DEVELOPMENT OF A COMPETENCY APPRAISAL MODEL BASED ON INTRINSIC PERSONAL TRAITS FOR MAINTENANCE WORKERS

by

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LIST OF SIMBOLS

N	Number of experts
n	Number of PSFs
μ_{PSF_a}	Mean value of one PSF item
δ	Score of level of influence for one PSF
$\sum_{I=1}^{N}$	Summation of item *I* to item *N*
w	Weight of PSF given by each expert
w_{PSF_a}	Weight of each PSF (mean value of the *N* experts)
w_x	PSF normalized weight
r	Rating of PSF given by each expert
r_{PSF_a}	Rating of each PSF (mean value of the *N* experts)
r_x	Rating of PSF in percentage value
x	One PSF
γ	Workforce performance level for one performance indicator
φ	Percentage of a workforce competency level

LIST OF ABBREVIATION

AHP	Analytical Hierarchy Process
ATHEANA	A Technique for Human Event Analysis
CPR	Cardiopulmonary resuscitation
CREAM	Cognitive Reliability and Error Analysis Method
CrM	Corrective Maintenance
DFN	Dual Flat-Pack-No-Lead
DOE	Department of Energy
EOL	End of Line
HEP	Human Error Probability
FOL	Front of Line
FRMM	Fault Recovery Management Mechanism
HEART	Human Error Assessment and Reduction Technique
HFACS	Human Factors Analysis and Classification System
HFACSS-RR	Human Factors Analysis and Classification System – Rail Road
HPM	Human Performance Model
HRA	Human Reliability Analysis
ICC	Intra-class Correlation
KPI	Key Performance Indicator
MIDAS	Man-machine Integrated Design and Analysis System
OEE	Overall Equipment Effectiveness
OSATS	Objective Structured Assessment of Technical Skills
PA	Performance Analysis
PC	Paired Comparison

PdM	Predictive Maintenance
PI	Performance Indicator
PM	Preventive Maintenance
PSF	Performance Shaping Factor
QFN	Quad Flat-Pack-No-Lead
QMPMS	Quantitative Model for Performance Measurement System
SLIM	Success Likelihood Index Methodology
SMART	Specific, Measurable, Attainable, Realistic, Timely effective
SME	Small and Medium Enterprise
SOIC	Small Outline Integrated Circuit
THERP	Technique for Human Error Rate Prediction
TPM	Total Productive Maintenance
TSOP	Thin Small Outline Package
VSOP	Very Small Outline Package

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1. Improving Maintenance System by Improving Human Performance
2. Development of Human Reliability Model for Evaluating Maintenance Workforce Reliability: A Case Study in Electronic Packaging Industry
3. Development of Framework for Human Error Assessment: Towards Improving Maintenance Effectiveness
4. Evaluating Plant Operator Maintenance Proficiency: A Model for Examining Personal Performance
5. Evaluation of Maintenance Workforce Competency through A Model of Human Performance.

