance performance, as the task is performed after failure has occurred. Therefore, this study focuses on the selection and implementation of preventive maintenance, including scheduled maintenance and condition-based maintenance.

1.2) Problem Statement

Building maintenance costs are rising rapidly from time to time (El-Haram and Horner, 2002). The statement is proven by the total spending on building maintenance in the UK, which has increased 66% over the last 10 years in 1990s (BMI, 1996). In Malaysian context, the development plan allocation for repair and maintenance works in building sector increased from RM296 million during the Eighth Malaysian Plan to RM1,079 million during the Ninth Malaysian Plan (Ali, 2009; Government of Malaysia, 2006). However, the development plan allocation for repair and maintenance works in the Tenth Malaysian Plan decreased to RM500 million (Government of Malaysia, 2010). In order to reduce or minimise the building maintenance cost while optimising the performance, the selection of maintenance strategies becomes an important decision making in construction and building industry.

According to Ruslan (2007) quoted from Kamaruzzaman and Zawawi (2010), low service quality is the main current issue of facilities management or maintenance management in Malaysia. The issue is due to the failures in planning of maintenance strategies or tactics caused by several factors such as lack of knowledge about the maintenance strategies, inadequate performance standard, lack of building performance monitoring data, failure to provide appropriate advice on design and planning based on overall performance, and others. As a result, many buildings are found to be unfit in terms of building use and function.

Lack of preventive measure is currently the problem that implicates poor maintenance performance. Thus, the research introduces and recommends the implementation of preventive maintenance to tackle the issue. However, the reviews as discussed in the following section reveal that the discussions and arguments on the implementation of preventive maintenance strategies, especially the scheduled maintenance and condition-based maintenance are widespread. Therefore, this study seeks to undertake comparative studies on the condition-based and scheduled maintenance towards the maintenance performance in building maintenance.

1.3) Rationale for Enhancing the Maintenance Performance with Appropriate Maintenance Strategy

According to Syed and Kamaruzaman (2008), the maintenance cost is high and therefore facility management is seen as one of the approaches to minimise high maintenance cost. However, facility management might not be able to avoid the rising of maintenance cost due to poor maintenance in the past. Hence, managing the issue of rising maintenance cost is a long term strategy. Proper study on the maintenance strategies is required to improve the maintenance performance.

Basically, planned maintenance strategies can be divided into corrective maintenance, as well as preventive maintenance that includes scheduled maintenance and condition-based maintenance. Horner et al. (1997) stated that the objective of maintenance management is to reduce or even avoid the reactive maintenance by proper planning and implementation of maintenance tasks using appropriate materials and tools at the right time. The statement is supported by Forster and Kayan (2009), who explained that corrective maintenance is not cost effective compared to preventive maintenance.

Scheduled maintenance is definitely the optimal strategy to be implemented in building maintenance (Forster and Kayan, 2009). Conventionally, many researchers suggested that the best way to optimise the performance of physical assets such as the building itself and the services or facilities fixed within it was to service, overhaul or replace them according to the predetermined plan with fixed interval. (Horner et al., 1997; Flores-Colen and de Brito, 2010).

However, Edward et al. (1998) stated that the unnecessary costs on replacement of parts might be incurred by adopting scheduled maintenance, though those component parts are occasionally fit in use. In addition, Moubray (2007) noted that the invasive undertakings that massively upset the stability of a system may be ignored during the routine inspection or scheduled maintenance. Consequently, they do induce unpredictable impacts, and thus causing the failure.

On the other hand, Ugechi et al. (2009) concluded that condition-based maintenance is the most advantageous compared to other maintenance strategies. They further noted that the implementation of condition-based maintenance enables one to have sufficient lead time to organise, schedule and carried out necessary repairs before any failure occurs. As a result, major breakdowns and costly downtime can be avoided.

However, the condition of an item must be able to be monitored in order to take the full advantage of condition-based maintenance (Horner et al., 1997). The statement is supported by Ellis (2008), who explained that condition-based maintenance is not applicable to all maintenance assets or services. Thus, condition monitoring techniques or equipments is required in advance to implement the condition-based maintenance practices.

In international context, the importance of maintenance is still neglected by some of the countries, which is not only in the property sector. In Nigeria, Eti et al. (2006) revealed that major ratio of scheduled maintenance should replace and reduce the need for corrective maintenance. In order to enhance the effectiveness of maintenance practices, allocation of proactive maintenance should be more than 80 percent and less than 20 percent for reactive maintenance. Unfortunately, less than 1 percent of those industries' management understands the significance of scheduled maintenance.

In property sector, it is found that the maintenance operation of condominiums in Taiwan suffers from lack of planning. Hsieh (2009) analysed that 52 percent of the management committees did not have proactive maintenance plan or any annual operation programmes. However, 16 percent of them did have the plan or programmes but without proper implementation. As a result majority of the condominiums operate their own condominium on an ad hoc basis, which is corrective maintenance.

In Malaysian context, buildings have not been effectively and well maintained throughout the years, though there is commitment from the government towards building maintenance. The importance of maintenance has been neglected by the building users. Lateef (2008) noted that building maintenance in Malaysia is conditionally driven and is usually concerned when there is cost allocation. There is no proper planning on building maintenance. Furthermore, maintenance operation is executed in reactive basis, whereby the maintenance task is performed after the system defect is determined (Olanrewaju et al., 2011).

Currently, the facilities management and maintenance management practices for most of the buildings rely heavily on corrective maintenance, where the item is repaired or replaced as it has damaged or broken (Lavy, 2008). In Malaysia, many buildings are even having lack of adequate maintenance (Lateef, 2008). Corrective maintenance is often carried out instead of other proper maintenance strategies. The statement is proven by Nik-Mat et al. (2011), who mentioned that the conventional maintenance strategy is dominantly applied compared to integrated facilities management systems although the new approach has been proven to be advantageous in maintenance operations.

However, higher maintenance cost is required to restore a building to its original function and purpose (Seeley, 1987). Thus, to overcome the issue of high building maintenance cost, the criteria such as cost performance, safety, security and others should be taken into consideration in the review, evaluation and assessment of the maintenance policies and strategies (Mohd Nizar, 1998). For example, Malaysian Government has taken the initiative by instructing their agencies to carry out maintenance operations from the early stage to avoid risk of higher maintenance cost due to continuous deterioration through time (Mohd-Noor et al., 2011).

1.4) Aspect in Selection and Implementation of Maintenance Strategies that Require Improvement

Review of existing literature indicated that the selection of maintenance strategies by maintenance personnel is relying on the availability of allocated maintenance resources. Ali (2009) pointed out that the budget allocated for building maintenance always influences the maintenance performance in terms of the quality. Although the primary aim of maintenance strategies is to enhance the sustainability of buildings, it has been neglected because of the limited maintenance resources (Lee and Scott, 2009).

The building owners or organisations always ignore the significance of building maintenance. They rather focus on the core business of the organisations than the maintenance activities. In fact, they do not understand that building maintenance is vital to support the core business of the organisations in the long term. Thus, the organisations are keen to achieve the maintenance standard with minimum maintenance operation cost (Lee and Scott, 2009). Undeniably, the cost allocation of building maintenance is usually not sufficient for the implementation of maintenance tasks.

According to Syed and Kamaruzaman (2008), lack of commitment and participation of the owners and organisations is one of the issues that causes poor planning and implementation of building maintenance. As a result, there are communication gaps between the organisations and maintenance personnel. Both parties have contrary opinion regarding maintenance activities (Lee and Scott, 2009). The maintenance personnel claim that budget allocation is not sufficient to meet with the maintenance requirements, whereas the organisations argue that maintenance resource is a waste apart from the core business.

Communication between managerial level staff and client is an essential aspect to improve building maintenance management. Horner et al. (1997) demonstrated that building managers should be able to make decision on selecting appropriate maintenance strategies for the building systems. Meanwhile, they must be able to prepare the optimal budget allocation for building maintenance in the planning stage, which includes expenditure on maintenance personnel, spare parts, tools, and so on. Hence, the building managers can communicate with the clients or organisations about the budget required for execution of maintenance activities.

The commitment of building manager plays an important role to develop effective maintenance management. A building manager should be able to organise and manage the maintenance management team by providing proper staff evaluation systems, staff motivation programs and staff trainings (Zawawi and Kamaruzzaman, 2009). Then, the building manager should understand the facilities and organisation objectives so that the implementation of maintenance activities is parallel to the organisation business (Kamaruzzaman and Zawawi, 2010).

The characteristics of maintenance personnel have been discussed in previous literature. In Malaysia, there is an issue about the lack of local expertise in maintenance management (Syed and Kamaruzaman, 2008). The standard of maintenance personnel is yet below expectation that can improve the effectiveness of building maintenance. This is mainly due to the characteristics of maintenance personnel such as (Zawawi and Kamaruzzaman, 2009):

- Lack of working experience
- Limited skill and knowledge in terms of technical and administrative aspects.
- Overworked staff
- Poor organisation structure

Involvement of building users and occupants in maintenance management is vital for selecting an adequate maintenance strategy. Lateef (2008) pointed out that the comments and opinions of the occupants must be taken into consideration while defining the maintenance policy. Hsieh (2009) explained that one of the issues in property management is occupants' unwillingness to involve in maintenance management. In fact, the involvement of building users in developing maintenance management system greatly affects the performance outcome.

There is an issue regarding information of building systems questioned by the maintenance personnel. In most of the cases, the maintenance personnel do have information on operation of the building systems from the manufacturer. However, they do not have information on the detailed specification and data about the maintenance and performance of the system components (De Silva et al., 2004). Thus, the manufacturers or suppliers should be responsible to provide the system information, especially the maintenance requirements and cautions.

Therefore, all the above mentioned aspects need to be studied and introduced in order to improve the effectiveness of the maintenance strategies.

1.5) Research Objective

The research is designed to study on the importance of maintenance strategies, including condition-based and scheduled maintenance. Difference between the maintenance strategies that affect the maintenance performance and cost benefit is to be identified. In order to achieve the aim of the research, the objectives are stated as below:

(a) To identify the characteristics of condition-based and scheduled maintenance.

(b) To review measures in improving maintenance performance by adopting the maintenance strategies.

(c) To establish relationship between characteristics of preventive maintenance towards maintenance performance.

(d) To develop prediction model on maintenance performance.

1.6) Limitation and Scope of Study

Since the research seeks to study on the maintenance strategies adopted in the buildings, it has been limited to those buildings that are managed by maintenance manager and personnel. In addition, the study excludes those buildings that are newly completed because the maintenance requirements of new buildings are different from the older buildings. Commonly, the maintenance tasks to be implemented for a new building are less compared to old building (Nik Mat, 2009). Thus, the age of selected buildings for this study must be two (2) years and above.

The study area is focused on the high-rise office buildings (7-storeys and above) that are located in Klang Valley. Meanwhile, the selected buildings must consist of centralised heat, ventilation and air conditioning (HVAC) system, as most of the maintenance program are developed based on HVAC maintenance program (Wu et al., 2006). Moreover, the case study is focused on the buildings completed in year 2008 and earlier. The maintenance expenditure of the selected buildings must be more than RM100,000 per annum to ensure that the range of case studies is similar.

In this study, the planning, implementation and outcome of maintenance strategies for those building systems were studied and analysed. The data were obtained from the maintenance personnel who are in charge of the maintenance planning and implementation for that particular building, such as building manager, building executive, building supervisor or technician. Thus, the data obtained from those professionals or experts can be accurate and reliable for the study.

1.7) Benefit of the Research

The results obtained from the research are expected to benefit the maintenance management personnel, organisations or owners who own the office buildings, building users, as well as the academicians involved in the construction and building industry. The benefits provided through the research are:

(a) Identification of cost related variables for scheduled maintenance and condition-based maintenance, which is able to indicate the organisations or building owners in allocating sufficient budget for maintenance activities.

(b) The research helps the maintenance team in determining the requirements and availability to adopt the maintenance strategies.

(c) The research eases the maintenance management team in selection and planning of maintenance strategies for a particular systems or even the entire building.

(d) The study describes the roles of maintenance personnel, organisations or building owners, and building users to improve the maintenance performance.

(e) The research model obtained through the study allows the organisations or maintenance personnel to predict the performance outcome of the maintenance strategies.

(f) The study is able to contribute the research findings into the body of knowledge in academic and building industries to deliver the importance between maintenance strategies and maintenance performance.

1.8) Structure of Thesis

This thesis is structured into seven chapters as shown in Figure 1.1.

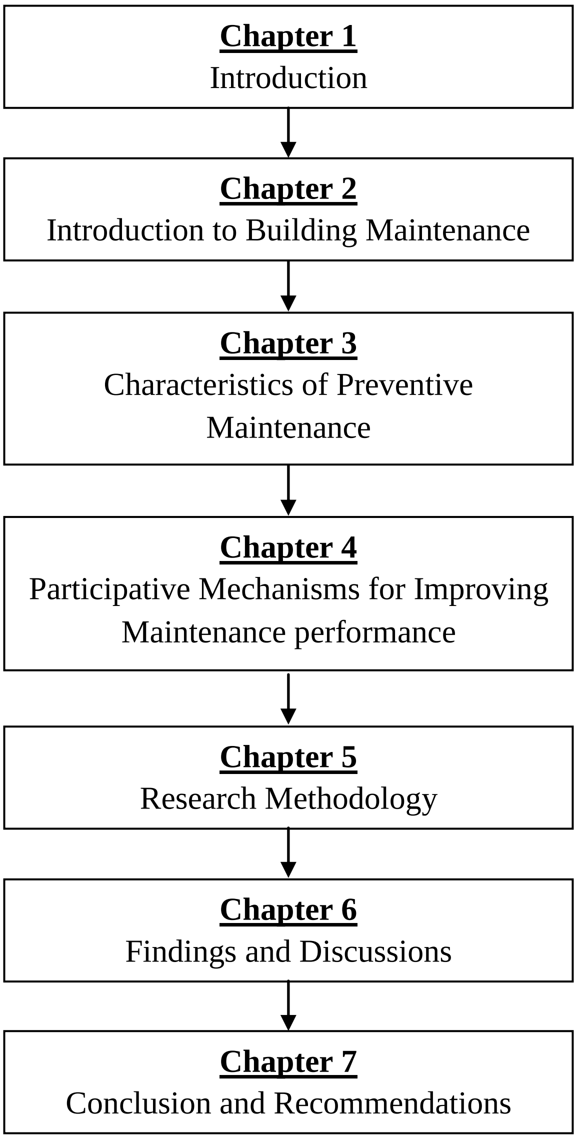

Figure 1.1: Structure of thesis

Chapter 1 introduces the research background and problem statements, followed by explanation of the rationale of the research and aspects that require improvement. In addition, it states the research objective, limitation and scope of study, as well as benefits of the research.

Chapter 2 presents the introduction to building maintenance and its importance, which includes related important elements such as maintenance cost, maintenance performance and others. Subsequently, this chapter describes the details of high-rise office building and HVAC system, as they are the determined scope of study.

Chapter 3 discusses the literature on characteristics of preventive maintenance, which include scheduled maintenance and condition-based maintenance. In overall, there are four main characteristics of scheduled maintenance, including skilled labour, spare parts and materials, predetermined interval for maintenance, as well as failure and maintenance downtime; while the four for condition-based maintenance are skilled manager, monitoring equipment and technique, acquisition of data and information, as well as monitoring and inspection. Then, this chapter continues with identification of independent variables from the main characteristics for data collection and analysis purposes.

Chapter 4 reviews the literature related to a component in improvement of maintenance performance, which is participative mechanism. Four elements related to participative mechanism that are likely to improve the maintenance performance are determined, such as managerial support, clients' commitment, occupants' commitment, as well as manufacturers and suppliers' commitment.

Chapter 5 indicates the research methodology adopted in this study. It further describes the employed research design, which is the triangulation approach that involves both quantitative and qualitative approaches. In addition, this chapter explains the data collection method, identification of population, selection of respondents, and types of analysis adopted.

Chapter 6 presents the discussions and findings from three stages of data collection, namely questionnaire survey, semi-structured interview and case study. Statistical Package for Social Sciences (SPSS) software produces analysis results for discussions and findings of questionnaire survey. The results represent the main findings of this research. Data collected from interview and case study is discussed to validate the results obtained from questionnaire survey.

Chapter 7 summarises overall research findings and results based on the objective. It includes the conclusions and recommendations of the study. It is important to provide recommendations for improving the particular industry in practical. Additionally, this chapter suggests potential research to be conducted in the future.

1.9) Chapter Summary

This chapter briefs the background of the study and highlights the issue and research gap related to selection of maintenance strategies towards improved performance. Then, it highlights the rationale and aspect to enhance and improve the implementation of maintenance strategies and its performance. After that, it lists down four research objectives, which are formulated based on the review of research background, problem statements, rationales, and aspects that require improvement. In order to ensure that the research objectives are studied and delivered accurately, this chapter also indicates the limitations and scopes of study. At the end, it indicates the expected benefits that will be gained through the research. As a foundation of the research, the following chapter introduces the general literature of building maintenance and some focuses of this research, such as development of maintenance management in Malaysia, high-rise office building and others.

CHAPTER 2

OVERVIEW OF BUILDING MAINTENANCE AND MAINTENANCE PERFORMANCE

2.1) Introduction

The sustainability of buildings is the main objective to be achieved nowadays. Building maintenance is defined as (Seeley, 1987; BSI, 1991):

> "The combination of technical and all sort of administrative actions to ensure the items and elements of a building in an acceptable standard to perform its required function under BS 3811."

Building maintenance management is an essential tool to organise and perform the activities of building maintenance efficiently. Excellent practice of maintenance management is necessary to increase the life cycle of buildings and to reduce or prevent unwanted deterioration effects (Emma and Syahrul, 2009). Francis et al. (2001) defined building maintenance management as:

> "An operation involving the interaction or combination of technical, social, legal and fiscal determinants that govern and manage the use of buildings."

According to Seeley (1987), building maintenance is subdivided into 'planned maintenance' and 'unplanned maintenance' under BS3811 as shown in Figure 2.1. There are various categories of building maintenance as stated below (Chanter and Swallow, 2007):

(a) Planned maintenance: "The maintenance is well organised and carried out with forethought, control and the use of records to a predetermined plan."

(b) Unplanned maintenance: "The maintenance implemented without predetermined plan."

(c) Preventive Maintenance: "The maintenance carried out at predetermined intervals of time or period and intended to reduce the probability of failure or unsatisfactory performance of an item." This type of maintenance relies on the predicted probability that the system, equipment or even a part of it will breakdown in a specific period of time (Swanson, 2001).

(d) Corrective maintenance: "The maintenance implemented after failure has occurred and intended to restore or repair an item to the state that can perform its required function." No maintenance work is carried out until there is failure (Nilsson, 2007). For instance, the water pump or centrifugal pump of the swimming pool is damaged and requires repair work to restore it to the functional state.

(e) Emergency maintenance: "The necessary maintenance to be implemented immediately in order to prevent further damage or serious impacts on an item." For example, the repair of serious structural cracks in a building is necessary to avoid further cracking or building collapse.

(f) Condition-based maintenance: "The preventive maintenance initiated as a result of knowledge of the condition of an item from routine or continuous monitoring and inspection."

(g) Scheduled maintenance: "The preventive maintenance implemented to a predetermined interval of time, number of operations, mileage and others." For example, change of light bulbs or tubes for best performance according to their lifetime.

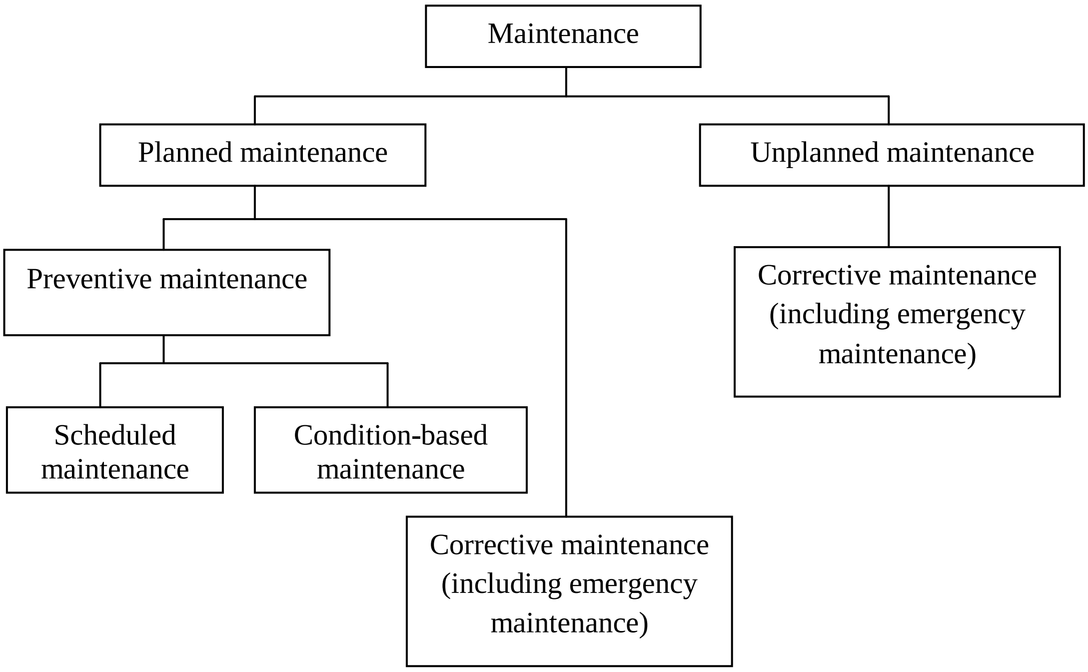

Figure 2.1: Categories of maintenance

Source: Seeley (1987)

2.2) Importance of Building Maintenance

According to Seeley (1987), building maintenance is essential in preserving a building to always be in its initial state. Furthermore, implementation of building maintenance allows the building to perform its function effectively. There are numerous objectives to maintain the buildings as stated below (Seeley, 1987; Alner and Fellows, 1990):

(a) Retaining investment and asset value, as well as quality of the building;

(b) Ensuring the building, services and facilities are safe and fit for use;

(c) Maintaining building in an acceptable condition and required standard to meet all statutory requirements;

(d) Presenting a good appearance of building;

(e) Generating income for building owner and surrounding activities;

(f) Conserving historical and architectural values of building.

Previously, most of the people do not understand the importance or significance of building maintenance and its management. They do not realise that the efficiency of a building maintenance system contributes to the income of the company's owning or renting the building (Zawawi and Kamaruzzaman, 2009). In fact, maintenance activities are not only to retain the building and system conditions, they even support the core business of an organisation with significant investment in physical assets (Hui and Tsang, 2004; Myeda et al., 2011). Most of the organisation activities are carried out with the use of building services and facilities. Without strategic maintenance management, the long term durability and function of the services and facilities can be affected (Wan-Hamdan et al., 2011). Consequently, it interrupts the smooth operation of the organisation. Therefore, well-maintained building and systems assist an organisation in achieving organisational goals.

Building maintenance has become a part of total performance approach, together with several factors such as productivity, quality, safety, and environment (Groote, 1995). For instance, building services are installed to perform the use and function of a building. The building service systems that consist of mechanical, electrical, security, safety information, communication systems and others are integrated to support the requirements and needs of the building owner or occupants (Wu et al., 2010). Thus, it is necessary to perform maintenance activities to minimise or even prevent the interruption of building use, which is often caused by the breakdown of building service systems.

Practically, all buildings begin to deteriorate or decay once they are completed (Arditi and Nawakorawit, 1999b). Due to the effects of climate, usage, wear and tear, whole elements and components of building including structures, material, finished, facilities and services deteriorate continuously (Chew et al., 2004). Definitely, this is the nature of building and the phenomenon is unavoidable. The process of decay can be reduced and physical life of building can be prolonged only with appropriate maintenance program. In other words, building defects and service breakdowns tend to occur if maintenance program is not properly planned, organised and then performed. As a result, the building performance requirements might be affected. According to Shohet (2006), one of the factors that resulted in significant increase in investment of building maintenance is the fact that building performance is highly dependent on its maintenance. Thus, the implementation of maintenance tasks is necessary that seeks to minimise building defects and enhance the building performance.

In previous time, the design of buildings was only focused on the spaces, functions, services and facilities required by the client or building occupants. The maintainability of building and its systems are often neglected. However, modern buildings are designed to meet higher building standard requirements nowadays. Arditi and Nawakorawit (1999a) stated that the maintenance of buildings has become one of the essential aspects to be taken into consideration during the design stage in construction project. The statement is supported by Wu et al. (2006) who stated that maintainability of building and services need to be incorporated in the design process. The researchers further explained that the building designer should study and understand the needs to achieve effective maintainability levels for the building systems. Thus, the importance of building maintenance is not only focused in post construction stage, but the pre-construction stage as well.

In general, building maintenance is one of the major activities that will have a visible effect on the national economy in most countries (Horner et al., 1997). Recently, Lateef

(2008) stated that the investment or expenditure in building maintenance is tremendously high all over the world. Whereby, the total turnover of building maintenance covers approximately 50% from the construction industry. Meanwhile, Ali (2009) noted that the quality of maintenance activities is often influenced by the budget allocation on building maintenance. Hence, it is proven that the importance of building maintenance is now a concern all over the world observed through the huge allocation for building maintenance.

2.3) Development of Building Maintenance in Malaysia

Since Malaysia has witnessed the enormous development in construction industry in last three decades, the need of investment in building maintenance is also increasing. The government recognises the importance of building maintenance by allocating huge resources for building repair and maintenance activities (Lateef, 2008). Meanwhile, the government emphasises the development of facilities management in Malaysia. For example, the government has privatised the non-clinical support services in hospitals to three facilities management firms in 1996, which were the largest facilities management contracts of all time (Kamaruzzaman and Zawawi, 2010).

However, the buildings are not well-maintained due to poor maintenance in the past, as well as lack of awareness about the importance of building maintenance. The owners of buildings and the public have very little knowledge regarding effective maintenance and facilities management. Although the government has allocated massive resources for building maintenance, there is no establishment of guideline or standard operation procedure as the blueprint to be followed by the building owners and public (Mohd-Noor et al., 2011) .

Despite the fact that budget allocation on building maintenance is in an increasing trend, Lateef (2008) demonstrated that there is still a substantial backlog of building maintenance in Malaysia. The backlog will keep on burdening the clients, users and public if effective maintenance management cannot be provided. Therefore, the government has set up Total Asset Management Manual through National Asset and Facility Management (NAFAM) conference in 2007 and 2009 as the manual to improve the strategic planning and implementation of building, asset and facility management (Mohd-Noor et al., 2011).

The establishment of NAFAM demonstrated the initiative to develop a holistic and effective management in terms of operational and maintenance of building (Kamaruzzaman and Zawawi, 2010). Therefore, study on maintenance management in terms of planning, implementation and performance is highly required to support the development of building maintenance in Malaysia.

2.4) Maintenance Policy

Maintenance policy is usually derived from the primary aims and objectives of the individual or organization that owns or occupies the building (Mills, 1980). Typically, the maintenance policy is a written document that covers the maintenance objectives, organisation visions and goals, clients' expectations, resources and capabilities, as well as maintenance strategy that need to be adopted (Parida and Kumar, 2006). Meanwhile, Lee and Scott (2009) pointed out that there are three fundamental elements in formulating the maintenance policy, which include:

- Choice of maintenance strategy
- Identification of maintenance standard
- Allocation of maintenance resources

In fact, maintenance policy is one of the significant criteria to be considered in the planning of maintenance strategies. On the other hand, selection of appropriate maintenance strategy plays an important role to meet organisation goals, increase return on investment, reduce maintenance downtime and failure, as well as minimise the maintenance and life cycle cost (Jafari et al., 2008). According to Lee and Scott (2009), it is a guideline for maintenance management team to select the maintenance strategies such as corrective maintenance, scheduled maintenance or condition-based maintenance. The maintenance strategy should be determined together by the clients and management team (Straub, 2010). Additionally, the selection of appropriate maintenance strategy must be based on an analysis of numerous strategies (Flores-Colen and de Brito, 2010). The suitability of maintenance strategy can be decided on the availability of resources, life cycle cost and its short-term or long-term outcomes.

Furthermore, Lee and Scott (2009) noted that maintenance standard is crucial for the implementation of maintenance strategies. Without defining maintenance standard, poor implications of the selected maintenance strategies might occur. Unfortunately, the enforcement of maintenance standard is always influenced by the available budget and resources. Yahya and Ibrahim (2011) argued that it is compulsory to develop a building maintenance standard to be imposed in the maintenance management legally. The maintenance standard will enhance the comfort and safety of users through proper maintenance execution and performance.

Furthermore, the maintenance policy is always related to budget allocation for maintenance activities and implementation of maintenance tasks. Weinstein et al. (2009) stated that the maintenance policy stipulates the allocation of resources for maintenance activities. Commonly, amount of resource allocation can influence the selection of maintenance strategies and determination of maintenance standard. For instance, the effective maintenance strategies and high maintenance standard can be selected and defined respectively with sufficient resource allocation.

Therefore, it is vital to formulate the maintenance policy in the planning stage, so that the maintenance personnel are able to plan the maintenance strategies appropriately. The formulation of maintenance policy must be agreed by the organisation and maintenance management team to ensure that the policy is beneficial to the organisation, as well as practicable by the management team (Lee and Scott, 2009). The significant components and their sequences for formulating maintenance policy are shown in Figure 2.2.

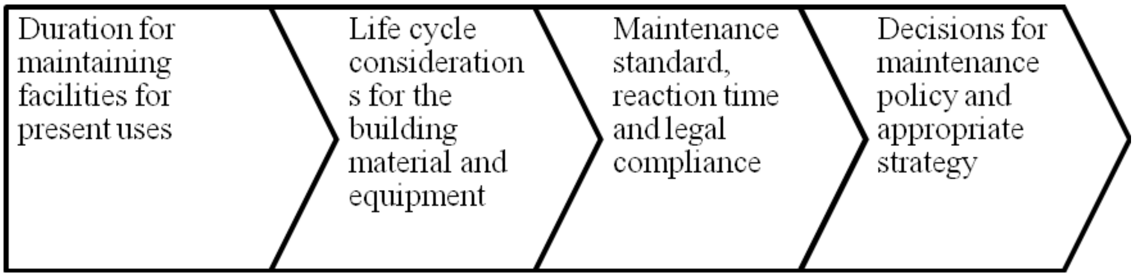

Figure 2.2: Sequences for formulating building maintenance policy and strategy

Source: Lee and Scott (2009)

2.5) Maintenance Cost

Maintenance cost covers the overall cost or budget, which is allocated to keep the building in its best performance, or to retain the building in good condition. According to Lee and Wordsworth (2001), the main objective of maintenance management organisation is to ensure that the required or acceptable standards and level of services provided in the building are continuously at the minimum cost.

However, Chanter and Swallow (2007) found that the cost of maintenance work is usually higher than the cost of new construction work because of several factors as stated below:

- Maintenance work is always carried out on small scale, leading to diseconomies of scale.
- Before the repair or replacement work is carried out, there is a need of striping out the existing work.
- Commonly, maintenance work has to be carried out in confined or occupied spaces, areas of places.
- The cost of making good and general clearing away is disproportionately high.
- It incurs substantial disturbance costs on the operation of the building and perhaps lost of production.

Chanter and Swallow (2007) further explained that the maintenance cost can be split into four elements, which are:

- Labour
- Material
- Plant
- Overhead

2.5.1) Labour Cost

Labour cost is termed as direct cost in maintenance management. According to Mjema (2002), maintenance activities are personal-intensive and the largest proportion of maintenance cost is allocated to the costs of maintenance personnel or labour. All the maintenance tasks or jobs require involvement of labour, including for inspection, supervision, observation, repair or replacement work. All the mentioned tasks are performed by the labour depending on the required skill or availability of such labour. Generally, there are 3 types of man power supplied in the construction industry, which are skilled, semi-skilled or unskilled worker. They have different amount of salaries based on their availability and skill. Definitely, in-house maintenance staff is not sufficient to provide all sorts of services in a building. It requires outsourcing maintenance staff in specific task such as routine maintenance of elevator, air conditioning system, fire fighting system and others. Lee and Wordsworth (2001) stated that in-house staff is more economic than outsourced staff. However, the decision in selecting either in-house staff or outsourced staff must be based on the analysis of the advantages and disadvantages in the context of the needs of the organisation. Thus, proper planning of labour cost allocation is necessary to ensure that there is no over budget in terms of labour cost.

2.5.2) Material Cost

Material cost is also termed as direct cost in maintenance management. Ali (2009) stated that material cost is included into a part of maintenance costs. The variation of material cost often occurs especially in several situations. For instance, the demand and supply of a material may affect the cost variation of such material, whereby the material cost increases when there is high demand but low supply. In addition, inflation and economic crisis can cause the rising of material cost. According to Lee and Wordsworth (2001), the quantities of each material should be stated in sufficient detail for stores requisitioning or purchase. In order to obtain proper management on material cost planning and budgeting, sufficient quantity of material should be purchased in every maintenance task, but it must not be over the acquired quantity to prevent wastage.

2.5.3) Plant Cost

Apart from labour and material costs, all other costs are termed as indirect cost. So, plant cost is determined as indirect cost too. In fact, the use of small plant items is not directly attributable to individual items of work. Normally, the plants are equipped and used in the building maintenance tasks to support the functionality of the building. However, the maintenance manager should be able to perform calculations, estimate the life cycle costs and life cycle profits in making choice of plants and supporting equipments to buy (Sherwin, 2000). Those plants are usually used during the repair or replacement work such as ‘gondola machine’, scaffolding, driller, compactor and others. For instance, the ‘gondola machine’ is used when cleaning work of external window glass is carried out for high-rise building. Lee and Wordsworth (2001) explained that plant costs are included in the overhead costs that cover small plant, hand tools, ladders and other equipments used in maintenance task.

2.5.4) Overhead Cost

The cost of building maintenance works or operations is viewed as an overhead on the operations of the building users. The overhead is a form of a direct cost for owner or occupants and for others as a service charge or rent. Lee and Wordsworth (2001) stated that the maintenance overhead must be charged against the revenue-generating processes within the building estate. The researchers further explained that building maintenance overhead is generally divided into two elements as stated below:

(a) Fixed cost overheads: Costs regarding to the provision of maintenance service such as core staff salaries, accommodation space for the maintenance operation, plant, vehicles, equipment and others.

(b) Variable cost overheads: Costs which depend on the actual amount of work done. These are usually incurred on a unit of production basis.

Due to economic downturn, the top management of the organisations tend to reduce maintenance operation cost and existing manpower. They seek for the best building performance to satisfy occupant and customer needs with minimal maintenance and operation cost (Lee and Scott, 2008). Inevitably, the allocation of maintenance budget is usually not sufficient for the maintenance activities (Pitt, 1997). As a result, maintenance personnel might not be able to perform some necessary maintenance tasks with limited cost allocation. The statement is proven by arguments about the fact that the approved maintenance cost and budget is not able to meet with the maintenance requirements (Shen and Lo, 1999; Lam, 2000; Lo et al., 2000; Tse, 2002; Lee and Scott, 2008).

High maintenance cost is always an issue in building and construction industry. According to Griffin (1993), the maintenance and operation cost for a building covers from 50% to 80% during its service life, which is the highest expenditure compared to the initial cost and other costs. This issue is concerned in maintenance management and solutions are discussed by researchers and practitioner lately. Horner et al. (1997) stated that maintenance management is keen to find out an optimal approach to reduce and minimise the maintenance expenditure and life cycle costs. One of the approaches is finding appropriate maintenance strategy to be implemented, which is the most difficult task.

2.6) Life Cycle Costs

Life cycle costs cover the cost of acquisition, operation, maintenance, repair, restoration, replacement of parts and others. Lee and Wordsworth (2001) defined life cycle costs (LCC) as:

"The total cost of owning and using an asset over its predicted life span".

Meanwhile, Barringer (2003) described life cycle costs as:

"The summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced in annual time increments during the project life with consideration for the time value of money".

According to Lee and Wordsworth (2001), life cycle costing is a technique used to ascertain a suitable balance between initial provision, operation and maintenance expenditures as stated below:

$$\mathbf{LCC = Ic + (Mc + Ec + Cc + Oc) + (Vc) - Rv}$$

where,

Ic is initial cost

Mc is maintenance cost

Ec is energy cost

Cc is cleaning cost

Oc is overhead and management cost

Vc is utilisation cost

Rv is resale value

In order to achieve the efficient and lowest long term cost of ownership for an equipment or project, life cycle cost analysis is an essential tool to choose the most cost effective approach from a series of alternatives (Barringer, 2003). The alternatives might be selected from different companies or tenders. For example, the decision in selecting the lift system to be installed in a building can be studied and obtained from several provision system of company such as Panasonic, Toshiba, Mitsubishi and others. Thus, life cycle cost analysis is an economic evaluation technique that determines the total cost of owning and operating a facility or system over period of time (Mearig et al., 1999).

Unfortunately, most of the construction projects do not perform life cycle cost analysis. Since the designers only work for the developers, they focus more on the profitability to their employee. Practically, the buildings will no longer be under the responsibility of the developers after the defect liability period. Thus, they usually ignore the future operation and maintenance cost of the buildings in the design and construction stage to maximise profit. By analysing the life cycle costs of building, Lavy (2008) demonstrated that major costs for a building occur after the building is completed or during the maintenance phase. This information is vital to owners, designers, and facility or building manager. Hence, this issue should be taken into consideration when planning and selecting maintenance strategy for building and systems.

In fact, there are 3 main concepts which are closely related to the aspects of life cycle costs as shown in Figure 2.3.

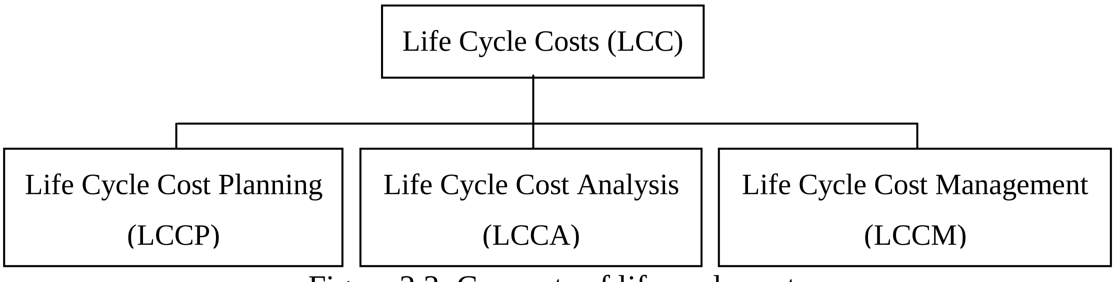

Figure 2.3: Concepts of life cycle costs

Source: Flanagan and Norman (1983)

The function and purpose of these 3 main concepts are stated by Flanagan and Norman (1983) as below:

(a) LCCP focuses on the planning of cost distribution from inception to disposal, which includes the initial costs and future costs.

(b) LCCA involves the systematic collection of running cost data on completed buildings and systems. Then, the physical, qualitative and performance characteristics of those buildings and systems are linked to the collected data.

(c) LCCM covers the application of the techniques and administrative actions to existing buildings and systems with the following aims:

- To monitor and explain differences between LCCP projections and actual performance.
- To improve the efficiency of the building through more effective utilisation.
- To provide information on asset lives and reliability factors for accounting purposes.
- To aid in the development of an appropriate maintenance policy for the building.
- To provide taxation advice on building related items.

Hence, life cycle cost is a continuous approach to reduce costs in building maintenance or even construction industry. It helps to evaluate the cost of alternative maintenance strategies and eases the maintenance personnel to identify the appropriate maintenance strategies for the building and its systems (Kong and Frangopol, 2003). Flores-Colen and de Brito (2010) explained that life cycle cost analysis is a simple approach for minimising maintenance cost. By computing the life cycle cost of different maintenance strategies, maintenance management would be able to determine the optimal maintenance strategy with minimal cost.

2.6.1) Relationships between Initial Costs, and Operating and Maintenance Costs

Barringer (2003) noted that the operating and maintenance costs always exceed the initial costs for a building and its systems. Whereby, the supporting costs are 2 to 20 times greater than the initial procurement costs. According to Wu and Clement-Croome (2007), the ratio of operating and maintenance costs to initial costs for buildings is an essential factor for the whole lifecycle of building services system in maintenance management. The relationships between initial costs, operating and maintenance costs involve the initial investment, project management, system design, building operations and maintenance management. Thus, it is very important to accurately estimate the ratio from a lifecycle cost perspective.

According to Horner et al. (1997), the maintenance management decision diagram is adopted to identify the best combination of maintenance strategies for a building by selecting the most optimum maintenance strategy for each individual item and element in the building. This approach takes two main aspects into consideration, which are the health, safety and satisfaction of the user or known as the quality of building performance and the costs of maintenance tasks. Flores-Colen and de Brito (2010) supported that in order to identify the appropriate maintenance strategies for buildings and systems, a technical and economic analysis, also known as the performance and cost benefit analysis, is required.

The building services systems are complex and complicated, which are encompassed by many different components such as electrical, mechanical and other components. The selection of system layout and the inter-connections between such components are crucial in order to ensure their quality of system performance. Hence, a balance must be obtained between components' quality or reliability and their lifecycle costs. In other words, the cost saving for the building services systems and their quality are both vital in order to obtain a sustainable development (Wu and Clement-Croome, 2007).

Wu and Clement-Croome (2007) also stated that the life cycle of building services systems is usually divided into several stages from the inception stage to the disposal stage, such as client requirement, design, installation and commissioning, operation and maintenance, as well as disposal and reusing stages in the construction industry. So, life cycle cost should be taken into consideration and appropriately analysed in each stage from inception to disposal stage. It is necessary to estimate the relationships between the initial costs, maintenance and operating costs at the design stage. This estimation is basically done by life cycle cost analysis, which is an essential tool used in the design stage for controlling the initial cost and the future cost of building ownership that includes the operation, maintenance, repair and disposal costs (Mearig et al., 1999).

2.7) Maintenance Performance

Amaratunga and Baldry (2002) stated that the development of performance measurement in management is to improve quality and service, as well as meeting cost parameters. Measurement of maintenance performance is an assessment that helps to identify the strengths and weaknesses of the maintenance activities. In addition, the result of performance measurement indicates the effectiveness of existing strategy. Consequently, the management team is able to plan and make appropriate decision for future maintenance strategy. The significance of maintenance performance measurement is reviewed as (Parida and Kumar, 2006):

(a) Measuring value created by the maintenance

(b) Justifying investment

(c) Revising resource allocations

(d) Considering health, safety and environmental issues

(e) Focus on knowledge management

(f) Adopting new trends in operation and maintenance strategy

(g) Organisational structural changes

In fact, the significance of measuring maintenance performance had been revealed earlier. According to Tsang et al. (1999), there are two stages of planning process in maintenance management. In the first stage, the maintenance management and organisation participate in the process of formulating maintenance policies, setting up objectives, planning, auditing, and measuring performance that will be applied in the maintenance programs. Then, second stage concerns about technical planning and selection of maintenance strategies for building and its systems. Hence, it is proven that the measurement of performance is vital in selection of optimal maintenance strategies.