PEMBINAAN MODEL PENILAIAN KECEKAPAN BERDASARKAN KEPADA ASAS KRITERIA PERIBADI BAGI PEKERJA PENYELENGGARA

ABSTRAK

Peranan penyelenggaraan dalam industri pembuatan moden kini semakin penting apabila organisasi-organisasi menganggap penyelenggaraan sebagai elemen penjana keuntungan sesebuah perniagaan. Memandangkan manusia memainkan peranan penting dalam keseluruhan operasi penyenggaraan, bidang kajian ini telah menerima banyak penekanan. 'Kecekapan individu'; termasuklah kemahiran teknikal, pengetahuan, dan sikap seseorang kakitangan penyelenggara, sering dianggap sebagai faktor penyumbang utama kepada kegagalan atau kejayaan operasi penyenggaraan bagi sesebuah organisasi. Oleh itu, prestasi yang mantap bagi setiap individu ini perlu diberi keutamaan and dipantau. Dalam kajian ini, sebuah model yang diberi nama Model Kecekapan Pekerja dibangunkan sebagai alat atau medium untuk mengukur prestasi seseorang pekerja penyelenggara. Mengambil pakar-pakar dalam organisasi penyenggara bagi menyediakan data yang dikehendaki, konsep asas model ini adalah kecekapan seseorang individu melakukan suatu tugasan bergantung kepada asas kritera peribadi yang mempengaruhi prestasi individu tersebut; iaitu Faktor-faktor Pembetukan Prestasi. Pengesahan bagi model ini dilakukan di sebuah industri pempakejan elektronik di Malaysia, bertumpu kepada juruteknik di bahagian proses ikatan dawai. Keputusan daripada model menunjukkan peringkat sebenar kecekapan seseorang juruteknik dan dikategorikan kepada lima tahap prestasi; 'Maju', 'Standard Yang Baik', 'Memuaskan', 'Memerlukan Penambahbaikan' dan 'Tidak Diterima'. Berdasarkan keputusan ini, panambahbaikan yang praktikal seharusnya dirancang untuk individu yang berprestasi rendah dengan memfokuskan kepada kelemahan khusus individu tersebut. Ini adalah bertujuan untuk mewujudkan

dan mengekalkan kualiti prestasi pekerja-pekerja penyelenggara, dengan cara yang berkesan dari segi kos dan masa.

DEVELOPMENT OF A COMPETENCY APPRAISAL MODEL BASED ON INTRINSIC PERSONAL TRAITS FOR MAINTENANCE WORKERS

ABSTRACT

The role of maintenance in modern manufacturing industry is becoming ever more important, with organizations adopting maintenance as a profit-generating business element. As the human aspect plays significant role in the overall maintenance operations, this area of study has received much emphasis recently. 'Personnel competent' which including the maintenance personnel's technical skills, knowledge and attitude is often considered as main contributing factors to success or failure of organization's maintenance operations. The competency of these personnel should therefore be paramount and need to be monitored. Thus, in this research, a model named Workforce Competency Model is developed as a tool to gauge or quantify the individual maintenance workforce performance. Utilizing of experts in maintenance organization for providing required data, the basic concept used in this model is that the competency of a person performing a given task is based on the combination effect of a set of intrinsic personal traits; or called performance-shaping factors (PSFs). Validation of this model is carried out in one of electronic packaging industry in Malaysia, focusing on technicians in wire bonding process area. Results from the model shown the actual level of the individual technician's competency, which are ranked into five performance level; 'Advanced', 'Good Standard', 'Satisfactory', 'Improvement Needed' and 'Unacceptable'. Therefore, this result implies that practical improvement should be planned for the lower performer with focusing to the persons' specific weaknesses. This is in order to establish and maintain high level of maintenance technicians' performance, with cost and timely effective manner.

CHAPTER 1

INTRODUCTION

1.0 Overview

This chapter is divided into five sections. The first section gives an overview of the research background. The importance of human involvement in maintenance system is discussed in section two. The next following section discusses on the research problem statement. The fourth deals with the research aim and objectives, and the final section highlighting on the focus and limitation.

1.1 Background

In the challenging and competitive industrial arena, companies are striving towards world-class competitiveness. Since maintenance attributes large portion of total production cost; around 15 percent to 40 percent (Al-Najjar and Alsyouf, 2003), this also puts maintenance under increasing pressure to reduce cost and waste in the daily production. Apart from influencing production efficiency, on-time deliveries, capacity, and total plant cost effectiveness, maintenance has a major impact on product quality which is depending on equipment conditions. Thus, maintenance is expected to be able to make long-term contribution to company's profitability by intensifying production efficiency, extending equipment life and improving equipment reliability and availability.

Maintenance in general can be described as the combination of a set of technical and administrative actions with a purpose to retain or restore an equipment or system in a state which it can perform its designated functions (Duffua et al., 1999; Dhillon, 2006). Maintenance is also considered as a system carried out in parallel with production system. It is also a key role in achieving organizational goals and objectives. According to Duffuaa et al. (1999), a maintenance system can be viewed as a simple input-output model. The inputs include labours, management, tools, spares, materials, equipments, etc. These desired resources should be optimized, thus maximizing the output of maintenance system; reliable and well configured equipments, in order to achieve the planned operations of a plant.