The measurement of performance can be obtained through the level of success or failure in terms of schedule, cost and functionality (Sidwell, 1990; Johnson, 1995). Groote (1995) further explained that measurement of maintenance performance should not only focus on quantifiable aspect, but also the quality of maintenance works. Salonen and Deleryd (2011) also argued that maintenance management should not only consider about the cost and budget, impact of poor quality would cost even more in most circumstances. Thus, maintenance performance is indicated by time, cost and quality as shown in Figure 2.4 (Ali, 2009; Lam et al. 2010). For instance, building services performance is measured by number of breakdowns, occupants' satisfaction, and maintenance expenditure.

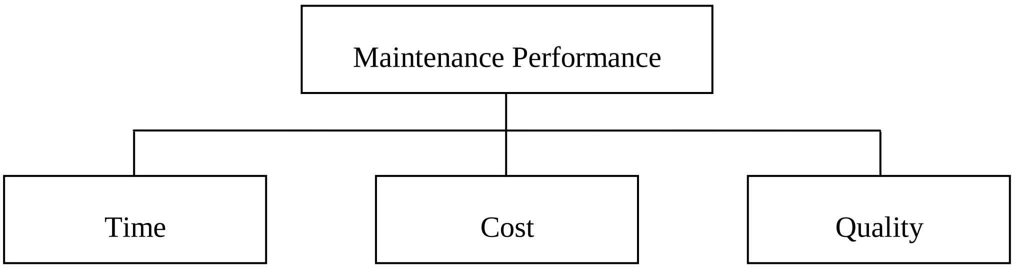

Figure 2.4: Indicators of maintenance performance

Source: Ali (2009)

Time or schedule is one of the aspects that determine the level of maintenance performance. Bubshait and Almohawis (1994) defined time as the degree of measurement in construction project performance, which is the completion time compared to the allocated duration. Moreover, Rahmat and Ali (2010a) measured the project performance by time variance in refurbishment projects. According to Ali et al. (2010), failure to execute maintenance task at the right time is one of the factors that affect maintenance performance. Delay in executing the required maintenance activities will prolong the breakdown time of building systems. As a result, the required standards of building functions for the owner or occupants are affected because of longer breakdown time. For example, extensive time failure of power supply in an office building restricts the officers to carry out their daily responsibilities such as documentation and printing works.

Furthermore, the aspect of cost or expenditure for building maintenance is mostly used in measuring the performance of buildings. Ali (2009) noted that maintenance performance is calculated using variance of actual expenditure and planned cost for building maintenance activities. Comparison between actual and planned cost is made to identify the level of maintenance performance. Rahmat and Ali (2010a) demonstrated that the project performance could be measured in terms of cost variance in refurbishment projects. For instance, maintenance performance of a building system is deemed below expectation when the actual spending for maintenance tasks is more than the planned cost. In contrast, high performance level is achieved when the total expenditure is less than the planned cost for the maintenance works.

Maintenance seeks to enhance the quality of buildings (Alner and Fellows, 1990; Horner et al., 1997; Ali, 2009). Thus, quality is another aspect to identify the maintenance performance. In terms of quality, it can be measured through several aspects such as number of breakdowns and others. Shonet (2003) pointed out that there are several ways to evaluate the quality performance of maintenance. One of the ways is to assess the frequency of building system failures. Lam et al. (2010) pointed out that the quality is also expressed in terms of technical specification, function and operability. Apart from quality of building construction, the quality of management services including maintenance, repair and replacement is critical to the building performance (Lai and Yik, 2011). The quality of maintenance management influences the satisfaction of building users and occupants.

According to Swanson (2001), the maintenance performance can be improved by implementation of proactive and aggressive maintenance strategies. Whereby, the maintenance strategies can only be planned and organised properly with a well-defined maintenance standard. The maintenance policies and allocation of maintenance resources such as manpower and budget influence the level of maintenance standard (Lee and Scott, 2009). Hence, it is required to have appropriate maintenance planning and management to achieve high maintenance performance. In this study, there are four maintenance performance measurements selected to cover the time, cost and quality performance, which include:

(a) Time variance for maintenance work

(b) Cost variance for maintenance work

(c) System breakdown rate

(d) Number of complaints received

2.7.1) Time Variance for Maintenance Work

Groote (1995) stated that the time for maintenance works is one of the measurements for maintenance performance. Then, Chan et al. (2001) noted that the responding and repairing time to a faulty system indicates the capability of maintenance personnel to rectify the defects. Whereby, the time for maintenance may also include downtime due to breakdown, preventive maintenance, repairs and replacements, inspection, lost time awaiting spare parts or materials, waiting time for maintenance personnel, vandalism, accident, and others (Nepal and Park, 2004).

Furthermore, the variance between time planned and time spent on the maintenance activities is adopted to be the performance measurement indicator (Coetzee, 1998; Kutucuoglu et al., 2001; Rahmat and Ali, 2010b). The time variance for maintenance works implies the functionality of building systems, labour utilisation and others. For example, the maintenance performance is deemed to be poor when the time spent is longer than the time planned for a maintenance task.

Thus, the time variance for maintenance work is used to measure the maintenance performance in this study.

2.7.2) Cost Variance for Maintenance Work

Financial measure is one of the performance indicators widely used. Tsang et al. (1999) pointed out that variance analysis is typically performed to assess the financial measures. Although there are some arguments about the reliability of variance analysis, it is found that the method is adoptable and reliable. Whereby, Rahmat and Ali (2010b) demonstrated that the effectiveness of refurbishment projects could be determined by cost variance analysis. The researchers computed the ratio of actual refurbishment cost to target refurbishment cost as the cost variance in their research.

In addition, Swanson (2001) proved that the maintenance performance is dependent to the implementation of maintenance strategies by analysing the reduction in production cost, which is cost variance. He compared the current production cost to the previous production cost. At the end of the study, he found that the proactive and aggressive maintenance strategies positively influenced the reduction in production cost; while reactive maintenance negatively affected the reduction in production cost.

As a result, credibility of cost variance analysis is supported in measuring the maintenance performance. The cost variance for maintenance work is adopted as one of the performance measurements in this study.

2.7.3) System Breakdown Rate

According to Halim et al. (2011), measuring the maintenance performance involves technical evaluation of mechanical and electrical systems provided in a building. The researchers proposed a systematic approach in measuring maintenance performance, named as “SPRINT”. In the approach, one of the aspects they focused on was the performance history of systems. For instance, the total number of system breakdowns and the duration of breakdowns were recorded and documented. In fact, the breakdown data could reflect the maintenance performance directly.

Moreover, Chan et al. (2001) suggested that system failure frequency could be identified by recording the sum of urgent and general repairs. The researchers further explained that if the maintenance personnel are capable to perform the maintenance tasks effectively, the failure rate of the building systems would be minimised or reduced from time to time. The example has proven that the measurement of system failure frequency could determine the maintenance performance in terms of labour skill and knowledge.

Therefore, one of the maintenance performance measurements adopted in this study is system breakdown rate for the building services and components.

2.7.4) Number of Complaints Received

In order to improve the quality of a product or service, performance measurement should consider customer's satisfaction, whether in business, product or service sectors (Parida and Kumar, 2006; Tucker and Pitt, 2009). Thus, the concept is adopted in maintenance management. Feedbacks from the building users and occupants should be taken into consideration in measuring the maintenance performance. Bandy (2003) pointed out the importance of understanding customer needs and expectations to deliver better service in facilities management. By getting feedbacks from building users, their continuous changing needs can be tracked from time to time. Then, further action can be done to improve the maintenance performance.

According to Bon et al. (1998), customer satisfaction is difficult and costly to be monitored. Nevertheless, the customer dissatisfaction can be obtained easily. The researchers demonstrated that help-desk calls are able to track the customers' complaint in several aspects, which are health, safety and security; building services and others. As a result, the degree of dissatisfaction in different aspects could be identified.

Therefore, the number of complaints received from the building users is used as one of the maintenance performance indicators in this study.

2.7.5) Selection of Dependent Variables

After a thorough study on performance measurements through literature review, four measures of maintenance performance are selected to test the independent and intervening variables of this research as tabulated in Table 2.1.

Table 2.1: Matrix of dependent variables and references

Performance Measurement	**Reference**
Time Variance for Maintenance Work	Bubshait and Almohawis (1994); Groote (1995); Coetzee (1998); Chan et al. (2001); Kutucuoglu et al. (2001); Nepal and Park (2004); Ali et al. (2010); Rahmat and Ali (2010a); Rahmat and Ali (2010b)
Cost Variance for Maintenance Work	Tsang et al. (1999); Swanson (2001); Ali (2009); Rahmat and Ali (2010a); Rahmat and Ali (2010b)
System Breakdown Rate	Chan et al. (2001); Shonet (2003); Lam et al. (2010); Halim et al. (2011)
Number of Complaints Received	Bon et al. (1998); Bandy (2003); Parida and Kumar (2006); Tucker and Pitt (2009)

2.8) High-Rise Office Building

In Malaysia, DBKL (1986) defined high-rise building as the building that is more than 7 floors (or the top floor of building is more than 60 feet). This definition is in accordance to the Uniform Building By-Laws 1984. The maintenance of buildings in Malaysia is more concerned lately, there are a number of researches discussing about the facilities and maintenance management of high-rise office building.

According to Zawawi and Kamaruzzaman (2009), office buildings always have their own maintenance management team to take care of the conditions of buildings, which are managed by maintenance or building managers. Basically, the services provided by building managers in office buildings are cleaning, landscaping, general maintenance, lightings, heating, ventilating and air conditioning (HVAC), lift or escalators, mechanical and electrical, sanitary and plumbing, access, signage, parking and others (Myeda et al., 2011). These services are the significant systems of office buildings to be concerned by maintenance management, as they provide function, safety, health and comfort to the building users in daily activities.

Unfortunately, Zawawi and Kamaruzzaman (2009) demonstrated that most of the building users were not satisfied with the services provided in the buildings understudied through building satisfaction survey. This was mainly due to issues such as lack of maintenance staff, lack of expertise, lack of tools and technology, insufficient budget allocated, inappropriate maintenance strategies and so on. Those issues often occur in high-rise office building as it is a medium-sized building, which is equipped with more sophisticated systems such as fire detection and protection systems, central heating, ventilating and air conditioning system, escalators and others (Halim et al., 2011).

Therefore, this research focuses about the issues that cause building users' dissatisfaction in high-rise office buildings. In other words, the impact of maintenance strategy characteristics towards maintenance performance is examined.

2.9) Heating, Ventilating and Air Conditioning (HVAC) System

HVAC system is a system to provide proper ventilation and air circulation for a building. A central HVAC system may serve one or more spaces. The system comprises two main sections, which are in-building section and out-building section as shown in Figure 2.5. Commonly, all the main components of HVAC system perform their own function as stated in Table 2.2. A central HVAC system consists of (Buys and Mathews, 2005):

(a) Chilled water plants (Chillers) complete with cooling towers

(b) Water distribution systems consisting of pumps and insulated steel pipes

(c) Air handling units

(d) Air distribution systems consisting of insulated ducts, fans, dampers and air terminals

(e) Electrical distribution systems

(f) Control systems

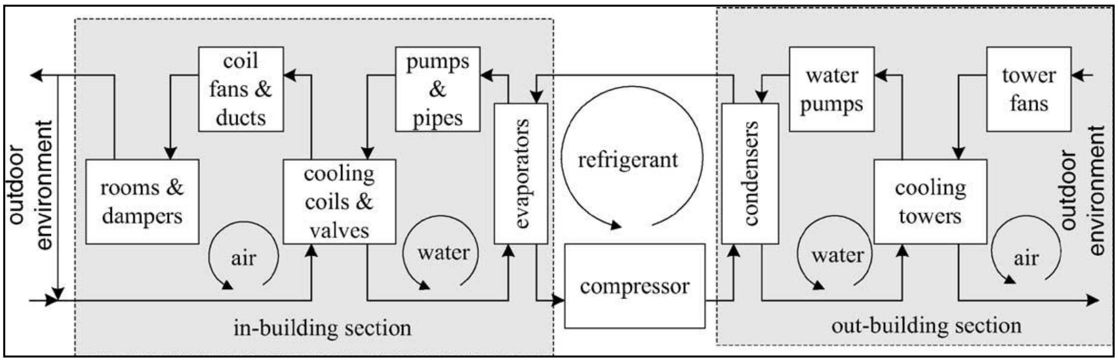

Figure 2.5: Schematic of a typical HVAC system

Source: Lu et al. (2005)

Table 2.2: Components of HVAC system and their functions

Component	**Function**
Chiller	A refrigeration unit designed to produce cool (chilled) water for space cooling purposes.
Cooling tower	A heat rejection device, installed outside of the building envelope, through which condensed water is circulated for heat removal purpose.
Air handling unit	Equipment packages for the operation of air-based central HVAC system. The equipments include a fan, a cooling coil, an air filter, control devices and occasionally a humidifier.

Source: Grondzik and Furst (n.d.)

Nowadays, central HVAC system is widely used in large buildings, such as office buildings, commercial buildings, shopping complexes and others. Definitely, this is due to the advantages of the system. Grondzik and Furst (n.d.) noted that central HVAC system allows major components to be isolated in a mechanical room. Thus, the maintenance personnel are able to perform the maintenance tasks without interrupting the building functions. Meanwhile, the isolation of components helps to reduce noise and enhances the building in terms of aesthetic aspect.

According to Kwak et al. (2004), the level of occupants’ productivity and comfort highly relates to service reliability of HVAC system. Suttell (2006) supported that heating and cooling system is necessary for a building. A building without heating and cooling system would be uninhabitable. Thus, the maintenance of HVAC system must be planned and performed effectively.

2.9.1) Maintenance of HVAC System

Generally, the manufacturers do recommend maintenance requirements and operating environment to the users. Wu et al. (2006) mentioned that there are four types of maintenance program for HVAC system including:

(a) Test and inspection

(b) Scheduled maintenance

(c) Condition-based maintenance

(d) Corrective maintenance

In order to plan, organise and execute maintenance program appropriately, it is vital to understand the components and functions of a particular system. Chandrashekaran and Gopalakrishnan (2008) demonstrated that the most important HVAC components are chiller, cooling tower, air handling unit, compressor and pump. Thus, the maintenance of HVAC system should focus on those essential components to enhance the performance and cost effectiveness of the system.

Since the HVAC system is centralised, it may affect the entire building when failure occurs in any component (Grondzik and Furst, n.d.). For example, the cooling of condensed water cannot be done if the chiller breakdowns and hence the entire system cannot convert the hot air into cool air. Furthermore, the maintenance of central HVAC system is more complicated and difficult because of the system size and complexity. Hence, preventive maintenance must be performed appropriately to replace the corrective maintenance, so that the downtime of HVAC system can be minimised.

As Wu et al. (2006) has proven, most of the maintenance programs of building systems are developed based on HVAC maintenance program, hence HVAC system is selected as one of the scopes of study in this research. In addition, Lavy (2008) demonstrated that HVAC system is the largest and most expensive system component in a building. Extensive high maintenance cost is required to retain the conditions of HVAC system without affecting maintenance performance.

2.10) Chapter Summary

This chapter reviews the literature related to introduction, importance, and some aspects of building maintenance in general. It is necessary to understand the basic concept and knowledge of related topic before an in-depth study can be performed. Thus, this chapter provides a foundation to the readers in understanding the theory of building maintenance.

Then, this chapter discusses four measurement indicators for maintenance performance. These indicators represent the dependent variables in this research, which are time variance for maintenance work, cost variance for maintenance work, system breakdown rate, and number of complaints received. Furthermore, this chapter covers some details on the limitations and scopes of study, such as the definition of high-rise office building and elaboration of HVAC system and its maintenance.

Due to poor maintenance in the past, selection and implementation of preventive maintenance strategies are deemed as the solution to improve the maintenance performance. Therefore, the next chapter investigates the characteristics of scheduled maintenance and condition-based maintenance that influence the performance.

CHAPTER 3

CHARACTERISTICS OF PREVENTIVE MAINTENANCE

3.1) Introduction

According to Marquez et al. (2009), maintenance management process is divided into definition of maintenance strategy and implementation of the strategy. Definition of maintenance strategy is the selection of maintenance strategy based on the organisation's objectives, maintenance policy, maintenance resources and others; while implementation of maintenance strategy focuses on the ability of management team to deal with the maintenance issues such as the ability to ensure proper skill levels, organised work preparation, appropriate equipments, schedule fulfilment and so on to perform the maintenance activities. The efficiency of maintenance implementation can be reflected by minimal waste, expense, downtime, failure or complaint.

Since planned maintenance is more effective compared to unplanned maintenance, the planned maintenance should be introduced and implemented. Generally, there are two main categories of planned maintenance, which are preventive maintenance and corrective maintenance. According to Mann et al. (1995) and Moghaddam and Usher (2010), preventive maintenance involves maintenance tasks such as inspection, monitoring, cleaning, lubrication, adjustment, alignment, repair, replacement and maintenance of building's and systems' components before failures or system breakdowns occur. Meanwhile, preventive maintenance is based on component reliability characteristics and aimed to reduce the probability of component failure, as well as to minimise the system downtime (Chareonsuk et al., 1997; Horner et al., 1997;

Yang, 2004; Fouladgar et al., 2012). The researchers further explained that the cost of preventive maintenance is definitely less than the cost of failure or corrective maintenance. This is because corrective maintenance arises immediately with unexpected and extensive need of maintenance resources (Batun and Azizoglu, 2009).

Rao (1992) described that preventive maintenance is an effective approach to enhance the reliability and quality of a system and its components. In order to prevent failure from occurring, preventive maintenance practiced should be able to indicate when a maintenance work needs to be performed (Yang, 2004). Eti et al. (2006) supported that maximising components reliability and extending the components' life are the main purpose of preventive maintenance. It also provides a critical service function that minimises interruptions to core business of an organisation.

Eti et al. (2006) pointed out that system failure causes negative impacts to the organisations, users and customers. The negative impacts could be on the aspects of output, safety, environmental integrity, system quality, customer satisfaction, and additional repair cost incurred. Thus, the implementation of preventive maintenance is necessary to replace the need of corrective maintenance (Suttell, 2006). Consequently, unnecessary cost such as emergency repair cost after occurrence of failure occurs can be reduced or avoided. The required capital investment on maintenance can be minimised as well.

However, Moghaddam and Usher (2010), argued that preventive maintenance involve a basic trade-off between the contradict aims, which are to minimise total maintenance costs and to maximise the overall reliability of the building and systems. For example, systems or components that are maintained or replaced frequently will require high maintenance cost, but they will provide high reliability. Therefore, a balance between the two aims must be reviewed and obtained in order to achieve the effectiveness of preventive maintenance.

Commonly, preventive maintenance is divided into two strategies, which are scheduled maintenance and condition-based maintenance (Seeley, 1987; Dessouky and Bayer, 2002; Kwak et al., 2004; Yang, 2004). Both maintenance strategies have their own advantages and disadvantages.

3.2) Scheduled Maintenance

Scheduled maintenance is defined as the preventive maintenance carried out in accordance with predetermined interval of time, number of operations, mileage and others to ensure that such components are performing in good condition (Seeley, 1987; Horner et al., 1997; Nilsson, 2007; Flores-Colen and de Brito, 2010). The maintenance strategy is a planned maintenance approach. Whereby, the implementation of maintenance activities is based on the planned program or schedule that has been determined by the maintenance personnel in the planning stage. Hence, the building systems or services are able to perform their functions as required by the owners and occupants.

Arditi and Nawakorawit (1999a) pointed out that scheduled maintenance is aimed to prevent premature failure or defect of the systems and their components. Normally, scheduled maintenance is the tasks of checking and replacement in predetermined period of time to overcome the problem of wear and tear (Bevilacqua and Braglia, 2000). Eventually, Hameed et al. (2010) supported that maintenance activities performed at fixed time interval are means to reduce the probability of failures and breakdowns. The researchers further explained that the expected downtime is low and spare logistics is easy by implementing scheduled maintenance.

However, some researchers argued that scheduled maintenance is not cost effective. Eti et al. (2006) stated that the preventive maintenance, such as replacement of components is often performed regardless of the condition. In some circumstances, the components are over maintained, implicating the waste of resources. On the other hand, Wu et al. (2006) argued that scheduled maintenance is only able to overcome predictable failures, but not to avoid occurrences of unpredictable failure. Hence, Irigaray et al. (2009) described that the scheduled maintenance implies unnecessary maintenance costs and system failures, as well as maintenance actions like disassembly that have negative effects on the performance and lifetime of components.

Since scheduled maintenance has its advantages and disadvantages, study on the cost characteristics of the maintenance strategy is required. Literature discussed above indicated that the maintenance performance of scheduled maintenance relies on the criteria stated below:

(a) Skilled labour – the maintenance personnel who are able to perform the check and replacement works.
(b) Spare parts and materials – the availability of spare part or material in terms of supply and cost.
(c) Predetermined interval for maintenance – the period of time, number of operation or mileage that is fixed between each maintenance or replacement task.
(d) Cost allocation for failure or downtime – the cost incurred due to unexpected failure (includes the system breakdown that requires additional repair and downtime for rectifying work) or regular maintenance downtime.

3.2.1) Skilled Labour

Since scheduled maintenance is carried out in a fixed time interval, it does require permanent maintenance personnel or technicians to perform the tasks. Lai et al. (2008) pointed out that one of the cost items that need to be considered in maintenance budgeting is labour cost. Meanwhile, Pandey et al. (2010) formulated the expected cost of preventive maintenance by considering labour cost in their research.

Typically, some of the scheduled maintenance works are determined by experienced and skilled technicians, who observe the wear and tear of the parts or components. Thus, the technicians should not only limit their capability to replacing and overhauling system components, but they must be capable to identify the need of scheduled maintenance. For example, technicians may decide to make adjustment on maintenance interval when they perform system inspection at each time of the maintenance interval (Mann et al., 1995).

According to Kangwa and Olubodun (2003), one of the main barriers to effective maintenance management is lack of skill and knowledge. They further explained that inability to determine quality of work done by the maintenance personnel themselves may lead to the occurrence of bad impact, such as incompetency in detecting unwanted error and mistake made by them.

Commonly, the organisation allocates different amount of salary for the maintenance personnel based on their category of competency. Groote (1995) pointed out that the competency of the maintenance labour force is an important factor that affects the maintenance outcome. In Malaysia, the maintenance personnel is divided into several categories of competency, which are A0, A1, A4, A4-1, A4-2, B0-1, B0-2, B0, B1 and B4 (Energy Commission Malaysia, 2011). The category of competency for maintenance staff identifies the skill availability and expertise of the maintenance personnel.

Horner et al. (1997) claimed that labour is highly demanded for scheduled maintenance activities. Unlike condition-based maintenance that can bring down the cost of labour, scheduled maintenance requires large amount of budget allocation in terms of labour aspect (Carnero, 2006). Ali et al. (2010) suggested employing minimum but optimum labour with acceptable qualification standard as one of the measures to minimise maintenance cost. Based on the statement, it is found that the number of skilled labour must be sufficient to maintain the reliability and quality of building and systems.

Idrus et al. (2009) explained that maintenance management is a process that allocates and coordinates the resources, including the labour to enhance the maintenance performance such as reliability, safety, function, comfort, and convenience. Thus, skilled labour is one of the main characteristics to be considered for implementation of scheduled maintenance.

3.2.2) Spare Parts and Materials

Hassanain et al. (2011) defined spare parts as all parts, equipments and expandable assets to operate a system for certain period of time. Every part or component in a system has its own lifetime, it needs to be replaced when it has reached the end of its lifetime. For example, preventive maintenance requires several categories of spare parts including exchange parts, lubricants, other materials for maintenance such as rags, cleaning solvents and others (Swanson, 2001; Salonen and Deleryd, 2011). Thus, it is important to have the spare part for replacement to ensure a system is operating consistently.

In order to improve the maintenance performance, one of the important criteria is proper management of spare parts and materials. Basically, management of spare parts and materials includes the study of spare part needs, efficiency of spare parts reordering, level of stocks of spare parts, and storage of spare parts (Groote, 1995). Tsang (1995) stated that accurate spare parts identification and stocking helps to control and reduce the operation and maintenance costs. Meanwhile, Yik and Lai (2005) pointed out that the cost for spare parts and materials required in scheduled maintenance is one of the major costs in building services maintenance.

According to Horner et al. (1997), spare parts and materials are much required for scheduled maintenance compared to other maintenance strategies. Some parts of building systems or services need to be replaced with new ones in fixed interval as determined in the maintenance program schedule, whether in cases where the items are damaged or not. Thus, the availability of spare parts is highly concerned in scheduled maintenance as it can affect the maintenance performance (Parida and Kumar, 2006). Eti et al. (2006) indicated that a good maintenance manager should be able to allocate adequate spare parts and materials for maintenance programs at minimum cost without jeopardising the quality of systems.

Ali et al. (2010) found that the quality of spare parts and materials always has an impact towards maintenance performance. Obviously, selection of good quality spare parts and materials can reduce the maintenance budget and downtime loss (De Silva and Ranasinghe, 2010). On the other hand, poor quality spare parts and materials have shorter service lifespan compared to the good ones, leading to more defects in a system (Zuashkiani et al., 2011). In some circumstances, poor quality items might be damaged before the predetermined replacement schedule and this would affect the whole system operation. As a result, repair works need to be carried out and additional maintenance cost is incurred. Therefore, the selection of spare parts and materials should not only concern cost saving, the quality of spare parts and materials is another essential aspect to be taken into consideration.

3.2.3) Predetermined Interval for Maintenance

In order to reduce the risk of failure, scheduled maintenance works are performed at fixed intervals regardless of other information (Tsang, 1995; Jardine et al., 2006). Nevertheless, Mann et al. (1995) observed that the scheduled maintenance is based on the use of statistical and reliability analysis of system and component failure. Specified interval where the component will be worn out is estimated (Swanson, 2001). Then, the fixed maintenance interval to replace or overhaul parts or components is established and optimised to achieve minimal maintenance expenditure.

The interval of maintenance activities is vital, whereby inappropriate predetermined maintenance interval affects the maintenance outcome. Tsang (1995) and Swanson (2001) pointed out that scheduled maintenance requires an intrusion of the system. It can only be back into operation when the maintenance task is completed. In some cases, often intrusion of the components may affect the effectiveness of the system. Moreover, Narayan (2003) had proven that unavailable or delayed action to perform maintenance task at the right time may cause further damages to the system components. It is necessary to apply appropriate preventive maintenance treatments at the right time to extend service life of the components (Chen et al., 2003). However, Yang (2004) argued that the scheduled maintenance programs might not be able to avoid the risk of failure from occurring in system components before the fixed replacement time. This problem occurs due to unknown condition of the system components.

Direct maintenance cost will increase with a tight scheduled maintenance or short interval; while downtime and remedial cost due to system breakdown may be expensive with a loose scheduled maintenance or long interval (Chareonsuk et al., 1997; Khalil et al., 2009). According to Bahrami et al. (1999), if scheduled maintenance activity is performed rarely, downtime due to sudden breakdown will increase. On the other hand, if scheduled maintenance work is performed too frequently, downtime due to maintenance interruptions will increase. Moghaddam and Usher (2010) further explained that frequent maintenance or replacement enhances the reliability of a system, but it is costly at the same time. Thus, Pandey et al. (2010) indicated that it is advisable to obtain an optimal maintenance interval that minimizes the cost of maintenance tasks.

A balance between direct maintenance cost and downtime maintenance cost is necessary to be obtained, as it influences the expenditure on building maintenance. Meanwhile, a compromise between the downtime due to maintenance interruptions and sudden breakdown is required (Bahrami et al., 1999). In order to achieve the balance and resolve the problem of under-maintaining or over maintaining of systems, an adequate maintenance interval must be identified and performed (Eti et al., 2006). For example, Pascual et al. (2008) demonstrated the maintenance interval as one of the variables in decision making model to enhance maintenance performance and maximise profit of core business.

3.2.4) Failure and Maintenance Downtime

Downtime is one of the causes that affect maintenance performance. However, building systems are subjected to downtime because of maintenance activities, components failure, inspection, and material shortages (Batun and Azizoglu, 2009). Groote (1995) noted that there are two types of downtimes including planned downtime and unplanned downtime. Planned downtime occurs when the regular scheduled maintenance task is performed; while unplanned downtime occurs when there is sudden breakdown or failure. Basically, downtime involves the time required for detection, repair or replacement and restarting the system (Bevilacqua and Braglia, 2000), which implies unavailability of services and facilities. The occurrence of downtimes is likely to affect the activities of core business such as lost of production.

Commonly, the maintenance downtime occurs due to the maintenance activities, which is divided into minor and major activities. Minor maintenance activities usually need shorter durations and involve some routine operations such as cleaning, lubrication, oil changes, re-alignment, and minor adjustments; while major maintenance activities take longer durations and involve system restoration like tool changeovers, replacement of components, major overhauls and inspection (Batun and Azizoglu, 2009). Major maintenance is compulsory after the system has operated for a long time frame. In order to minimise the maintenance downtime, a few minor maintenances are regularly performed between two consecutive major maintenances.

Since Yang (2004) had mentioned that the scheduled maintenance is not able to prevent the risk of failure, budget allocation for cost of failure and downtime should be considered when planning the maintenance approach. In addition, Chandrashekaran and Gopalakrishnan (2008) proposed that the maintenance downtime is one of the potential risk impact parameters for maintenance management in the event of system failure. According to Zuashkiani et al. (2011), breakdown may cause collateral damage in a particular system. For instance, insufficient or polluted engine oil of a standby generator set may damage the engine. Relatively, additional cost will be incurred for the failures occurring before the predetermined maintenance time.

Chareonsuk et al. (1997) noted that most of the maintenance managers compute maintenance expenditure only in terms of direct maintenance cost. They often neglect the downtime cost that might be very costly, especially in the production industry. Inevitably, implementation of maintenance and repair works requires certain downtime with possible lost production cost (Marquez and Gupta, 2006). Thus, the downtime for maintenance must be well managed to avoid unnecessary cost. For instance, data centres and telecommunications switching rooms, which provide mission-critical support to the daily operations of all kinds of organisation. Due to the downtime, the organisations' operations can be jeopardised critically (Wu et al., 2010).

Pandey et al. (2010) argued that the amount of downtime is required to estimate the expected cost of scheduled maintenance. In fact, the significances of estimating and allocating downtime cost in maintenance decision-making were also determined which include (Pascual et al., 2008):

(a) It allows maintenance personnel to measure the impact of component on system efficiency.
(b) It may be used to assess the effectiveness of maintenance policies (key performance indicator) and ensure the budget allocation is sufficient.

(c) It allows the use of a series of mathematical models and formulas applied in decision-making contest, such as replacement policies, maintenance strategies and spares stock levels.

Parida and Kumar (2006) found that maintenance and failure downtime always have an impact on the system quality, as well as health, safety and the environment. Hence, the cost allocation for failure and maintenance downtime must be taken into consideration for the planning and execution of scheduled maintenance activities. For example, Pascual et al. (2008) demonstrated that the downtime cost is one of the variables in decision making model to enhance maintenance performance and maximise profit of core business.

3.3) Condition-Based Maintenance

Condition-based maintenance is defined as the maintenance initiated as a result of knowledge of the condition or significant deterioration of an item or component through continuous monitoring and routine inspection to minimise the total cost of repairs (Kelly and Harris, 1978; Seeley, 1987; Horner et al., 1997; Ellis, 2008; Flores-Colen and de Brito, 2010). The maintenance strategy is carried out upon the knowledge of condition for an item or system. Thus, continuous monitoring and inspection are necessary to identify the condition and performance of building systems to fulfil the owners and occupational needs. However, the condition monitoring may be on request depending on the priority of component (Fouladgar et al., 2012).

According to Knapp and Wang (1992) quoted from Ellis (2008), condition-based maintenance is aimed to minimise the total maintenance cost by collecting and gathering the condition data of the building systems, especially those critical components. Mann et al. (1995) and Tsang (1995) stated that condition-based maintenance involves continuous condition monitoring of system and components in order to detect the deterioration of the components and predict their lifetimecomponents. Then, maintenance work is only performed when needed in order to minimise system downtime. Jardine et al. (2006) supported that condition-based maintenance attempts to reduce or even avoid unnecessary maintenance expenditures by performing maintenance tasks only when there is evidence of abnormal behaviours of a component or system. Hence, the components will be used up to almost their full lifetimes (Hameed et al., 2010).

However, the maintenance strategy might not be applicable to all building systems or assets in terms of availability of such maintenance technology and cost effectiveness (Horner et al., 1997). The condition-based maintenance system is too specific in some cases and it is not suitable to be applied in most of the components. For instance, knowledgeable maintenance personnel are required to perform the maintenance tasks by adopting condition monitoring techniques (Ellis, 2008). Furthermore, high effort for condition monitoring tools, hardware and software are required for different techniques (Hammed et al., 2010). As a result, it is expensive to implement condition-based maintenance at the inception stage.

Since condition-based maintenance has its advantages and disadvantages, study on the cost characteristics of the maintenance strategy is required. The characteristics and constituents of condition-based maintenance towards maintenance performance are stated below:

(a) Skilled manager – the building manager who is able to plan, manage, organise, supervise, and monitor the implementation of the maintenance strategy.

(b) Monitoring equipment and technique – the tools that are used to monitor and inspect the building systems, which is then formulated by technical software to indicate the condition of the building systems.

(c) Acquisition of data and information – the application and software that are used to gather and record the condition data and information of the building system components.

(d) Frequency of monitoring and inspection – the frequency or interval of inspection carried out towards the building systems.

3.3.1) Skilled Manager

Condition-based maintenance requires vigorous analysis on the data and information of systems condition and reliability, as well as financial maintenance data. This requires an adequate allocation of manpower and training on correct methods for the use of monitoring tools, data acquisition and processing, as well as data interpretation (Mann et al., 1995). Meanwhile, building managers must have proper understanding on the failure modes and rates, asset criticality, and other significant factors while implementing condition-based maintenance (Ellis, 2008). Thus, a skilled manager is required to ensure the success of the maintenance strategy.

Ugechi et al. (2009) argued that condition monitoring is not reliable because the judgment and decisions are often made by the maintenance personnel who relied on their senses of hearing and sight. In order to perform condition-based maintenance effectively, there must be qualified maintenance personnel with related experience, skills and knowledge. High level of training is required for the supervisors and technicians to carry out the maintenance works including condition monitoring, routine inspection, as well as repair and replacement (Swanson, 2001; Carnero, 2006). Skilled manager should be able to provide or conduct training session for the maintenance personnel to improve their skill and knowledge.

Nevertheless, in-house maintenance personnel might not be able to perform the tasks in some circumstances. Therefore, building managers need to carry out a comparative study to determine whether the in-house skilled maintenance personnel or the outsourced maintenance staffs are more reliable and cost-effective. Thus, Kangwa and Olubodun (2003) stated that building manager should be able to judge accurately the extent of skill and knowledge required for a particular maintenance task. Then, the building manager must supervise quality of work carried out by the maintenance personnel or service providers.

Carnero (2006) pointed out the aspects that influence the decision-making in relation to outsourcing are lack of historical information regarding system and components, lack of computerised maintenance management system, lack of computer skills in relation to maintenance personnel and no qualified manager for the condition-based maintenance approach. Pascual et al. (2008) stated that knowledge and skill of maintenance personnel or technician are prominent factors that influence the maintenance performance. The statement proves that the quality of maintenance personnel does affect the maintenance performance.

Ellis (2008) demonstrated that the introduction of condition-based maintenance without a skilled manager is unlikely to achieve the result. For example, a skilled manager should be capable in obtaining appropriate data and analysis, as well as providing training to produce disciplined and knowledgeable maintenance staff. Therefore, the support from skilled manager is highly required to plan, manage, organise, supervise, and monitor the implementation of condition-based maintenance in different aspects.

3.3.2) Monitoring Equipment and Technique

Mann et al. (1995) described that condition monitoring technology has matured at an explosive rate in recent years. The technology assists the maintenance personnel in determining the condition of building systems and allows them to predict mechanical breakdown (Davies, 1995; Edward et al., 1998). Wood (2005) supported that other than being used to monitor the performance of building and systems, the technology is able to initiate and record maintenance operations and to evaluate their effectiveness. One of the reasons that condition-based maintenance becomes well recognised is the rapid advancing of monitoring technology.

Building inspection or condition monitoring is categorised into two methods, which are intrusive test and non-destructive test. Intrusive test is carried out with sample of materials that are obtained from the buildings or building systems. However, the test may affect the performance of building systems by disturbing the components, structures, or materials of buildings. Thus, non-destructive test is recommended in building inspection nowadays. Non-destructive test is performed to evaluate the properties of materials and performance of systems without causing damage. There is a wide range of techniques used and applied in non-destructive test. By implementing condition-based maintenance, the system and components can be monitored via non-destructive testing (Mann et al., 1995). This can significantly eliminate the system downtime.

Tsang (1995) indicated that there are several factors to be concerned in selecting the parameters to be monitored. The factors are type of services and facilities to be covered, availability of reliable monitoring and inspection technology, budget allocation in instrumentation and training, manpower requirement and operating costs. According to Edward et al. (1998), there is a wide range of techniques to examine the condition of specific items or assets. Infrared thermography, vibration monitoring, tribology are some examples of technologies and techniques adopted in condition-based maintenance.

However, some specific measuring and monitoring equipments such as scanning equipment, are required by expertise to perform such technologies and techniques. This might be complicated and costly for an organisation (Carnero, 2006). Due to the increase in the technical complexity of building systems and the level of sophistication of monitoring tools, Veldman et al. (2011) argued that the need for training to use and operate the monitoring tools also increases. Moreover, Hassanain et al. (2011) demonstrated that an organisation should gain new skills and technical knowledge in maintenance management, so that the maintenance personnel will be able to develop themselves for adaptation of advanced and new monitoring techniques.

Therefore, the availability of monitoring equipments and capability of the maintenance personnel to use the equipments should be taken into consideration for condition-based maintenance. Meanwhile, the selection of appropriate monitoring techniques should be determined.

a) Infrared Thermography

Infrared thermography is one of the non-destructive testing introduced to most of the industries, including building and construction industry. Tsang (1995) and Li et al.

(2000) defined infrared thermography as a method to measure the emissions of infrared energy or radiation from objects and display them in the form of visual heat image, which is also as a means to determine the operating condition of plant machinery and system.

Liithi (1998) stated that the use of infrared thermography in building and construction industry is well known. The professionals do use the infrared cameras to determine the heat loss behaviour of buildings and building systems. In maintenance context, infrared thermography is adopted to measure the deviation of temperature conditions in building and system components (Edward et al., 1998). For example, infrared image indicates the problem of a component when such component is hotter or colder than its normal operating temperature. As quoted from Budaiwi (2007), Colantonio (2001) also suggested that infrared thermography should be adopted in office buildings to detect and rectify thermal-comfort issues. Practically, the use of infrared cameras allows surveyor or technician to focus the scope of an investigation on potential problem areas because they can quickly examine large areas (Li et al., 2000).

During a building inspection, application of infrared thermography is able to locate problems or defects that are undetectable by human naked eyes. Maintenance of building and its systems becomes more effective by identifying abnormal conditions before they evolved into serious damages or failures (Balaras and Argiriou, 2002). Lo and Choi (2004) demonstrated that the application of infrared thermography is a reliable and accurate monitoring method for the inspection of buildings and systems. According to Eti et al. (2006), infrared thermography is one of the condition monitoring techniques that is involved in condition-based maintenance. Meanwhile, Parida and Kumar (2006) encouraged maintenance personnel to adopt condition-based inspection technology including infrared thermography instead of scheduled maintenance.

Thus, the application of infrared thermography should be introduced in building maintenance. It is likely to enhance maintenance performance by reducing systems downtime and minimising repair and replacement costs (Balaras and Argiriou, 2002). Consequently, this technique is adopted in the case study of this research.

i) Equipment of Infrared Thermography

There are a number of equipments required for application of infrared thermography, such as infrared camera and other necessary accessories. Commonly, those equipments are mobile and allow operations on site (Liithi, 1998). The advantages of infrared thermography such as the reliability, accuracy and mobility have been well recognised in different sectors, though there are some limitations of using infrared thermography as shown in Table 3.1. For instance, the conditions of overhead electrical power lines and components, naval aircraft, tyres of race cars, power plants, shipbuilding, large refrigerant compressor units, radioactive plants, and buildings are monitored by application of infrared thermography (Lo and Choi, 2004).

Table 3.1: Advantages and limitations of using infrared thermography

Advantages	**Limitations**
• Mobile and fast operation • Non-contacting and non-destructive • Safe, harmless radiation to operator • Easy to interpret thermographs • Deployment on one side of an object only	• Applicable to limited surface thickness (boundary technique) • Affected by thermal losses due to convection, radiation etc. • Affected by weather and air pollution • Interference from extraneous heat sources

Source: Lo and Choi (2004)

According to Lo and Choi (2004), the infrared scanner or camera detects the emission of heat and energy and illustrates the temperature contours across the surface of an object to indicate its thermal conditions. Basically, the infrared radiation is an electromagnetic wave with the wavelength ranging from 0.78 to 1,000 μm. However, most of the infrared cameras are divided into short-wave and long-wave devices. The ranges of short-wave and long-wave devices are from 2 to 5 μm and 8 to 14 μm band respectively (Minkina and Dudzik, 2009). They further stated that lately manufacturers offer imaging infrared cameras with cheaper price, which show only colour map of the object's thermal conditions. In order to carry out infrared thermography, the most appropriate infrared camera with different working spectral band should be selected depending on several factors, which are related to object surface nature and atmospheric absorption (Carlomagno and Cordone, 2010).

Lo and Choi (2004) demonstrated that both long-wave and short-wave infrared cameras are used in building inspections, depending on several factors such as target temperatures, reflection effects and others. Nevertheless, Carlomagno and Cordone (2010) argued that short-wave infrared cameras are more preferred because of their lower cost detectors and optics, higher detectivity for quantum detectors and due to the fact that some surfaces have higher emissivity coefficient in that particular infrared band. Meanwhile, the short-wave infrared cameras are more sensitive towards temperatures higher than 10 ℃, rather than the long-wave infrared cameras. Therefore, thorough study should be done on the characteristics and properties of components to be inspected, as well as the types of infrared camera to be used before an inspection is carried out.

Nowadays, continuous condition monitoring is adopted in maintenance program. The condition monitoring system is integrated in maintenance management to implement performance monitoring, data collection, automatic failure diagnostics and failure prediction (Gao, 2001). The conditions data is tracked and recorded in the system software. Infrared thermography was only applicable independently on visual image result without tracking and recording software package in the past. Nevertheless, infrared cameras and diagnostic software that enable conditions data tracking and recording are introduced in the market lately (Hameed et al., 2009). Therefore, the technique is utilised by continuous condition monitoring system to enhance building maintenance performance (Qingfeng et al., 2011).

ii) Basic Principles of Radiation Heat Transfer

Balaras and Argiriou (2002) stated that each body or object emits thermal radiation at temperatures higher than 0 K (-273.15 ℃), the absolute zero temperature. The intensity of the radiation depends on wavelength, λ and the body's temperature (Balaras and Argiriou, 2002; Minkina and Dudzik, 2009). Thermal radiation is an energy transport mechanism, which is occurring in nature in the form of electromagnetic waves (Minkina and Dudzik, 2009; Carlomagno and Cardone, 2010).