In modern industries, in order to fulfil the operational goals, organizations have adopted a large proportion of equipment's complexities. An extensive maintenance system and maintenance management become more crucial. The widespread mechanization and automation as example, has reduced the number of production personnel and increased the capital employed in production equipment and civil structures. As a result, the fractions of peoples working in the maintenance area and maintenance expenses on the total operational costs are escalating (Dekker, 1996).

1.2 Peoples in Maintenance System

Roles and responsibilities of peoples in maintenance are not only limited in handling and repairs the down equipment, but also diagnosing and error recovering, analyzing the problems occurred and plan for the effective solutions or improvement. As people or humans become involved in any system, their abilities and limitations are manifested in their performance of mission tasks. And, since humans are essential to the operation of such systems, it is important to study the effects of human performance on the maintenance system.

It is well known that the success of a maintenance system can be partly achieved through excellent equipment performance and reliability. However, the other core ingredient must be a skilful operator to operate the equipment as well as managing the overall maintenance system. Role of qualified technicians, as example, is essential for high-quality of maintenance. Their performance in fact may directly or indirectly influence the maintenance quality. This is proven by Duffuaa et al. (1999) who claimed that much maintenance ineffectiveness can be traced from the lack of skilled of technical workers, which is also resulted in various errors. According to Mason (2000), human error in maintenance can give an impact on safety and overall performance in a number of ways. Poor repairs, for example, can increase the amount of breakdown which in turn can increase the risk associated with equipment failure and personal accident.

In addition, skills desired by maintenance workers are also quite different with skills needed by production workers. Unlike production works that are routine and require less information to be performed, maintenance works conversely present different levels of information processing as well as problem solving and decision making.

1.3 Problem Statement

Because of the maintenance work is mostly non-repetitive and has more variability; establishing and sustaining high level of technical employees' performance is crucial. Meaning that, the workers need to be trained. But, the question is: How much and in what areas?

Due to cost and time constraints, most companies cannot afford to send all their technicians to formal trainings for improving or enhancing their performance level. As an alternative, training is only provided to the most required persons for the specified types of training. For that purpose, a properly developed and implemented maintenance skills assessment is a valuable tool in determining the strengths and weaknesses of individual maintenance personnel in order to design a high-impact training program, and accordingly answering the questions.

Another problem is most organizations often found that it is difficult to upgrade their maintenance workers' technical skills and knowledge because much of training programs that is available is redundant or does not take the workers' current skill level into consideration (Smith, in Higgins and Mobley, 2002). Furthermore, due to the subjective nature of human, there is less concern among researchers to discuss and develop the best assessment tool for measuring the maintenance workers' performance.

Therefore, as an initial effort towards filling this void and address the stated problems, in the present work, a model will be developed as a human performance evaluation tool.

1.4 Research Aim

The emphasis of this research is to develop a model as an aid to assess and evaluate worker's performance carrying out maintenance tasks. The individual workforce's capability; which including their knowledge, skill and attitude are the main focus in this assessment. The primary target is to close or eliminate workforce performance gap in the most cost-effective manner. Modelling approach is chosen in this study because it will contribute to a better understanding of human performance in maintenance tasks. Since human performance might be affected by various variables, this model will consist of several appropriate parameters as a model indicator. The developed model then will be verified and validated in a real case study company. It is hope that the result from the model can be used to assist organization in decision making for the right man in the right training for the right work in order to establish and maintain high levels of technical employees' performance. This thus may enhance their capabilities and providing the competencies amongst the maintenance employees.

1.5 Research Focus

The human performance model in this study is developed based upon some considerations and constrains; which are:

1. In this assessment, extra attention has been paid to individual worker's competency or capability in performing their daily tasks, which include their knowledge, skills and attitudes.
2. The quantitative evaluation of human performance by using modelling approach should be practical and relevant in industrial plant maintenance application. Thus, it requires considerable quantitative resources such as maintenance data from an organization.
3. A number of appropriate human performance indicators will be proposed to be the model parameters. Each of the parameter will be evaluated on the basis of a number of individual factors influencing the worker's performance as variables; which is known as Performance Shaping Factors (PSFs).
4. Only a set of individual PSFs is considered in this model because the evaluation is carried out for the individual maintenance personnel, with assumptions that any external (e.g. equipment condition, workload, ect.) and stress factors are the same for every persons.