By using Wien's displacement law, the wavelength at which the body or object emits its maximum spectral emissive power is a function of its surface absolute temperature, formulated as (Minkina and Dudzik, 2009; Carlomagno and Cardone, 2010):

$$\boldsymbol{\lambda_{max} T = 2898}\ \mu\text{m K}$$

Therefore,

$$\mathbf{T = 2898}\ \mu\text{m K} / \boldsymbol{\lambda_{max}}$$

where, **T** is the surface absolute temperature, K

λ_{max} is the maximum wavelength of a body or object, μm

According to Balaras and Argiriou (2002), all bodies or objects radiate energy that travels at the speed of light. The total emissive power from an object over a surface of 1 m^2 is proportional to the fourth power of its temperature, formulated as (Balaras and Argiriou, 2002; Minkina and Dudzik, 2009; Carlomagno and Cardone, 2010):

$$\mathbf{E^b = \sigma \cdot T^4}$$

where, $\mathbf{E^b}$ is the hemispherical total emissive power (radiated energy per unit area), W m^{-2}

σ is the Stefan-Boltzmann constant, 5.6704×10^{-8} W m^{-2} K^4

T is the surface absolute temperature, K

However, the above laws and formulae refer to black bodies that can only be considered as an idealised model of a real body (Minkina and Dudzik, 2009). The researchers further explained that the concept of emissivity needs to be considered in measurements of infrared thermography, because the objects are not perfect absorbers of incident radiation in reality, which are called gray bodies. Thus, the statements support the definition of emissivity, which was given by Balaras and Argiriou (2002) and Al-Kassir et al. (2005) as:

$$\mathbf{E^b = \varepsilon \cdot \sigma \cdot T^4}$$

where, $\mathbf{E^b}$ is the hemispherical total emissive power (radiated energy per unit area), W m^{-2}

ε is the emissivity of the gray body

σ is the Stefan-Boltzmann constant, 5.6704×10^{-8} W m^{-2} K^4

T is the surface absolute temperature, K

Therefore, it is important to understand the basic concept of radiation heat transfer so that the infrared thermography can be fully utilised by surveyor or technician in building maintenance and inspection.

b) Vibration Analysis

Typically, vibration analysis is adopted to monitor mechanical rotating equipment (Mann et al., 1995; Tsang, 1995; Edward et al., 1998). They further stated that the vibration characteristics of a system will change when the components start to deteriorate. According to Tsang (1995) and Eti et al. (2006), maintenance personnel is able to use vibration monitoring technique to detect fatigue, wear, imbalance, misalignment, loosened assemblies, turbulence and other defects. When a system operates normally, the amplitude of vibration will remain constant. If the amplitude of vibration is not constant, there might be a problem occurring in the system. Tsang et al. (2006) pointed out that the vibration level interprets the system conditions and allows the maintenance personnel to schedule the maintenance actions accordingly.

However, Edward et al. (1998) argued that vibration monitoring is a compromise because in an ideal situation it is the forces themselves that cause the vibrations, which require measurement. In fact, a high vibration level does not indicate an occurrence of defect on a system. The high vibration level is probably due to high level of mobility within the system. Wang and Christer (2000) supported that high frequency of vibration may indicate a pending malfunction of a component, but it is not clearly describing the specific condition of a system. In addition, Tsang et al. (2006) found that the raw signals of vibration contain a lot of background noise, which affects the accuracy of information by simply measuring the overall signal.

Therefore, continuous monitoring is required to ensure that the system's vibration level is constant. Once, the system's vibration varies from the constant level, further inspection is needed to identify whether any defect has occurred. Meanwhile, it is necessary to develop an appropriate filter to eliminate the operationally and environmentally contaminated components of signals such as the background noise, to ensure the obtained data is precise and clear in indicating the conditions of system (Tsang et al., 2006). Ugechi et al. (2009) noted that the vibration analysis should be performed systematically and intelligently, so that the maintenance personnel will not only be able to determine the condition of the system but also permit the prediction of mechanical fault.

c) Tribology

Tribology covers three techniques in condition-based maintenance, which are oil analysis, wear particle analysis and ferrography (Tsang, 1995). Edward et al. (1998) stated that tribology analysis is a range of techniques that scrutinise oil condition. It is the field of study that encompasses surface sliding, rolling or otherwise interacting with each other among the components. The problem of friction occurs when there are contacts among the components' surface. In order to inhibit the effect of wear and heat generation caused by friction within mechanical system, lubricants are used.

In oil analysis, particles in lubricating oils or greases are collected at regular intervals and analysed by using some form of spectrographic analysis to determine the lubricating condition of a system (Mann et al., 1995; Tsang, 1995). In order to retain the optimum system operation, the lubricant oil will be replaced when it reaches an unacceptable state. Furthermore, the analysis results may also help in decision-making of changing the type of lubricant oil or grease for performance improvement or variety reduction purposes (Tsang, 1995). Hameed et al. (2009) pointed out that the purpose of oil analysis is to safeguard the oil quality and the system components involved.

Tsang (1995) explained that wear particle analysis provides direct information about wearing condition of the machine. Generally, maintenance personnel identify the condition of system by analysing particle size, size distribution, concentration of particles, trace elements in suspension, and the shape of particles (Mann et al., 1995). There are two types of wear particle analysis, which are analysis on solid content of the machine lubricant to detect its changes with time and particulate matter in each lubricating oil sample to determine type of wear. This technique is limited to the study of particulate matters with a size not exceeding 10 μm (Tsang, 1995).

According to Tsang (1995), ferrography is the technique to analyse larger particles separated from an oil sample. In order to collect the particles from oil sample, the oil is allowed to flow down an inclined slide, passing through a magnetic gradient field so that the particles are separated. In some circumstances, non-magnetic particles are separated as well by using calibrated membrane filters. The wear condition can be monitored by adopting this technique to detect trends indicating abnormal wear. In fact, this technique is particularly useful for measuring lubricant quality in one of the most fundamental component in all mechanical systems, which is the gear (Davies, 1995; Edward et al., 1998).

Unfortunately, there are several limitations to adopt tribology analysis in condition-based maintenance, which are (Tsang, 1995):

(a) High equipment costs

(b) Being a laboratory-based procedure

(c) Reliance on acquisition of accurate oil samples

(d) Skills needed for proper interpretation of data

Therefore, the decision making on the monitoring technique must be planned and studied in advance to ensure the monitoring task is performed effectively.

3.3.3) Acquisition of Data and Information

Jardine et al. (2006) defined data acquisition as a process of collecting and storing useful information from selected building systems for the purpose of condition-based maintenance. There are four categories of maintenance data needed for the maintenance strategy including failure or replacement data, inspection data, maintenance action data, and installation data (Tsang et al., 2006). Bevilacqua and Braglia (2000) argued that the data and information acquisition systems are the necessary applications to perform condition-based maintenance. One of the reasons that condition-based maintenance will not be able to succeed or even be executed is lack of data due to incorrect data collecting approach, or even no data collection and storage at all (Jardine et al., 2006; Irigaray, 2009).

The documentation and record of information are essential to ensure the reliability of information about the conditions and remaining lifetime of system components. Tsang et al. (2006) stated that the data and information are kept in databases of condition monitoring maintenance program, which is a typically computerised system or software. Carnero (2006) supported that once the data and information have been gathered, they must be transferred to the computer system or a workstation to be processed and analysed. In order to obtain and maintain the reliable information, effective software is required and this incurs additional cost (Hameed et al., 2010).

Analysis of collected data and information regarding the conditions of building and systems is vital to allow the maintenance personnel in setting up maintenance tasks. Nowadays, the inspection and monitoring equipment packages often come together with associated software programs that enable data recording, storing, processing and analysing (Carnero, 2006). Thus, the maintenance personnel are able to identify the needs of maintenance tasks based on the analysed data, which is presented by the software programs. Then, the maintenance personnel will only perform the maintenance tasks when there is a need. Qingfeng et al. (2011) explained that the analysis results such as failure analysis, maintenance task optimisation and risk analysis are highly dependent on the reliability of condition and maintenance data.

In order to minimise the resources for acquiring data including time and cost, the acquisition of data is organised by means of routes (Carnero, 2006). Ali (2009) further explained that the conditions of buildings and systems must be considered to allocate adequate maintenance cost. Thus, the maintenance personnel are necessary to acquire accurate data and information regarding the conditions of building system components with minimum resources to enhance the maintenance performance.

3.3.4) Monitoring and Inspection

Condition-based maintenance can only be implemented with proper system monitoring and inspection. The statement is proven by Sherwin (2000), stating that the downtime of a system can be reduced by increasing maintenance personnel care in condition monitoring. Hameed et al. (2010) supported that planning of appropriate maintenance activities prior to failure and maintenance cost is greatly influenced by the ability to monitor and inspect the condition of systems.

Tsang (1995) found that the frequency of inspection must be determined, either by monitoring the components continuously or performing inspections with fixed interval, so that action can be taken in time to prevent the failures or breakdowns that have occurred. The maintenance personnel need to identify an optimal frequency or interval of inspection to avoid over-inspection or under-inspection. Then, the resources will not be wasted and the changes of system condition will not be neglected and jeopardised too. Lo and Choi (2004) and Jardine et al. (2006) demonstrated that for optimum monitoring of building, inspections should preferably be executed at regular intervals in order to select the most cost-effective method for maintenance action and to minimise the risk and hazards to the building users.

Although condition monitoring and inspection are carried out in regular interval basis, it may not enhance the profitability of the maintenance strategy, especially when the inspection task is costly (Grall et al., 2002). Condition monitoring or inspection may be scheduled, on request or in a continuous basis, depending on the criticality of the systems or components. Kwak et al. (2004) had proven that the monitoring and inspection frequency affects the profit of condition-based maintenance. In other words, the risk of failure can be reduced or even avoided by presenting optimal monitoring and inspection frequency. In addition, Jardine et al. (2006) argued that periodic inspection is more cost-effective and provides more accurate diagnosis using filtered and processed data.

Thus, it is necessary to identify the optimal frequency of monitoring and inspection, so that condition-based maintenance can improve the performance in terms of cost-effectiveness. Meanwhile, the risk of failure can be avoided and the system downtime is minimised. Eventually, the organisation gains profits because of the effective maintenance expenditure and minimum system downtime in maintenance management.

3.4) Selection of Independent Variables

After a thorough study on characteristics of preventive maintenance through literature review, the independent variables are derived and selected from the four main characteristics of scheduled maintenance and four of condition-based maintenance. Ten and nine variables are derived from the characteristics of scheduled and condition-based maintenance respectively as tabulated in Table 3.2.

Table 3.2: Matrix of independent variables and references

Characteristic of Preventive Maintenance	**Reference**
<u>Scheduled Maintenance</u>	
Skilled Labour-Budget Allocation	Carnero (2006); Lai et al. (2008); Idrus et al. (2009); Pandey et al. (2010)
Skilled Labour-Skill and Knowledge	Groote (1995); Mann et al. (1995); Kangwa and Olubodun (2003); Energy Commission Malaysia (2011)
Skilled Labour-Number of Labours	Horner et al. (1997); Carnero (2006); Idrus et al. (2009); Ali et al. (2010)
Spare Parts and materials-Budget Allocation	Yik and Lai (2005); Swanson (2001); Eti et al. (2006); Hassanain et al. (2011); Salonen and Deleryd (2011)
Spare Parts and materials-Level of Stock	Groote (1995); Tsang (1995); Horner et al. (1997); Eti et al. (2006); Parida and Kumar (2006)
Spare Parts and materials-Quality	Ali et al. (2010); De Silva and Ranasinghe (2010); Zuashkiani et al. (2011)
Predetermined Maintenance Interval-Budget Allocation	Chareonsuk et al. (1997); Khalil et al. (2009); Moghaddam and Usher (2010); Pandey et al. (2010)

Predetermined Maintenance Interval-Length of Interval	Mann et al. (1995); Tsang (1995); Bahrami et al. (1999); Swanson (2001); Chen et al. (2003); Narayan (2003); Eti et al. (2006); Jardine et al. (2006); Moghaddam and Usher (2010); Pandey et al. (2010)
Failure and Maintenance Downtime-Budget Allocation	Yang (2004); Chareonsuk et al. (1997); Marquez and Gupta (2006); Parida and Kumar (2006); Pascual et al. (2008); Wu et al. (2010); Zuashkiani et al. (2011)
Failure and Maintenance Downtime-Amount of Downtime	Groote (1995); Bevilacqua and Braglia, 2000); Chandrashekaran and Gopalakrishnan (2008); Batun and Azizoglu (2009); Pandey et al. (2010)
Condition Based Maintenance	
Skilled Manager-Budget Allocation	Ellis (2008)
Skilled Manager-Skill and Knowledge	Mann et al. (1995); Swanson (2001); Kangwa and Olubodun (2003); Carnero (2006); Ellis (2008); Pascual et al. (2008); Ugechi et al. (2009)
Equipment and Technique-Budget Allocation	Tsang (1995); Carnero (2006); Hassanain et al. (2011)
Equipment and Technique-Availability	Davies (1995); Mann et al. (1995); Tsang (1995); Edward et al. (1998); Wood (2005)
Equipment and Technique-Capability to Adopt	Tsang (1995); Carnero (2006); Hassanain et al. (2011); Veldman et al. (2011)
Acquisition of Data-Budget Allocation	Bevilacqua and Braglia (2000); Jardine et al. (2006); Irigaray (2009); Hameed et al. (2010)
Acquisition of Data-Reliability	Carnero (2006); Jardine et al. (2006); Tsang et al. (2006) ; Ali (2009); Irigaray (2009); Qingfeng et al. (2011)
Monitoring and Inspection-Budget Allocation	Grall et al. (2002); Kwak et al. (2004); Jardine et al. (2006); Hameed et al. (2010)
Monitoring and Inspection-Frequency	Tsang (1995); Sherwin (2000); Kwak et al. (2004); Lo and Choi (2004); Jardine et al. (2006)

3.5) Chapter Summary

This chapter reviews the literature related to characteristics of scheduled maintenance and condition-based maintenance. The main characteristics of scheduled maintenance are skilled labour, spare parts and materials, predetermined interval for maintenance, as well as failure and maintenance downtime; while condition-based maintenance are skilled manager, monitoring equipment and technique, acquisition of data and information, as well as monitoring and inspection.

In the study, it is found that the characteristics always have some impacts towards the maintenance performance. Therefore, this research determines the characteristics as independent variables. Relationship between the characteristics and maintenance performance has been studied and analysed in this research. In order to enhance the implementation of maintenance strategies and their performance, participative mechanism is found to be the intervening variable. It was investigated and is reported in the following chapter.

CHAPTER 4

PARTICIPATIVE MECHANISMS FOR IMPROVING MAINTENANCE PERFORMANCE

4.1) Introduction

The theory of participation is widely accepted in different fields, as the participation theory is beneficial to be adopted in information systems development, management science, as well as planning and evaluation practices (Gregory, 2000). In fact, Flynn (1992) pointed out four key notes that support the theory of participation in decision-making, design and planning:

(a) Ethics – everyone that is involved in a project or activity has the right to express their own demand.

(b) Expediency – people who are not involved in decision-making may comment or subvert decisions made by others.

(c) Expert knowledge – certain decisions require expert knowledge and to ensure the decisions are made according to the knowledge, the related experts should be involved in the decision-making process.

(d) Motivating force – participation in decision-making process ensures that people are aware of the rationale for the decision and works are implemented efficiently and effectively.

Participative management is extensively discussed in the fields of management based on the theory of participation. Lawler et al. (1992) argued that effective participative management requires sharing of information, communication, rewards, and investment in training. Then, participative management is defined as the management process that confers greater decision-making authority and responsibility to the front-line employees, so that they have some involvement in the control and coordination of the basic activities and functions of a project (Cotton, 1994). According to Kaufman (2001), the term participative management is often used interchangeably with employee involvement.

In the past, building maintenance had been neglected because of the extensive costs required for maintenance programs. However, Groote (1995) argued that proper maintenance is vital in an organisation to achieve the organisation's objective and long-term profitability. Furthermore, Tsang et al. (1999) stated that performance measures should be associated to the organisation's strategy, so that it can provide useful information for making accurate decisions and framing an effective maintenance strategy. In facilities management thus, it is necessary to have understanding between the organisation and management so that the maintenance activities are able to guide the organisation towards meeting its objectives (Lavy and Shohet, 2007).

According to the Chartered Institute of Building (1990) quoted from Fakhrudin et al. (2011), the methods to enhance the efficiency of building management include:

- Documenting maintenance records of buildings, services, facilities, service agreements, expenditures and others.
- Working with standard operation procedures.
- Initiating proper maintenance planning, include the maintenance policy, standard and strategy.
- Training managers, executives and other maintenance personnel more effectively.

- Examining the liabilities of involved parties under the service contract.
- Ensuring good communication and dissemination of information, especially the strategies that help to enhance performance outcome.

In fact, it is vital to provide a participative mechanism in maintenance management to seek additional and different viewpoints, comments, opinions, suggestions and solutions over the maintenance activities (Low and Omar, 1997; Newig et al., 2008). This requires the willingness of client or organisation, maintenance manager and personnel, building users and customers, as well as manufacturers and suppliers to commit and contribute in maintenance management. They all are the key participants in management. Low (1998) supported that the organisation and management would be benefited by accepting valuable and unexpected individual contributions. Furthermore, Arca and Prado (2008) emphasised that improvement of any project always relies on participation and involvement of all related personnel, not only in the planning stage, but also in the implementation and feedback stages.

Repetti and Prelaz-Droux (2003) demonstrated that participation, individual capabilities and coordination of all the key participants have been determined as dominant factors in improving the efficiency of management. In order to achieve success in maintenance management, the participative mechanism should focus on information, knowledge and skill, communication, and training among the key participants. Whereby, Newig et al. (2008) described that the main purpose of participative mechanism is to incorporate different sources of knowledge and to foster learning process. In addition, Arca and Prado (2008) stated that participative mechanism is not only the key of success, but also to ensure continuous improvement in a project.

In order to improve maintenance performance, the involvement of key participants is compulsory. Rahmat and Ali (2010a) noted that the involvement of key participants helps to improve communication flow and feedback systems. Then, it leads to the better teamwork and job satisfaction. Commonly, the reasons that motivate the interest of key participants to involve themselves in maintenance management are (Bon et al., 1998):

(a) To identify internal and external best practice, in this case selecting appropriate maintenance strategy.
(b) To link maintenance and facilities management to other corporate total quality management initiatives.
(c) To enable a meaningful measure of shareholder value.

Literature review indicated that the performance criteria involving the communication and commitment of key participants include (Dainty et al., 2003; Bassioni et al. 2005; Yang et al., 2010):

(a) Team building
(b) Leadership
(c) Decision making
(d) Communication
(e) External relations
(f) Information and analysis
(g) Customers and stakeholder focus
(h) People, partnership, suppliers, physical resources, and flexible capital

Based on the performance criteria that literature review has revealed, the coordination and communication among the key participants are of main concerns. Proper coordination and communication allow the key participants to express and discuss the demands, expectations, issues and problems regarding the existing maintenance program, as well as knowledge sharing (Goh et al., 2005). In addition, Lee and Scott (2009) further explained that the relationship between clients or organisations and maintenance personnel is essential where it would affect the outcome of building maintenance operation processes. For example, it is vital to allow key participants to exert influence on decision making practices, so that the existing experience, skills, knowledge, and competence can be shared among the key participants (Rahmat and Ali, 2010a). Therefore, the measures in improving maintenance performance are identified below:

(a) Managerial support
(b) Clients' commitment
(c) Occupants' commitment
(d) Manufacturers and suppliers' commitment

4.2) Managerial Support

Building or maintenance manager plays an important role in maintenance management. According to Pintelon and Puyvelde (1997), the maintenance manager must be able to handle the entire management complexity in building maintenance, which includes planning, purchasing, personnel, quality control, inventories, technical problems and budgets. Thus, the capability of maintenance manager in managing the maintenance process is of concern, so that the support from him or her would significantly improve the maintenance performance.

In order to achieve the organisation objectives, maintenance planning is required in setting up maintenance policy, allocating sufficient maintenance budget, selecting appropriate maintenance strategy and other processes. Inevitably, the maintenance manager is required to be involved in these processes together with the client or building owner. The decision making in maintenance planning is often based on the manager's opinion, advice and support due to his or her experience and expertise in maintenance industry. In maintenance planning, the maintenance program is not the only responsibility of the maintenance manager alone, but the impact of technological changes, economic factors and investment criteria are taken into consideration as well (Pintelon et al., 1999). These decisions are usually supported by the life cycle cost model.

Based on the decisions obtained from the organisation and maintenance department, a maintenance manager would need to plan and organise some further actions to achieve the maintenance objective and resolve the existing problems. For instance, by organising a meeting that involves clients, building users and maintenance personnel to share the knowledge and discuss the problems occurred. Then, training should be provided when it is necessary. Without understanding the needs of all the parties, implementation of maintenance tasks will be in contrast with the organisation objective (Kamaruzzaman and Zawawi, 2010). Since the availability of services and facilities supports the organisation business critically, it is necessary for the maintenance manager to be aware of the organisational business objective, as he or she manages the maintenance resources such as the maintenance personnel, information, and others (Simoes et al., 2011).

4.2.1) Provision of Knowledge-Sharing and Communication Platform

Arditi and Nawakorawit (1999a) described that the effectiveness of maintenance actions will have major influence to the maintenance performance. It is essential that all parties such as the organisation, building users and maintenance personnel, to have a universal objective in which these actions can be planned, organised, performed, monitored, and controlled. In order to achieve the objective, a communication platform is required to coordinate and review the actions with all parties.

Lee and Scott (2009) revealed that there are always some gaps between the organisation and maintenance personnel, a middle man should exist to deliver the issues and requirements between the two parties. In this circumstance, a building manager is considered as the middle man. In fact, building manager must have a close relationship with the client or organisation, as well as the maintenance personnel. The building manager plays an important role to provide a platform of communication between maintenance personnel and the organisation. For example, building manager should be able to deliver problems faced by maintenance personnel to the clients. On the other hand, the building manager must also understand the requirements of the organisation.

The performance of maintenance is influenced by the level of communication among the key participants in a building. Arditi and Nawakorawit (1999b) demonstrated that the maintenance performance is likely to be improved if the maintenance manager efficiently communicates with all other participants. For instance, the maintenance manager provides communication platform such as meeting, feedback and complaint forms to gather the participants' concerns and take action to eliminate these concerns (Bandy, 2003). Therefore, the provision of communication platform is deemed to enhance the effectiveness of maintenance actions and result in performance improvement.

4.2.2) Provision of Training

Groote (1995) pointed out that training and human resources development is one of the measures recommended for improvement of maintenance performance. It is necessary that the maintenance personnel to be trained on the technical and practical issues related to maintenance. The new techniques and technology are introduced in building maintenance industry incessantly. As the technical complexity of the systems and the level of sophistication of monitoring and maintenance tools increase, the maintenance personnel requires increased levels of maintenance training (Swanson, 2001; De Silva et al., 2004; Veldman et al., 2011). For example, inspection by using infrared thermography should be performed during suitable weather and radiation conditions, and the maintenance staff must have sufficient background training to carry out the inspection accurately (Lo and Choi, 2004).

According to Al-Hammad et al. (1997), insufficient technical updating or staff training leads to incapability of the staff to maintain and monitor performance of new techniques and technology. Meanwhile, Edward et al. (1998) found that one of the root causes of failure in maintenance is inadequate operative training. Elmualim et al. (2010) argued that the lack of professional training provision may be a barrier to the understanding of maintenance management issues and affecting the implementation of sustainable maintenance technology. According to Ali et al. (2010) and Zuashkiani et al. (2011), lack of training always leads to human error and low maintenance capacity. As a result, problems such as longer repair time, lower quality repairs, and less efficient use of resources are likely to occur.

Since there are seminars, short courses, and workshops organised by related authorities to train the industry, the maintenance manager should arrange the maintenance personnel to participate in such courses to update their knowledge of maintenance techniques from time to time (De Silva et al., 2004). Hui and Tsang (2004) had proven that training is desirable for development of multi-skilled maintenance personnel. Thus, a building manager should be able to devise a policy of training and development programs that help to enhance the knowledge and skills of maintenance personnel.

4.3) Clients' Commitment

A building serves its function with provision of spaces, facilities, services and other components. Definitely, all the components deteriorate continuously and maintenance is required to retain such components to perform in good condition. In order to ensure that the maintenance strategy is parallel to the organisation's objective, the organisation or client should clearly indicate their needs and requirements towards core business. According to Amaratunga and Baldry (2002), communication between organisation and maintenance management team helps to set agreed-upon performance goals, allocate and prioritise sufficient resources or budgets, inform the management on policy and direction changes to meet these goals, and report the performance of meeting these goals.

The literature review indicated the significance of communication between clients and maintenance management team towards the improvement of maintenance performance. According to Goh et al. (2005), clients' feedback and opinion is one of the factors to generate effective communication. In addition, clients' attitudes are deemed to be affecting the effectiveness of communication. The commitment of clients in terms of comments and satisfactions are taken into account while formulating maintenance policy, allocating maintenance budget, as well as selecting maintenance strategy (Lateef, 2008). Furthermore, clients' commitment in maintenance management would create better understanding between the parties and help to avoid major disruptions in the maintenance activities (Rahmat and Ali, 2010a).

Clients' decisions are often the final decisions to tackle most of the maintenance issues. The maintenance manager only plays the role to providing information, suggestion and advice to assist the decisions made by clients. Thus, the commitment of clients towards decision making on maintenance related issues would substantially influence the maintenance process and outcome. Chau et al. (2003) observed that most of the maintenance works are selected solely on the basis of the lowest capital cost in the past or even now. However, this practice is likely to implicate quality problems. In fact, the clients should consider all the aspects that affect maintenance performance by using life cycle costing approach, instead of the initial cost alone (De Silva et al., 2004).

As the input from client organisation is a key factor for maintenance success, it is necessary that the clients and organisations to involve themselves in the maintenance management (Marquez and Gupta, 2006). Syed and Kamaruzaman (2008) argued that lack of commitment and participation of the clients and organisations cause poor planning and implementation of maintenance management. Eventually, there are no understandings between the organisations and maintenance personnel. Ali (2009) supported that poor briefing and ineffective communication often occur when the clients are not committed in the maintenance processes. The communication gaps are then implicating the unachievable universal objectives from both parties.

Consequently, the commitment of clients and organisations in maintenance management is deemed to be greatly influencing the effectiveness of maintenance strategy and maintenance performance. For instance, a committed client would ensure that the budget allocation is sufficient for implementation of adequate maintenance actions (Ali, 2009).

4.4) Occupants' Commitment

Building users and occupants are the people who most frequently utilise the building services and facilities in their daily activities. There is a close relationship between the building users and building services or facilities. The way of utilising the services and facilities by the building users would influence the quality of services provided and vice versa. Yik et al. (2010) observed that the perception of building users about the performance of services will provide feedback on the users' expectations. The users' expectation would assist the maintenance personnel in determining the maintenance standards.

On the other hand, the degradation of services components may reflect the level of care of building users towards the services other than the effectiveness of maintenance programs. Douglas (1996) pointed out that actual building performance often relates to the users' abuse or misuse of building systems. For example, one of the major deficiencies and irregularities with respect to fire safety in buildings is the misuse of building and systems by building users, such as the use of hose reel for car wash (Yung et al, 2008). High level of care towards building and systems may reduce the needs of maintenance.

It is important to understand and control the expectation and users' attitude towards the performance of building services and facilities. Building occupants and users play a vital role in evaluating the effectiveness of maintenance management system (Oladapo, 2006). Hence, the commitment of building users and occupants is essential in terms of providing feedbacks on the satisfaction and expectation of maintenance programs, as well as sustaining the level of care towards the building and systems. Furthermore, participation of building users in maintenance management helps to reduce inefficiency of maintenance activities and hence enhance the cost of operations and maintenance (Yip, 2011).

Therefore, the maintenance management is necessary to provide a platform for the building users and customers to speak out their comments and opinions on the maintenance services provided, so that the maintenance personnel are able to improve the maintenance performance continuously (Myeda et al., 2011). Meanwhile, co-operation should be given by the users and customers to take care of the building and systems.

4.4.1) Users' Satisfaction and Feedback towards Maintenance Management

Building users' satisfaction is one of the essential building maintenance management factors, which is usually measured by the users' comfort in the aspect of building service systems and facilities. Arditi and Nawakorawit (1999b) and Chew et al. (2004) demonstrated that users' satisfaction is considered as the most important factor in property management by building managers. In addition, Myeda et al. (2011) highlighted that customers' satisfaction on providing building services and facilities plays an essential role towards the core business of an organisation.

There are many methods that the building users can provide feedbacks and opinions to the maintenance personnel such as by using the feedback and complaint form, post occupancy evaluation, and others. In fact, building users have the responsibility to report defects to maintenance management team for rectification (Oladapo, 2006).

Moreover, Rahmat and Ali (2010b) demonstrated that informal communication including face-to-face meeting, provides additional communication, immediate feedback and hence enables the relevant remedial works to be executed. Myeda et al. (2011) acknowledged the significant role of building users in evaluating the performance of maintenance services with their needs, requirements and feedbacks.

Whereby, building users' comfort and satisfaction directly reflect the quality of service provided by the maintenance management team (Kwon et al, 2011). It is vital to have a systematic feedback system in the continuous improvement of the maintenance management process (De Silva and Ranasinghe, 2010). Meanwhile, the building users should utilise the feedback system to provide comments, suggestions, complains and so on to the maintenance management. Air-conditioning system issues such as the thermal-comfort affect the comfort, morale, as well as productivity of building users; therefore, the related issues must be attended and responded immediately (Budaiwi, 2007). Eventually, the maintenance process could be improved by taking these feedbacks into account.

4.4.2) Level of Care towards Building and Systems

On the other hand, the level of care that building occupants and users give to the building and systems would affect the conditions and need for maintenance of the building and systems (Honstede, 1990; Olubodun and Mole, 1999). Therefore, the attitudes of building users in using the services and facilities are concerned.

Whereby, Olubodun (2001) had proven that the issue of vandalism is one of the factors that significantly affect the maintenance need. Indeed, abuse of buildings, especially through active or passive vandalism by the users is likely to cause unwanted damage and deterioration (Oladapo, 2006). Ali et al. (2010) supported that one of the factors that affect maintenance cost or performance is vandalism by building occupants. Disgracefully, the issue of vandalism occurs because of the selfish attitude from the building occupants. They deem that the services and facilities are not of their own asset. So, they would not care about the conditions and some of them even damage the services and facilities.

As a result, the irresponsible action and lack of commitment from the users to take care of the services directly and indirectly affect the maintenance outcome. For instance, Kuala Lumpur City Hall (DBKL) spent RM 2.5 million solely for repairing defective lifts, which were mainly caused by vandalism (Bavani, 2010).

4.5) Manufacturers and Suppliers' Commitment

According to Groote (1995), the variety of manufacturers and suppliers is one of the criteria that should be concerned for enhancing maintenance performance. The commitment of manufacturers and suppliers towards maintenance management is necessary, whereby they need to provide complete technical documentation to the maintenance personnel. Carnero (2006) supported that manufacturer documentation is important to select appropriate maintenance strategies and provide diagnoses. Furthermore, the manufacturers or suppliers may need to provide training session for the maintenance personnel so that the maintenance personnel are able to maintain the conditions of the system.

In fact, most of the maintenance personnel do not have any idea about the lifetime of the system components. The lifetime stated by manufacturers is always referred, while the lifetime is based on average conditions and regular maintenance. Thus, the maintenance manuals and guidelines provided by manufacturers or suppliers will greatly assist the management in planning the maintenance programs. Arditi and Nawakorawit (1999b) pointed out that maintenance and replacement under recommendations of manufacturers are necessary at times because the conditions of building or system components affect the operation directly and subsequent downtime is unacceptable.

In order to ensure the maintenance personnel to get used of the maintenance operations for building systems, training and development programs are essential. Those programs are to enable effectiveness of maintenance tasks towards performance improvement. Therefore, close relationship between clients or management and manufacturers must be obtained. Marquez and Gupta (2006) pointed out the benefits of maintaining a proper relationship with the manufacturers and suppliers. For instance, they may work in cross functional teams by providing training and development programs and share useful information to enhance the system reliability and maintainability.

However, De Silva et al. (2004) had proven that there is lack of commitment from the suppliers, contractors and manufacturers as they feel that their responsibility ends when the systems and components are delivered and installed. They even feel that this would be an extra burden with greater responsibility. In this case, poor communication between management and manufacturers occurs and implicates lack of data and inaccurate reliability of data from manufacturers to plan the maintenance strategies. Wu et al. (2010) suggested to sign contracts for reliability option or extended warranty between both parties to eliminate the issue on lack of commitment.

The commitment of manufacturers and suppliers is proven to be substantially influencing the maintenance process and maintenance performance. Thus, it should be taken into consideration for improving the maintenance performance.

4.6) Selection of Intervening Variables

After a thorough study on participative mechanisms through literature review, the intervening variables are derived and selected from the four main mechanisms. There are six variables derived from the participative mechanisms as shown in Table 4.1.

Table 4.1: Matrix of intervening variables and references

Participative Mechanism	**Reference**
Provision of Knowledge-Sharing and Communication Platform	Arditi and Nawakorawit (1999a); Arditi and Nawakorawit (1999b); Pintelon et al. (1999); Bandy (2003); Lee and Scott (2009); Kamaruzzaman and Zawawi (2010); Simoes et al. (2011)
Provision of Training	Groote (1995); Al-Hammad et al. (1997); Edward et al. (1998); Swanson (2001); De Silva et al. (2004); Hui and Tsang (2004); Lo and Choi (2004); Ali et al. (2010); Elmualim et al. (2010); Veldman et al. (2011); Zuashkiani et al. (2011)
Clients' Commitment	Amaratunga and Baldry (2002); Chau et al. (2003); De Silva et al. (2004); Goh et al. (2005); Marquez and Gupta (2006); Lateef (2008); Syed and Kamaruzaman (2008); Ali (2009); Rahmat and Ali (2010a)
Users' Satisfaction and Feedback	Arditi and Nawakorawit (1999b); Chew et al. (2004); Oladapo (2006); Budaiwi (2007); De Silva and Ranasinghe (2010); Rahmat and Ali (2010b); Yik et al. (2010); Kwon et al. (2011); Myeda et al. (2011)
Level of Care by Users	Honstede (1990); Douglas (1996); Olubodun and Mole (1999); Olubodun (2001); Oladapo (2006); Yung et al (2008); Ali et al. (2010); Bavani (2010)

Manufacturers and Suppliers' Commitment	Groote (1995); Arditi and Nawakorawit (1999b); De Silva et al. (2004); Carnero (2006); Marquez and Gupta (2006); Wu et al. (2010)

4.7) Chapter Summary

This chapter highlights participative mechanisms to be applied in building maintenance management. Four main participative mechanisms have been discussed, namely managerial support, clients' commitment, occupants' commitment, as well as manufacturers and suppliers' commitment.

This chapter also explains some advantages of participative mechanisms in enhancing the implementation maintenance strategies and improving the maintenance performance. Taking into cognizance the influence of participative mechanisms towards maintenance performance, correlation analysis between both of the aspects will be performed.

Since all the research variables have been identified through literature review, the method of carrying out the research must be studied thoroughly, such as the data collection approaches, data analysis approaches and others. Hence, the next chapter explains the research method adopted in this research before the research findings are presented in Chapter 6.

CHAPTER 5

RESEARCH METHODOLOGY

5.1) Introduction

Yin (2009) defined research design as a logical sequence that connects the empirical data to the initial research questions, as well as the conclusions at the end of the research. Graziano and Raulin (2010) described that research is a systematic search for information and a process of inquiry. Basically, a research should involve the procedures of posing a question, developing procedures to answer the question, planning for and making appropriate empirical observations, rationally interpreting the empirical observation, and finally using those interpretations to predict other events. With reference to the procedures involved in research, the phases of research are simplified as shown in Figure 5.1. In this research, the phases of research study were followed.

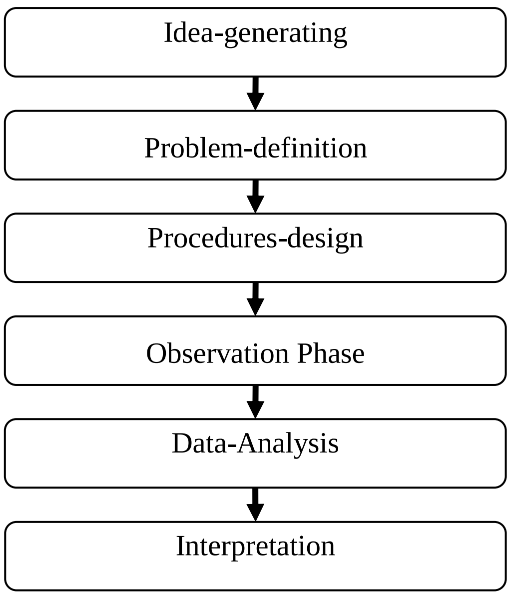

Figure 5.1: Phases of a research study

Source: Graziano and Raulin (2010)

5.2) Idea-Generating Phase

Literature review is the finding of topic related articles, journals, books and others to explain the facts that have been published by relevant professional. Basically, the literature findings are categorised in primary and secondary sources. Graziano and Raulin (2010) stated that the primary sources report research studies; while secondary sources provide reviews of entire areas of research. Both sources are required to get ideas and understandings on a research.

The reliability and authenticity of the reference materials are assured before they are referred and included in the research report. For example, primary sources include recognised journal articles and dissertations; while secondary sources include review articles, books and annual reviews. By having literature review, basic understanding regarding the research topic can be obtained accordingly.

In idea-generating phase, researchers are to identify a topic that is related to their interest of study. The researchers are about to come out with an idea that would be contributing to the knowledge. Commonly, the researchers will begin a research by reading articles and books and other information materials to identify the current issues in the related area. Then, vague thoughts and initial ideas are made by the researchers to produce a relevant research topic.

In this research, related articles and reading materials are read to determine the research topic in his research area. Consequently, the research topic is established as "The Relationship between Preventive Maintenance Characteristics and the Maintenance Performance of High-Rise Office Buildings in Malaysia".

5.3) Problem-Definition Phase

After the idea-generating phase, the initial ideas must be clarified and justified. In problem-definition phase, researchers are required to review the literature. Generally, the literature provides reliable and detailed information that is needed to understand the existing research problem and gap. Meanwhile, research questions will be suggested. Yin (2009) demonstrated that the research questions provide an important clue regarding the most relevant research method to be used.

Using the information, the researchers would be able to create problem statements based on the well-developed knowledge of previous researches and theories, as well as the ideas and speculations of the researchers themselves. Then, objectives of the research are generated and followed in executing the whole research process. In addition, the researchers would thoroughly review and cover the related literature in the area to understand the area of research. In fact, literature review is an essential process to study on the existing theories, concepts, knowledge, and information used in the field.

In this research, the author identified the research problem, where there are a lot of discussions and arguments between the scheduled maintenance strategy and condition-based maintenance strategy towards maintenance performance. Therefore, the objectives of this research are to study the relationships of both maintenance strategies and review measures to improve the maintenance performance. The theoretical framework of the research was developed as shown in Figure 5.2.

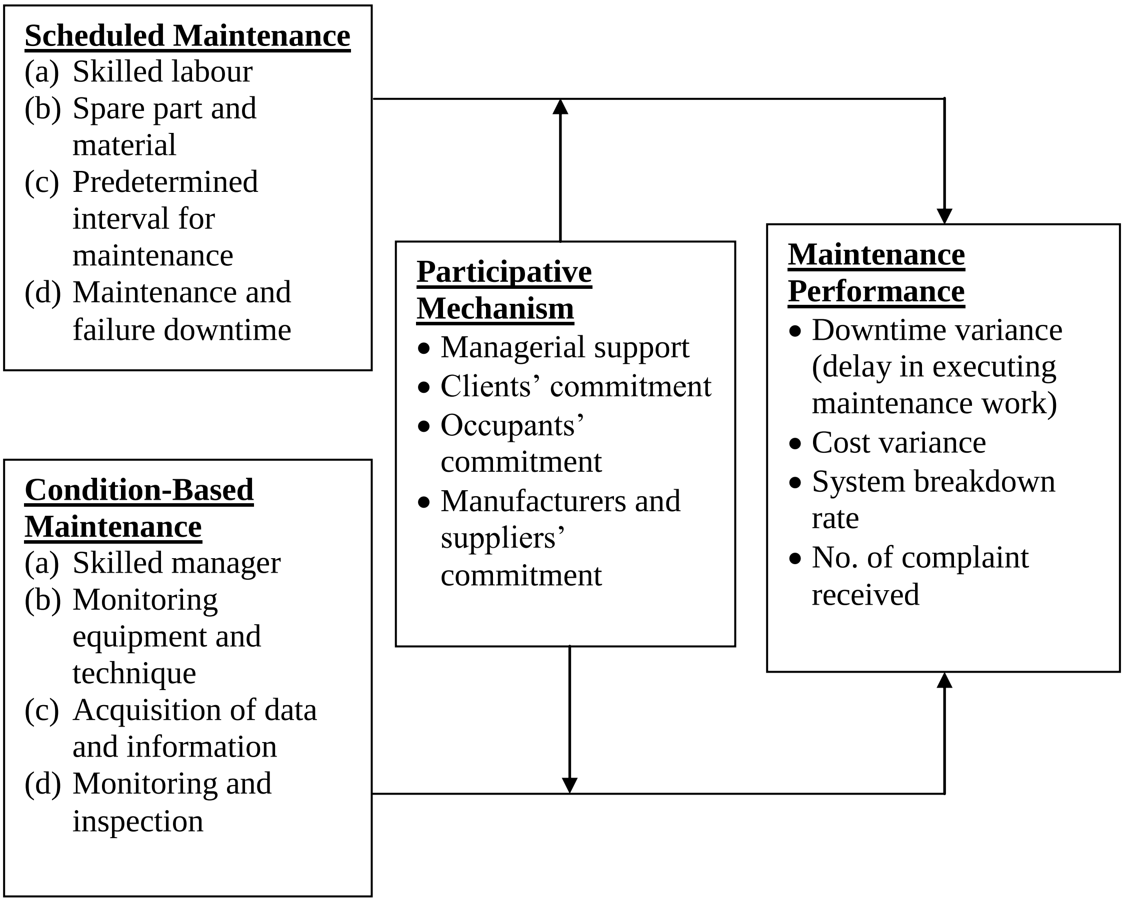

Figure 5.2: Theoretical framework

The theoretical framework indicates the relationships among the variables. The characteristics of both maintenance strategies influence the maintenance performance. In order to improve the maintenance performance, participative mechanism is introduced to improve the effectiveness of the maintenance strategies and hence, optimise the maintenance performance. The author examined the relationships among the variables based on the theoretical framework.

5.4) Procedures-Design Phase

According to Graziano and Raulin (2010), the procedures-design phase is active, systematic, and complex. In this phase, researchers focus on the research methods to be adopted in the research. It is vital to determine the methods of data collection before the data can be collected. The methods of data collection include questionnaire survey, case study, interview, observation and others. Furthermore, the researchers must identify the statistical methods to be used to analyse the collected data. In addition, the respondents or participants to be tested are determined in this phase.

By adopting appropriate methods of data collection and analysis, the reliability and validity of the research can be confirmed and assured. Basically, the validity of research that should be tested involves (Sapsford, 2007):

(a) Validity of measurement – the extent to which the data constitute accurate measurements of what is supposed to be measured.

(b) Population validity – the extent to which the sample gives an accurate representation of the research population which it is supposed to represent.

(c) Validity of design – the extent to which the comparisons being made are appropriate to establish arguments of the research.

In this research, the author adopted triangulation approach to obtain required data. Meanwhile, the author identified the participants and respondents to be tested accordingly. High-rise office buildings located in Klang Valley are the scope to be studied. Then, the respondents would be the maintenance management personnel such as building manager, building executive, building supervisor, technician and others.

5.4.1) Research Approach – Triangulation Design

According to Creswell and Plano Clark (2007), triangulation design is the most common and well-known mixed methods approach. Morse (1991) explained that the main purpose of this design is to obtain different but complementary data on the same topic, as well as to best understand the research problems. Meanwhile, Yin (2009) described that the mixed methods approach allows researchers to address more complicated research questions and achieve higher reliability and validity for the research. Basically, there are two conditions in adoption of triangulation design in the research, which are (Creswell and Plano Clark, 2007):

(a) To directly compare and contrast quantitative statistical results with qualitative findings; or

(b) To validate or expand quantitative results with qualitative data.

In this research, the author adopted the convergence model of triangulation design as shown in Figure 5.3 to collect research data. Creswell and Plano Clark (2007) stated that this model allows the researchers to collect and analyse quantitative and qualitative data separately on the same phenomenon and then compare and converge the results from both quantitative and qualitative data. Nevertheless, the aim of the author to use this model was to validate, confirm, and corroborate quantitative results with qualitative findings.

The research design was based on the methodology adopted by Ali (2008), which had studied the relationship between uncertainties of refurbishment design process and project performance, then introduced integrative mechanism to improve the performance. Meanwhile, the research design referred to the methodology implemented by Nik Mat (2009), which investigated the area of high-rise office building maintenance. Therefore, the author planned to conduct questionnaire survey to collect the quantitative data. On the other hand, interview and archive documentation were also designed to be conducted to collect the qualitative data. Then, the qualitative results would be used to validate the quantitative results.

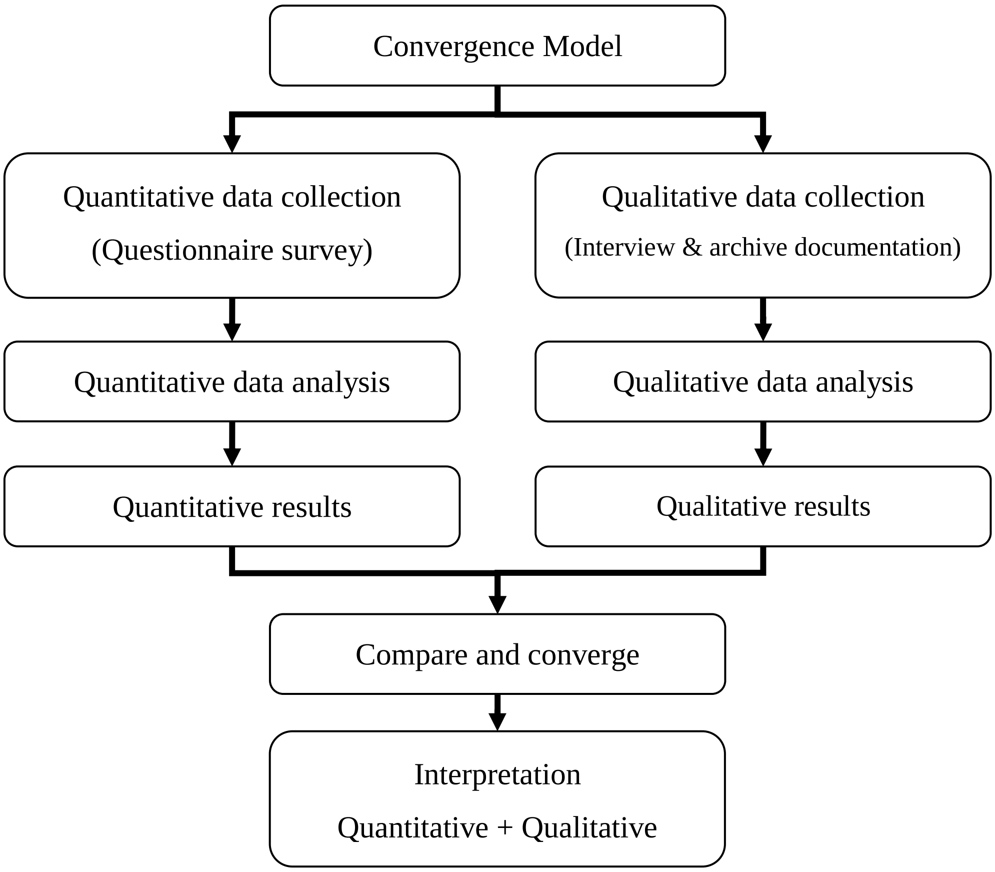

Figure 5.3: Triangulation design – convergence model

Source: Creswell and Plano Clark (2007)

5.4.2) Identification of Research Population and Sample Size

In order to ensure the research outcomes are valid and accurate, it is vital to identify a research population for questionnaire survey research. Since the research focused on the maintenance strategies and performance of office buildings in Klang Valley, the total number of office buildings in Klang Valley was considered as the research population. In the study, office buildings are defined as (NAPIC, 2011a):

> "The places where service-orientated businesses are carried out as opposed to goods being manufactured or sold. The office space is required to attend to paperwork for communication and other office activity."

Krejcie and Morgan (1970) stated that an appropriate sample size is required to represent the research population. Hence, they had created a table for determination of sample size from a given population to ease future researchers. In addition, Bartlett et al. (2001) demonstrated that the ratio of observations to independent variables should not fall below five when a research is to use regression analysis. They even supported other researchers' statement that ten observations for each independent variable is the most optimal ratio in using regression analysis. For example, when a research is to study on ten independent variables, the minimum sample size should be one hundred to follow the ratio of ten to one.

According to NAPIC (2011b), the total number of office buildings located in Klang Valley was 536 during the 1st quarter of year 2011, which included 386 in Kuala Lumpur Federal Territory and 150 in Selangor. Since the scope of study is to focus on high-rise office building that are 7-storeys and above, the office buildings below 7-storeys were filtered out. After filtration process was done, it was found that the total number of high-rise office building located in Klang Valley (see Appendix A) is 398. Thus, the questionnaires set would only be sent to the maintenance personnel of those particular high-rise office buildings. As the research population is 398, the sample size should not be less than 196. The sample size is based on the table created by Krejcie and Morgan (1970), which has listed that population of 400 in a research should have a sample size of at least 196. However, Sekaran and Bougie (2009) noted that the return rates of postal questionnaires are typically low. A response rate of 30 percent is acceptable for the research. Hoxley (2008) also mentioned that response rate for postal questionnaire survey should not be less than 30 percent to ensure its adequacy. Therefore, minimum sample size for this research should be 120.

5.5) Observation Phase

Observation phase is also known as data collection phase. In this phase, the researchers will carry out the procedures as determined in the previous phase. For example, collecting data from respondents through questionnaire survey or interview, or observing the participants' activities or behaviours under the specified conditions through case study or observation. It is necessary to make sure that the process of data collection and observation is precise, because this will directly affect the accuracy of research outcome.

In this research, the author collected quantitative data by questionnaire survey; while qualitative data by interview and archived documentation.

5.5.1) Quantitative Method – Questionnaire Survey

Presser (1984) defined that survey is any data collection procedure that gathers information by distributing the standardised questionnaire to respondents. Saris and Gallhofer (2007) stated that survey research is often used for descriptive research. Generally, questionnaire survey gathers information by asking respondents about their experiences, attitudes, characteristics or knowledge in their natural environments (Graziano and Raulin, 2010). The researchers further explained that questionnaire survey often tests among variables or a variation of correlational research. In other words, the survey research allows the researchers to discover relationships among variables.

Before a questionnaire is distributed to the respondents, the researchers should check the quality of questionnaire. Davies and Smith (2005) suggested that it is necessary to execute pilot testing of the questionnaire survey before final questionnaire survey is implemented. During this preliminary stage, a small number of respondents from the research population are tested to help determine and improve the adequacy and quality of the questions. Generally, there are several approaches to check the questionnaire, including (Saris and Gallhofer, 2007):

(a) Check on face validity

(b) Control of the routing in the questionnaire

(c) Prediction of quality of the questions with some instrument

(d) Use of a pilot study to test the questionnaire

Then, corrections of the questionnaire need to be made according to feedback from the checking and testing of questionnaire. This is to ensure that the respondent actually understand the question better after correction (Sekaran and Bougie, 2009). After the final questionnaire is drafted and confirmed, it can be printed and sent out to the respondents for data collection. Once the completed questionnaires are returned to the researchers, they would analyse and interpret the data that is extracted from the questionnaires.

Typically, there are several forms of question that can be asked in a questionnaire, such as open-ended items or close-ended items. However, open-ended items are not applicable for quantitative method. Thus, close-ended questions that include multiple-choice questions and Likert-scale questions were adopted in this research. Saunders et al. (2009) stated that close-ended questions are usually simple and quicker to answer. The respondent is only required to choose one of the alternative answers provided in a question. Meanwhile, they help the researchers to code the information easily for data analysis (Sekaran and Bougie, 2009). An example of a multiple-choice question is stated as follows (see Appendix A):

How long have you been involved in the building maintenance industry?

[ ] Less than 5 years [ ] 6 - 10 years [ ] 11 - 15 years [ ] More than 15 years

In Likert-scale questions, researchers arrange the choices on a continuum, with extreme positions at the end points. Commonly, 5-points-scale is the most used scale in questionnaire (Saunders et al., 2009; Sekaran and Bougie, 2009). For instance, respondents might be asked to indicate the degree of influence with a statement as stated below (see Appendix A):

Please rate the degree of influence of "clients' commitment" in obtaining adequate maintenance budget, information, and/or skill and knowledge.

	1	2	3	4	5	
Very low degree						*Very high degree*

In fact, the main purpose of a survey is to discover and learn about the ideas, knowledge, theories, feelings, opinions, attitudes or self-reported behaviour of a defined population. Hence, it is necessary to identify the population and representative sample of the research topic before the questionnaires are sent out. In order to describe the population accurately, sampling is a procedure to select limited number of data from that particular population (Saris and Gallhofer, 2007). The researchers further explained that the recommended procedure to obtain accurate samples is to select the respondents at random, which is so called random sampling method.

It was found that the survey method suited the purpose of this research. Thus, questionnaire survey was used to collect the quantitative data. The overall process of questionnaire survey is summarised in Figure 5.4. Preliminary questionnaire was drafted and put through a pilot study. Then, corrections were made according to the feedback and comment received. The questionnaire (see Appendix A) was divided into two main categories, which are demographic and content questions. Demographic questions included the respondents' particulars and building information in multiple-choice; while content questions included characteristics of maintenance strategies, maintenance performance, as well as measures to improve maintenance performance in multiple-choice and Likert-scale. Then, random sampling method was adopted so that the author has no influence on the selection of the respondents.

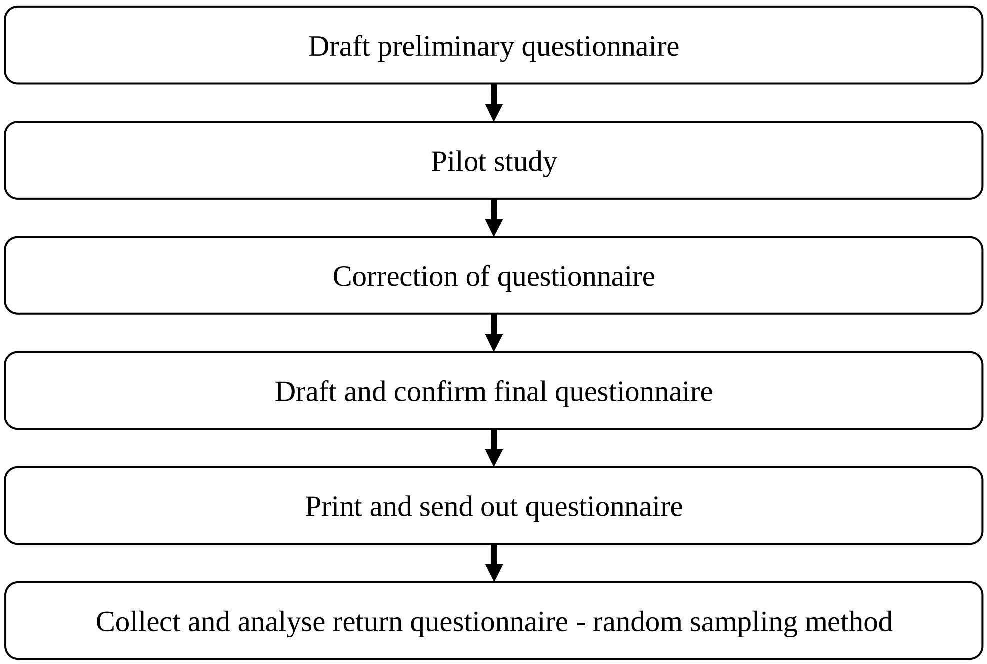

Figure 5.4: Overall process of questionnaire survey

Although the population of this research is 398 of high-rise office buildings in Klang Valley, only 331 of them are provided with contact details by National Property Information Centre (NAPIC). Thus, questionnaire was sent out to the 331 maintenance management departments of those buildings. After one month, 64 completed questionnaires were received. Unfortunately, it was far from the targeted sample size. Therefore, reminder was sent out to those who had not returned the questionnaire. After another month, 58 of questionnaires were returned. In order to increase the response rate, the author had walked-in the high-rise office buildings to collect answered questionnaire. However, only 6 answered questionnaires were collected.

Table 5.1: Response of questionnaire survey

Description	Frequency	Percentage
Total population	398	100.0
Sent out questionnaire	331	83.2
Returned questionnaire	128	32.2
Unanswered questionnaire	3	0.8
Incomplete questionnaire	5	1.3
Valid questionnaire	120	30.2

Note: Percentage is based on the total population

Overall, the total number of returned questionnaires is 128 as shown in Table 5.1. This number does not meet the targeted sample size as mentioned by Krejcie and Morgan (1970). It was found that the unsatisfactory response rate is mostly due to the confidentiality and privacy to be kept by the maintenance management departments of the office buildings. However, minimal response rate was achieved, which is 30 percent as suggested by Hoxley (2008). After all the questionnaires were gathered, checking on those questionnaires was done. It was identified that 120 of them are valid, 5 are incomplete, and 3 are unanswered.

5.5.2) Qualitative Method – Interview and Archived Documentation

Yin (2009) stated that qualitative method may be part of a research that is used to compare or validate the quantitative results. In fact, the main investigation relies on quantitative approach. In this study, qualitative method including interview and archived documentation, were adopted to validate the results obtained from quantitative method, which is questionnaire survey. The overall process of interview and archived documentation is summarised in Figure 5.5. In order to execute the interview smoothly, questions directed to the participants were prepared in advance. After the buildings and participants were determined, the interview sessions were executed. Meanwhile, archived documents and records were obtained and gathered for data analysis. Finally, the preparation of report on interview and content analysis was done.

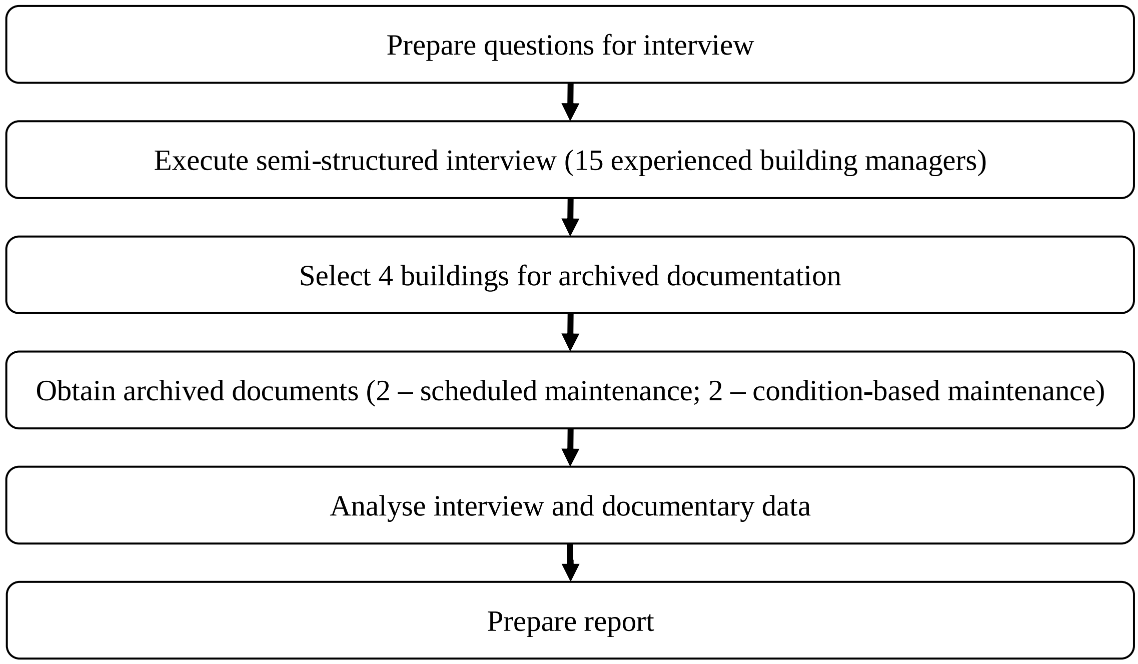

Figure 5.5: Overall process of interview and archived documentation

a) Semi-Structured Interview

According to Marshall and Rossman (2006), interview allows the researchers to explore a few general topics to help in uncovering the respondents' views. In fact, this method is based on an assumption fundamental to qualitative research. Whereby, the respondents' perspective on the phenomenon of interest should be stated as the respondents' views instead of the researchers' views. In order to obtain respondents' views instead of solely depending on literature, interview was executed to gather more detailed information from the respondents for this study. As a result, the study would be able to make more objective assumptions by triangulating interview data with data gathered through questionnaire survey.

In this research, semi-structured interview was adopted. Saunders et al. (2009) explained that semi-structured interview could be used to understand the relationships between variables, such as those revealed from a descriptive study. This explanation matched exactly to the aim of this study, which is to establish relationship between preventive maintenance towards maintenance performance. Furthermore, semi-structured interview could gather more detailed information to validate the result of questionnaire survey in this study.

In order to ensure the accuracy and reliability of data collected through semi-structured interview, several actions were taken to eliminate the issues of response bias and reliability. Sekaran and Bougie (2009) revealed that the willingness of individuals to take part in the interview may result response bias. Thus, the author requested permission and asked about willingness to take part from the potential participants before the interview was carried out. A consent form (see Appendix B) was distributed to the participants to acknowledge their rights when participating in the interview.

In addition, credibility may also be promoted through the supply of relevant information to participants before the interview (Saunders et al., 2009). Hence, in this study, an information sheet (see Appendix B) was distributed and explained to the participants before the interview began. The information sheet consisted of the brief of study, aim of study, participant's requirements, and the confidentiality. Basically, the participant's requirements are to ensure the reliability of response, including:

(a) Participants for this discussion must be building managers, executives, supervisors, or any maintenance personnel in managerial level who:
    - Have working experience of more than 5 years in maintenance management.

- Are experienced in implementing scheduled maintenance, condition-based maintenance, or both.

(b) Participants will be informed of the discussion intended.

(c) Participants will be asked to sign the Consent Form for participation in the discussion.

(d) Participant is entirely voluntary and participants will have the rights to withdraw at any time without prejudice or negative consequences.

In fact, careful preparation can lead to a successful interview (Saunders et al., 2009). Thus, proper planning and preparation of interview were done in this study. In order to ensure that the interview run smoothly, interview questions (see Appendix B) were designed prior to the interview session. This would allow the author to prepare the way of asking questions in advance, so that the questions could be clearly delivered to the participants during the interview session. Meanwhile, mock interview was conducted with two potential participants to explore the problems that might occur during the interview session.

Potential participants were obtained from the respondents of questionnaire survey in the earlier stage. Seventy-six (76) respondents were found to meet the participant's requirement of interview. Then, forty-three (43) among seventy-six (76) of them did provide their contact information in the questionnaire set for further studies. Therefore, they were identified as the potential participants. After that, the potential participants were contacted to request for their permission to take part in the interview session. However, only fifteen (15) potential participants agreed to take part in the interview session. Apparently, the answers provided by the participants reached a saturation after twelve (12) of them were interviewed, where the answers given by the participants were similar and predictable without new information (Ali, 2008). Nevertheless, the interview session was carried on until all fifteen (15) participants were interviewed.

Among the fifteen (15) participants, each five of them are experts in scheduled maintenance, condition-based maintenance, and both maintenance strategies. They are coded in discussion of findings as shown in Table 5.2.

Table 5.2: Coding of interview participants based on their expertise

Expertise	**Coding of Participants**
Scheduled maintenance	Participant S1 to S5
Condition-based maintenance	Participant C1 to C5
Both maintenance strategies	Participant B1 to B5

b) Archived Documentation

Archived documentation was adopted in this study as it could be a useful research method that involves examining records and identifying categories of events. Nik Mat (2009) stated that it is constructive to assess the archived documents and records from respective organisations to get the scenario of maintenance management. In addition, Graziano and Raulin (2010) noted that existing records or archived documents may provide information about events that have already occurred. For example, the data of previous expenditure on a particular maintenance activity could be documented. Meanwhile, existing records could be used to determine variables, observe contingencies, calculate correlations, and make prediction about future events based on those correlations. Therefore, the data obtained through archive documentation are suitable to be compared with the data and results obtained through questionnaire survey. The documentation includes maintenance reports, documents of service providers, meeting minutes, and others, which focus on the planning, implementation and performance of maintenance strategies, as well as the participative mechanism.

Four (4) high-rise office buildings were selected for archived documentation, where two buildings implement scheduled maintenance and another two implement condition-based maintenance. The data obtained from the four (4) buildings are sufficient to be compared with the questionnaire and interview results, because each case provided in-depth information about the implementation of the maintenance strategies. Due to limitation of time allowed by the building managers, collection of archived documents and information had only focused on general maintenance and air-conditioning system. Meanwhile, criteria of case studies were set to ensure the relevancy and reliability of data to compare with the questionnaire survey result. The criteria include:

(a) High-rise office building (minimum 7-storeys)

(b) Consists of centralised air-conditioning system

(c) Building age of two (2) years or above

5.6) Data-Analysis Phase

After the data has been gathered, the researchers will make use of it to analyse the result. Commonly, statistical procedures are used to describe and evaluate numerical data and to determine the significance of data and observations in data-analysis phase. Then, the statistical result would identify the cause-and-effect relation between variables (Davies and Smith, 2005). For instance, researchers often utilise the SPSS software to analyse the data such as correlation test, regression analysis and others. According to Hoxley (2008), SPSS software is the most used statistical analysis software and is extremely powerful. The type of analysis must be appropriate with the purpose of study and fits the research questions.

In this phase, critical thinking of the researchers is necessary to evaluate and examine the accuracy of the collected and analysed data. Tables and charts will be produced by statistical analysis to convert the data into statistical value. Then, elaborations can be made by referring to the statistical data.

5.6.1) Frequency Distributions and Descriptive Statistics

In a research, statistical simplification involving computing frequencies is done for most nominal and ordinal data. “Frequency distributions” is a method to organise the data into categories, which is usually shown in table form (Graziano and Raulin, 2010). Since the data obtained through the questionnaire are nominal and ordinal data, “frequency distributions” was adopted for data analysis in this study.

“Descriptive Statistics” covers measures of central tendency, variability, and relationship of research data (Graziano and Raulin, 2010). In order to achieve the objectives of this study, which are to establish relationship between preventive maintenance towards maintenance performance and to develop prediction model on maintenance performance, this technique was adopted to analyse the data obtained in this study.

a) Mean and Standard Deviation

In this study, mean and standard deviation were used to measure the data. Mean is known as a measure of average or arithmetic average of the scores in a distribution (Diamond and Jefferies, 2006; Graziano and Raulin, 2010). The mean (x-bar) is computed by summing the scores and dividing by the number of scores as formulated as:

$$\overline{X} = \frac{\sum X}{N}$$

where, Σx = sum of the X scores; N = total number of scores

Standard deviation is used when mean is being used as a measure of average (Diamond and Jefferies, 2006). Generally, standard deviation indicates the size of the residuals, which is the difference between a particular observation and the mean. Thus, the larger the standard deviation, the greater the spread of data. Greater spread of data indicates the randomness of data and eliminates the bias issue. The equation of standard deviation (S) is stated below:

$$S = \sqrt{\frac{\Sigma (X - \bar{X})^2}{n - 1}}$$

where, x = observations; x-bar = mean; n = total number of observations

5.6.2) Reliability Analysis

It is important to ensure that the data is reliable in a study. Generally, reliability of data can be established by testing the consistency and stability (Sekaran and Bougie, 2009). In social science research, Cronbach's alpha is widely used to test the reliability of data. This measure indicates the consistency of data (Leech et al., 2011). In other words, it is computed in terms of the average intercorrelations among the items measuring the outcome (Sekaran and Bougie, 2009). By using SPSS software, the Cronbach's alpha coefficient can be computed and obtained easily. The alpha should be above 0.70 that reflects acceptable reliability. However, Leech et al. (2011) argued that lower alpha of 0.60 to 0.69 is acceptable as well when there is only a handful of items in the scale. Meanwhile, Sekaran and Bougie (2009) stated that coefficient less than 0.60 is considered poor reliability and coefficient more than 0.80 is deemed good.

In this study, the reliability analysis (see Appendix C) was performed for both characteristics of scheduled maintenance and condition-based maintenance to test the reliability of collected data. The Cronbach's alpha coefficient for characteristics of scheduled maintenance and condition-based maintenance are 0.741 and 0.888 respectively, which indicated that the scale and data obtained are reliable.

5.6.3) Bi-Variate Analysis – Spearman Rank-Order Correlation

According to Diamond and Jefferies (2006), correlation measures the association between two continuous variables. Thus, this study used correlation test to examine the strength of the relationship between variables, which are the variables of preventive maintenance, participative mechanism, and maintenance performance. In order to quantify an association, the correlation coefficient (*r*) can be calculated with the formula shown below:

$$r = \frac{\sum(x-\bar{x})\times(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\times\sum(y-\bar{y})^2}}$$

where, (*x* – *x-bar*) = residual of variable X; (*y* – *y-bar*) = residual of variable Y

However, the data can be analysed using SPSS software. Commonly, there are several correlation coefficients for different types of data, including Pearson product-moment correlation, Spearman rank-order correlation and others. In this study, the data collected are in nominal and ordinal scale. Graziano and Raulin (2010) stated that Spearman rank-order correlation is the appropriate coefficient to analyse either or both independent and dependent variables are ordinal. The Spearman rank-order correlation is calculated using the following formula:

$$1 - \left(\frac{6\Sigma d^2}{n(n^2 - 1)}\right)$$

where, *d* is the difference in ranks; *n* is amount of pairs of data

Therefore, Spearman rank-order correlation was adopted in this study. The interpretation of correlation is shown in Table 5.3.

Table 5.3: Interpretation of correlation

Value	Interpretation
-1.00	Perfect negative relationship
0	No linear relationship exists
+1.00	Perfect positive relationship

5.6.4) Regression Analysis – Logistic Regression

After the correlation coefficients had quantified the degree and direction of relationship between variables, another objective of this research is to make prediction on maintenance performance. A strong relationship between two variables provides information that will help to predict one variable by knowing the values of the other (Graziano and Raulin, 2010). Regression is the prediction of the value of one variable from the value of another. A simple linear regression equation is stated as follows:

$$Y = a + bX$$

where, Y = dependent variable; X = independent variable; a = constant; b = change in Y for a change of one unit in X

In fact, study on numerous variables that affect the dependent variable would be able to make a more accurate prediction. Miles and Shevlin (2007) noted that a research that has more than one independent variable is known as multiple regression. The multiple linear regression equation is stated below:

$$\boldsymbol{Y = a + b_1X_1 + b_2X_2 + \ldots\ldots + b_nX_n + \varepsilon}$$

where,

Y = dependent variable

X_1, X_2, ... , X_n = independent variables

a = constant

b_1, b_2, ... , b_n = change in Y for a change of one unit in X_1, X_2, ... , X_n respectively

ε = random error

In order to ensure the obtained result is accurate in linear regression analysis, there are numerous conditions to be fulfilled and tested. Leech et al. (2011) mentioned that the dependent variable should be an interval or scale level variable, which is normally distributed in the population from which it is drawn. Meanwhile, the independent variables should be mostly interval or scale level variables. In this study however, the dependent variables are in ordinal level instead of interval or scale level. The conditions of linear regression are violated.

Therefore, logistic regression analysis was adopted in this study. The function of logistic regression is similar to multiple regression, which is to predict an outcome from a set of independent variables. Specifically, logistic regression is useful to predict categorical variable from a set of predictors or independent variables (Leech et al., 2011). Furthermore, this analysis is often preferred when the dependent variable has only two categories, because it does not require conformance to the strict assumptions (Sekaran and Bougie, 2009).

Unlike multiple regression, logistic regression is able to predict a discrete outcome (Sekaran and Bougie, 2009). For instance, the logistic regression can clearly indicate an outcome of a situation whether it will happen or will not. This is the advantage of logistic regression compared to multiple regressions. Logistic regression calculates changes in the log odds of the dependent variable, not changes in the dependent variable itself as linear regression does (Chua, 2009). Thus, probability of an event can be measured by using logistic regression. The logistic regression function is stated as follows:

$$\boldsymbol{Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_k X_k + \varepsilon}$$

where,

Z = latent variable

$X_1, X_2, \ldots\ldots, X_k$ = independent variables

β_0 = constant

$\beta_1, \beta_2, \ldots\ldots, \beta_k$ = change in Y for a change of one unit in $X_1, X_2, \ldots\ldots, X_k$ respectively

ε = error term

Then, Z value is transformed using a link function to obtain the probability of the event occurring. For a binary outcome, the link function is stated below:

P[Event] = $\boldsymbol{e^z/1+e^z}$, the value is between 0 to 1.

The ratio of sample size to independent variable is an important consideration for the use of regression. Peduzzi et al. (1996) recommended that the dependent variable should be tested with at least ten events per parameter in the model. Coakes and Ong (2011) demonstrated that the minimum requirement is to have at least five times more sample size than the number of independent variable. In this study, the sample size for characteristics of scheduled maintenance is 101 and the number of independent variable is 10; while the sample size for characteristics of condition-based maintenance is 100 and the number of independent variable is 9. Both of the ratios are more than ten. Therefore, they satisfy this particular requirement.

Furthermore, the logistic regression model must be tested with chi-square test of goodness of fit (Hosmer and Lemeshow, 2000). Using SPSS software, the test can be run through Hosmer and Lemeshow's goodness of fit. If chi-square goodness of fit is not significant, then the model has adequate fit. If the test is significant, the model does not adequately fit the data.

The practitioners incline towards logistic regression, as they could predict an outcome or decision discretely. Therefore, this study had used binary logistic regression (see Appendix D) to produce the prediction model for maintenance performance. Whereby, the dependent variables were re-coded to be dichotomous from 6-point scale.

5.6.5) Qualitative Data Analysis – Data Reduction and Display

Qualitative data are data in the form of words such as interview notes, transcripts of focus groups, answers to open-ended questions, and others (Sekaran and Bougie, 2009). Generally, there are three main steps in qualitative data analysis, which include data reduction, data display, and the drawing of conclusions (Miles and Huberman, 1994).

Firstly, qualitative data analysis concerns on data reduction that refers to the process of selecting, summarising, and categorising the data (Sekaran and Bougie, 2009). The aim of this process is to transform the data and to compact it (Saunders et al., 2009). In this research, the process was used to produce the interview summaries, categorising the data, and constructing a narrative. The interview results were divided into categories and subcategories, whereby categories represent the significant characteristics and their significant relationship to maintenance performance; while subcategories represented the view of participants, including the number of participants that acknowledged the significances and relationship with reasons or elaborations.

In the second stage, researchers focus on data display that involves the presentation of reduced data in an organised and condensed manner (Sekaran and Bougie, 2009). Commonly, data display is in the form of diagrammatic or visual displays (Saunders et al., 2009). For instance, data can be displayed in matrices or networks (Miles and Huberman, 1994). Matrices are basically tabular in form with defined columns and rows. Networks are collection of linked nodes or boxes that indicate relationships. In this research, the interview results are presented in tabular forms. The numbers of responses toward the interview questions were recorded, and the influential reasons and elaborations were listed.

Finally, the process of conclusion drawing for qualitative data analysis takes place, which determines whether the results do answer the research questions (Sekaran and Bougie, 2009). In this research, the views and elaborations of participants are discussed, and some of them are quoted. In addition, the interview results were compared with the questionnaire survey results.

5.6.6) Qualitative Data Analysis – Content Analysis

Marshall and Rossman (2006) stated that content analysis is an unobtrusive method, as it can be conducted without interfering the setting in any way. This method can be used to analyse newspapers, websites, advertisements, recording of interviews, archive documents, and others. The main function of this method is to analyse textual information and systematically identify its properties, such as the presence of certain words, concepts, characters, themes, number figures, or sentences.

In this research, the historical data of maintenance management were analysed. The exact circumstances related to the maintenance characteristics and performance was also examined. Then, comparison of the content analysis for archive documents and questionnaire survey results was made.

5.7) Interpretation Phase

In interpretation phase, the analysed data is reviewed and compared to the previous research from literature. Then, the researchers will discuss and interpret the statistical results and findings to respond the research problems and contribute to knowledge in the area. Generally, the researchers relate the findings not only to the research questions, but also to other concepts and findings in the area. Whereby, they interpret research results to compare with past research and theory (Davies and Smith, 2005). The researchers either support the previous concepts and findings or reject them with the newly achieved results. Furthermore, the results of research may recommend methods to modify, expand or enhance the existing theory to increase its applicability and validity.

In this research, the findings are discussed based on the analysis results, including questionnaire survey result, semi-structured-interview result, and archive documentation result. The results obtained from questionnaire survey are compared with the past research and theory. Then, the interview and archive documentation results are compared with the questionnaire survey results for validation purpose. Finally, the findings and analysis are tied-up with objectives as the conclusion of the research. Recommendations or suggestions are produced as the conclusion of the research too.

5.8) Chapter Summary

Understanding the research methodology is necessary upon performing a research. The study on research design provides an input in selecting appropriate approaches to perform the research. After thorough study and consideration, this chapter elaborates the adopted research design for this study, which is triangulation design. The research design is the combination of quantitative and qualitative approaches for data collection and analysis. Indeed, it allows researchers to address more complicated research questions and achieve higher reliability and validity for the research. Three stages of data collection methods are designated including questionnaire survey, semi-structured interview and archive documentation. The main findings collected through questionnaire survey were then analysed through SPSS software; while findings of semi-structured interview and archive documentation were analysed to validate the results of questionnaire survey. All the findings are presented in the following chapter.

CHAPTER 6

FINDINGS AND DISCUSSION

6.1) Introduction

This chapter presents the analysis result of both quantitative and qualitative data collected. Quantitative data were obtained through questionnaire survey; while qualitative data were collected through semi-structured interview and archived documentation. Then, all the data were analysed to achieve the research objectives.

Since triangulation approach was adopted in this study, the interview and archive documentation results were meant to support and validate the questionnaire survey result. Thus, comparison of the findings obtained through the three data collection and analysis methods was discussed and presented at the end of this chapter.

6.2) Questionnaire Survey Result

In this research, questionnaire survey is the main approach to collect the research data. Then, SPSS software was used to analyse the collected data. Typically, it produces three types of analysis results that include descriptive analysis result, correlation analysis result, and regression analysis result. Each of the analysis results is means to satisfy the research objective as tabulated in Table 6.1.

Table 6.1: Questionnaire survey analysis result to research objective

Type of Analysis Result	Research Objective
Descriptive	• To identify the characteristics of condition-based and scheduled maintenance • To review measures in improving maintenance performance by adopting the maintenance strategies
Correlation	• To establish relationship between preventive maintenance towards maintenance performance
Regression	• To develop prediction model on maintenance performance

6.2.1) Descriptive Analysis Result

Figure 6.1 demonstrated that the respondents of the questionnaire survey comprised of building managers, building executives or supervisors, building technicians, and others. Based on the data obtained through the survey, some of the respondents, who selected the category of "others", are either managing directors of a property management firm or mechanical and electrical engineers.

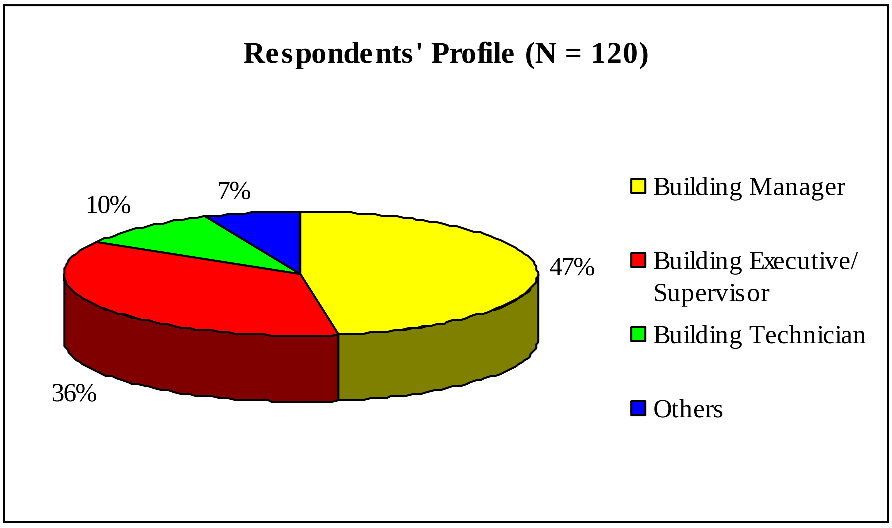

Figure 6.1: Respondents' profile

Majority of the respondents are building managers, which accounts for 47.5 percent. Then, it is followed by 35.8 percent of building executives or supervisors. In addition, the building technicians and category of “others” cover the low percentage overall, which are 10.0 percent and 6.7 percent respectively. Commonly, building managers and building executives or supervisors are the personnel who are involved in planning and executing maintenance programs instead of only in executing maintenance activities. In other words, they are the experts and professionals in maintenance management. Therefore, the researcher may summarise that the responses on the questionnaire are reliable.

Table 6.2 shows the working experience of respondents. Basically, the working experience is reflected by the number of years that the respondents have been involved in maintenance management.

Table 6.2: Working experience of respondents

Working Experience	Frequency	Percentage (N=120)
<6 years	34	28.3
6-10 years	50	41.7
11-15 years	19	15.8
>15 years	17	14.2
Total	**120**	**100.0**

The respondents who have six (6) to ten (10) years working experience are 41.7 percent, which are the majority. Meanwhile, 28.3 percent of the respondents have working experience of less than six (6) years. Followed by the respondents who have eleven (11) to fifteen (15) years working experience, which is 15.8 percent. Then, only 14.2 percent of the respondents have working experience of more than six (15) years. Since maintenance management is considerably new in Malaysia, maintenance personnel who have working experience of six (6) years and above are known to be experienced in maintenance management. Based on Table 6.2, respondents that have been involved in maintenance management for six (6) years and above cover 71.7 percent in overall. Hence, once again the findings are deemed reliable and accurate.

Table 6.3 reveals the number of buildings that the respondents have been involved in maintenance management. Indeed, the number of building involved by respondents also reveals the experience of respondents in maintenance management.

Table 6.3: Number of building involved by respondents

Involved Building	**Frequency**	**Percentage (N=120)**
<3	29	24.2
3	18	15.0
4	23	19.1
>4	50	41.7
Total	**120**	**100.0**

Majority of the respondents have been involved in more than four (4) buildings, which is 41.7 percent. Then, 24.2 percent of the respondents are involved in less than three (3) buildings. Furthermore, the respondents involved in three (3) and four (4) buildings cover 15.0 and 19.1 percent respectively. In fact, the number of buildings involved by the respondents may reflect the level of exposure that they deal with or in maintenance management. Since 75.8 percent of the respondents have been involved in three (3) or more buildings, it is fair to say that the respondents have broad experience and knowledge in maintenance management.

Figure 6.2 indicated the ownership of buildings that the respondents are in charge. Commonly, the maintenance process of a building can differ from the ownership of building, such as maintenance approval process.

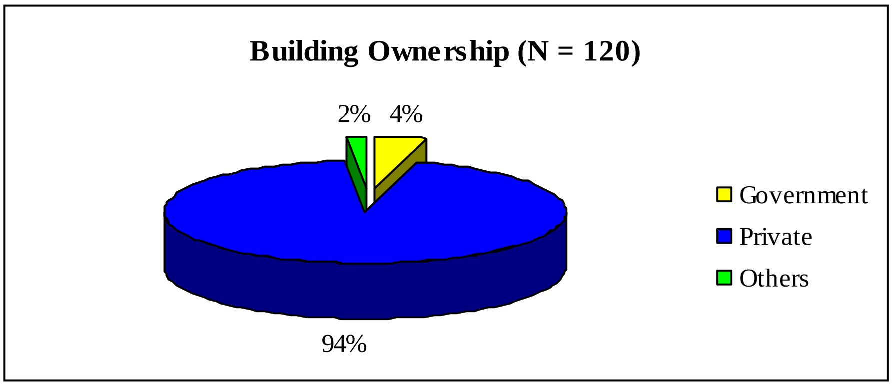

Figure 6.2: Building ownership

Majority of the buildings are private buildings, covering 94.1 percent. This is followed by 4.2 percent of government buildings. Based on the answers given by the respondents, buildings under the category of “others” are government-linked building. There are only 1.7 percent of the responses under the category of “others”. Generally, private buildings have their in-house maintenance team or outsourced maintenance managing agent allocated in the buildings for execution of maintenance programs. The maintenance personnel work in the buildings permanently. On the other hand, most of the government buildings are managed and maintained by the Public Work Department, whereby the maintenance personnel take care of several buildings. They would only visit a particular building for inspection, repair or replace, and other maintenance purposes occasionally, but not to stay permanently in a building. Therefore, there are more different individuals involved in private buildings instead of government buildings. However, all the managements from different types of building managed and concerned on the characteristics of maintenance strategy. Hence, there is no significant difference that would affect the outcome.

Table 6.4 demonstrated the age of buildings that the respondents are involved in. The maintenance requirement always varies according to the building age.

Table 6.4: Building age

Building Age	**Frequency**	**Percentage (N=120)**
2-5 years	22	18.4
6-10 years	26	21.7
11-15 years	34	28.3
16-20 years	13	10.8
>20 years	25	20.8
Total	**120**	**100.0**

28.3 percent of buildings are eleven (11) to fifteen (15) years of age, which is the majority. This is followed by 21.7 percent of six (6) to ten (10) years old buildings in overall. Moreover, building age of more than 20 years and two (2) to five (5) years cover 20.8 percent and 18.4 percent respectively. Minority age of the buildings is sixteen (16) to twenty (20) years, with only 10.8 percent. In fact, the age of buildings reflects the level of maintenance required relatively. However, there are moderate involvements of respondents for each category of building age. Thus, the influence of building age towards the result of survey is considered as not significant.

Table 6.5 reveals the annual maintenance costs of buildings managed by the respondents. The annual maintenance cost can vary and may be influenced by numerous aspects, such as building age, building ownership, complexity of building systems, and others.

Table 6.5: Annual maintenance cost

Annual Maintenance Cost	**Frequency**	**Percentage (N=120)**
<RM100,001	11	9.2
RM100,001-RM200,000	28	23.3
RM200,001-RM300,000	34	28.3
>RM300,000	47	39.2
Total	**120**	**100.0**

Majority of the respondents stated that the annual maintenance cost is more than RM300,000, which is 39.2 percent. This is followed by annual maintenance cost of RM200,001 to RM300,000, which is 28.3 percent in overall. Additionally, 23.3 percent of the respondents noted that the annual maintenance cost is RM100,001 to RM200,000. Lastly, annual maintenance costs of RM100,000 and below accounts for only 9.2 percent. Based on the findings, majority of the building incur more than RM200,000 annual maintenance cost, and only a few buildings have annual maintenance costs below RM100,000.

Figure 6.3 shows the maintenance strategy adopted by the respondents in maintenance management. The question only focuses on scheduled maintenance and condition-based maintenance.

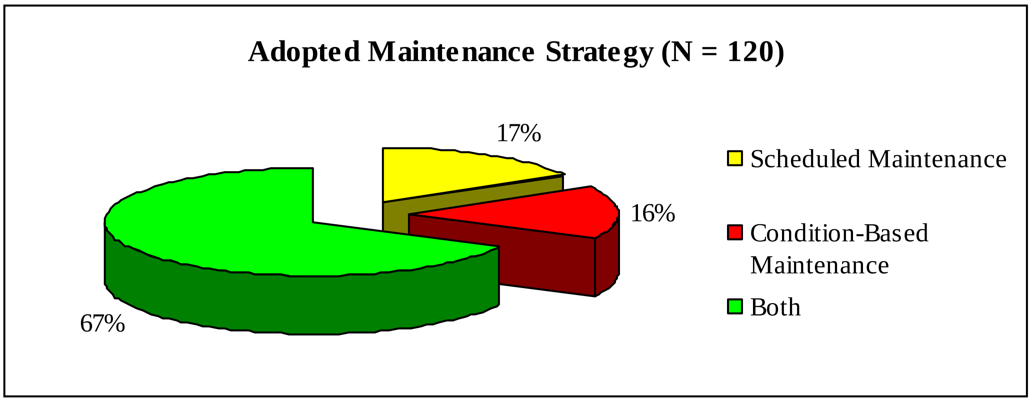

Figure 6.3: Adopted maintenance strategy

Majority of the respondents adopted both maintenance strategies in maintenance management, which is 67.5 percent. While 16.7 percent of the respondents only adopted scheduled maintenance, the remaining 15.8 percent of the respondents only adopted condition-based maintenance in their maintenance management. Therefore, the response rates toward the questions regarding scheduled maintenance and condition-base maintenance are about the same.

Table 6.6 listed the ranking of characteristics of scheduled maintenance based on the mean scores. The ranking analysis reflects the significance of scheduled maintenance characteristics.

Table 6.6: Ranking of characteristics of scheduled maintenance

Rank	Variable	Mean (N=101)	Std. Deviation
1	Spare Parts and Materials-Quality	3.53	.944
2	Skilled Labour-Skill and Knowledge	3.41	.982
3	Skilled Labour-Budget Allocation	3.32	.871
4	Spare Parts and Materials-Budget Allocation	3.19	.880
5	Predetermined Maintenance Interval-Length of Interval	3.16	.914
6	Predetermined Maintenance Interval-Budget Allocation	2.98	.787
7	Spare Parts and Materials-Level of Stock	2.83	.861
8	Skilled Labour-Number of Labours	2.83	.873
9	Failure and Maintenance Downtime-Budget Allocation	2.78	.867
10	Failure and Maintenance Downtime-Amount of Downtime	2.74	1.163

It was found that quality of spare parts and materials is at the highest rank, with a mean score of 3.53. Meanwhile, the standard deviation value of 0.944 indicated the widespread of data and eliminated the issue of biased data. Practically, the quality of spare part was identified as the most important characteristics in executing scheduled maintenance. The findings supported the statement of Ali et al. (2010) that the quality of spare parts and materials is essential, as it always has an impact towards the maintenance performance. By having good quality spare parts and materials, the building systems could operate effectively with minimal breakdown or failure. Additionally, the replacement interval of the parts could be extended, as the parts and materials usually have longer lifetime.

Then, skill and knowledge of maintenance labour is ranked second with 3.41 mean score. The data are normally distributed with a standard deviation value of 0.982. Error and mistake occurred during maintenance works could be reduced or minimized. Furthermore, the skilled labor would be able to detect abnormal condition of a system when executing the maintenance tasks. The result confirmed the importance of labor qualification in building maintenance (Groote, 1995).

In order to employ skilful and knowledgeable maintenance labour, budget allocation for labour recruitment becomes an important aspect. Generally, the amount salary of a labour is positively proportional to his level or skill and knowledge. Thus, the result stated that the budget allocation for skilled labour is ranked third with the mean score of 3.32, and standard deviation value of 0.871. The findings verified that large amount of budget allocation is required for skilled labour (Carnero, 2006). Apart from the skill and knowledge of maintenance labour, the morale of labour in an organisation is essential. By having better pay, the labour would be likely to work more effectively.

Table 6.7 states the ranking of characteristics of condition-based maintenance based on the mean scores. The ranking analysis reveals the significance of condition-based maintenance characteristics.

Table 6.7: Ranking of characteristics of condition-based maintenance

Rank	Variable	Mean (N=100)	Std. Deviation
1	Skilled Manager-Skill and Knowledge	3.71	.808
2	Acquisition of Data-Reliability	3.46	.915
3	Skilled Manager-Budget Allocation	3.43	.807
4	Acquisition of Data-Budget Allocation	3.34	.901
5	Equipment and Technique-Budget Allocation	3.28	.900
6	Equipment and Technique-Capability to Adopt	3.25	.796
7	Monitoring and Inspection-Frequency	3.23	.874
8	Equipment and Technique-Availability	3.09	.911
9	Monitoring and Inspection-Budget Allocation	3.04	.777

In Malaysia, condition-based maintenance is a new strategy to be adopted in building maintenance management. Thus, skill and knowledge of building manager towards condition-based maintenance are necessary to introduce this strategy to the management team. The skill and knowledge of building manager is rank the highest in the survey result, with a mean score of 3.71. The data were proven to be normally distributed with a standard deviation value of 0.808. This finding supports the statement of Ellis (2008) that building managers must have adequate skill and knowledge on the aspects of condition-based maintenance. In fact, the building manager must be able to plan, monitor and coordinate the overall process of this maintenance strategy, such as the adopted technique, required equipment and software, as well as type of training provided.

Then, the reliability of data on system condition is ranked second with 3.46 mean score and standard deviation value of 0.915, which demonstrated the widespread of data and eliminated the issue of bias. The statement of Qingfeng et al. (2011) is supported here, who stated that the success of condition-based maintenance is highly dependent on the reliability of condition and maintenance data. In condition-based maintenance, the need of maintenance tasks always relies on the system condition, which could be observed and monitored through the data recorded using monitoring techniques. Therefore, the reliability of data is deemed to be significant by the practitioners. Indeed, accurate data would ensure the success of condition-based maintenance. On the other hand, wrong data would lead to unwanted breakdown or failure occurs.

Similar to scheduled maintenance, budget allocation for building manager is one of the essential characteristics of condition-based maintenance. According to the survey result, the budget allocation for building manager is ranked third with a mean score of 3.43. The data are normally distributed with a standard deviation value of 0.807. Commonly, an experienced, skilful and knowledgeable manager would request high salary for his job. The level of experience, skill and knowledge are the influential aspects towards the amount of salary. Hence, budget allocation to recruit a skilled manager must be optimal.

In order to improve performance outcome by adopting the scheduled and condition-based maintenance, this study had suggested and reviewed a mechanism for the improvement, which is known as participative mechanism. The ranking of participative mechanisms is shown in Table 6.8.

Table 6.8: Ranking of participative mechanisms

Rank	Variable	Mean (N=120)	Std. Deviation
1	Provision of Training	3.62	1.014
2	Provision of Knowledge-Sharing and Communication Platform	3.46	.916
3	Clients' Commitment	3.42	.949
4	Level of Care by Users	3.36	.848
5	Users' Satisfaction and Feedback	3.21	.888
6	Manufacturers and Suppliers' Commitment	3.19	.833

Among six of the participative mechanisms, provision of training is ranked the highest, with a mean score of 3.62. Meanwhile, the standard deviation value of 1.014 indicates the widespread of data and eliminates the issue of bias. The statement of Groote (1995) that pointed out the significance of training and human resources development for maintenance performance improvement is hence supported. Definitely, provision of training would help to increase skill and knowledge of the maintenance personnel. After which, their quality of work could be improved. In fact, provision of training should be continuous because new technology and techniques emerge from time to time.

Then, provision of knowledge-sharing and communication platform is ranked second with 3.46 mean score. The data are proven to be normally distributed with a standard deviation value of 0.916. According to the result, the provision of knowledge-sharing and communication platform is deemed significant by the respondents, because it allows all the key participants of a building to communicate to each others. The findings supported the statement of Arditi and Nawakorawit (1999b) that the maintenance performance is likely to be improved if the communication among the key participants is effective. By having a good communication platform, understanding among the clients, maintenance personnel and building users could be achieved. For example, those understandings may include the objectives of the clients or organisations, problems encountered by the maintenance personnel, as well as needs of the building users.

Next, clients' commitment in maintenance management is ranked third, with a mean score of 3.42, and standard deviation value of 0.949. The statement of Marquez and Gupta (2006) revealing the involvement of clients and organisations in maintenance management as the key factor for maintenance success is supported. Basically, clients are the highest decision maker in maintenance management. It is vital that the clients involve themselves in maintenance management to deliver their objectives and needs to be achieved through the management. Indeed, maintenance personnel play a role to plan and execute the maintenance tasks, while clients are the party who decide and approve the maintenance plan that is prepared and suggested by the maintenance personnel. Meanwhile, amount of budget allocation for maintenance activities is decided by the clients. Therefore, the clients must be committed in maintenance management.

6.2.2) Correlation Analysis Result

a) Correlation between Characteristics of Scheduled Maintenance and Maintenance Performance

The relationship between characteristics of scheduled maintenance and maintenance performance was studied and analysed through SPSS software. The correlation analysis result is shown in Table 6.9.

Table 6.9: Correlation between characteristics of scheduled maintenance and maintenance performance

	Maintenance Downtime Variance	Maintenance Expenditure Variance	System Breakdown Rate	Number of Complaint Received
Skilled Labour-Budget Allocation	-.145	-.153	-.106	-.037
Skilled Labour-Skill and Knowledge	**-.332****	**-.417****	**-.337****	**-.285****
Skilled Labour-Number of Labours	-.112	-.182	-.133	-.024
Spare Parts and Materials-Budget Allocation	-.191	**-.232***	-.115	.000
Spare Parts and Materials-Level of Stock	**-.280****	**-.255***	**-.219***	-.093
Spare Parts and Materials-Quality	**-.283****	**-.327****	**-.333****	-.114
Predetermined Maintenance Interval-Budget Allocation	.058	.027	.038	-.169
Predetermined Maintenance Interval-Length of Interval	**.199***	**.301****	.144	-.044
Failure and Maintenance Downtime-Budget Allocation	-.114	-.099	.041	.124
Failure and Maintenance Downtime-Amount of Downtime	**.220***	**.207***	.189	.191

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

i) Relationship of Labour Skill and Knowledge to Maintenance Performance

According to the correlation analysis result obtained shown in Table 6.9, the skill and knowledge of maintenance labour was found to be significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate
- Number of complaint received

In scheduled maintenance, execution of maintenance tasks relies on the labour. Thus, the quality of work provided by the maintenance labour directly influences the maintenance performance outcomes (Groote, 1995). The statement is proven by the analysis result.

The findings demonstrated that the level of skill and knowledge of maintenance labour is significantly correlated to the maintenance downtime variance. When the maintenance labours are trained with proper skill and knowledge in executing a task, they can detect and fix the problem quickly and accurately without delay. Furthermore, the probability of mistake and error made by the labours can be minimised. Consequently, the exact maintenance downtime will be minimal in accordance to the planned maintenance downtime. In this case, the higher the level of labour skill and knowledge, the lesser the maintenance downtime variance will occur.

Then, the level of skill and knowledge of labour is significantly correlated to the maintenance expenditure variance and system breakdown rate. The labour without proper skill and knowledge are more likely to misjudge and misinterpret the condition or problem of a system. The repair and replacement works done by such labour might not be appropriate. As a result, further damages will occur and additional repair works will be required. As such, the task spends additional maintenance cost and this leads to the issue of over-budget. Meanwhile, the system breakdown rate increases.

Building clients and users demand the maintenance labours to provide good quality of work at all time. The result stated that the level of labour skill and knowledge is significantly correlated to the number of complaints received from building clients and users. When the maintenance labours fail to perform the tasks to maintain the building systems above the acceptable standard, the daily activities of building clients and users can be affected. Therefore, they will be complaining on the poor skilled labours that lead to the occurrence of unwanted maintenance problems.

ii) Relationship of Spare Parts and Materials Budget Allocation to Maintenance Performance

A significant correlation was detected between budget allocation for spare part and maintenance expenditure variance as shown in Table 6.9. Since Horner et al. (1997) noted that spare parts and materials is much more required for scheduled maintenance compared to other maintenance strategies, the budget allocation for spare parts and material must be adequate. In fact, sufficient budget allocation for spare parts could ensure the adequate level of stock. Furthermore, better quality spare parts could be obtained without budget constraint. In some circumstances, the organisations refuse to allocate adequate budget for spare part. At the end, the issues of poor management on stock and quality of spare parts came up, which is the factor that leads to delay of maintenance task and unwanted damage. Hence, the exact maintenance expenditure exceeds the amount of planned maintenance expenditure.

iii) Relationship of Spare Parts and Materials Stock Level to Maintenance Performance

Table 6.9 states that the level of spare parts and materials stock is significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

Level of spare parts and materials stock is another aspect highly concerned in scheduled maintenance. By implementing scheduled maintenance, the parts of a building system are required to be replaced at a fixed interval, without inspecting the condition and remaining lifetime of such parts. Thus, greater amount of spare parts are needed to replace the existing parts.

The findings demonstrated that the level of spare parts and materials stock is significantly correlated to the maintenance downtime variance. Sufficient stock of spare part ensures the replacement or maintenance tasks to be done on time. In some circumstances, maintenance labour finds no spare part available for the execution of maintenance tasks. Thus, delay of maintenance works occur and the system downtime is forced to be extended. Consequently, the exact maintenance downtime varies from the planned downtime.

Then, the level of spare parts and materials stock is found to be significantly correlated to the maintenance expenditure variance. The analysis result supported the statement of Tsang (1995) that said accurate spare parts identification and stocking help to control and reduce the operation and maintenance cost. In fact, proper management of spare parts ensures sufficient amount of spare parts to be used for the maintenance works. For example, the maintenance personnel will be urged to order small amount of spare parts to execute the maintenance works when there are no adequate spare part stocks. It usually costs higher to order small amount of spare part instead of large amount. As a result, the variance of maintenance expenditure occurs.

Furthermore, the findings revealed that the level of spare parts and materials stock is significantly correlated to the system breakdown rate. The statement of Eti et al. (2006) is supported, which pointed out that adequate spare parts and materials allocation will be able to minimise maintenance cost without jeopardising the quality of building systems. When there are no sufficient spare parts and materials available for the execution of maintenance works, the condition of the building systems are likely to be deteriorated. Further damages might occur due to the deterioration. Therefore, the system breakdown rate increases.

iv) Relationship of Spare Parts and Materials Quality to Maintenance Performance

The quality of spare parts and materials is demonstrated to be significantly correlated with the maintenance performance as shown in Table 6.9, which includes:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

The analysis result supports the statement of Ali et al. (2010) mentioning that the quality of spare parts and materials always has an impact towards maintenance performance. Good quality spare parts and materials ensure the building systems to operate effectively without affecting the activities of building users.

The Spearman's rank correlation coefficient detected a significant correlation between the quality of spare part and maintenance downtime variance. The result supported the statement of De Silva and Raninghe (2010) that selection of good quality spare parts and materials can reduce the maintenance downtime loss. As Zuashkiani et al. (2011) mentioned poor quality spare parts and materials have shorter service lifespan instead of the good one, using poor quality spare parts and materials will lead to more defects in a system. Hence, the quality of spare parts and materials influences the variance of maintenance downtime.

Meanwhile, the findings demonstrated that the quality of spare part and maintenance expenditure variance are significantly correlated. Again, the statement of De Silva and Ranasinghe (2010) is supported, which revealed that good quality spare parts and materials can optimise the maintenance expenditure. Poor quality spare parts and materials are likely to damage and cause unwanted failure to the building systems. Thus, additional repair and replacement works are required. Extra maintenance expenditure is needed and variance of maintenance expenditure exists.

The analysis result is also signifying that the quality of spare parts and materials is significantly correlated to the system breakdown rate. This is parallel with the statement by Zuashkiani et al. (2011) stating that use of poor quality spare parts and materials will lead to more defects and increases the system breakdown rate. The building clients always request to obtain the lowest price for spare parts and materials, but ignoring the quality. This implicates more occurrence of unpredictable failure. Consequently, the system breakdown rate increases.

v) Relationship of Predetermined Maintenance Interval to Maintenance Performance

According to the correlation analysis result shown in Table 6.9, the length of predetermined maintenance interval is significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance

The length of predetermined maintenance interval is a vital aspect to be considered in scheduled maintenance. Planning of accurate predetermined maintenance interval ensures the parts of building systems to be replaced and repaired on time, so that the conditions of building systems stay above the acceptable standard and operate effectively to support the building purpose.

In this study, the length of predetermined maintenance interval is found to be significantly correlated to the maintenance downtime variance. The analysis result supported the statement of Bahrami et al. (1999), pointing out that if scheduled maintenance is performed rarely, downtime due to sudden breakdown will increase. In fact, the length of fixed maintenance interval must be optimal to ensure that there are no over intrusions to the building systems due to frequent maintenance works, or unwanted failure due to the delay on execution of maintenance works.

Furthermore, the length of fixed maintenance interval is significantly correlated to the maintenance expenditure variance. The correlation analysis result is in line with the statement of Narayan (2003), which has proven that delay or failure to perform maintenance work at the right time may implicate further damages or defects to the system components. Thus, additional repair and replacement costs are required to restore the system back to its acceptable operation standard. Nevertheless, optimal maintenance interval must be achieved. Although frequent maintenance is able to enhance the quality of a system, it is costly at the same time (Moghaddam and Usher, 2010).

vi) Relationship of Failure and Maintenance Downtimes to Maintenance Performance

Table 6.9 also reveals that the amount of failure and maintenance downtimes is significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance

Failure and maintenance downtimes involve the time required for detection, repair or replacement and restarting the system (Bevilacqua and Braglia, 2000). The downtimes imply unavailability of services and facilities. Thus, proper planning for the downtimes is necessary to retain and improve the maintenance performance.

The analysis result shows that the amount of failure and maintenance downtimes allocated during the planning stage is significantly correlated to its variance. In this study, the variance is the difference of the planned and exact maintenance downtimes. When there is a high amount of downtimes, more downtime variance will occur. In fact, the failure downtime needs to be minimised, because as Zuashkiani et al. (2011) noted, the breakdown may cause collateral damage in the system. As a result, additional maintenance downtime will be required to repair the system.

Meanwhile, the amount of failure and maintenance downtimes is significantly correlated to the maintenance expenditure variance. The statement of Chareonsuk et al. (1997) is supported, which stated that the downtime might be very costly. The maintenance expenditure is likely to vary as more downtimes occur in a building system. Therefore, the downtime for maintenance must be well managed to avoid unnecessary cost. Minimal failure and maintenance downtimes should be obtained in building maintenance.

b) Correlation between Characteristics of Condition-Based Maintenance and Maintenance Performance

The relationship between characteristics of condition-based maintenance and maintenance performance was studied and analysed through SPSS software. The correlation analysis result is shown in Table 6.10.

Table 6.10: Correlation between characteristics of condition-based maintenance and maintenance performance

	Maintenance Downtime Variance	Maintenance Expenditure Variance	System Breakdown Rate	Number of Complaint Received
Skilled Manager-Budget Allocation	-.062	-.089	-.041	-.046
Skilled Manager-Skill and Knowledge	**-.222***	**-.276****	**-.291****	**-.269****
Equipment and Technique-Budget Allocation	-.152	**-.249***	-.114	-.102
Equipment and Technique-Availability	**-.281****	**-.350****	-.168	-.176
Equipment and Technique-Capability to Adopt	**-.341****	**-.240***	**-.318****	**-.239***
Acquisition of Data-Budget Allocation	-.176	**-.210***	-.140	-.052
Acquisition of Data-Reliability	**-.348****	**-.394****	**-.383****	**-.200***
Monitoring and Inspection-Budget Allocation	-.186	-.187	-.075	-.084
Monitoring and Inspection-Frequency	-.170	-.138	**-.218***	-.146

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

i) Relationship of Manager Skill and Knowledge to Maintenance Performance

The correlation analysis result shown in Table 6.10 demonstrates that the skill and knowledge of maintenance manager is found to be significantly correlated with:

- Maintenance downtime variance

- Maintenance expenditure variance
- System breakdown rate
- Number of complaint received

In condition-based maintenance, vigorous analysis on the data and information of systems condition is required. In order to ensure the efficiency of condition-based maintenance, skilful and knowledgeable maintenance manager is needed for allocating appropriate manpower, providing training, monitoring the system conditions, as well as supervising the execution of inspection and maintenance works.

It is found that the level of manager skill and knowledge is significantly correlated to the maintenance downtime variance. Maintenance manager must be able to detect abnormal condition of building systems through data collected from monitoring and inspection. Next, the manager should instruct the maintenance technician to execute appropriate maintenance work, such as replacing a deteriorated part from the system. Failure to rectify the problem may cause failure to the system. Consequently, downtime increases as the maintenance team needs to spend more time to fix the system back to its original state. These findings are supported by the statement of Ellis (2008), mentioning that building manager should understand the failure modes and rates, asset criticality, and other essential factors while working on condition-based maintenance.

Then, the analysis result stated that the level of manager skill and knowledge is significantly correlated to the maintenance expenditure variance. Condition-based maintenance is meant to prevent system failure by monitoring the system condition and restoring the system to its required standard before failure occurs. When a manager does not have sufficient skill and knowledge to adopt the condition-based maintenance effectively, defects and failures are likely to occur. Thus, additional maintenance cost will be required for the repair works. As a result, the exact maintenance expenditure varies from the planned maintenance expenditure.

Meanwhile, significant correlation is demonstrated between the skill and knowledge of manager and the system breakdown rate. In fact, the efficiency of condition-based maintenance relies on the skill and knowledge of maintenance manager. In order to execute the maintenance efficiently, high level of training is required for the maintenance personnel (Swanson, 2001; Carnero, 2006). Due to inadequate skill and knowledge of manager in condition-based maintenance, lack of proper provision in training the maintenance personnel often occurs. So, the maintenance personnel are likely to make mistake and error in executing the maintenance tasks. Therefore, the probability of system breakdown rate increases.

Moreover, the level of manager skill and knowledge is significantly correlated to the number of complaints received. Since the correlation analysis result had supported the statement of Ellis (2008), mentioning that the maintenance performance can be jeopardised without a skilled and knowledgeable manager, the building clients and users will definitely be unsatisfied with the maintenance outcome. For instance, the building clients will complain about the issue of poor management by the manager; while building users will complain about the delay of maintenance work and increased failure rate that causes the unavailability of building services and facilities. Hence, the number of complaints increases because of the insufficient manager skill and knowledge.

ii) Relationship of Equipment and Technique Budget Allocation to Maintenance Performance

The Spearman's rank correlation coefficient as shown in Table 6.10 reveals significant correlation between the equipment and technique budget allocation and the maintenance expenditure variance. The findings supported Carnero (2006) who noted that the equipment and technology for condition based monitoring system might be complicated and costly for an organisation. It is important to have adequate budget allocation for obtaining the condition monitoring equipment and technique. The budget should cover the cost to buy the tools and equipment and cost to train the maintenance personnel in adopting the condition monitoring technique. If allocated budget is not adequate, the condition monitoring system might be ineffective. Thus, the inaccurate monitoring and inspection data lead to misinterpretation of defective and deteriorated system. Sudden failure might occur to the system. As a result, exact maintenance cost varies from the planned maintenance cost due to additional cost for repair works.

iii) Relationship of Equipment and Technique Availability to Maintenance Performance

Table 6.10 reveals that the availability of equipment and technique is significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance

According to Davies (1995) and Edward et al. (1998), the condition monitoring technology assists the maintenance personnel in tracking the condition of building systems and to prevent failure that occurs by executing maintenance tasks when necessary. The availability of condition monitoring technology may help to improve the maintenance outcome.

The result stated that the availability of equipment and technique is significantly correlated to maintenance downtime variance. Without proper equipment and technique, the condition-based maintenance will not be efficient. This supported Ugechi et al. (2009), who argued that condition monitoring is not reliable because the judgement and decisions are often made by the maintenance personnel who relied on their senses of hearing and sight without proper tools and equipment. When the equipment and technology are not available in condition monitoring, the condition data collected will not be accurate. In this case, sudden breakdown tends to occur because of the inefficient maintenance strategy. Consequently, downtime for failure and repair work is extended. In the end, the exact maintenance downtime varies from the planned maintenance downtime.

In addition, it is found that the availability of equipment and technique is significantly correlated to the maintenance expenditure variance. Since Tsang (1995) mentioned that the availability of reliable monitoring and inspection technology is one of the factors to be concerned about in condition-based maintenance, the selection of monitoring equipment and technique must be suitable for the monitoring and inspection of building systems. If the maintenance team owns the proper equipment and technology to execute condition-based maintenance, the building systems can be retained in the acceptable standard. Therefore, the probability of system failure is minimised. The maintenance expenditure variance is prevented as well because emergency repair cost is reduced.

iv) Relationship of Capability to Adopt Equipment and Technique to Maintenance Performance

According to the correlation analysis result obtained as shown in Table 6.10, the capability to adopt equipment and technique is found to be significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate
- Number of complaints received

Specific monitoring and inspection tools and equipment require the expertise to operate and use them in condition-based maintenance. Whereby, Veldman et al. (2011) mentioned that the need of training is highly demanded for condition-based maintenance to ensure that the maintenance personnel are capable to use and adopt the tools and technique.

The analysis result demonstrated that the capability to adopt equipment and technique is significantly correlated to the maintenance downtime variance. In fact, one of the purposes of condition-based maintenance is to prevent failure and minimise downtime. However, if the maintenance personnel are not capable to use the condition based monitoring tools appropriately, the efficiency of the maintenance system will be jeopardised. For example, the observation of system condition is inaccurate as the maintenance personnel inspect and monitor the building system by using wrong technique. Subsequently, sudden damage is likely to occur and further repair work is required to treat the problem. This causes the variation of maintenance downtime.

Meanwhile, the capability to adopt equipment and technique is found to be significantly correlated to the maintenance expenditure variance. According to Carnero (2006), it is complicated and costly for an organisation to acquire the condition monitoring tools and technology. If yet, the maintenance personnel are not capable to utilise those tools and technology, more maintenance issues might be occurring. Additional maintenance cost will be needed to solve the problems. Therefore, the exact maintenance expenditure varies from the planned one.

Moreover, the damage of parts and failure of a building system reflects the system breakdown rate of the system. Since the incapability to adopt condition-based monitoring equipment and technique is likely to implicate unwanted damage and failure to occur, system breakdown rate increases accordingly. The statement is supported by the correlation analysis result. Whereby, the capability to adopt equipment and technique for condition monitoring is significantly correlated to the system breakdown rate. In other words, lower system breakdown rate is obtained as the level of capability to utilise condition monitoring tools and technology is higher.

Furthermore, the Spearman's rank correlation coefficient detected significant correlation between the capability to adopt condition monitoring technique and the number of complaints received. When the building clients have allocated large amount of budget in acquiring the condition monitoring tools and technology, they will expect better maintenance outcome. Unfortunately, in case where the maintenance personnel are not capable to utilise the tools and technology, as well as improve the maintenance performance, the building clients and users will not be satisfied with the service provided by the maintenance team. Hence, number of complaints received from the building clients and users will increase.

v) Relationship of Budget Allocation for Data Acquisition to Maintenance Performance

The correlation analysis result as shown in Table 6.10 demonstrated that the budget allocation for data acquisition is significantly correlated to the maintenance expenditure variance. In fact, budget allocation for acquisition of maintenance data is required as Bevilacqua and Braglia (2000) argued that the data and information systems are the necessary applications to perform condition-based maintenance. Commonly, acquisition and documentation of maintenance data require various items to serve the purposes, such as computer, related hardware and software programs. Thus, adequate budget allocation is required to set up the data acquisition and documentation system. Otherwise, an efficient data acquisition and documentation system cannot be obtained. Without accurate data, the execution of condition-based maintenance will not be successful. Unwanted errors and defects are likely to occur. As a result, more maintenance expenses are required to fix such errors and defects. The findings supported Hameed et al. (2010) that had stated that there is a cost to acquire an effective data acquisition and documentation system.

vi) Relationship of Reliable System Data to Maintenance Performance

Table 6.10 shows that the reliability of system data and information is significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate
- Number of complaints received

System condition data and information is one of the most important aspects to be considered in condition-based maintenance. In this maintenance strategy, the maintenance tasks such as replacement works are implemented when the parts are almost at the end of their lifetime by referring to the condition data. Hence, the condition-based maintenance can only be successful, provided that the system condition data are reliable and accurate.

According to the correlation analysis result, it is found that the reliability of maintenance data and information significantly is correlated to the maintenance downtime variance. Unreliable system condition data are indeed the factor that causes inappropriate maintenance program. The deterioration and defect of building systems might not be able to be detected because of the inaccurate data. Hence, damage will occur and extending to maintenance downtime for repair purpose. The statement of Qingfeng et al. (2011) is supported here, which explains that the planning and execution of maintenance task are highly dependent on the reliability of condition and maintenance data.

Furthermore, the reliability of data and information is found to be significantly correlated to the maintenance expenditure variance. The primary aim of condition-based maintenance is to prevent failure from occurring by monitoring the condition of building systems. Basically, emergency repair cost will not be allocated in planning stage of this maintenance strategy. However, when the obtained system condition data is not reliable and accurate, the occurrence of sudden breakdown may not be able to be avoided. As a result, additional maintenance expenditure is required for the repair work and varies from the planned maintenance expenditure.

The findings also revealed that the reliability of data and information is significantly correlated to the system breakdown rate. Definitely, when the condition and maintenance data are not reliable, the performed maintenance activities might not accurately upkeep the condition of building systems. The building systems deteriorate continuously and finally damage and breakdown occur. Therefore, unreliable condition and maintenance data are not able to prevent the occurrence of damage and failure, but it increases the system breakdown rate.

Furthermore, the reliability of condition and maintenance data is significantly correlated to the number of complaints received. After spending certain amount of money for setting up the data acquisition and documentation system, the reliability of data and information still is not able to be acquired. Undoubtedly in this case, the building clients and users will surely be unsatisfied with the maintenance team. The number of complaints will be increasing as the defect and failure cannot be prevented. Thus, the correlation analysis result on reliability of data and information supported Jardine et al. (2006) and Irigaray (2009), who noted that condition-based maintenance will not be successful with lack of reliable data.

vii) Relationship of Monitoring and Inspection Frequency to Maintenance Performance

The Spearman's rank correlation coefficient as shown in Table 6.10 shows a significant correlation between the monitoring or inspection frequency and the system breakdown rate. Basically, frequency of monitoring and inspection towards the building systems ensures the accuracy of awareness on the changes of systems' condition. The result supported the statement of Hameed et al. (2010), that the ability to monitor and inspect the condition of systems at the right time influences the planning of maintenance activities prior to failure. In other words, the more frequent the conditions of building systems are monitored and inspected, the earlier the defects of building systems can be identified. Then, maintenance tasks can be planned and performed to prevent the occurrence of part damage or system failure. Consequently, the system breakdown rate can be minimised.

c) Correlation between Participative Mechanisms and Maintenance Performance

The relationship between participative mechanisms and maintenance performance was studied and analysed through SPSS software. The correlation analysis result is shown in Table 6.11.

Table 6.11: Correlation between participative mechanisms and maintenance performance

	Maintenance Downtime Variance	Maintenance Expenditure Variance	System Breakdown Rate	Number of Complaint Received
Provision of Knowledge-Sharing and Communication Platform	**-.268******	**-.250******	**-.213****	-.065
Provision of Training	**-.310******	-.164	**-.384******	-.125
Clients' Commitment	**-.260******	**-.231****	**-.217****	-.060
Users' Satisfaction and Feedback	**-.200****	-.169	-.165	-.169
Level of Care by Users	-.089	-.125	-.140	-.128
Manufacturers and Suppliers' Commitment	.006	.036	-.046	-.152

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

i) Relationship of Knowledge-Sharing and Communication Platform to Maintenance Performance

According to the correlation analysis result as shown in Table 6.11, the provision of knowledge-sharing and communication platform is found to be significantly correlated with:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

A good provision of knowledge-sharing and communication platform in maintenance management is vital to discuss and understand the objectives of organisation, needs of building users, as well as the strategies of maintenance team (Arditi and Nawakorawit, 1999a). Thus, the involvement of the key participants is compulsory, which includes the building clients, users or occupants, and maintenance personnel.

The findings stated that the provision of knowledge-sharing and communication platform is significantly correlated to the maintenance downtime variance. By having periodical meeting among the clients, users and maintenance personnel, issues and problems related to maintenance can be discussed and resolved. For example, when the maintenance personnel detect abnormal condition on the building system, they can raise up the issue to client and get permission to acquire fund or material for the maintenance task in the meeting. Therefore, maintenance task can be performed on time and this will minimise the downtime, which include the maintenance and failure downtime.

Meanwhile, it is also found that the provision of knowledge-sharing and communication platform is significantly correlated to the maintenance expenditure variance. It is important that the meeting to be organised regularly to ensure all the maintenance activities are kept on track. The clients and users must be able to supervise the maintenance team on the execution of maintenance works. If the clients and users always keep an eye on the performance of the maintenance team, the quality of tasks performed by the maintenance team can be guaranteed. Hence, the building systems are maintained in good condition with minimal defect or failure. In this case, planned maintenance expenditure will be sufficient and variation on maintenance expenditure can be avoided.

In addition, the provision of knowledge-sharing and communication platform is found to be significantly correlated to the system breakdown rate. Besides meeting, the provision of feedback and complaint forms allows the building users to inform the maintenance team when there is any abnormal condition detected in a building system. Then, immediate maintenance action can be implemented to treat the problem. Consequently, the system breakdown rate can be reduced and minimised. The result is supported Bandy (2003), who demonstrated the importance of maintenance management to provide feedback and complaint forms to gather the users' concerns and take action to eliminate these concerns.

ii) Relationship of Training Provision to Maintenance Performance

Table 6.11 also reveals that the provision of training is identified to be significantly correlated with:

- Maintenance downtime variance
- System breakdown rate

The maintenance personnel must be well trained in executing the maintenance activities as Groote (1995) pointed out that training and human resources development is one of the significant criteria for improvement of maintenance performance. Without proper provision of training, the maintenance personnel might not be able to perform their tasks efficiently.

The Spearman's rank correlation coefficient detected significant correlation between the provision of training and maintenance downtime variance. The statement of Ali et al. (2010) and Zuashkiani et al. (2011) is supported, which noted that lack of training always leads to human error and low maintenance capacity. The skill and knowledge of maintenance personnel can always be gathered from training. Then, lack of training affects the quality of maintenance works. Errors and mistakes are likely to be made by the maintenance personnel. As a result, longer and additional maintenance time is required.

Furthermore, the provision of training is found to be significantly correlated to the system breakdown rate. The findings supported the statement of Edward et al. (1998) that one of the root causes of failure in maintenance is inadequate operative training. Normally, the maintenance personnel with lack of training are more likely to make errors while performing their task. For example, in cases where they connect the wire or cable wrongly among the parts of system, this will cause malfunction to the system. Then, it may further damage other parts and implicates failure of the system. Therefore, the system breakdown rate increases when there is lack of training provision.

iii) Relationship of Clients' Commitment to Maintenance Performance

The Spearman's rank correlation coefficient as shown in Table 6.11 revealed significant correlation between the clients' commitment with:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

Generally, one of the aims of building maintenance is to support the core business and activities of the organisations and building users respectively. Thus, the planning of maintenance policy must be parallel to the organisation's objective. Whereby, Amaratunga and baldry (2002) pointed out that the organisation should be able to commit in setting agreed-upon performance goals, allocating and prioritising sufficient resources or budgets, and other responsibilities in maintenance management. It is important that the clients commit themselves in maintenance management to deliberate and deliver their needs and requirements with the maintenance team.

In this study, the clients' commitment is found to be significantly correlated to the maintenance downtime variance. In most circumstances, clients' decisions are the final decisions to initiate most of the maintenance programs. The maintenance team always follows the instructions and decisions from clients in executing the maintenance works. Thus, the clients' commitment in giving instructions and making decisions related to the maintenance issues on a regular basis is necessary so that the maintenance team can perform their tasks at the right time. Otherwise, the severity of system deterioration may become worse. As a result, more maintenance downtime is required to restore the system back to its original state.

Moreover, the analysis result demonstrated that the clients' commitment is significantly correlated to the maintenance expenditure variance. Majority of the clients neglect the significance of building maintenance, they are not willing to spend much on maintenance activities without understanding the impacts. This is in agreement with the statement from Chau et al. (2003), which argued that the most of the maintenance works are selected solely on the basis of lowest capital cost and hence implicating the quality problems. By allocating insufficient budget for maintenance programs, the maintenance outcome or quality could be affected. Then, unpredictable damage and failure are likely to occur. Consequently, the exact maintenance expenditure increases and varies from the planned maintenance expenditure.

Moreover, it is also found that the clients' commitment is significantly correlated to the system breakdown rate. Lack of clients' commitment is an issue that leads to poor planning and implementation of maintenance management (Syed and Kamaruzaman, 2008). In other words, commitment of clients in maintenance management directly influences the maintenance process and its outcome. For instance, without permission and budget allocation given by the clients, a maintenance task could not be executed. Therefore, the building systems deteriorate continuously and the system breakdown rate increases at the end.

iv) Relationship of Users' Satisfaction and Feedback to Maintenance Performance

According to the correlation analysis result as shown in Table 6.11, the users' satisfaction and feedback is found to be significantly correlated to the maintenance downtime variance. The findings supported Rahmat and Ali (2010b), who mentioned that informal communication such as face-to-face meeting between building users and maintenance personnel is able to provide immediate feedback regarding the system condition. Hence, it enables relevant remedial works to be executed at the right time before any failure occurs. For instance, when the building users detect that the movement of lift is not smooth and report to the management office immediately, the maintenance personnel can examine and inspect the condition of lift instantly. Then, maintenance work can be performed if it is required to prevent system breakdown from occurring. So, the maintenance and failure downtime can be minimised and avoided respectively.

6.2.3) Binary Logistic Regression Analysis Result

a) Binary Logistic Regression: Characteristics of Scheduled Maintenance towards Maintenance Performance

Binary logistic regression was conducted to access whether the ten independent variables from characteristics of scheduled maintenance and the nine independent variables characteristics of condition-based maintenance can significantly predict the maintenance performance, which include:

- Maintenance downtime extension
- Maintenance expenditure over-budget
- Non-Zero breakdown
- Non-Zero complaint

i) Characteristics of Scheduled Maintenance that Affect Probability of Downtime Extension

According to the correlation analysis result, five characteristics are found to be significantly correlated with maintenance downtime variance. So, logistic regression analysis for downtime extension was run by including the significant characteristics as its predictors, which are:

- Level of labour skill and knowledge (LSK)
- Level of spare parts and materials stock (PMS)
- Quality of spare parts and material (PMQ)
- Length of predetermined maintenance interval (LPM)
- Amount of failure and maintenance downtime (AMD)

In the analysis, downtime extension was coded with value 0 and 1, while "no extension" and "extension" were labelled as 0 and 1 respectively. By using forward stepwise method, SPSS produced one step to include the predictor that significantly contributed to the logistic regression model. As an outcome, only one independent variable ca significantly predicts whether or not the downtime extension has occurred ($X^2 = 13.13$, $p < .05$).

In this case, 16.3% of the variance in downtime extension could be predicted from the level of labour skill and knowledge. Furthermore, the p-value for Hosmer-Lemeshow goodness of fit is 0.746, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation is produced as follows (refer Table 6.12):

$$Z = 3.064 - 0.812 \text{ LSK}$$

Table 6.12: Variables in the Equation (characteristics of scheduled maintenance - downtime extension)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.812	.243	11.163	1	.001	.444
	Constant	3.064	.877	12.207	1	.000	21.404

a. Variable(s) entered on step 1: LabourSkill.

Therefore, level of labour skill and knowledge is a significant characteristic that affect probability of downtime extension.

ii) Characteristics of Scheduled Maintenance that Affect Probability of Over-Budget

The correlation analysis result pointed out that six characteristics were found to be significantly correlated with maintenance expenditure variance. Thus, logistic regression analysis for probability of over-budget was run by including the significant characteristics as its predictors, they are:

- Level of labour skill and knowledge (LSK)
- Budget allocation for spare parts and materials (PMB)
- Level of spare parts and material stock (PMS)
- Quality of spare parts and materials (PMQ)
- Length of predetermined maintenance interval (LPM)
- Amount of failure and maintenance downtime (AMD)

The SPSS coded the probability of over-budget with 0 as “no over-budget” and 1 as “over-budget”. By using forward stepwise method, SPSS produced four steps to include the predictors that significantly contributed to the logistic regression model. Step 1 revealed first independent variable significantly predicting the odds of over-budget with $X^2 = 16.79$, $p < .05$. Then, Step 2 computed second independent variable with $X^2 = 8.26$, $p < .05$. Therefore, there are two independent variables significantly predicting whether or not the over-budget has occurred ($X^2 = 25.05$, $p < .05$).

In this case, 29.4% of the variance in over-budget could be predicted from the level of labour skill and knowledge as well as length of predetermined maintenance interval.

Meanwhile, the p-value for Hosmer-Lemeshow goodness of fit is 0.869, which is more than 0.05. Thus, the model adequately fit the data. Then, the logistic regression equation is produced as follows (refer Table 6.13):

$$Z = 1.237 – 0.963\ \text{LSK} + 0.728\ \text{LPM}$$

Table 6.13: Variables in the Equation (characteristics of scheduled maintenance – over-budget)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.936	.253	13.653	1	.000	.392
	Constant	3.403	.908	14.049	1	.000	30.059
Step 2[b]	LabourSkill	-.963	.265	13.248	1	.000	.382
	IntervalLength	.728	.269	7.328	1	.007	2.072
	Constant	1.237	1.185	1.091	1	.296	3.446

a. Variable(s) entered on step 1: LabourSkill.

b. Variable(s) entered on step 2: IntervalLength.

Hence, levels of labour skill and knowledge as well as length of predetermined maintenance interval are the significant characteristics that affect probability of over-budget.

iii) Characteristics of Scheduled Maintenance that Affect Probability of Non-Zero Breakdown

According to the correlation analysis result, three characteristics were found to be significantly correlated with system breakdown rate. Thus, logistic regression analysis for non-zero breakdown was executed by including the significant characteristics as its predictors, which are:

- Level of labour skill and knowledge (LSK)
- Level of spare parts and materials stock (PMS)

- Quality of spare parts and materials (PMQ)

The logistic regression analysis result stated that probability of non-zero breakdown is coded as 0 and 1 for "zero breakdown" and "no zero breakdown" respectively. By using forward stepwise method, SPSS produced a step to include the predictor that significantly contributes to the logistic regression model. As an outcome, only one independent variable can significantly predict whether or not the zero breakdown has occurred ($X^2 = 4.61$, $p < .05$).

In this case, 11.3% of the variance in zero breakdown could be predicted from the level of labour skill and knowledge. In addition, the p-value for Hosmer-Lemeshow goodness of fit is 0.609, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation is produced as follows (refer Table 6.14):

$$Z = 6.182 - 0.952 \text{ LSK}$$

Table 6.14: Variables in the Equation (characteristics of scheduled maintenance – non-zero breakdown)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.952	.482	3.901	1	.048	.386
	Constant	6.182	2.009	9.474	1	.002	484.080

a. Variable(s) entered on step 1: LabourSkill.

As a result, level of labour skill and knowledge are the significant characteristics that affect the odds of non-zero breakdown.

iv) Characteristics of Scheduled Maintenance that Affect Probability of Non-Zero Complaint

The correlation analysis result determined that only one characteristic is significantly correlated with number of complaints received. Thus, logistic regression analysis for non-zero complaint was run by including the only significant characteristic as its predictor, which is level of labour skill and knowledge (LSK).

According to the analysis result, non-zero complaint was coded with value 0 and 1. Whereby, "zero complaint" and "no zero complaint" were labelled as 0 and 1 respectively. By using forward stepwise method, SPSS produced one step to include the predictor that significantly contributes to the logistic regression model. As an outcome, only one independent variable significantly predicts whether or not the zero complaint has occurred ($X^2 = 5.85$, $p < .05$).

In this case, 10.5% of the variance in zero complaint could be predicted from the level of labour skill and knowledge. Furthermore, the p-value for Hosmer-Lemeshow goodness of fit is 0.059, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation is produced as follows (refer Table 6.15):

$$Z = 4.833 – 0.796 \text{ LSK}$$

Table 6.15: Variables in the Equation (characteristics of scheduled maintenance – non-zero complaint)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.796	.351	5.133	1	.023	.451
	Constant	4.833	1.407	11.807	1	.001	125.595

a. Variable(s) entered on step 1: LabourSkill.

Consequently, level of labour skill and knowledge is the significant characteristics that affect the odds of non-zero complaint.

According to the four (4) regression models, it is summarised that the significant predictors of maintenance performance for scheduled maintenance are level of labour skill and knowledge, as well as length of predetermined maintenance interval.

b) Binary Logistic Regression: Characteristics of Condition-Based Maintenance towards Maintenance Performance

Binary logistic regression analysis was conducted to access whether the nine independent variables from characteristics of scheduled maintenance can significantly predict the maintenance performance, which are:

- Maintenance downtime extension
- Maintenance expenditure over-budget
- Zero breakdown
- Zero complaint

i) Characteristics of Condition-Based Maintenance that Affect Probability of Downtime Extension

According to the correlation analysis result, four characteristics were found to be significantly correlated with maintenance downtime variance. So, logistic regression analysis for downtime extension was run by including the significant characteristics as its predictors including:

- Level of manager skill and knowledge (MSK)
- Availability of monitoring equipment and technique (AET)
- Capability to adopt monitoring equipment and technique (CAT)

- Reliability of maintenance data (RMD)

The logistic regression analysis result stated that odds of downtime extension are coded as 0 and 1 for “no extension” and “extension” respectively. By using forward stepwise method, SPSS produced one step to include the predictor that significantly contributes to the logistic regression model. As an outcome, only one independent variable significantly predicts whether or not the downtime extension has occurred (X^2 = 13.73, $p < .05$).

In this case, 17.2% of the variance in downtime extension could be predicted from the capability to adopt monitoring equipment and technique. Moreover, the p-value for Hosmer-Lemeshow goodness of fit is 0.354, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation is produced as follows (refer Table 6.16):

$$Z = 3.734 - 1.061 \text{ CAT}$$

Table 6.16: Variables in the Equation (characteristics of condition-based maintenance - downtime extension)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	EquipmentAdopt	-1.061	.318	11.148	1	.001	.346
	Constant	3.734	1.079	11.983	1	.001	41.828

a. Variable(s) entered on step 1: EquipmentAdopt.

Therefore, the capability to adopt monitoring equipment and technique is the significant characteristic that affects probability of downtime extension.

ii) Characteristics of Condition-Based Maintenance that Affect Probability of Over-Budget

The correlation analysis result pointed out that six characteristics were found to be significantly correlated with maintenance expenditure variance. Thus, logistic regression analysis for probability of over-budget was performed by including the significant characteristics as its predictors and they are:

- Level of manager skill and knowledge (MSK)
- Budget allocation for monitoring equipment and technique (BET)
- Availability of monitoring equipment and technique (AET)
- Capability to adopt monitoring equipment and technique (CAT)
- Budget allocation for maintenance data acquisition (BDA)
- Reliability of maintenance data (RMD)

According to the analysis result, probability of over-budget was coded with value 0 and 1. Whereby, "no over-budget" and "over-budget" were labelled as 0 and 1 respectively. By using forward stepwise method, SPSS produced one step to include the predictor that significantly contributes to the logistic regression model. As an outcome, only one independent variable significantly predicts whether or not the over-budget has occurred (X^2 = 11.29, $p < .05$).

In this case, 14.4% of the variance in over-budget could be predicted from the reliability of maintenance data. Meanwhile, the p-value for Hosmer-Lemeshow goodness of fit is 0.085, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation is produced as follows (refer Table 6.17):

$$Z = 3.173 - 0.812 \text{ RMD}$$

Table 6.17: Variables in the Equation (characteristics of condition-based maintenance – over-budget)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	DataReliability	-.812	.261	9.704	1	.002	.444
	Constant	3.173	.950	11.164	1	.001	23.879

a. Variable(s) entered on step 1: DataReliability.

So, reliability of maintenance data is the significant characteristic that affects the odds of over-budget.

iii) Characteristics of Condition-Based Maintenance that Affect Probability of Non-Zero Breakdown

According to the correlation analysis result, four characteristics were found to be significantly correlated with the system breakdown rate. So, logistic regression analysis for non-zero breakdown was executed by including the significant characteristics as the predictors, which are:

- Level of manager skill and knowledge (MSK)
- Capability to adopt monitoring equipment and technique (CAT)
- Reliability of maintenance data (RMD)
- Frequency of monitoring and inspection (FMI)

The SPSS coded the probability of non-zero breakdown with 0 as “zero breakdown” and 1 as “no zero breakdown”. By using forward stepwise method, SPSS produced one step to include the predictor that significantly contributes to the logistic regression model. As an outcome, only one independent variable has significantly predicted whether or not the zero breakdown has occurred ($X^2 = 4.28$, $p < .05$).

In this case, 10.5% of the variance in zero breakdown could be predicted from the level of manager's skill and knowledge. Additionally, the p-value for Hosmer-Lemeshow goodness of fit is 0.936, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation produced is as follows (refer Table 6.18):

$$Z = 7.104 - 1.132 \text{ MSK}$$

Table 6.18: Variables in the Equation (characteristics of condition-based maintenance – non-zero breakdown)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	ManagerSkill	-1.132	.589	3.690	1	.055	.322
	Constant	7.104	2.529	7.893	1	.005	1217.177

a. Variable(s) entered on step 1: ManagerSkill.

As a result, level of manager's skill and knowledge is the significant characteristic that affects the odds of non-zero breakdown.

iv) Characteristics of Condition-Based Maintenance that Affect Probability of Non-Zero Complaint

The correlation analysis result determined that three characteristics were found to be significantly correlated with the number of complaints received. Thus, logistic regression analysis for non-zero complaint was run by including the significant characteristics as its predictors including:

- Level of manager's skill and knowledge (MSK)
- Capability to adopt monitoring equipment and technique (CAT)
- Reliability of maintenance data (RMD)

The logistic regression analysis result stated that probability of non-zero complaint was coded as 0 and 1 for “zero complaint” and “no zero complaint” respectively. By using forward stepwise method, SPSS produced one step to include the predictor that significantly contributes to the logistic regression model. As an outcome, only one independent variable significantly predicted whether or not the zero complaint has occurred (X^2 = 9.30, p < .05).

In this case, 17.1% of the variance in zero complaint could be predicted from the level of manager skill and knowledge. Moreover, the p-value for Hosmer-Lemeshow goodness of fit is 0.957, which is more than 0.05. Thus, the model adequately fits the data. Then, the logistic regression equation produced is as follow (refer Table 6.19):

$$Z = 7.421 - 1.357 \text{ MSK}$$

Table 6.19: Variables in the Equation (characteristics of condition-based maintenance – non-zero complaint)

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	ManagerSkill	-1.357	.493	7.579	1	.006	.257
	Constant	7.421	2.114	12.328	1	.000	1670.938

a. Variable(s) entered on step 1: ManagerSkill.

Hence, the level of manager’s skill and knowledge is a significant characteristic that affects the probability of non-zero complaint.

According to the four (4) regression models, it is summarised that the significant predictors of maintenance performance for condition-based maintenance are level of manager’s skill and knowledge, capability to adopt monitoring equipment and technique, as well as reliability of maintenance data.

6.3) Semi-Structured Interview Result

Since the purpose of collecting qualitative findings in this research is to validate, confirm, and corroborate the questionnaire survey result, interview questions were constructed based on the ranking analysis and correlation analysis result obtained from the quantitative approach. Therefore, it is expected that the interview result will be matching and supporting the questionnaire survey result.

Some conversations of the participants were quoted in the discussion of findings to further validate the result. The participants who are experts in scheduled maintenance were coded as Participant S1 to S5; experts in condition-based maintenance were coded as Participant C1 to C5; and experts in both maintenance strategies were coded as Participant B1 to B5.

6.3.1) Comparison of Interview Result to Ranking Analysis Result

The comparative analysis between the findings of the semi-structured interview and the ranking analysis result focused on the following three (3) main aspects:

(a) Characteristics of scheduled maintenance

(b) Characteristics of condition-based maintenance

(c) Participative mechanisms

a) Characteristics of Scheduled Maintenance

According to the ranking analysis result of scheduled maintenance characteristics, the three most significant characteristics are quality of spare parts and material, level of labour skill and knowledge, as well as budget allocation for skilled labour. Thus, the interview questions are focused on the three significant characteristics. The interviewer asked about the significance of the characteristics providing reasons. Among fifteen (15) participants, ten (10) of them were involved in implementation of scheduled maintenance. The interview result as tabulated in Table 6.20 totally supported the ranking analysis result of scheduled maintenance.

Table 6.20: Investigation on significant characteristics of scheduled maintenance

Characteristic	**No. of Participants Confirmed the Significance**	**Reason(s)**
Spare Parts and Materials-Quality	10	• Effective and accurate systems operation • Better lifespan • Reasonable expenditure
Skilled Labour-Skill and Knowledge	10	• Ensure parts are installed according to the requirement • Proper maintenance works performed • Prevent human error and mistake
Skilled Labour-Budget Allocation	10	• Provide good workmanship • Increase the initiation, motivation, and morale of workers

Firstly, all participants agree that the quality of spare parts and material is the significant characteristic of scheduled maintenance. Good quality spare parts and material ensures the building systems to operate effectively and accurately. It minimises the probability of defect and unpredictable failure. Thus, the lifespan of the building systems is guaranteed. Furthermore, it is cost saving in long term aspect without any additional repair or replacement cost. Participant B1 mentioned that:

> “... Use of good quality parts and components is important to ensure systems operate smoothly at optimal cost.”

Then, the significance of labour skill and knowledge were recognised by all participants. Commonly, skilful and knowledgeable labours will ensure that the maintenance work is done with proper workmanship and minimal error. They are able to perform the task according to maintenance requirement and even more effective, such as to detect system defect, as well as complete task at minimal time and cost. In the interview conversation, Participant B3 quoted:

> "... Skilled and experienced technician understands the operation of systems and procedures of maintenance execution."

In the aspect of budget allocation for skilled labour, all participants acknowledged its significance in scheduled maintenance. Indeed, satisfactory salary payment is able to ensure good workmanship, increase the morale and commitment of maintenance staff in their job. Meanwhile, sufficient budget allocation encourages the management to recruit more skilful and responsible labours. Without proper budget allocation, the management will be suffering in hiring competent staff, as quoted from conversation with Participant B5:

> "... We cannot expect skilful and responsible staff with low salary payment."

In addition, the participants pointed out some other significant characteristics of scheduled maintenance and their elaborations are shown in Table 6.21.

Table 6.21: Additional significant characteristics of scheduled maintenance

Characteristic	Elaboration(s)
Legal Compliance	• To avoid breach of law
Preventive Measures	• To avoid inconvenience and major repair cost • To extend the lifespan of building systems • To ensure all systems are in tip top condition
Budgeting	• To ensure the tasks can be performed without cost restriction • To ensure sufficient fund is allocated for maintenance tasks (manpower, tools and equipment, parts, etc.)
Maintenance Policy	• Able to plan the maintenance tasks appropriately (budget allocation, planning and execution) • To ensure maintenance works are done based on the policy (meet the customer requirements)

The interview results validated the ranking analysis result of scheduled maintenance characteristics. Furthermore, the findings demonstrated other significant characteristics that were not covered in this research. Therefore, it provides an opportunity for future research.

b) Characteristics of Condition-Based Maintenance

The ranking analysis result of condition-based maintenance characteristics demonstrated that the three most significant characteristics are level of manager's skill and knowledge, reliability of data about system condition, and budget allocation for skilled manager. In this section, ten (10) of the fifteen (15) participants were able to provide information, as they were involved in implementation of condition-based maintenance. Table 6.22 presents the interview results which support the ranking analysis result of condition-based maintenance.

Table 6.22: Investigation on significant characteristics of condition-based maintenance

Characteristic	No. of Participants Confirmed the Significance	Reason(s)
Skilled Manager-Skill and Knowledge	10	• Ensure all the maintenance works run smoothly and accordingly to the requirement • Lead to the success of condition-based maintenance
Acquisition of Data-Reliability	10	• Ensure proper maintenance execution by reviewing accurate data about the system condition
Skilled Manager-Budget Allocation	10	• Qualification of maintenance manager is positively proportionate to the amount of salary

Level of manager's skill and knowledge is ranked first in ranking analysis of condition-based maintenance. In semi-structured interview, all participants confirmed the significance of the characteristic. Skilled manager is the key that leads to the success of condition-based maintenance. Whereby, a skilful and knowledgeable manager ensures all the monitoring and inspection works are correctly performed, maintenance records are accurately documented. In addition, he provides training to the staff for adaptation of condition-based maintenance. Participant C3 explained that:

> "... Building manager must be able to bring in new technique, supervise and train the staff as condition-based maintenance is a new concept in facilities management in Malaysia."

Secondly, all participants revealed that the reliability of data about system condition is significant in implementation of condition-based maintenance. In implementing this maintenance strategy, the maintenance team plans and schedules the tasks based on the system condition data. Thus, reliable data can indicate the need of maintenance tasks accurately. It ensures the tasks are performed at the right time to prevent further damage.

The maintenance strategy cannot be effective without reliable system condition data, as quoted from Participant B4:

> "... Incorrect data implicates the inadequacy of maintenance execution. Damage tends to occur in this case."

Then, all participants recognised the significance in terms of budget allocation for skilled manager. In reality, the organisation only manages to employ a high qualification manager with good paid salary. An experienced and skilful manager always expects better paid salary. Furthermore, good salary payment motivates the manager's commitment on his job most of the time. Conversely, the organisation is likely to get a low skilled or irresponsible manager if salary payment is dissatisfactory, as quoted from conversation of Participant C2:

> "... Do not expect an experienced and skilful manager with low paid salary. You get what you pay."

In addition, the interviewer explored some other significant characteristics of condition-based maintenance and elaborations from the participants as shown in Table 6.23.

Table 6.23: Additional significant characteristics of condition-based maintenance

Characteristic	**Elaboration(s)**
Preventive Measures	• To achieve zero defect or breakdown • To minimise the service downtime • Prevention is better than cure
Budgeting	• To ensure sufficient fund for maintenance execution • Require much allocation in initial state, eg. setting up appropriate technology, hiring expertise and acquiring tools and equipment

The interview result validated the ranking analysis result of condition-based maintenance characteristics. Furthermore, the findings discovered other significant characteristics that have not been covered in this research. Therefore, this extended the research opportunity in future.

c) Participative Mechanisms

According to the ranking analysis result of participative mechanisms, the three most significant participative mechanisms include provision of training, provision of knowledge-sharing and communication platform, as well as clients' commitment. Thus, the interviewer focused on these three aspects during the interview sessions. Fifteen (15) participants provided their information and opinion in this particular section. Overall, the interview results as shown in Table 6.24 are in parallel with the ranking analysis results of participative mechanisms.

Through interview sessions, all participants confirmed that the provision of training is one of the significant participative mechanisms. Basically, training is important to improve the skill and knowledge of staff, so that they can perform the tasks effectively and minimise human error and mistake. In terms of new staff, provision of training makes them more compatible to existing maintenance strategies adopted in the building. Moreover, training is a means to update on the latest technique and technology in building maintenance. Participant B5 also mentioned that:

> "... Training is important to introduce standard operation procedures so that the effective maintenance outcome can be achieved."

Table 6.24: Investigation on significant participative mechanisms

Mechanism	**No. of Participants Confirmed the Significance**	**Reason(s)**
Provision of Training	15	• Improve the skill and knowledge of staff. • To learn new maintenance technique and technology
Provision of Knowledge-Sharing and Communication Platform	15	• Ensure the other maintenance staffs are able to perform a specific task when the expert is not available (absent/ on leave). • Effective running of maintenance activities (everyone aware of the planning and execution of maintenance works). • Improve the building facilities and services based on the clients and users' needs
Clients' Commitment	15	• Effective running of maintenance activities (budget support from clients) • To ensure the management understands the needs of the organisation or clients

The provision of knowledge-sharing and communication platform is another significant participative mechanism recognised by all participants. In fact, frequent meeting or notification enhances the effective running of maintenance activities, as everyone is aware of the planning and execution of maintenance works. For instance, the building users or maintenance personnel will rearrange their schedule or task to avoid the disruption due to maintenance work. Additionally, sharing of skill and knowledge among the maintenance personnel allows them to perform a specific task when the expert is not available because of absence or on leave. By having effective communication platform, all issues regarding maintenance can be discussed together to meet the organisation's or clients' requirement, as quoted from Participant S3:

"... In weekly meeting, clients and users may deliver the needs of building services or facilities (for supporting business purposes) to the maintenance team; while maintenance team may deliberate the current maintenance issues to the clients and users. Then, solutions can be sought together."

In the aspect of clients' commitment, all participants acknowledged its significance in maintenance management. Generally, clients' commitment in terms of sufficient budget allocation is necessary for effective planning and implementation of maintenance activities. Meanwhile, the client should always follow up with the pending maintenance tasks and fasten the approval process, so that the works can be completed on time. Additionally, the client must be able to brief their needs regarding building maintenance clearly and accurately as soon as possible. Taking into cognizance the clients' needs, maintenance personnel can perform the maintenance tasks accordingly. In this case, Participant C5 argued that:

"... Most of the time, the clients do not brief and clarify their exact needs from the maintenance team accurately. In the end, they blame the maintenance team for not providing good service to support their business operation."

Therefore, the interview result validated the ranking analysis result of participative mechanisms. Unfortunately, none of the participants suggested any new participative mechanisms that are not covered in this research.

6.3.2) Comparison of Interview Result to Correlation Analysis Result

Overall, there are three parts of interview result compared to correlation analysis result that involve:

(a) Influence of characteristics of scheduled maintenance to maintenance performance

(b) Influence of characteristics of condition-based maintenance to maintenance performance

(c) Influence of participative mechanisms to maintenance performance

a) Influence of Characteristics of Scheduled Maintenance to Maintenance Performance

Based on the correlation analysis result, six (6) characteristics of scheduled maintenance were significantly correlated to the maintenance performance. Therefore, the interview questions focused on those characteristics, namely:

(a) Labour skill and knowledge

(b) Budget allocation for spare parts and materials

(c) Stock level of spare parts and materials

(d) Quality of spare parts and materials

(e) Length of predetermined maintenance interval

(f) Amount of failure and maintenance downtimes

The interviewer asked about significant relationship between the maintenance characteristics and performance providing elaborations. Among fifteen (15) participants, ten (10) of them were involved in implementation of scheduled maintenance. The interview result as tabulated in Table 6.25 supported the correlation analysis result of scheduled maintenance.

Table 6.25: Investigation on relationship between characteristics of scheduled maintenance and maintenance performance

Characteristic	**No. of Participants Confirmed the Significance Relationship**	**Performance & Elaboration(s)**
Skilled Labour-Skill and Knowledge	10	Downtime Variance • Work done on time without delay Cost Variance • Minimal error in performing maintenance tasks (avoid extra expenditure) Breakdown Rate • Work done accurately and appropriately No. of Complaint • Satisfactory work performance
Spare Parts and Materials-Budget Allocation	10	Downtime Variance • Expedite the approval and spare part requisition process ○ Insufficient fund to buy spare part, delays maintenance execution Cost Variance • Bulk order of spare part can get lower price • Inadequate budget forces to obtain poor quality spare part (shorter lifespan and easily broken)
Spare Parts and Materials-Level of Stock	9	Downtime Variance • Spare part available for replacement (zero waiting time) Cost Variance • Avoid ad-hoc requisition of spare part that always cost more expensive Breakdown Rate • Maintenance task performed on time without affecting the system conditions (further damage)
Spare Parts and Materials-Quality	10	Downtime Variance • Reduce frequency of part replacement, less maintenance requirement (long lifespan) Cost Variance • Avoid unwanted damage or failure, reduce maintenance need Breakdown Rate • Longer lifespan and minimal defective spare part

Predetermined Maintenance Interval-Length of Interval	9	<u>Downtime Variance</u> • Loose maintenance interval increases risk of failure <u>Cost Variance</u> • Tight maintenance interval incurs more cost of replacement and maintenance <u>Breakdown Rate</u> • Earlier detection of the problem
Failure and Maintenance Downtime-Amount of Downtime	6	<u>Downtime Variance</u> • Extensive downtime implicates more problems and requires more time to resolve the problems <u>Cost Variance</u> • Require extra expenditure when downtime is extended

Note: ● indicates positive impact; ○ indicates negative impact

All the participants agreed that the labour skill and knowledge significantly influences the maintenance performance. Basically, skilled and experienced labours ensure their works are done correctly without delay. They are able to utilise the resources while performing the maintenance tasks. Furthermore, they take care of the building systems at minimal defect. Hence, the systems can operate smoothly without affecting the users' activities. As such, the clients and users will be satisfied with their performance. The significant relationship of labour skill and knowledge to maintenance performance was proven by the following quotes from the participants:

> "... Labours who have lack of skill and knowledge often damage the tools and equipments. As a result, it affects the budget plan for acquiring new tools and equipments."
>
> (Participant S3)

"... Labours who have lack of skill and knowledge tend to make mistake. It is waste of time and cost as further impact occurs on the system, such as system failure."

(Participant B4)

In the aspect of budget allocation for spare parts and material, all participants confirmed that it is significantly influencing the maintenance performance. Adequate budget allocation is important as it ensures the available fund in acquiring parts to perform maintenance on time. Meanwhile, sufficient budget allows bulk order of spare parts that usually get cheaper cost. Participant S2 revealed that:

"... When the budget to buy spare parts is insufficient, poor quality spare parts will be obtained. They usually have shorter lifespan and are easily broken. In the end, the need of parts replacement increases, time for replacement extends."

Then, 9 participants recognised that the stock level of spare parts and material is likely to influence the maintenance performance. Adequate spare part stocking allows the maintenance task to be performed on time without jeopardising the system condition. On the other hand, further damage may occur when repair or replacement works cannot be done due to unavailable of spare parts. Some participants argued that:

"... Sometime, maintenance works are simply delayed because there are no spare parts available."

(Participant B1)

"... We must avoid ad-hoc requisition of spare part that always cost more expensive"

(Participant S5)

> “... The Management must keep the level of stock updated frequently to avoid unavailability of spare parts.”
>
> (Participant B4)

Furthermore, all participants validated the significant influence of spare parts quality to maintenance performance. Good quality spare parts usually last longer and requires less maintenance need. Thus, it reduces the frequency of replacement or breakdown issues that involve downtime. Although good quality spare parts are slightly expensive, they ensure that the system will operate smoothly in a long term. It is beneficial by considering the life cycle cost of the system. Participant S5 quoted an example:

> “... Good quality part may need to be replaced once in 2 years. On the other hand, poor quality may need to be replaced every 6 months. So, good quality parts reduce maintenance need. They save time and cost, as well as minimise possibilities of defect.”

Length of predetermined maintenance interval is another significant characteristic that influence the maintenance performance. The significant relationship was determined by nine (9) participants. In fact, the maintenance team should plan the maintenance interval based on the priority of services and level of harm to human being. Therefore, optimal maintenance interval is the key to save time and cost, as well as to reduce risk of damage. The statement is supported by Participant S1:

> “... Implementation of maintenance task must be at a reasonable interval. Too frequent incurs more cost; too loose increases the risk of failure and downtime.”

Lastly, six (6) among ten (10) of the participants admitted that there is significant relationship between amount of downtime and maintenance performance. This aspect is similar to the length of maintenance interval. It should be optimal because low downtime affects the quality of maintenance work; while extensive downtime implicates more problems to the system such as further damage that incurs additional maintenance time and cost. Participant S4 also mentioned that:

> "... Extensive downtime may affect the image or reputation of organisation"

The interview result validated the correlation analysis result between characteristics of scheduled maintenance and maintenance performance. Moreover, the findings discovered some suggestions to improve the maintenance performance and other impacts of the maintenance characteristics.

b) Influence of Characteristics of Condition-Based Maintenance to Maintenance Performance

The correlation analysis result revealed seven (7) characteristics of condition-based maintenance significantly correlated to the maintenance performance. Therefore, the interview questions focused on those characteristics including:

(a) Manager's skill and knowledge

(b) Budget allocation for equipment and technique

(c) Availability of equipment and technique

(d) Capability to adopt equipment and technique

(e) Budget allocation for data acquisition

(f) Reliability of system condition data

(g) Frequency of monitoring and inspection

In the interview session, the interviewer was concerned about significance of relationship between the maintenance characteristics and performance, providing elaborations by the participants. Among fifteen (15) participants, ten (10) of them were able to provide related information. The interview result as shown in Table 6.26 confirmed the correlation analysis result of condition-based maintenance.

Table 6.26: Investigation on relationship between characteristics of condition-based maintenance and maintenance performance

Characteristic	**No. of Participants Confirmed the Significance Relationship**	**Performance & Elaboration(s)**
Skilled Manager-Skill and Knowledge	10	Downtime Variance • Able to instruct and supervise the staff efficiently to perform maintenance work on time Cost Variance • Able to ensure the optimal workforce, tools and parts allocated for each maintenance task Breakdown Rate • Able to monitor and detect abnormal system condition No. of Complaint • Able to solve the maintenance issues raised up by the clients and users
Equipment and Technique-Budget Allocation	9	Cost Variance • By owning the complete monitoring equipment and technique with sufficient budget allocation, effective maintenance works are guaranteed (minimise repair and replacement cost)
Equipment and Technique-Availability	10	Downtime Variance • Inspecting and monitoring the system condition accurately can be achieved by using suitable tools. This will ensure the system to be maintained in good condition based on the optimum maintenance need

		Cost Variance • Condition of building systems can be easily tracked and monitored, maintenance work is performed before failure occur
Equipment and Technique-Capability to Adopt	10	Downtime Variance • Able to perform the monitoring and inspection task in advance without requiring the system shutdown Cost Variance & Breakdown Rate • Utilise the equipment and technique in monitoring the system condition, then execute preventive maintenance work (prevent failure occurs) No. of Complaint • Proper monitoring and inspection using the tools reduce downtime, cost and breakdown. Subsequently, clients and users satisfy with the maintenance team
Acquisition of Data-Budget Allocation	8	Cost Variance • To set up a proper monitoring and tracking system that provides accurate maintenance data, so that works can be executed accordingly with minimal cost
Acquisition of Data-Reliability	10	Downtime Variance • Indicate exact maintenance need Cost Variance, Breakdown Rate & No. of Complaint • Ensure maintenance work is performed to prevent system failure
Monitoring and Inspection-Frequency	10	Breakdown Rate • Ensure maintenance work is performed to prevent system failure

All the participants supported that the manager's skill and knowledge significantly influences the maintenance performance. A skilful and experienced building manager is usually able to provide service as required by the clients and users above satisfactory level. He ensures all the maintenance tasks run smoothly and accordingly to prevent failure, additional expenditure and downtime. For instance, the manager organises the maintenance task effectively with appropriate allocation of staff, tools and parts. The conversations with participants are quoted as follows:

> "... One of the most important aspects is that a manager must be able to solve the complaints raised up by the clients or users."
>
> (Participant B1)

> "... Manager is the leader in management that coordinates the staff to do the right work at the right time. This will help to avoid major breakdown and extra expenditure."
>
> (Participant B5)

Then, nine (9) participants agreed that budget allocation for maintenance equipment and technique significantly influences the maintenance performance. It is important to have sufficient budget in obtaining required equipment and technique to run condition-based maintenance smoothly. The willingness to spend on the equipment and techniques required for implementation of condition-based maintenance ensures the success of maintenance process. Eventually, maintenance issues can be reduced and minimised, cost and time for maintenance work are optimised as well. Some arguments of participants were quoted:

> "... Although it is expensive to acquire the equipment and technique at the initial stage, it saves cost in the long term since the equipment and technique will be used for preventing major breakdown, which is even more costly."
>
> (Participant C1)

> "... If there is no budget to acquire the monitoring equipment and technique, the effectiveness of condition-based maintenance will be greatly affected. It increases risk of failure, which implicates extra maintenance cost and downtime.

In fact, there are various useful tools that we should have, but yet we cannot get them due to budget constraint. One of the examples is the infrared camera."

(Participant B3)

Availability of maintenance equipment and technique is another significant characteristic that influences the maintenance performance. The significant relationship was identified by all the participants. In condition-based maintenance, monitoring equipment and technique are necessary to track the system condition. With the monitoring tools, the maintenance personnel are able to detect the abnormal condition of system. Thus, they will only perform remedial work when defect is detected. This can reduce the maintenance downtime and save cost as the parts are fully utilised until the end of their lifespan. Participant C2 mentioned that:

"... Having the advanced tools such as infrared camera and vibration detector, defective parts can be detected accurately. Then, technician will replace the part when it is about to fail. This helps to save cost and time by optimising part replacement."

Furthermore, all participants acknowledged that the capability to adopt maintenance equipment and technique has a significant relationship with the maintenance performance. Indeed, capability in using the monitoring tools correctly can improve the quality of maintenance works. It minimises maintenance cost and time, as well as prevents system failure. On the other hand, if the staffs are not capable to utilise the tools, the monitoring system will not be able to indicate the exact condition of system. This will implicate poor outcomes, such as system failure, waste of resources, increase of downtime, and dissatisfaction of clients and users. Participant B1 pointed out that:

> “... If we are not capable to utilise the equipment and technique, it will just be a waste of money and time, yet it will affect the system quality. We know how advanced and expensive is the infrared camera, but when no one understands the way of using it, it is just nothing.”

In the aspect of budget allocation for data acquisition, eight (8) among ten (10) participants supported that it significantly influences the maintenance performance. It is compulsory to set up a proper monitoring and tracking system that provides accurate maintenance data, so that works can be executed accordingly with minimal cost. Thus, sufficient budget must be allocated for data acquisition to ensure the effectiveness of data recording and documentation system. Accurate maintenance data expedites the planning and execution of maintenance works to prevent breakdown. Participant B2 revealed that:

> “... Adequate budget allocation for data recording and documentation system increases the reliability of maintenance data that helps to improve the maintenance process in terms of cost, time and quality.”

Meanwhile, all participants confirmed the significant relationship between reliability of system condition data and maintenance performance. The success of condition-based maintenance is highly dependent on the accurate maintenance data. Whereby, reliable data indicates the need of maintenance task to be executed precisely. This will help to enhance the quality of system operation, as well as utilise the resources and time. Various comments from the participants were quoted as follows:

> "... Reliable maintenance data improves the process of maintenance and its outcome, hence fulfilling the requirement of clients and users. As such, they will not complain on the provided maintenance service."
>
> (Participant C2)

> "... It is important to provide accurate data for implementation of a specific maintenance task without any hidden threat or problem that might cost more for additional remedial work."
>
> (Participant C4)

Finally, the significant influence of monitoring and inspection frequency to maintenance performance was recognised by all participants. Regular inspection on the building systems is one of the unavoidable tasks in condition-based maintenance. Optimal frequency of inspection allows the technicians to detect abnormal system condition effectively. Then, defective parts can be rectified to prevent further damage. This will make sure the system operates smoothly without disruption from damage. Participant B2 expressed that:

> "... Inspection should be carried out as frequent as possible to detect and rectify the defective component as soon as possible."

The interview results validated the correlation analysis result between characteristics of condition-based maintenance and maintenance performance. Therefore, the maintenance personnel must take into account the significant relationships to enhance the effectiveness of condition-based maintenance.

c) Influence of Participative Mechanisms to Maintenance Performance

According to the correlation analysis result, four (4) participative mechanisms are significantly correlated to the maintenance performance. Hence, the interview questions are focused on those mechanisms, namely:

(a) Provision of knowledge-sharing and communication platform

(b) Provision of training

(c) Clients' commitment

(d) Users' satisfaction and feedback

The interviewer asked about the significant relationship between the participative mechanisms and performance providing elaborations. Fifteen (15) participants did provide their information and opinion in this particular section. Overall, the interview result as shown in Table 6.27 is parallel with the correlation analysis result of participative mechanisms and maintenance performance.

Table 6.27: Investigation on relationship between participative mechanisms and maintenance performance

Mechanism	No. of Participants Confirmed the Significance Relationship	Performance & Elaboration(s)
Provision of Knowledge-Sharing and Communication Platform	15	Downtime Variance & Breakdown Rate • Ensure the other maintenance staffs are able to perform a specific task when the expert is not available (absent/ on leave) • Fast approval and response of maintenance process (requisition of maintenance fund, spare part, tool and equipment, outsourcing contract and others) Cost Variance • ensure maintenance work is done according to the plan and allocated budget
Provision of Training	15	Downtime Variance • Ensure all the maintenance staffs are eligible to maintain or observe the conditions of all the existing building systems in a building Breakdown Rate • Improve the staff performance in inspecting and detecting the system problem before breakdown occurs
Clients' Commitment	13	Downtime Variance & Breakdown Rate • Full support in approving the maintenance task (response to the maintenance related issues and requisitions regularly) Cost Variance • Allocate sufficient amount of maintenance budget to improve quality of maintenance
Users' Satisfaction and Feedback	11	Downtime Variance • Immediate action can be taken to fix the problem that is notified by the users as they use the systems frequently and able to observe abnormal conditions instantly

All participants acknowledged that the provision of knowledge-sharing and communication platform has a significant influence on the maintenance performance. This platform allows the clients, maintenance personnel, users and even service providers to discuss the maintenance-related topics. Frequent meeting ensures the maintenance works to be done according to the policy and plan. In addition, sharing of knowledge enhances the skill of maintenance personnel in multi-tasking aspect. Some conversations of the participants were recorded:

> "... Meeting allows the maintenance staff to notify the clients and users about current maintenance issues, then request approval and response of maintenance process as soon as possible (requisition of maintenance fund, spare parts, tool and equipment, outsourcing contract and others) to prevent extra expenditure due to further impact caused by delay."
>
> (Participant S3)

> "... Close communication is to keep track of maintenance progress and expenditure, so that the tasks can be done on time and within budget."
>
> (Participant B1)

Additionally, all the participants supported that the provision of training is significantly influencing the maintenance performance. Generally, training provided for maintenance personnel is a means to improve their skill and knowledge, as well as to introduce the use of the latest maintenance tools and technique. When the maintenance personnel are well-trained, they will perform the maintenance tasks effectively with minimal error. This will help to reduce the downtime needed for maintenance execution and minimise the probability of unwanted failure. Various examples were provided by the participants:

"... A well-trained technician is able to complete a task at minimal time, as he has already been familiar with the maintenance procedures. "

(Participant S5)

"... After the technicians are trained to check and inspect the components of systems, such as lift system or air-conditioning system, they are able to detect the problem occurring in the system. Then, they can call the outsourced contractor to attend for servicing of the system immediately. Fast response to the problem will help to avoid failure of the system."

(Participant C3)

In the aspect of clients' commitment, thirteen (13) among fifteen (15) of the participants determined its significant influence to maintenance performance. Clients' commitment in attending issues faced by the maintenance team is important to achieve better maintenance outcome. For instance, the issues might be related to maintenance policy and plan, budgeting, human resource management, and others. The clients must fully commit themselves in reviewing and approving the maintenance planning, so that the tasks can be performed at the right time and optimal expenditure. Some participants expressed that:

"... When clients expect the building services to operate smoothly without disruption from failure, they must contribute more in monetary aspect. We must know that everything needs money, such as outstanding maintenance staff, good quality parts and materials, advanced maintenance tools and technology, expert service providers, and many more."

(Participant B1)

> "... The clients must clearly direct and inform the maintenance team to fulfil their needs. Whereby, vague information provided by the clients is always a root cause of time and budget overrunning."
>
> (Participant B3)

Furthermore, eleven (11) out of the fifteen (15) participants confirmed that the users' satisfaction and feedback significantly influences the maintenance performance. Commonly, the maintenance personnel need to take immediate action to fix the defective building system when it is identified and complained by the users. In other words, the maintenance staff will be urged to respond on the maintenance issue without delay, as it has affected the activities of the building users. Since the occupants use the building services frequently, their feedback is always taken into consideration. The satisfaction level of occupants towards the building performance reflects the maintenance benchmark to be practised. Participant C1 suggested that:

> "... We should carry out a survey on the level of users' satisfaction towards the building performance regularly. Then, the maintenance team will be able to realise the aspect that requires improvement. As a result, the maintenance outcome can be improved simultaneously."

The interview result validated the correlation analysis result between participative mechanisms and maintenance performance. Furthermore, some measures to improve the maintenance performance were suggested by the participants. Consequently, participative mechanisms should be practised to enhance the effectiveness of the maintenance strategies and improve the maintenance performance.

6.4) Archived Documentation Result – Content Analysis

After the interview sessions, data collection through archived documentation was arranged to validate, confirm, and corroborate the questionnaire survey results, some historical data related to maintenance management were collected from four office buildings. The archived documentation results would reflect actual circumstances of maintenance management in the industry.

Overall, four buildings were involved in the collection of data through archived documents and information. Due to the privacy and confidential concerns raised by the respondents, the name of buildings would be represented as follow:

(a) Scheduled maintenance – Building A and Building B

(b) Condition-based maintenance – Building C and Building D

6.4.1) Case Study 1 – Building A

Building A is a 32-storey office tower under the management of an in-house maintenance and management team. It is a private building with total floor area of 493,000 square feet. Currently, the building is five (5) years old, which was completed in 2008. It is accommodated with comprehensive facilities such as centralised air-conditioning system, sixteen (16) lifts, 24-hour security with CCTV, card access and retractable barrier gate, covered parking and others. Hence, the building fulfils the criteria for this study.

a) Characteristics of Scheduled Maintenance

Since the significant characteristics of scheduled maintenance were identified in the earlier stages, the collection of archived documents and information for Building A was focused on those characteristics, including:

- Skilled labour
- Spare parts and materials
- Predetermined maintenance interval
- Maintenance and failure downtime

In the aspect of skilled labour, the management allocated minimal salary for the maintenance staff. The average salary of a maintenance labour is around RM1,200 only. This is considerably a low range salary payment. Thus, the management did not determine a specific qualification requirement while hiring the maintenance staff, except the staff at managerial level. However, the management did employ large number of maintenance staff, which are sixty (60) people. This would be able to provide immediate response towards the allocated tasks, either scheduled in advance or ad-hoc maintenance.

Then, the management of Building A spent approximately RM30,000 per year in acquiring spare parts and materials. The stock of spare parts was updated at optimum level regularly. Whereby, acquisition of spare parts depends on the amount of usage. In addition, the management would ensure only good quality spare parts to be acquired. Normally, the lifespan of the parts is two (2) to five (5) years. Thus, it was found that the management is concerned more on the aspect of spare parts and materials.

According to the literature in Chapter 3, predetermined interval for maintenance is another significant characteristic for scheduled maintenance. The amount of expenditure for routine maintenance is RM3,000 to RM5,000 annually. The expenditure amount is sufficient because the building is managed by in-house maintenance team. Thus, the outsourcing cost could be exempted. Furthermore, they have a short interval for routine maintenance as they have adequate number of staff. They usually perform the maintenance tasks once in two weeks time, especially for the critical components.

Maintenance and failure downtime may influence the daily operation of office activities. Therefore, the management would allocate more budgets in managing the downtime. The sum of allocated budget for downtime is RM6,000 to RM10,000 yearly. For example, the management was likely to arrange the maintenance downtime after the office operating hour to minimise disruption to building users. Definitely, this would cost more for paying overtime working allowance to the staff. In terms of planned downtime, the management only allows six (6) hours of downtime during office operating time in a year.

b) Participative Mechanisms

Involvement of key participants is an important factor to improve the maintenance performance. In Building A, the management would organise maintenance meeting to meet the clients and users representatives once in a week. In the meeting, the clients, users, and maintenance personnel would discuss the maintenance-related issues and problems. Meanwhile, solutions would be suggested to tackle the issues and problems accordingly. In comparison of the case study with the correlation analysis result, the provision of knowledge-sharing and communication platform significantly contribute to the maintenance performance as follows:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

Since the management did not determine specific qualification requirement when hiring the maintenance staff, they would provide training courses to improve the skill and knowledge of the staff at least twice a year. Commonly, the training sessions focused on the maintenance of facilities accommodated in the building. Thus, the staff would be able to perform the maintenance tasks based on the standard operation procedures. Mistake and error could be minimised during the execution of maintenance works. By comparing the case study to the correlation analysis result, it was found that the performance measures are significantly influenced by the provision of training, including:

- Maintenance downtime variance
- System breakdown rate

According to the building manager, the clients are supportive in budget allocation of maintenance activities. The clients would approve the maintenance budget if it is deemed reasonable or needed. Thus, there is no issue in terms of budget allocation for maintenance activities. The clients believe and rely on the maintenance management that the staff could perform their tasks effectively to retain the building in good condition. In comparison of the case study with the correlation analysis result, the clients' commitment is significantly correlated to the maintenance performance as follows:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

Moreover, the management would collect and gather feedback from the building users every month. Basically, the feedback includes the service performance delivered by the in-house maintenance personnel, conditions of building facilities and services, maintenance aspects that need to be improved, and others. In addition, there is no report of vandalism identified in the building. The level of care towards the building and systems by the users is acknowledged in the maintenance report. By comparing the case study to the correlation analysis result, it was identified that the maintenance downtime variance is significantly influenced by the users' satisfaction and feedback.

In the aspect of manufacturers and suppliers' commitment, the records could be found in the service providers' documents. Majority of the manufacturers commit themselves to provide maintenance team in the building in case of emergency events and services. For example, the manufacturers would send the maintenance team over the building if there is sudden system failure.

In conclusion, the management does have a serious concern on the participative mechanisms to improve the maintenance performance. All the key participants are willing to involve themselves in planning, organising, implementing, and reviewing of the maintenance activities.

c) Maintenance Performance

Overall, the maintenance performance of Building A is good. Although the planned downtime is six (6) hours, the actual downtime caused by system failure is nil so far. The preventive maintenance is mostly executed after the office operating hour. In comparison of the case study with the correlation analysis result, the characteristics of scheduled maintenance that significantly contribute to the variance of downtime include:

- Stock level of spare parts and materials
- Quality of spare parts and materials

- Length of predetermined maintenance interval
- Amount of maintenance and failure downtime

In the aspect of maintenance expenditure, the management was able to get rid from the issue of over-budget, which is a usual situation that could be seen in building maintenance industry. The management determined the planned maintenance expenditure as RM60,000 to RM80,000 per year, excluding the salary of maintenance staff. However, the actual expenditure is only RM50,000 to RM60,000. By comparing the case study to the correlation analysis result, it was found that the scheduled maintenance characteristics that significantly influence the variance of expenditure are:

- Budget allocation for spare parts and materials
- Stock level of spare parts and materials
- Quality of spare parts and materials
- Length of predetermined maintenance interval
- Amount of maintenance and failure downtime

Then, the system breakdown rate per year in Building A was nil. The management led to success of the maintenance strategy by preventing major system breakdown from occurring. In comparison of the case study with the correlation analysis result, the characteristics of scheduled maintenance that significantly contribute to the zero-breakdown rate included:

- Stock level of spare parts and materials
- Quality of spare parts and materials

According to the maintenance report, the management received about seven (7) minor complaints from the users and customers every month. They were mainly related to the temperature of air-conditioning system and unavailability of the maintenance staff to handle some minor maintenance works such as water leaking from the air-conditioning system. Consequently, it was proven that the level of labour skill and knowledge could affect the number of complaints received.

Overall, the content analysis result for Case Study 1 supported the correlation analysis result obtained through questionnaire survey.

6.4.2) Case Study 2 – Building B

Building B is a 33-storey office tower under the management of an in-house maintenance and management team. It is a private building with total floor area of 348,998 square feet. Presently, the building is seventeen (17) years old, which was completed in 1996. Then, the building was refurbished in 2009 to upgrade the building facade, facilities, security systems and gating. It is accommodated with comprehensive facilities such as centralised air-conditioning system, high speed lift system, 24-hour security with CCTV, indoor car park, under-floor trunking system for cabling, and others. Hence, the building fulfilled the criteria for this study.

a) Characteristics of Scheduled Maintenance

Similar to case study of Building A, the collection of archived documents and information for Building B focused on the scheduled maintenance characteristics, which include:

- Skilled labour
- Spare parts and materials
- Predetermined maintenance interval
- Maintenance and failure downtime

In Building B, the management allocated optimal salary for the maintenance staff. The salary of a maintenance personnel is RM1,500 or above. The payment range is in satisfactory level. Then, the management did specify the qualification requirement of maintenance personnel based on the position. For example, the building executive must possess diploma or degree in relevant field, as well as working experience of two (2) years. Meanwhile, the management did employ sufficient number of maintenance staff, which consists of twenty (20) people.

According to the maintenance report, the management of Building B spends approximately RM28,000 per year in acquiring spare parts and materials. The stock of spare parts is updated at optimum level regularly, where the management would ensure that the spare parts are always available. In addition, the quality of spare parts and materials is another concern. Basically, the lifespan of the parts is one (1) to five (5) years.

In the aspect of predetermined interval for maintenance, the amount of expenditure for routine maintenance is RM5,000 to RM8,000 annually. The expenditure amount is adequate because the building is managed by in-house maintenance team. Thus, the outsourcing cost could be exempted. Furthermore, they would determine the optimal interval for routine maintenance based on the historical maintenance records, maintenance manuals and guides. They usually perform the maintenance tasks daily, weekly, monthly, and yearly depending on the priority of components.

Maintenance and failure downtime may influence the daily operation of office activities. Therefore, the management imposed a policy that the planned maintenance downtime must not affect the operation of offices. The sum of allocated budget for downtime is RM5,000 to RM10,000 per year. Similar with Building A, the management would arrange the maintenance downtime after office operating hour to minimise disruption to building users. In terms of planned downtime, the management only allows nine (9) hours of downtime during office operating time in a year.

b) Participative Mechanisms

In Building B, the management would organise monthly meeting with the clients. In the meeting, the clients and maintenance personnel would discuss the maintenance-related issues and problems, as well as report maintenance progress and status. In addition, they would have maintenance personnel daily meeting to brief the tasks to be performed. For building users, the management did set up an "eService Request" system to receive the maintenance request from the users. By comparing the case study to the correlation analysis result, it is found that the performance measures are significantly influenced by the provision of knowledge-sharing and communication platform, including:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

In order to ensure that the maintenance staffs are familiar with the standard operation procedures for maintenance execution, the management would provide training courses to the staff every six (6) months. As usual, the training sessions focus on the maintenance of facilities accommodated in the building. Thus, the staff would be able to perform the maintenance tasks efficiently with minimal mistake and error. In comparison of the case study with the correlation analysis result, the provision of training is significantly correlated to the maintenance performance as below:

- Maintenance downtime variance
- System breakdown rate

According to the building manager, the clients are supportive in budget allocation of maintenance activities. The clients would approve the maintenance budget if they think it is reasonable or needed. 90 percent of budget would be approved by the clients. Commonly, the approval of budget would be based on the exact need of the maintenance work to be performed. By comparing the case study to the correlation analysis result, the performance measures that are significantly influenced by the clients' commitment include:

- Maintenance downtime variance
- Maintenance expenditure variance
- System breakdown rate

Furthermore, the management would collect and gather feedback from the building users every week. Basically, the feedbacks include the service performance delivered by the in-house maintenance personnel, conditions of building facilities and services, maintenance aspects that needed to be improved, and others. In addition, there was no report of vandalism identified in the building. The level of care towards the building and systems by the users was acknowledged. In comparison of the case study with the correlation analysis result, the users' satisfaction and feedback significantly contribute to the maintenance downtime variance.

In the aspect of manufacturers and suppliers' commitment, the records could be found in the service providers' documents. Majority of the manufacturers commit themselves to provide maintenance team at the building in case of emergency events and services.

For instance, the manufacturers promised that they would be able to attend breakdown event with minimal downtime.

In summary, the management did focus on the participative mechanisms to improve the maintenance performance. All the key participants were willing to involve themselves in planning, organising, implementing, and reviewing of the maintenance activities.

c) Maintenance Performance

In general, the maintenance performance of Building B is good. Although the planned downtime is nine (9) hours, the actual downtime caused by system failure is only 4 hours. The maintenance tasks are mostly performed after the office operating hour. In comparison of the case study with the correlation analysis result, the characteristics of scheduled maintenance that significantly influence the variance of downtime include:

- Level of labour skill and knowledge
- Stock level of spare parts and materials
- Quality of spare parts and materials
- Length of predetermined maintenance interval
- Amount of maintenance and failure downtime

In the aspect of maintenance expenditure, the management has been able to avoid from the issue of over-budget, which is a usual situation that could be seen in building maintenance industry. The management has determined the planned maintenance expenditure as RM70,000 yearly, excluding the salary of maintenance staff. However, the actual expenditure is only RM68,000. By comparing the case study to the correlation analysis result, it is found that the scheduled maintenance characteristics that significantly contribute to the variance of expenditure are:

- Level of labour skill and knowledge
- Budget allocation for spare parts and materials
- Stock level of spare parts and materials
- Quality of spare parts and materials
- Length of predetermined maintenance interval
- Amount of maintenance and failure downtime

Then, the system breakdown rate per year in Building B is nil. The management leads to the success of the maintenance strategy by preventing major system breakdown that have occurred. In comparison of the case study with the correlation analysis result, the characteristics of scheduled maintenance that significantly lead to the achievement of zero-breakdown include:

- Level of labour skill and knowledge
- Stock level of spare parts and materials
- Quality of spare parts and materials

According to the maintenance report, the management has received about 5 minor complaints from the users and customers every month. They are mainly related to the temperature of air-conditioning system. Otherwise, the users did not have any complaint related to maintenance aspect. Thus, it is proven that the level of labour skill and knowledge could influence the number of complaints received.

As a conclusion, the content analysis result for Case Study 2 confirms the correlation analysis result obtained through questionnaire survey.

6.4.3) Case Study 3 – Building C

Building C is a 27-storey office tower under the management of an in-house maintenance and management team. It is a private building with total floor area of 324,000 square feet. Currently, the building is thirteen (13) years old, which was completed in 2000. It is accommodated with comprehensive facilities such as centralised air-conditioning system, passenger lifts, 24-hour security with CCTV, building automation system (BAS), under-floor trunking, indoor car park, and others. Hence, the building fulfilled the criteria for this study.

a) Characteristics of Condition-Based Maintenance

Since the significant characteristics of condition-based maintenance were identified in the earlier stages, the collection of archived documents and information for Building C focused on those characteristics, including:

- Skilled manager
- Monitoring equipment and technique
- Acquisition of data and information
- Monitoring and inspection

In the aspect of skilled manager, the management allocated minimal salary for the building manager. The salary range of a building manager is from RM3,000 to RM4,000 only. This is considered as low range salary payment. On the other hand, the management did expect the manager to possess at least a degree in construction-related field with minimum of three (3) years working experience in maintenance work. There is an imbalance situation that the management specified high qualification requirement with low salary payment in employing the building manager. This would probably affect the morale and commitment of the manager.

Monitoring equipment and technique are compulsory for implementation of condition-based maintenance. The management spent approximately RM30,000 in acquiring the equipments. In Building C however, there is no record of acquiring advanced equipments and techniques as stated in Chapter 3, such as vibration detector, infrared camera and others. The maintenance report only documented the acquisition of scaffolding, Genie lifts (personal lift and scissor lift) and other access equipments. The condition-based maintenance was executed mainly by the technicians without monitoring equipment. Nevertheless, the management would ensure the technicians are properly trained before practising the monitoring and inspection work on site. This might increase the accuracy of inspection and minimise accident or error.

Since there was no use of advanced monitoring equipments and techniques in the building, the budget allocation for acquisition of maintenance data only covers the documentation cost, such as filings and stationeries. However, the building manager mentioned that the management did allocate sufficient amount of budget for BAS monitoring system. According to the maintenance report, 80 to 85 percent of the maintenance data reflected the exact condition of the building systems. Therefore, the documented maintenance data were deemed accurate to indicate the maintenance needs.

For BAS monitoring system, the management spent approximately RM8,000 to RM10,000 for maintenance of the system. The system is a computerised system. Thus, condition monitoring of the BAS in this building is continuous. Then, there was no other extra expenditure on monitoring and inspection works, as the works were done by the in-house maintenance staff. Regularly, the maintenance staff would inspect the conditions of building systems every month.

b) Participative Mechanisms

In Building C, the management would organise maintenance meeting to meet the clients' and users' representatives twice in a year. In the meeting, the clients, users, and maintenance personnel would discuss the major maintenance-related issues and problems. Meanwhile, solutions would be suggested to tackle the issues and problems accordingly. Undeniably, the commitment of key participants to communicate with each other in this building was low. In comparison of the case study with the correlation analysis result, the provision of knowledge-sharing and communication platform significantly affect the maintenance performance as below:

- Maintenance expenditure variance
- System breakdown rate

In order to ensure the maintenance staffs are capable in monitoring, inspecting and retaining the conditions of building systems, the management would provide training courses to improve the skill and knowledge of the staff twice a year, especially for the new staff. Generally, the training sessions focus on the inspection and maintenance of the facilities accommodated in the building. Hence, the staffs would be able to detect the abnormal condition of building system and perform the preventive maintenance tasks immediately. By comparing the case study to the correlation analysis result, the maintenance downtime variance is significantly influenced by the provision of training.

According to the building manager, the clients are supportive in budget allocation of maintenance activities. The clients would approve the maintenance budget if it is deemed reasonable or needed. Thus, there is no issue in terms of budget allocation for maintenance activities. The clients believed and relied on the maintenance management that the staffs could perform their tasks effectively to retain the building in good condition. In comparison of the case study with the correlation analysis result, the clients' commitment is significantly correlated to the maintenance downtime variance.

Moreover, the management would collect and gather feedback from the building users every month. Basically, the feedbacks include the service performance delivered by the in-house maintenance personnel, conditions of building facilities and services, maintenance aspects that needed to be improved, and others. On the other hand, there have been two (2) to five (5) cases of vandalism identified in the building per year. The level of care towards the building and systems by the users was questioned and raised in the maintenance report. By comparing the case study to the correlation analysis result, the maintenance downtime variance is significantly contributed by the users' satisfaction and feedback.

In the aspect of manufacturers' and suppliers' commitment, the records could not found any commitment from the manufacturers and suppliers after the systems or goods were delivered. This is worse, as the manufacturers and suppliers are more familiar with the products that they have delivered. All the maintenance tasks needed to be done by the in-house team. As a result, this might cause delay of maintenance execution.

In conclusion, the management did concern a lot on the participative mechanisms to improve the maintenance performance. Unfortunately, only the maintenance team and clients were willing to involve themselves in the maintenance activities.

c) Maintenance Performance

In general, the maintenance performance of Building C is below expectation. The planned downtime is four (4) hours and the actual downtime caused by system failure is also four (4) hours annually, excluding the major breakdown that had required more than a day to repair it. In fact, the implementation of condition-based maintenance should have reduced the downtime. In comparison of the case study with the correlation analysis result, the characteristics of condition-based maintenance that significantly influence the variance of downtime include:

- Availability of monitoring equipment and technique
- Capability to adopt monitoring equipment and technique

In the aspect of maintenance expenditure, the issue of over-budget for maintenance activities occurred in Building C. The management estimated the maintenance expenditure as RM48,000 in a year, excluding the salary of maintenance staffs. However, the actual expenditure is RM55,000. By comparing the case study to the correlation analysis result, it was found that the characteristics of condition-based maintenance that significantly affect the variance of expenditure are:

- Budget allocation for monitoring equipment and techniques
- Availability of monitoring equipment and technique
- Budget allocation for acquisition of data and information

Furthermore, the system breakdown that had required more than a day to fix in Building C was two (2) to three (3) times per year. The management was unable to take the advantage of condition-based maintenance, which is to prevent system failure. In comparison of the case study with the correlation analysis result, the characteristic of condition-based maintenance that significantly influence the system breakdown rate is availability of monitoring equipment and technique.

According to maintenance report, the management received about ten (10) to fifteen (15) minor complaints from the users and customers every month. They are mainly related to the temperature of air-conditioning system. Otherwise, the users did not have any other complaints related to the maintenance aspect. By comparing the case study to the correlation analysis result, it was found that the condition-based maintenance characteristics that are significantly contributing to the number of complaints received are:

- Level of manager skill and knowledge
- Reliability of maintenance data

Consequently, the content analysis result for Case Study 3 validates the correlation analysis result obtained through questionnaire survey.

6.4.4) Case Study 4 – Building D

Building D is a 19-storey office tower under the management of an in-house maintenance and management team. It is a private building with total floor area of 276,612 square feet. At this time, the building is twenty (20) years old, which was completed in 1993. It is accommodated with facilities such as centralised air-conditioning system, passenger lifts, 24-hour security with CCTV, car park, and others. Hence, the building fulfils the criteria for this study.

a) Characteristics of Condition-Based Maintenance

Similar to case study of Building C, the collection of archived documents and information for Building D had been focused on the characteristics of condition-based maintenance, including:

- Skilled manager
- Monitoring equipment and technique
- Acquisition of data and information
- Monitoring and inspection

In Building D, the management has allocated RM7,000 of monthly salary payment for the building manager. The amount of salary is persuasive in order to obtain a committed manager. For that reason, the requirement to employ a building manager is austere. The manager should at least possess a degree in relevant field and with minimum five (5) years of relevant working experience in facilities or maintenance management. Overall, the salary payment and qualification of building manager are encouraging and reasonable.

However, the management only spent approximately RM3,000 in acquiring the equipments. The budget allocation for acquiring monitoring equipment and technique is critically low compared to Building C. Similarly, there is no record of acquiring advanced equipments and techniques as stated in Chapter 3, such as vibration detector, infrared camera and others. The maintenance report only documented the acquisition of basic and essential air conditioning tools. Since the monitoring tools purchased were those basic ones, most of the maintenance staffs are capable to utilise the tools when performing monitoring and inspection works. The building manager noted that 95 percent of them are capable in using the tools with given instructions.

In the aspect of acquisition of maintenance data, the management has spent RM1,000 in a year for the documentation cost, such as filings and stationeries, as well as some records in computer system. Typically, the monitoring and inspection outcomes would be documented in an organised system, so that the maintenance personnel could follow up on the maintenance tasks based on the inspection and maintenance records. According to the maintenance report, 95 percent of the maintenance data reflected the exact condition of the building systems. Therefore, the reliability of maintenance data is conceded.

Then, the expenditure for monitoring and inspection works is RM4,000 per year. The expenditure covers the personal safety equipments, consumable items and others. Regularly, the maintenance staff would inspect the conditions of building systems according to the inspection checklists. Whereby, the management had already produced the list of inspection tasks with assigned frequency. For example, they would monitor and inspect the building systems in daily, weekly or monthly terms.

b) Participative Mechanisms

In Building D, the management would arrange monthly meeting with the clients. In the meeting, the clients and maintenance personnel would discuss the maintenance-related issues and problems, as well as report maintenance progress and status. Furthermore, they would have maintenance personnel daily meeting to brief the tasks to be performed. Similar to Building B, the management did also set up an “eService Request” system to receive the maintenance request from the users. By comparing the case study to the correlation analysis result, the performance measures that are significantly influenced by the provision of knowledge-sharing and communication platform include:

- Maintenance downtime variance
- System breakdown rate

In order to ensure that the maintenance staffs are familiar with the standard operation procedures for maintenance execution, especially the monitoring and inspection works, the management would organise training courses to the staff every 6 months. Basically, the training sessions concern on the maintenance of facilities accommodated in the building. Thus, the staff would be able to perform the inspection and maintenance tasks efficiently. As a result, the obtained maintenance data could accurately indicate the maintenance tasks that need to be carried out. In comparison of the case study with the correlation analysis result, the provision of training is significantly correlated to the maintenance performance as follows:

- Maintenance downtime variance
- System breakdown rate

According to the building manager, the clients are supportive in budget allocation of maintenance activities. The clients would approve the maintenance budget if it is deemed reasonable or needed. 85 percent of budget would be approved by the clients. Commonly, the approval of budget would be based on the exact need of the maintenance work to be performed. Unfortunately, there is no allocation for acquisition of advanced monitoring equipment and technique. By comparing the case study to the correlation analysis result, the performance measures are significantly influenced by the clients' commitment, including:

- Maintenance downtime variance
- System breakdown rate

Additionally, the management would collect and gather feedback from the building users on a regular basis, which is once in a week. Generally, the feedback include the service performance delivered by the in-house maintenance personnel, conditions of building facilities and services, maintenance aspects that needed to be improved, and others. Meanwhile, there is no report of vandalism identified in the building. The level of care towards the building and systems by the users was credited. In comparison of the case study with the correlation analysis result, the users' satisfaction and feedback significantly influence the maintenance downtime variance.

In the aspect of manufacturers and suppliers' commitment, the records could be found in the service providers' documents. Majority of the manufacturers took the responsible to provide maintenance team in the building in case of emergency events and services. For example, the manufacturers promised that they would be able to attend breakdown event with minimal downtime.

As a conclusion, the management did concern on the participative mechanisms to improve the maintenance performance. All the key participants are willing to involve themselves in planning, organising, implementing, and reviewing of the maintenance activities.

c) Maintenance Performance

Overall, the maintenance performance of Building D is satisfactory. The planned downtime is twenty-four (24) hours and the actual downtime caused by system failure is only three (3) hours in a year. Thus, this has proven that the implementation of condition-based maintenance is able to minimise the downtime. In comparison of the case study with the correlation analysis result, the characteristics of condition-based maintenance that significantly influence the variance of downtime include:

- Level of manager skill and knowledge
- Capability to adopt monitoring equipment and technique
- Reliability of maintenance data

In the aspect of maintenance expenditure, the issue of over-budget for maintenance activities occurred in Building D. The budget allocation for maintenance activities is RM44,400 in a year, excluding the salary of maintenance staffs. However, the actual expenditure is RM50,000. Over-budget of RM5,600 was identified in the maintenance account report. By comparing the case study to the correlation analysis result, it is found that the characteristics of condition-based maintenance that significantly affect the variance of expenditure are:

- Budget allocation for monitoring equipment and techniques
- Availability of monitoring equipment and technique

Furthermore, the maintenance report revealed that the system breakdown rate per year in Building D is nil. The management has succeeded in preventing the occurrence of major system breakdown by implementing condition-based maintenance. In comparison of the case study with the correlation analysis result, the characteristics of condition-based maintenance that significantly lead to the achievement of zero-breakdown include:

- Level of manager skill and knowledge
- Capability to adopt monitoring equipment and technique
- Reliability of maintenance data
- Frequency of monitoring and inspection

According to the previous maintenance report, the management has received about 10 minor complaints from the users and customers every month. They are mainly related to the temperature of air-conditioning system that affects the comfort of building users. Other than that, the users did not have any complaint related to maintenance aspect. By comparing the case study to the correlation analysis result, it is found that the condition-based maintenance characteristics that significantly contribute to the number of complaints received are:

- Level of manager's skill and knowledge
- Capability to adopt monitoring equipment and technique
- Reliability of maintenance data

As a result, the content analysis result for Case Study 4 corroborated the correlation analysis result obtained through questionnaire survey.

6.5) Discussion on Overall Findings

Since this research adopts triangulation approach for collecting, analysing, and interpreting the data and findings, it requires a tie-up of the methods, which include questionnaire survey, semi-structured interview and archive documentation. The core research findings were obtained through questionnaire survey. Then, the findings would be compared with the interview and archived documentation results for validation purpose. Basically, the validation process covers the results of ranking analysis and correlation analysis.

6.5.1) Validation of Ranking Analysis Result

The ranking analysis result for scheduled maintenance revealed three (3) of the most significant characteristics as quality of spare parts and materials, level of labour skill and knowledge, as well as budget allocation for skilled labour. The interview results demonstrated that all participants confirmed these three (3) as the significant characteristics. Meanwhile, the archived documentation result revealed that both case studies supported the quality of spare parts as a significant characteristic. However, only one (1) case study confirmed the significance of level of skill and knowledge, as well as budget allocation for skilled labour.

For condition-based maintenance, the ranking analysis result demonstrated the level of manager's skill and knowledge, reliability of maintenance data, and budget allocation for skilled manager as the three (3) most significant characteristics. All the participants who were involved in the interview session, supported the three (3) of them as the significant characteristics. Then, the archived documentation results show that both case studies confirmed that the level of manager's skill and knowledge, as well as reliability of maintenance data as significant characteristics. On the other hand, only one (1) case study supported the significance of budget allocation for skilled manager.

Subsequently, the ranking analysis result for participative mechanism revealed three (3) of the most significant mechanisms as provision of training, provision of knowledge-sharing and communication platform, as well as clients' commitment. Similarly, all the interviewed participants acknowledged the three (3) of them as significant participative mechanisms. According to the archived documentation results, all four (4) case studies supported the provision of training and clients' commitment as the significant mechanisms. Then, three (3) case studies demonstrated the provision of knowledge-sharing and communication platform as the significant mechanism.

Overall, the ranking analysis findings were validated through both interview and archived documentation results.

6.5.2) Validation of Correlation Analysis Result

The correlation analysis result revealed that there are six (6) characteristics of scheduled maintenance that are significantly correlated to maintenance performance. These include labour skill and knowledge, budget allocation for spare parts and materials, stock level of spare parts and materials, quality of spare parts and materials, length of predetermined maintenance interval, as well as amount of failure and maintenance downtimes. In interview session, all participants acknowledged the labour skill and knowledge, budget allocation for spare parts and materials, as well as quality of spare parts and materials as having significant relationships towards performance. Then, 90 percent of the participants revealed the significant relationship of stock level of spare parts and materials, as well as length of predetermined maintenance interval towards maintenance performance. 60 percent of the participants demonstrated that the amount of failure and maintenance downtimes is significantly correlated to the performance. Moreover, the archived documentation results of both case studies show that the six (6) characteristics have significant relationships towards the performance.

Furthermore, the correlation analysis result for condition-based maintenance demonstrated seven (7) characteristics that are significantly correlated to maintenance performance, namely manager skill and knowledge, budget allocation for equipment and technique, availability of equipment and technique, capability to adopt equipment and technique, budget allocation for data acquisition, reliability of system condition data, as well as frequency of monitoring and inspection. All interview participants confirmed that the manager’s skill and knowledge, availability of equipment and technique, capability to adopt equipment and technique, reliability of system condition data, as well as frequency of monitoring and inspection are having significant relationships towards the performance. Then, 90 percent of the participants supported the significant relationship of budget allocation for equipment and technique towards the performance. Followed by the budget allocation for data acquisition and performance, 80 percent of participants acknowledged their significant relationship. According to the archives documentation results, both case studies determined the significant relationships of the five (5) characteristics towards the performance, except frequency of monitoring and inspection. Only one (1) case study revealed that the frequency of monitoring and inspection is significantly correlated to the performance.

For participative mechanism, the correlation analysis result demonstrated that four (4) mechanisms are significantly correlated to the maintenance performance, including provision of knowledge-sharing and communication platform, provision of training, clients' commitment, as well as users' satisfaction and feedback. According to the interview result, all participants agreed that the provisions of knowledge-sharing and communication platform, as well as provision of training are significantly correlated to the performance. Meanwhile, 87 percent of the participants confirmed the significant relationship between clients' commitment and the performance. 73 percent of the participants supported that users' satisfaction and feedback has significant relationship towards the performance. In archive documentation session, all case studies acknowledged the significant relationships of the four (4) mechanisms towards maintenance performance.

In general, both interview and archived documentation results validated the correlation analysis findings.

6.6) Chapter Summary

Through literature review, ten (10) variables of scheduled maintenance and nine (9) variables of condition-based maintenance were found to be significant for implementation of the maintenance strategies. Meanwhile, six (6) variables of participative mechanisms were suggested to improve the maintenance performance. The ranking of the variables was analysed. Then, a correlation analysis was performed to test the relationship between the variables and maintenance performance variables.

For characteristics of scheduled maintenance, six (6) of the variables were identified to be significantly correlated with at least one of the performance variable, including:

- Level of labour skill and knowledge
- Budget allocation for spare parts and materials
- Level of spare parts and materials stock
- Quality of spare parts and materials
- Length of predetermined maintenance interval
- Amount of failure and maintenance downtime

For characteristics of condition-based maintenance, seven (7) of the variables were determined to be significantly correlated with at least one of the performance variable as follows:

- Level of manager’s skill and knowledge
- Budget allocation for equipment and technique
- Availability of monitoring equipment and technique
- Capability to adopt monitoring equipment and technique
- Budget allocation for acquisition of maintenance data

- Reliability of maintenance data
- Frequency of monitoring and inspection

For participative mechanisms, four (4) of the variables were found to be significantly correlated with at least one of the performance variables below:

- Provision of knowledge-sharing and communication platform
- Provision of training
- Clients' commitment
- Users' satisfaction and feedback

Then, logistic regression models were produced for prediction purpose. Four models were produced to predict the maintenance performance through variables of scheduled maintenance and four models were developed to predict the performance through variables of condition-based maintenance. The regression models would be useful for the practitioners to predict the maintenance outcome based on the selected maintenance strategy. They could also improve the performance by enhancing the participative mechanisms.

The main research findings were obtained through questionnaire survey results. Nevertheless, the semi-structured interview and archived documentation results were analysed as well to validate the analysis results of questionnaire survey. The results from the three research methods were matched to each other. Therefore, the results were deemed valid and reliable. The conclusion of the research would be discussed in Chapter 7.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1) Introduction

This chapter presents the conclusion of the study. The conclusion is made by matching the research objectives accordingly. Basically, the conclusion is derived from the findings and discussions of this research as presented in previous chapters. Then, contribution to the knowledge is stated and recommended to be applied in the industry. Furthermore, various recommendations for future research related to facilities and maintenance management are suggested.

7.2) Conclusion of the Study

This study was initiated with the review of literature that has revealed the poor maintenance management in Malaysia, especially the selection and implementation of maintenance strategies. Most of the management teams perform the maintenance programs in reactive or corrective basis, which is an ineffective strategy. Therefore, the preventive maintenance strategy that includes scheduled maintenance and condition-based maintenance were introduced and studied.

In order to select and implement the preventive maintenance strategies effectively, an in-depth understanding about the characteristics of the maintenance strategies is required. Through literature review, the characteristics were determined to have some influences toward maintenance performance in terms of time, cost and quality. Thus, it is necessary to study and focus on the characteristics of the maintenance strategies and their relationship with maintenance performance.

In addition, the author has also revealed some measures to improve the implementation of the maintenance strategies and their performance. Participative mechanisms were studied and identified as the measures to improve the strategies and performance. Typically, participative mechanisms are the involvement and commitment of the key participants in building maintenance management.

After a thorough review of literature, a theoretical framework was constructed to reflect the framework of the study. Then, the questionnaire survey, semi-structured interview and archive documentation were carried out to collect the data based on the theoretical framework. As a form of triangulation approach, collected data through the three data collection methods were analysed and compared. In the end it is observed that the analysis results supported and validated each other.

In conclusion, the characteristics of scheduled maintenance and condition-based maintenance are significant for selection and implementation of maintenance strategies. Furthermore, these characteristics have significant influences towards the maintenance performance. Then, participative mechanisms were introduced to enhance and improve the implementation of the maintenance strategies and their performance respectively. The conclusions from the study related to the research objective are discussed in the following subsections.

7.2.1) Objective 1: To Identify the Characteristics of Condition-Based and Scheduled Maintenance

The identification of characteristics was completed through a detailed review of literature. Then, a matrix of variables and references was produced for the purpose of selecting the variables. Overall, there are ten variables derived from the characteristics of scheduled maintenance and nine derived from the characteristics of condition-based maintenance. Then, the significance level of the characteristics were identified through questionnaire survey and validated through semi-structured interview as well as archived documentation. The significant variables are stated as follows (sorted with descending significance rank):

Scheduled Maintenance:

(i) Quality of spare parts and materials

(ii) Level of labour skill and knowledge

(iii) Budget allocation for skilled labour

(iv) Budget allocation for spare parts and materials

(v) Length of predetermined maintenance interval

(vi) Budget allocation for predetermined maintenance interval

(vii) Level of spare parts and materials stock

(viii) Number of skilled labour

(ix) Budget allocation for failure and maintenance downtime

(x) Amount of failure and maintenance downtime

Condition-Based Maintenance:

(i) Level of manager's skill and knowledge

(ii) Reliability of maintenance data

(iii) Budget allocation for skilled manager

(iv) Budget allocation for acquisition of maintenance data

(v) Budget allocation for equipment and technique

(vi) Capability to adopt equipment and technique

(vii) Frequency of monitoring and inspection

(viii) Availability of equipment and technique

(ix) Budget allocation for monitoring and inspection

Then, it was determined that the top five variables of scheduled maintenance are more of concern by the practitioners, as the mean scores are above 3.00 (indicating that the level of significance is above average). On the other hand, all the nine variables of condition-based maintenance were concerned by the practitioners. Consequently, the significance of the preventive maintenance characteristics was confirmed.

7.2.2) Objective 2: To Review Measures in Improving Maintenance Performance by Adopting the Maintenance Strategies

In order to improve the maintenance performance by adopting the preventive maintenance strategies, participative mechanisms were studied and suggested. The mechanisms ensure all the key participants involve themselves in maintenance management. A matrix of variables and references was made after an extensive review of literature for selecting the variables. Continuously, significance level of the variables were investigated through questionnaire survey and validated through semi-structured interview as well as archived documentation. They are (sorted with descending significance rank):

(i) Provision of training

(ii) Provision of knowledge-sharing and communication platform

(iii) Clients' commitment

(iv) Level of care by users

(v) Users' satisfaction and feedback

(vi) Manufacturers' and suppliers' commitment

Notably, all the six participative mechanisms were deemed significant by the respondents, which results in mean scores of above 3.00 (indicating that the level of importance is above average). Meanwhile, the participative mechanisms were found to be significantly correlated to the maintenance performance as stated below:

Maintenance Downtime Variance:

(i) Provision of knowledge-sharing and communication platform

(ii) Provision of training

(iii) Clients' commitment

(iv) Users' satisfaction and feedback

Maintenance Expenditure Variance:

(i) Provision of knowledge-sharing and communication platform

(ii) Clients' commitment

System Breakdown Rate:

(i) Provision of knowledge-sharing and communication platform

(ii) Provision of training

(iii) Clients' commitment

As a conclusion, willingness of the key participants to involve and commit themselves in maintenance management is likely to improve the implementation of the maintenance strategies, as well as the maintenance performance.

7.2.3) Objective 3: To Establish Relationship between Characteristics of Preventive Maintenance towards Maintenance Performance

SPSS software was used to analyse the relationship between characteristics of preventive maintenance towards maintenance performance. Ten and nine characteristics of scheduled and condition-based maintenance were tested with the maintenance performance respectively. According to the analysis results, it is proven that the characteristics of preventive maintenance are significantly correlated to the maintenance performance.

The characteristics of scheduled maintenance that are significantly correlated to the maintenance performance are as follows:

Maintenance Downtime Variance:

(i) Level of labour skill and knowledge

(ii) Level of spare parts and materials stock

(iii) Quality of spare parts and materials

(iv) Length of predetermined maintenance interval

(v) Amount of failure and maintenance downtime

Maintenance Expenditure Variance:

(i) Level of labour skill and knowledge

(ii) Budget allocation for spare parts and materials

(iii) Level of spare parts and materials stock

(iv) Quality of spare parts and materials

(v) Length of predetermined maintenance interval

(vi) Amount of failure and maintenance downtime

System Breakdown Rate:

(i) Level of labour skill and knowledge

(ii) Level of spare parts and materials stock

(iii) Quality of spare parts and materials

Number of Complaint Received:

(i) Level of labour skill and knowledge

On the other hand, the characteristics of condition-based maintenance that are significantly correlated to the maintenance performance are listed below:

Maintenance Downtime Variance:

(i) Level of manager's skill and knowledge

(ii) Availability of equipment and technique

(iii) Capability to adopt equipment and technique

(iv) Reliability of maintenance data

Maintenance Expenditure Variance:

(i) Level of manager's skill and knowledge

(ii) Budget allocation for equipment and technique

(iii) Availability of equipment and technique

(iv) Capability to adopt equipment and technique

(v) Budget allocation for acquisition of maintenance data

(vi) Reliability of maintenance data

System Breakdown Rate:

(i) Level of manager's skill and knowledge

(ii) Capability to adopt equipment and technique

(iii) Reliability of maintenance data

(iv) Frequency of monitoring and inspection

Number of Complaints Received:

(i) Level of manager's skill and knowledge

(ii) Capability to adopt equipment and technique

(iii) Reliability of maintenance data

In conclusion, the characteristics of preventive maintenance significantly influence the performance outcome. Taking into cognizance the significant relationship between the characteristics and performance, the practitioners must be concern about these characteristics when implementing particular maintenance strategies. Consequently, the performance outcomes can be controlled and optimised.

7.2.4) Objective 4: To Develop Prediction Model on Maintenance Performance

Planning the maintenance strategies can be effective with prediction of the maintenance performance. Thus, the logistic regression models were developed in this study for prediction purpose. SPSS software was used to analyse and produce the regression models. As a result, eight regression models were produced to predict the probability of events.

Four models were developed to predict the maintenance outcomes by characteristics of scheduled maintenance as follows:

(i) P [downtime extension]: $Z = 3.064 – 0.812$ LSK

(ii) P [over-budget]: $Z = 1.237 – 0.963$ LSK + 0.728 LPM

(iii) P [non-zero breakdown]: $Z = 6.182 – 0.952$ LSK

(iv) P [non-zero complaint]: $Z = 4.833 – 0.796$ LSK

Additionally, four models were produced to predict the maintenance outcomes according to the characteristics of condition-based maintenance as below:

(i) P [downtime extension]: $Z = 3.734 – 1.061$ CAT

(ii) P [over-budget]: $Z = 3.173 – 0.812$ RMD

(iii) P [non-zero breakdown]: $Z = 7.104 – 1.132$ MSK

(iv) P [non-zero complaint]: $Z = 7.421 – 1.357$ MSK

As a conclusion, the significant predictors of maintenance outcomes for scheduled maintenance are level of labour skill and knowledge, as well as length of predetermined maintenance interval; while the significant predictors of maintenance outcomes for condition-based maintenance are level of manager skill and knowledge, capability to adopt equipment and technique, as well as reliability of maintenance data.

7.3) Contribution to the Knowledge

The importance of maintenance management is always neglected by most of the people. The maintenance activities of building are usually handed-over to managing agent by the owners of the building. Unfortunately, effective maintenance management cannot be achieved by sole commitment of managing agent. It requires participation and commitment of building occupiers. Generally, participative mechanism is the involvement of key participants in an event to ensure its success. In maintenance management, the key participants include building owners or clients, organisations, managing agent or maintenance personnel, building users or occupants, service providers and so on. In order to enhance the planning, execution and outcome of the maintenance activities, communication among the key participants is compulsory for sharing knowledge, information, opinions, suggestions, feedbacks, comments, and advices. Then, they must be willing to commit themselves in maintenance management based on their own responsibilities. Therefore, participative mechanism is seen as an input to improve the overall process of maintenance management. The key participants must realise that they have the responsibility to take part in the management of the building to achieve a sustainable, comfortable, and safe living or working environment. This research recommends the practitioners to raise up the awareness of public to involve themselves in building maintenance management.

7.4) Recommendations for Future Research

This research is absolutely not covering all available perspectives in the studied area and certainly cannot be said as the end on preventive maintenance, participative mechanism, and maintenance performance. It provides more research opportunities for further research in the future. Hence, the research recommends further study in the following areas:

(i) An in-depth study to identify the characteristics of preventive maintenance that significantly influence the maintenance performance. The identification of additional variables could be useful to develop more comprehensive prediction model.

(ii) An exclusive study on participative mechanism to explore its applicability and benefit to building maintenance or facilities management. The mechanism should be widely introduced to the industry to achieve effective management.

(iii) A study to identify and explain the role and responsibility of key participants in maintenance management. Whereby, the public is still lacking of awareness about their role and responsibility in maintenance management.

(iv) Similar study to be carried out in other geographical area. Comparative study is required to further validate the theoretical framework and research outcomes. However, the research outcomes might be different due to the contrasts in terms of culture, environment and others.

(v) Similar research to cover different scopes of study, such as the residential or institutional buildings should be carried out. The results obtained might be varied as the functions of the buildings and the needs of the building occupants are different from each other.

(vi) Further study on different maintenance strategies that influence the maintenance performance such as the reliability-centred maintenance and risk-based maintenance.

(vii) Detailed study can be undertaken on the equipment, tools, technique and technology that can be adopted in condition-based maintenance. Whereby, the industry is still lacking of knowledge and information to introduce the advanced equipment and technique, such as infrared thermography.

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APPENDIX A: Questionnaire Survey

Location of Sample

The samples of buildings were located in (refer to Figure A1):

- Kuala Lumpur
- Petaling Jaya
- Subang Jaya
- Shah Alam
- Puchong
- Klang
- Gombak

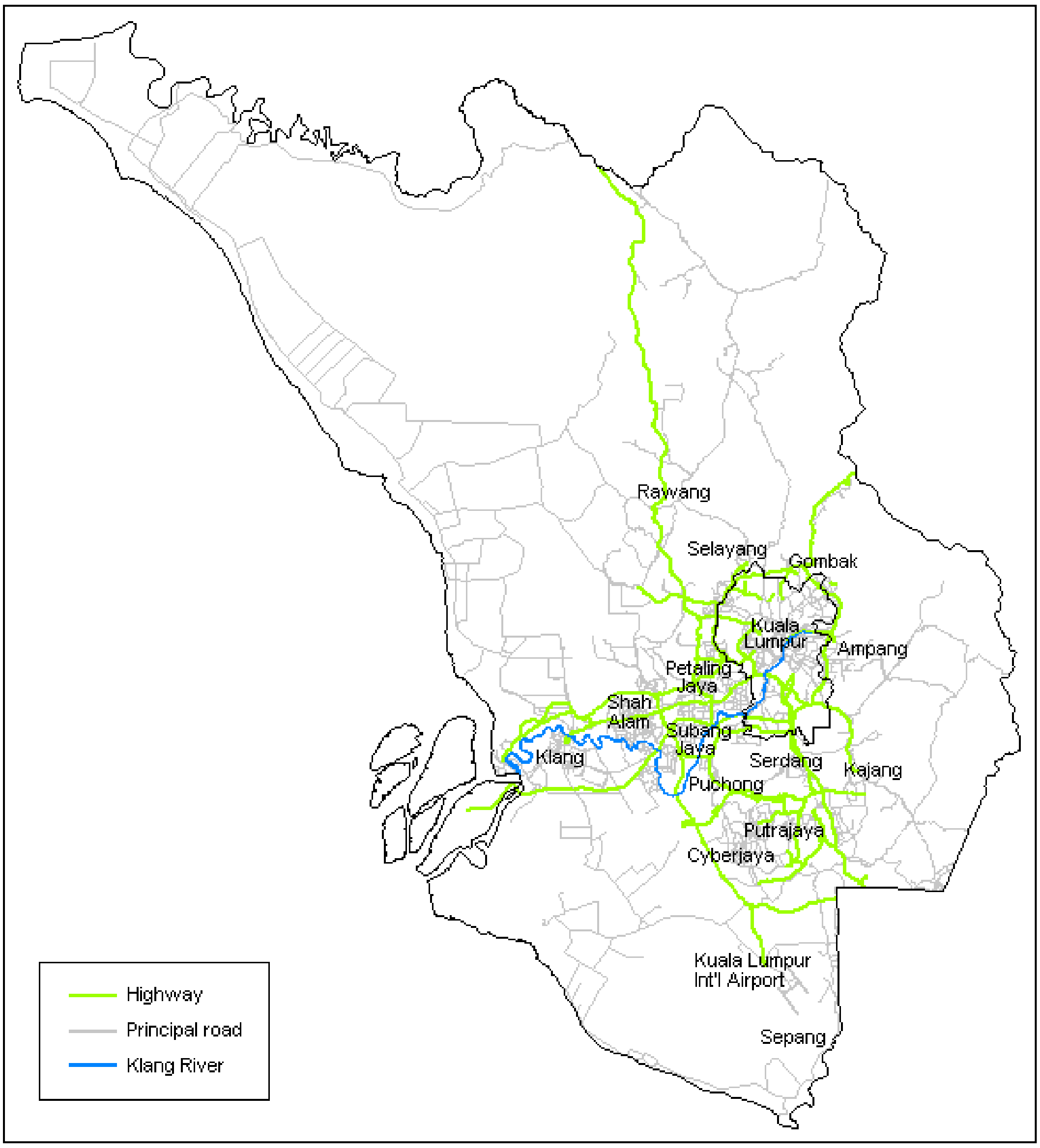

Figure A1: Klang Valley Map

QUESTIONNAIRE ON CHARACTERISTICS OF SCHEDULED MAINTENANCE AND CONDITION-BASED MAINTENANCE TOWARD MAINTENANCE PERFORMANCE

Return Address:
AU YONG CHEONG PENG
C/O: Assoc Prof Dr. AZLAN SHAH ALI
Department of Building Surveying,
Faculty of Built Environment,
University of Malaya,
50603 Kuala Lumpur.

Reference No.: UM/FBE/BHA100019/____
Contact No.: 017-2731281
Email Address: auyongcp@gmail.com

Notes:
(a) Please answer all questions by ticking (/) in appropriate bracket or space.
(b) Please return the completed questionnaire by using the envelope provided.
(c) Your identity and related information of your firm will remain strictly confidential to us.

Definitions:
Scheduled Maintenance, the preventive maintenance carried out in accordance with predetermined interval of time, number of operations, mileage and others to ensure that the components perform in good condition.
Condition-Based Maintenance, the maintenance initiated as a result of knowledge of the condition or significant deterioration of an item or component through continuous monitoring and routine inspection to minimise the total cost of repairs.
Maintenance Performance, the level of success or failure in terms of schedule, cost and functionality.

SECTION A – Respondent's Particular

1. What is your job title?
   [ ] Building Manager　　[ ] Building Executive/ Supervisor
   [ ] Building Technician　　[ ] Others, please specify __________________

2. How long have you involved in the building maintenance industry?
   [ ] Less than 5 years　　[ ] 6 - 10 years　　[ ] 11 - 15 years　　[ ] More than 15 years

3. How many office buildings that you have involved in maintenance management?
   [ ] Less than 2　　[ ] 3　　[ ] 4　　[ ] More than 5

For the following sections will be based on the particular of maintenance management that satisfies the following criteria:-

- **High-rise office building (minimum 7 storeys) located in Klang Valley**
- **Office building is managed by official management body**
- **Building completed in 2008 or earlier.**
- **Building consists of central heat, ventilation and air conditioning (HVAC) system**

Your answer should be based on the maintenance of central HVAC system in the high-rise office building <u>that you have chosen</u>

SECTION B – Building Information

1. Ownership of office building.
   [ ] Government [ ] Private [ ] Others, please specify
   ____

2. Building age.
   [ ] 2 – 5 years [ ] 6 – 10 years [ ] 11 – 15 years [ ] 16 - 20 years [ ] More than 20 years

3. Annual maintenance management cost.
   [ ] Less than RM 100,001 [ ] RM 100,001 to RM 200,000
   [ ] RM 200,001 to RM 300,000 [ ] > RM 300,000

4. Type of maintenance strategy used for HVAC system. (Please refer to the definitions in Page 1)
   [ ] Scheduled maintenance (Please answer Question 1 in Section C)
   [ ] Condition-based maintenance (Please answer Question 2 in Section C)
   [ ] Both (Please answer all the questions in Section C)

SECTION C – Characteristics of Scheduled Maintenance and Condition-Based Maintenance

1. Characteristics of Scheduled Maintenance

Please rate the level of scales of the following variables in the HVAC system maintenance tasks by using the scales below:

- 1=Very low amount; 2=Low amount; 3=Optimal; 4=High amount; 5=Very high amount
- 1=Very poor; 2=Poor; 3=Moderate; 4=Good; 5=Very good
- 1=Very short; 2=Short; 3=Optimal; 4=Long; 5=Very long

			1	2	3	4	5	
1.1	Skilled labour							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Skill and knowledge	*Very poor*						*Very good*
	(c) Number of labours	*Very low amount*						*Very high amount*

			1	2	3	4	5	
1.2	Spare part and material							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Level of stock	*Very low amount*						*Very high amount*
	(c) Quality	*Very poor*						*Very good*

			1	2	3	4	5	
1.3	Predetermined interval for maintenance							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Length of the interval	*Very short*						*Very Long*

			1	2	3	4	5	
1.4	Failure and maintenance downtime							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Amount of downtime	*Very low amount*						*Very high amount*

2. Characteristics of Condition-Based Maintenance

Please rate the level of scales of the following variables in the HVAC system maintenance tasks by using the scales below:

- 1=Very low amount; 2=Low amount; 3=Optimal; 4=High amount; 5=Very high amount
- 1=Very poor; 2=Poor; 3=Moderate; 4=Good; 5=Very good
- 1=Very inadequate; 2=Inadequate; 3=Moderate; 4=Adequate; 5=Very adequate
- 1=Very rare; 2=Rare; 3=Optimal; 4=Often; 5=Very often

			1	2	3	4	5	
2,1	Skilled manager							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Skill and knowledge	*Very poor*						*Very good*
2.2	Monitoring equipment and technique							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Availability of equipment	*Very inadequate*						*Very adequate*
	(c) Capability to adopt the technique	*Very poor*						*Very good*
2.3	Acquisition of data and information							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Reliability of data information	*Very inadequate*						*Very adequate*
2.4	Monitoring and inspection							
	(a) Budget allocation	*Very low amount*						*Very high amount*
	(b) Frequency of inspection	*Very rare*						*Very often*

SECTION D – Participative Mechanisms

1. Please rate the degree of influence of the following variables in obtaining adequate maintenance budget, information, and/or skill and knowledge by using the scale below:
   - 1=Very low degree; 2=Low degree; 3=Moderate; 4=High degree; 5=Very high degree

			1	2	3	4	5	
1.1	Provision of knowledge-sharing and communication platform	*Very low degree*						*Very high degree*
1.2	Provision of training	*Very low degree*						*Very high degree*
1.3	Clients' commitment	*Very low degree*						*Very high degree*
1.4	Users' satisfaction and feedback toward maintenance management	*Very low degree*						*Very high degree*

1.5	Level of care towards building and systems by building users	*Very low degree*	[ ] [ ] [ ] [ ] [ ]	*Very high degree*
1.6	Manufacturers and suppliers' commitment	*Very low degree*	[ ] [ ] [ ] [ ] [ ]	*Very high degree*

SECTION E – Maintenance Performance

1. Please specify the ratio of actual HVAC system maintenance downtime to planned maintenance downtime of the maintenance tasks. (E.g. if the actual maintenance downtime was 10 days and planned maintenance downtime was 8 days, divide 10 by 8, so the ratio is 1.25)
   [ ] 0 – 0.80 [ ] 0.81 – 0.90 [ ] 0.91 – 1.00
   [ ] 1.01 – 1.10 [ ] 1.11 – 1.20 [ ] more than 1.20

2. Please specify the ratio of actual HVAC system maintenance expenditure to planned maintenance expenditure of the maintenance tasks. (E.g. if the actual maintenance expenditure was RM15,000 and planned maintenance expenditure was RM10,000, divide 15,000 by 10,000, so the ratio is 1.5)
   [ ] 0 – 0.80 [ ] 0.81 – 0.90 [ ] 0.91 – 1.00
   [ ] 1.01 – 1.10 [ ] 1.11 – 1.20 [ ] more than 1.20

3. Please indicate the average rate of HVAC system breakdown (that requires 1 day or more to repair it) per year.
   [ ] 0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 and above

4. Please indicate the number of complaint received from building users and customers about HVAC system per month.
   [ ] 0 - 1 [ ] 2 - 3 [ ] 4 - 5 [ ] 6 - 7 [ ] 8 - 9 [ ] 10 and above

If you have any comment concerning the questionnaire or the research topic, please write on the space at the back of this page

____

____

____

____

____

THANK YOU VERY MUCH FOR TAKING PART IN THIS SURVEY

If you would like to get the summary of this **final research results**, free of charge, please fill in your name and email address below.

Name: Email:

APPENDIX B: Semi-Structured Interview

Information Sheet

Interviewer's Information

Research Title: The Relationship between Preventive Maintenance Characteristics and the Maintenance Performance of High-Rise Office Buildings in Malaysia

Researcher: Au Yong Cheong Peng (BHA100019)

Department: Department of Building Surveying, Faculty of Built Environment, University of Malaya

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Brief:

This study is conducted to discover the characteristics of preventive maintenance (scheduled maintenance and condition-based maintenance) in maintenance management of high-rise office buildings. Then, relationship of those characteristics toward maintenance performance is studied. In fact, the overall data and information have been gathered through questionnaire survey in early stage. After that, semi-structured discussion with the experienced building manager, executive, supervisor, or any other maintenance personnel in managerial level are to be conducted as following data collection stage. The information gathered will be used to discuss the importance of those characteristics toward maintenance performance and to review measures for improving maintenance performance. Meanwhile, the information will be used to compare and validate the questionnaire survey result. Consequently, better understanding about the relationship between characteristics of preventive maintenance and maintenance performance is expected to be established. At the end of the study, prediction models will be developed and effective measure to improve maintenance performance can be recommended.

Aims of Study:

The aim of this research is to study on the importance of maintenance strategies, include condition-based and scheduled maintenance. Difference between the maintenance strategies that affect the maintenance performance and cost benefit is to be identified.

More specifically the study is to:

(a) Identify characteristics of condition-based and scheduled maintenance.
(b) Review measures for improving maintenance performance by adopting the maintenance strategies.
(c) Establish relationship between preventive maintenance towards maintenance performance.
(d) Develop prediction models on maintenance performance.

Requirements:

(e) Participants for this discussion must be building managers, executives, supervisors, or any maintenance personnel in managerial level who:

- Have working experience of more than 5 years in maintenance management.
- Are experienced in implementing scheduled maintenance, condition-based maintenance, or both.

(f) Participants will be informed of the discussion intended.

(g) Participants will be asked to sign the Consent Form for participation in the discussion.

(h) Participant is entirely voluntary and participants will have the rights to withdraw at any time without prejudice or negative consequences.

Confidentiality:

(a) Participants will be informed that discussions are confidential and that their identity will be abstracted in the thesis.

(b) All data collected from this study could only be assessed by the researcher and his supervisors.

Consent Form

Interviewer's Information

Research Title: The Relationship between Preventive Maintenance Characteristics and the Maintenance Performance of High-Rise Office Buildings in Malaysia

Researcher: Au Yong Cheong Peng (BHA100019)

Department: Department of Building Surveying, Faculty of Built Environment, University of Malaya

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Participant's Agreement

I have been informed of and understand the purposes of the study and my role as a participant. I am also aware of my rights of asking questions and withdrawing from the research at any time without prejudices. Therefore, I agree to participate voluntarily in the study as outlined to me.

I understand that the interview will be audio recorded/ documented to facilitate the collection of information with the understanding that all information which I provide will be held in confidence. Besides that, I understand that my identity will be abstracted in the thesis. I also understand that I may withdraw this consent at any time without penalty by advising the researcher.

Name: ______________________________

Job Title: ______________________________

Signature: ______________________________

Date: ______________________________

INTERVIEW QUESTION

Section A – Scheduled Maintenance

1. What are the important characteristics for scheduled maintenance? Why do they important for this maintenance strategy? (if answer not relevant, ask characteristics below)
(a) Quality of spare part
(b) Skill and knowledge of labour
(c) Budget allocation for skilled labour

2. Do the characteristics you mentioned significantly influence the maintenance performance (cost, time, quality)? How they influence the maintenance performance? What about:
(a) Skill and knowledge of labour
(b) Budget allocation for spare part
(c) Level of spare parts' stock
(d) Quality of spare part
(e) Length of maintenance interval
(f) Amount of downtime (failure and repair)

3. What are the common issues of scheduled maintenance? How your management team solve such issues?

Section B – Condition-Based Maintenance

1. What are the important characteristics for condition-based maintenance? Why do they important for this maintenance strategy? (if answer not relevant, ask characteristics below)
(a) Skill and knowledge of manager
(b) Budget allocation for skilled manager
(c) Reliability of data obtained

2. Do the characteristics you mentioned significantly influence the maintenance performance (cost, time, quality)? How they influence the maintenance performance? What about:
(a) Skill and knowledge of manager
(b) Budget allocation for equipment and technique
(c) Availability of equipment and technique
(d) Capability to adopt equipment and technique
(e) Budget allocation for data acquisition
(f) Reliability of system condition data
(g) Frequency of monitoring and inspection

3. What are the common issues of condition-based maintenance? How your management team solve such issues?

Section C – Participative Mechanism

1. What are the important participative mechanisms in maintenance management? Please explain. (if answer not relevant, ask mechanisms below)

(a) Provision of training

(b) Provision of knowledge-sharing and communication platform

(c) Clients' commitment

2. Do the participative mechanisms you mentioned significantly influence the maintenance performance (cost, time, quality)? How they influence the maintenance performance? What about:

(a) Provision of knowledge-sharing and communication platform

(b) Provision of training

(c) Client commitment

(d) Users' satisfaction and feedback

3. Does your management team adopt any other mechanism or method to improve the maintenance performance? Can you further explain on it?

Section D – Comparison

1. Apart from the maintenance strategy your management team adopts, do you have any idea on scheduled maintenance/ condition-based maintenance*?

APPENDIX C: Reliability Analysis

Scale: Alpha for Characteristics of Scheduled Maintenance

Case Processing Summary

		N	%
Cases	Valid	101	84.2
	Excluded[a]	19	15.8
	Total	120	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.741	.771	10

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Skilled Labour-Budget Allocation	27.46	19.610	.652	.626	.684
Skilled Labour-Skill and Knowledge	27.37	19.894	.518	.573	.702
Skilled Labour-Number of Labours	27.94	20.856	.474	.348	.710
Spare Part and Material-Budget Allocation	27.58	19.325	.685	.614	.678
Spare Part and Material-Level of Stock	27.94	20.016	.602	.460	.692
Spare Part and Material-Quality	27.24	19.803	.560	.582	.696
Predetermined Maintenance Interval-Budget Allocation	27.79	21.126	.505	.476	.708
Predetermined Maintenance Interval-Length of Interval	27.61	23.799	.086	.139	.765
Failure and Maintenance Downtime-Budget Allocation	27.99	20.250	.563	.414	.697
Failure and Maintenance Downtime-Amount of Downtime	28.03	26.949	-.241	.263	.829

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
30.77	25.398	5.040	10

Scale: Alpha for Characteristics of Condition-Based Maintenance

Case Processing Summary

		N	%
Cases	Valid	100	83.3
	Excluded[a]	20	16.7
	Total	120	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.888	.888	9

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Skilled Manager-Budget Allocation	26.40	25.960	.567	.585	.881
Skilled Manager-Skill and Knowledge	26.12	25.076	.685	.541	.872
Equipment and Technique-Budget Allocation	26.55	24.533	.665	.703	.873
Equipment and Technique-Availability	26.74	24.073	.713	.651	.869
Equipment and Technique-Capability to Adopt	26.58	24.953	.715	.605	.870
Acquisition of Data-Budget Allocation	26.49	23.505	.796	.713	.862
Acquisition of Data-Reliability	26.37	24.357	.673	.629	.873
Monitoring and Inspection-Budget Allocation	26.79	25.804	.616	.521	.877
Monitoring and Inspection-Frequency	26.60	27.253	.357	.371	.898

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
29.83	31.274	5.592	9

APPENDIX D: Logistic Regression Analysis

Logistic Regression - Scheduled Maintenance to Downtime Extension

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	101	84.2
	Missing Cases	19	15.8
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No Extension	0
Extension	1

Block 0: Beginning Block

Classification Table[a,b]

			Predicted		
			Downtime Extension		Percentage Correct
	Observed		No Extension	Extension	
Step 0	Downtime Extension	No Extension	0	44	.0
		Extension	0	57	100.0
	Overall Percentage				56.4

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	.259	.201	1.664	1	.197	1.295

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	LabourSkill	12.399	1	.000
		PartStock	8.444	1	.004
		PartQuality	10.929	1	.001
		IntervalLength	1.737	1	.188
		DowntimeAmount	.657	1	.418
	Overall Statistics		16.237	5	.006

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	13.130	1	.000
	Block	13.130	1	.000
	Model	13.130	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	125.208[a]	.122	.163

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.586	2	.746

Contingency Table for Hosmer and Lemeshow Test

		Downtime Extension = No Extension		Downtime Extension = Extension		
		Observed	Expected	Observed	Expected	Total
Step 1	1	11	10.220	3	3.780	14
	2	17	18.005	16	14.995	33
	3	12	12.521	24	23.479	36
	4	4	3.254	14	14.746	18

Classification Table[a]

	Observed		Predicted		
			Downtime Extension		Percentage Correct
			No Extension	Extension	
Step 1	Downtime Extension	No Extension	28	16	63.6
		Extension	19	38	66.7
	Overall Percentage				65.3

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.812	.243	11.163	1	.001	.444
	Constant	3.064	.877	12.207	1	.000	21.404

a. Variable(s) entered on step 1: LabourSkill.

Correlation Matrix

		Constant	LabourSkill
Step 1	Constant	1.000	-.970
	LabourSkill	-.970	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	LabourSkill	-69.169	13.130	1	.000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	PartStock	2.396	1	.122
		PartQuality	1.694	1	.193
		IntervalLength	1.223	1	.269
		DowntimeAmount	.053	1	.818
	Overall Statistics		4.482	4	.345

```
             Step number: 1

             Observed Groups and Predicted Probabilities

      40 +                                                                                                    +
         |                                                                                                    |
         |                                                                 E                                  |
F        |                                             E                   E                                  |
R     30 +                                             E                   E                                  +
E        |                                             E                   E                                  |
Q        |                                             E                   E                                  |
U        |                                             E                   E                                  |
E     20 +                                             E                   E                                  +
N        |                                             N                   E                                  |
C        |                           E                 N                   E              E                   |
Y        |                           E                 N                   N              E                   |
      10 +                           N                 N                   N              E                   +
         |                           N                 N                   N              E                   |
         |                           N                 N                   N              N                   |
         |                           N                 N                   N              N         E         |
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE

          Predicted Probability is of Membership for Extension
          The Cut Value is .50
          Symbols: N - No Extension
                   E - Extension
          Each Symbol Represents 2.5 Cases.
```

Logistic Regression - Scheduled Maintenance to Over-Budget

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	101	84.2
	Missing Cases	19	15.8
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No overbudget	0
Overbudget	1

Block 0: Beginning Block

Classification Table[a,b]

			Predicted		
			Overbudget		Percentage Correct
	Observed		No overbudget	Overbudget	
Step 0	Overbudget	No overbudget	0	46	.0
		Overbudget	0	55	100.0
	Overall Percentage				54.5

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	.179	.200	.800	1	.371	1.196

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	LabourSkill	15.630	1	.000
		PartBudget	5.575	1	.018
		PartStock	6.276	1	.012
		PartQuality	12.176	1	.000
		IntervalLength	8.529	1	.003
		DowntimeAmount	2.499	1	.114
	Overall Statistics		23.760	6	.001

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	16.791	1	.000
	Block	16.791	1	.000
	Model	16.791	1	.000
Step 2	Step	8.261	1	.004
	Block	25.052	2	.000
	Model	25.052	2	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	122.422[a]	.153	.205
2	114.161[a]	.220	.294

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	1.146	2	.564
2	2.496	6	.869

Contingency Table for Hosmer and Lemeshow Test

		Overbudget = No overbudget		Overbudget = Overbudget		
		Observed	Expected	Observed	Expected	Total
Step 1	1	12	10.942	2	3.058	14
	2	18	19.272	15	13.728	33
	3	12	12.786	24	23.214	36
	4	4	3.000	14	15.000	18
Step 2	1	10	9.775	2	2.225	12
	2	8	8.238	3	2.762	11
	3	9	10.413	8	6.587	17
	4	5	5.482	7	6.518	12
	5	9	6.660	9	11.340	18
	6	3	3.107	10	9.893	13
	7	2	1.826	9	9.174	11
	8	0	.499	7	6.501	7

Classification Table[a]

Observed			Predicted: Overbudget: No overbudget	Predicted: Overbudget: Overbudget	Predicted: Percentage Correct
Step 1	Overbudget	No overbudget	30	16	65.2
		Overbudget	17	38	69.1
	Overall Percentage				67.3
Step 2	Overbudget	No overbudget	27	19	58.7
		Overbudget	15	40	72.7
	Overall Percentage				66.3

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.936	.253	13.653	1	.000	.392
	Constant	3.403	.908	14.049	1	.000	30.059
Step 2[b]	LabourSkill	-.963	.265	13.248	1	.000	.382
	IntervalLength	.728	.269	7.328	1	.007	2.072
	Constant	1.237	1.185	1.091	1	.296	3.446

a. Variable(s) entered on step 1: LabourSkill.

b. Variable(s) entered on step 2: IntervalLength.

Correlation Matrix

		Constant	LabourSkill	Constant	LabourSkill	IntervalLength
Step 1	Constant	1.000	-.971			
	LabourSkill	-.971	1.000			
Step 2	Constant			1.000	-.692	-.602
	LabourSkill			-.692	1.000	-.128
	IntervalLength			-.602	-.128	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	LabourSkill	-69.606	16.791	1	.000
Step 2	LabourSkill	-65.140	16.119	1	.000
	IntervalLength	-61.211	8.261	1	.004

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	PartBudget	.129	1	.719
		PartStock	.687	1	.407
		PartQuality	1.353	1	.245
		IntervalLength	8.054	1	.005
		DowntimeAmount	.260	1	.610
	Overall Statistics		9.980	5	.076
Step 2	Variables	PartBudget	.805	1	.370
		PartStock	1.067	1	.302
		PartQuality	1.397	1	.237
		DowntimeAmount	.015	1	.904
	Overall Statistics		2.204	4	.698

```
           Step number: 1

           Observed Groups and Predicted Probabilities

      40 +                                                                                                    +
         |                                                                                                    |
         |                                                                O                                   |
F        |                                         O                      O                                   |
R     30 +                                         O                      O                                   +
E        |                                         O                      O                                   |
Q        |                                         O                      O                                   |
U        |                                         O                      O                                   |
E     20 +                                         O                      O                                   +
N        |                                         N                      O                                   |
C        |                     O                   N                      O                 O                 |
Y        |                     N                   N                      N                 O                 |
      10 +                     N                   N                      N                 O                 +
         |                     N                   N                      N                 O                 |
         |                     N                   N                      N                 N                 |
         |                     N                   N                      N                 N         O       |
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0       .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO

          Predicted Probability is of Membership for Overbudget
          The Cut Value is .50
          Symbols: N - No overbudget
                   O - Overbudget
          Each Symbol Represents 2.5 Cases.
```

```
           Step number: 2

           Observed Groups and Predicted Probabilities

      20 +                                                                                                    +
         |                                                                                                    |
         |                                                               O                                    |
F        |                                                               O                                    |
R     15 +                                       O                       O                                    +
E        |                                       O                       O                                    |
Q        |                                       O                       O                                    |
U        |                                       O                       O                                    |
E     10 +                   O                   O                       O             O                      +
N        |                   O                   O                       N             O                      |
C        |                   N   O               N                 O     N             O   O                  |
Y        |                   N   N               N                 O     N             O   O                  |
       5 +                   N   N               N                 O     N             O   O                  +
         |                   N   N               N                 O     N             O   O        O         |
         |                   N   N    N    N     N     O           N     N    O        O   N     O  O         |
         |          N  N     N   N    N    N     N     O    NN     N     N    N    N   N   N     O  O    OO O |
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0       .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO

          Predicted Probability is of Membership for Overbudget
          The Cut Value is .50
          Symbols: N - No overbudget
                   O - Overbudget
          Each Symbol Represents 1.25 Cases.
```

Logistic Regression - Scheduled Maintenance to System Breakdown

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	101	84.2
	Missing Cases	19	15.8
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Yes	0
No	1

Block 0: Beginning Block

Classification Table[a,b]

	Observed		Predicted		
			Zero Breakdown		Percentage Correct
			Yes	No	
Step 0	Zero Breakdown	Yes	0	7	.0
		No	0	94	100.0
	Overall Percentage				93.1

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	2.597	.392	43.952	1	.000	13.429

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	LabourSkill	4.281	1	.039
		PartStock	2.112	1	.146
		PartQuality	1.846	1	.174
	Overall Statistics		4.700	3	.195

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	4.609	1	.032
	Block	4.609	1	.032
	Model	4.609	1	.032

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	46.263[a]	.045	.113

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.993	2	.609

Contingency Table for Hosmer and Lemeshow Test

		Zero Breakdown = Yes		Zero Breakdown = No		Total
		Observed	Expected	Observed	Expected	
Step 1	1	3	2.717	11	11.283	14
	2	2	2.807	31	30.193	33
	3	2	1.247	34	34.753	36
	4	0	.229	18	17.771	18

Classification Table[a]

Observed			Predicted		
			Zero Breakdown		Percentage Correct
			Yes	No	
Step 1	Zero Breakdown	Yes	0	7	.0
		No	0	94	100.0
	Overall Percentage				93.1

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.952	.482	3.901	1	.048	.386
	Constant	6.182	2.009	9.474	1	.002	484.080

a. Variable(s) entered on step 1: LabourSkill.

Correlation Matrix

		Constant	LabourSkill
Step 1	Constant	1.000	-.980
	LabourSkill	-.980	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	LabourSkill	-25.436	4.609	1	.032

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	PartStock	.401	1	.526
		PartQuality	.025	1	.875
	Overall Statistics		.534	2	.766

```
          Step number: 1

          Observed Groups and Predicted Probabilities

      40 +                                                                                                    +
         |                                                                                                    |
         |                                                                                                N   |
F        |                                                                                           N    N   |
R     30 +                                                                                           N    N   +
E        |                                                                                           N    N   |
Q        |                                                                                           N    N   |
U        |                                                                                           N    N   |
E     20 +                                                                                           N    N   +
N        |                                                                                           N    N   |
C        |                                                                                N          N    N N |
Y        |                                                                                N          N    N N |
      10 +                                                                                N          N    N N +
         |                                                                                N          N    N N |
         |                                                                                N          N    N N |
         |                                                                                Y          Y    Y NN|
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  YYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

          Predicted Probability is of Membership for No
          The Cut Value is .50
          Symbols: Y - Yes
                   N - No

          Each Symbol Represents 2.5 Cases.
```

Logistic Regression - Scheduled Maintenance to Complaint Received

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	101	84.2
	Missing Cases	19	15.8
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Yes	0
No	1

Block 0: Beginning Block

Classification Table[a,b]

			Predicted		
			Zero Complaint		Percentage Correct
	Observed		Yes	No	
Step 0	Zero Complaint	Yes	0	13	.0
		No	0	88	100.0
	Overall Percentage				87.1

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	1.912	.297	41.424	1	.000	6.769

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	LabourSkill	5.519	1	.019
	Overall Statistics		5.519	1	.019

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	5.850	1	.016
	Block	5.850	1	.016
	Model	5.850	1	.016

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	71.705[a]	.056	.105

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	5.647	2	.059

Contingency Table for Hosmer and Lemeshow Test

		Zero Complaint = Yes		Zero Complaint = No		
		Observed	Expected	Observed	Expected	Total
Step 1	1	6	4.178	8	9.822	14
	2	3	5.315	30	27.685	33
	3	2	2.870	34	33.130	36
	4	2	.637	16	17.363	18

Classification Table[a]

			Predicted		
			Zero Complaint		Percentage Correct
	Observed		Yes	No	
Step 1	Zero Complaint	Yes	0	13	.0
		No	0	88	100.0
	Overall Percentage				87.1

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LabourSkill	-.796	.351	5.133	1	.023	.451
	Constant	4.833	1.407	11.807	1	.001	125.595

a. Variable(s) entered on step 1: LabourSkill.

Correlation Matrix

		Constant	LabourSkill
Step 1	Constant	1.000	-.976
	LabourSkill	-.976	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	LabourSkill	-38.777	5.850	1	.016

```
             Step number: 1

             Observed Groups and Predicted Probabilities

      40 +                                                                                                     +
         |                                                                                                     |
         |                                                                                             N       |
F        |                                                                                    N        N       |
R     30 +                                                                                    N        N       +
E        |                                                                                    N        N       |
Q        |                                                                                    N        N       |
U        |                                                                                    N        N       |
E     20 +                                                                                    N        N       +
N        |                                                                                    N        N       |
C        |                                                                       N            N        N   N   |
Y        |                                                                       N            N        N   N   |
      10 +                                                                       N            N        N   N   +
         |                                                                       N            N        N   N   |
         |                                                                       Y            N        N   N   |
         |                                                                       Y            Y        Y   Y N |
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  YYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

          Predicted Probability is of Membership for No
          The Cut Value is .50
          Symbols: Y - Yes
                   N - No
          Each Symbol Represents 2.5 Cases.
```

Logistic Regression - Condition-Based Maintenance to Downtime Extension

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	100	83.3
	Missing Cases	20	16.7
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No Extension	0
Extension	1

Block 0: Beginning Block

Classification Table[a,b]

			Predicted		
			Downtime Extension		Percentage Correct
	Observed		No Extension	Extension	
Step 0	Downtime Extension	No Extension	0	44	.0
		Extension	0	56	100.0
	Overall Percentage				56.0

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	.241	.201	1.433	1	.231	1.273

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	ManagerSkill	4.822	1	.028
		EquipmentAvailability	11.170	1	.001
		EquipmentAdopt	12.677	1	.000
		DataReliability	12.168	1	.000
	Overall Statistics		16.687	4	.002

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	13.734	1	.000
	Block	13.734	1	.000
	Model	13.734	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	123.452[a]	.128	.172

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.076	2	.354

Contingency Table for Hosmer and Lemeshow Test

		Downtime Extension = No Extension		Downtime Extension = Extension		
		Observed	Expected	Observed	Expected	Total
Step 1	1	3	3.313	1	.687	4
	2	23	20.630	10	12.370	33
	3	15	17.930	34	31.070	49
	4	3	2.127	11	11.873	14

Classification Table[a]

			Predicted		
			Downtime Extension		Percentage Correct
	Observed		No Extension	Extension	
Step 1	Downtime Extension	No Extension	26	18	59.1
		Extension	11	45	80.4
	Overall Percentage				71.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	EquipmentAdopt	-1.061	.318	11.148	1	.001	.346
	Constant	3.734	1.079	11.983	1	.001	41.828

a. Variable(s) entered on step 1: EquipmentAdopt.

Correlation Matrix

		Constant	EquipmentAdopt
Step 1	Constant	1.000	-.980
	EquipmentAdopt	-.980	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	EquipmentAdopt	-68.593	13.734	1	.000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	ManagerSkill	.035	1	.851
		EquipmentAvailability	2.498	1	.114
		DataReliability	2.747	1	.097
	Overall Statistics		4.443	3	.217

```
            Step number: 1

            Observed Groups and Predicted Probabilities

      80 +                                                                                                    +
         |                                                                                                    |
         |                                                                                                    |
F        |                                                                                                    |
R     60 +                                                                                                    +
E        |                                                                                                    |
Q        |                                                               E                                    |
U        |                                                               E                                    |
E     40 +                                                               E                                    +
N        |                                     E                         E                                    |
C        |                                     E                         E                                    |
Y        |                                     N                         E                                    |
      20 +                                     N                         E                                    +
         |                                     N                         N                                    |
         |                                     N                         N                   E                |
         |                 N                   N                         N                   E                |
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE

          Predicted Probability is of Membership for Extension
          The Cut Value is .50
          Symbols: N - No Extension
                   E - Extension
          Each Symbol Represents 5 Cases.
```

Logistic Regression - Condition-Based Maintenance to Over-Budget

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	100	83.3
	Missing Cases	20	16.7
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No overbudget	0
Overbudget	1

Block 0: Beginning Block

Classification Table[a,b]

			Predicted		
			Overbudget		Percentage Correct
	Observed		No overbudget	Overbudget	
Step 0	Overbudget	No overbudget	0	42	.0
		Overbudget	0	58	100.0
	Overall Percentage				58.0

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	.323	.203	2.538	1	.111	1.381

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	ManagerSkill	6.586	1	.010
		EquipmentBudget	5.370	1	.020
		EquipmentAvailability	8.729	1	.003
		EquipmentAdopt	3.680	1	.055
		DataBudget	4.822	1	.028
		DataReliability	10.679	1	.001
	Overall Statistics		14.143	6	.028

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	11.287	1	.001
	Block	11.287	1	.001
	Model	11.287	1	.001

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	124.771[a]	.107	.144

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	4.940	2	.085

Contingency Table for Hosmer and Lemeshow Test

		Overbudget = No overbudget		Overbudget = Overbudget		
		Observed	Expected	Observed	Expected	Total
Step 1	1	11	9.918	3	4.082	14
	2	16	16.086	15	14.914	31
	3	11	14.246	33	29.754	44
	4	4	1.750	7	9.250	11

Classification Table[a]

			Predicted		
			Overbudget		
	Observed		No overbudget	Overbudget	Percentage Correct
Step 1	Overbudget	No overbudget	27	15	64.3
		Overbudget	18	40	69.0
	Overall Percentage				67.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	DataReliability	-.812	.261	9.704	1	.002	.444
	Constant	3.173	.950	11.164	1	.001	23.879

a. Variable(s) entered on step 1: DataReliability.

Correlation Matrix

		Constant	DataReliability
Step 1	Constant	1.000	-.974
	DataReliability	-.974	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	DataReliability	-68.029	11.287	1	.001

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	ManagerSkill	.963	1	.327
		EquipmentBudget	1.178	1	.278
		EquipmentAvailability	1.924	1	.165
		EquipmentAdopt	.058	1	.809
		DataBudget	.029	1	.864
	Overall Statistics		3.704	5	.593

```
            Step number: 1

            Observed Groups and Predicted Probabilities

      80 +                                                                                                    +
         |                                                                                                    |
         |                                                                                                    |
F        |                                                                                                    |
R     60 +                                                                                                    +
E        |                                                                                                    |
Q        |                                                                                                    |
U        |                                                                   O                                |
E     40 +                                                                   O                                +
N        |                                                                   O                                |
C        |                                                O                  O                                |
Y        |                                                O                  O                                |
      20 +                                                O                  O                                +
         |                             O                  N                  O                                |
         |                             N                  N                  N              O                 |
         |                             N                  N                  N              N                 |
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO

          Predicted Probability is of Membership for Overbudget
          The Cut Value is .50
          Symbols: N - No overbudget
                   O - Overbudget
          Each Symbol Represents 5 Cases.
```

Logistic Regression - Condition-Based Maintenance to System Breakdown

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	100	83.3
	Missing Cases	20	16.7
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Yes	0
No	1

Block 0: Beginning Block

Classification Table[a,b]

	Observed		Predicted		
			Zero Breakdown		Percentage Correct
			Yes	No	
Step 0	Zero Breakdown	Yes	0	7	.0
		No	0	93	100.0
	Overall Percentage				93.0

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	2.587	.392	43.558	1	.000	13.286

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	ManagerSkill	3.862	1	.049
		EquipmentAdopt	1.239	1	.266
		DataReliability	2.649	1	.104
		InspectionFrequency	2.332	1	.127
	Overall Statistics		5.253	4	.262

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	4.276	1	.039
	Block	4.276	1	.039
	Model	4.276	1	.039

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	46.452[a]	.042	.105

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.133	2	.936

Contingency Table for Hosmer and Lemeshow Test

		Zero Breakdown = Yes		Zero Breakdown = No		
		Observed	Expected	Observed	Expected	Total
Step 1	1	3	2.859	12	12.141	15
	2	3	3.318	44	43.682	47
	3	1	.789	32	32.211	33
	4	0	.034	5	4.966	5

Classification Table[a]

Observed			Predicted		
			Zero Breakdown		Percentage Correct
			Yes	No	
Step 1	Zero Breakdown	Yes	0	7	.0
		No	0	93	100.0
	Overall Percentage				93.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	ManagerSkill	-1.132	.589	3.690	1	.055	.322
	Constant	7.104	2.529	7.893	1	.005	1217.177

a. Variable(s) entered on step 1: ManagerSkill.

Correlation Matrix

		Constant	ManagerSkill
Step 1	Constant	1.000	-.987
	ManagerSkill	-.987	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	ManagerSkill	-25.364	4.276	1	.039

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	EquipmentAdopt	.025	1	.874
		DataReliability	.256	1	.613
		InspectionFrequency	1.309	1	.253
	Overall Statistics		2.162	3	.539

```
            Step number: 1

            Observed Groups and Predicted Probabilities

      80 +                                                                                                    +
         |                                                                                                    |
         |                                                                                                    |
F        |                                                                                                    |
R     60 +                                                                                                    +
E        |                                                                                                    |
Q        |                                                                                                    |
U        |                                                                                            N       |
E     40 +                                                                                            N       +
N        |                                                                                            N    N  |
C        |                                                                                            N    N  |
Y        |                                                                                            N    N  |
      20 +                                                                                            N    N  +
         |                                                                                N           N    N  |
         |                                                                                N           N    N  |
         |                                                                                Y           Y    N N|
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  YYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

          Predicted Probability is of Membership for No
          The Cut Value is .50
          Symbols: Y - Yes
                   N - No
          Each Symbol Represents 5 Cases.
```

Logistic Regression - Condition-Based Maintenance to Complaint Received

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	100	83.3
	Missing Cases	20	16.7
	Total	120	100.0
Unselected Cases		0	.0
Total		120	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Yes	0
No	1

Block 0: Beginning Block

Classification Table[a,b]

	Observed		Predicted		
			Zero Complaint		Percentage Correct
			Yes	No	
Step 0	Zero Complaint	Yes	0	12	.0
		No	0	88	100.0
	Overall Percentage				88.0

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	1.992	.308	41.921	1	.000	7.333

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	ManagerSkill	8.203	1	.004
		EquipmentAdopt	2.415	1	.120
		DataReliability	6.396	1	.011
	Overall Statistics		10.064	3	.018

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	9.300	1	.002
	Block	9.300	1	.002
	Model	9.300	1	.002

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	64.085[a]	.089	.171

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.089	2	.957

Contingency Table for Hosmer and Lemeshow Test

		Zero Complaint = Yes		Zero Complaint = No		
		Observed	Expected	Observed	Expected	Total
Step 1	1	5	5.198	10	9.802	15
	2	6	5.644	41	41.356	47
	3	1	1.120	32	31.880	33
	4	0	.038	5	4.962	5

Classification Table[a]

			Predicted		
			Zero Complaint		Percentage Correct
	Observed		Yes	No	
Step 1	Zero Complaint	Yes	0	12	.0
		No	0	88	100.0
	Overall Percentage				88.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	ManagerSkill	-1.357	.493	7.579	1	.006	.257
	Constant	7.421	2.114	12.328	1	.000	1670.938

a. Variable(s) entered on step 1: ManagerSkill.

Correlation Matrix

		Constant	ManagerSkill
Step 1	Constant	1.000	-.988
	ManagerSkill	-.988	1.000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	ManagerSkill	-36.692	9.300	1	.002

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	EquipmentAdopt	.115	1	.735
		DataReliability	.892	1	.345
	Overall Statistics		1.662	2	.436

```
            Step number: 1

            Observed Groups and Predicted Probabilities

      80 +                                                                                                    +
         |                                                                                                    |
         |                                                                                                    |
F        |                                                                                                    |
R     60 +                                                                                                    +
E        |                                                                                                    |
Q        |                                                                                                    |
U        |                                                                                       N            |
E     40 +                                                                                       N            +
N        |                                                                                       N        N   |
C        |                                                                                       N        N   |
Y        |                                                                                       N        N   |
      20 +                                                                                       N        N   +
         |                                                                 N                     N        N   |
         |                                                                 N                     N        N   |
         |                                                                 Y                     Y        N  N|
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  YYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

          Predicted Probability is of Membership for No
          The Cut Value is .50
          Symbols: Y - Yes
                   N - No
          Each Symbol Represents 5 Cases.
```

LIST OF PUBLICATIONS

Article in Academic Journal

Cheong-Peng Au-Yong, Azlan-Shah Ali, Faizah Ahmad (2013). Significant characteristics of scheduled and condition-based maintenance in office building, *Journal of Performance of Constructed Facilities, ASCE*. *(ISI/SCOPUS Cited Publication)* – Accepted for Publication

Au Yong Cheong Peng, Azlan Shah Ali, Faizah Ahmad (2012), Characteristics of Scheduled Maintenance toward Cost Performance in Office Building, *Archives Des Sciences, 65* (7), pp 80-88. (*ISI-Cited Publication*) – Published

Proceeding

Au Yong Cheong Peng, Azlan Shah Ali & Faizah Ahmad (2012). *Establishing Relationship between Characteristics of Preventive Maintenance and Cost Performance*, Proceeding of RICS COBRA 2012, pp 593-601, 11-13 September 2012, Las Vegas, Nevada, USA. (*Non-ISI/Non-SCOPUS Cited Publication*) – Published

Au Yong Cheong Peng & Azlan Shah Ali (2011). *Cost Characteristics of Scheduled and Condition-Based Maintenance*, Proceeding of ICoPFM 2011, pp 123-127, 18-19 May 2011, Kuala Lumpur. (*Non-ISI/Non-SCOPUS Cited Publication*) – Published

LIST OF PRESENTATIONS

Scheduled Maintenance and Condition-Based Maintenance, Seminar on Sustainable Facilities and Life Cycle Management, 08 Nov 2012, Department of Building Surveying, Faculty of Built Environment, University of Malaya, (National)

Establishing Relationship between Characteristics of Preventive Maintenance and Cost Performance, RICS COBRA 2012, 11 Sep 2012 to 13 Sep 2012, RICS & Arizona State University, (International)

Cost Characteristics of Scheduled and Condition-Based Maintenance, 2nd International Conference on Project & Facilities Management 2011, 18 May 2011 to 19 May 2011, Centre for Construction, Building & Urban Studies, University of Malaya, (International)

Scale of Measurement for Benchmarking in Building Maintenance, 1st International Symposium on Conducive Learning Environment for Smart School, 17 Jan 2011, UKM & UM, (International)