5. Only a group of operation technicians will be the subject in the case study, because the mission in this study is to enhance their technical knowledge and skills, in addition to their attitude.
6. Most of the evaluation criteria used in this measurement are based on judgement by experts in the maintenance area. It is because these people usually have most knowledge and experience about the system and operation, and they are the best persons who can provide meaningful quantitative evaluation regarding to the subjective matter of human performance.

1.6 Thesis Outlines

The overview of this thesis is as follows; Chapter 2 provides a literature review of the related subjects. Chapter 3 then deals with the development of the model. The model is validated in a case study carried out at electronic packaging industry in Malaysia which will be discussed in Chapter 4. Chapter 5 presents the overall discussion on the model validation and Chapter 6 finally addresses the conclusions and recommendations for the future research.

CHAPTER 2

REVIEW ON THE LITERATURE

2.0 Overview

This chapter discusses the literatures on the topic of maintenance, maintenance in human factor perspective, performance measurement and human performance measurement, modelling methods for evaluating human performance, and the validation issues. In the early discussion, past studies related with maintenance will be briefed before continuing to the study that integrates human factor in maintenance. Studies on human factor will then be discussed deeply, including issues on human performance measurement and several approaches used for the measurement purpose. However, models that have been developed and used for evaluating human performance will be the main focus in this chapter. Issues on human performance model validation will also be discussed. Findings from the literature review will then be discussed at the end of this chapter.

2.1 Maintenance: An Introduction

Referring to a brief introduction in Chapter 1, it has been described that the fundamental purpose of maintenance system in any business is to provide the required capacity for production at the lowest cost. It is also noted that maintenance in manufacturing has a responsibility not only to ensure the system and assets used to manufacture will be usable tomorrow, but also to develop products that are safe to use, pose no threat to the environment, and produce product without an interruption in terms of cost that the organization can afford. Through the positive maintenance efforts, condition based monitoring, good troubleshooting, root cause analysis, and other functions with the involvement of the entire teams; Business Management, Engineering, Operations, and Maintenance itself, technical as well as operational integrity thus can be achieved.

Research in the maintenance system and management has focused on various elements, where one of them is maintenance strategies. Concerning on the plant production and other related functions, this field of study is allied of formulating the best life plan for each item in a plant and determining the optimal maintenance schedule and events (Alsyouf, 2006). Over the several decades, maintenance strategies have rapidly changed to keep pace with the increase of complexity in manufacturing processes and the growth of technology. From the literature review, these changes have moved gradually from fixing the equipment when it is broken, to plan the scheduled maintenance and prediction of the failures and nowadays it moves to the more aggressive strategies, such as Total Productive Maintenance (TPM).

Apart from maintenance strategies, previous studies also emphasis on issues including maintenance policies (Zhou et al., 2006; Pinjala et al., 2006), maintenance performance measurement (Parida and Kumar, 2006; Alsyouf, 2006), maintenance scheduling (Roberts and Escudero, 1983; Mosley et al., 1998), and training issues for the technical workers (Smith and Hawkins, 2004). Those studies are not only limited for maintenance in manufacturing facilities, but also have been expanded to maintenance in construction industries and the high-risk and hazardous industries such as aviation, nuclear and chemical power plant, and oil and gas industries. However, most researches associated with the high-risk and hazardous industries have put strong emphasised on employee safety and securing and safeguard the plant in managing the effectiveness of the maintenance activities (Mason, 2000).

Yet, equipment performance is still the main focus on maintenance studies when dedicating the overall equipment effectiveness (OEE) with the machine's availability, performance efficiency and quality rate as the key indicators for maintenance performance measure (Jonsson and Lesshammar, 1999; Oechsner et al., 2003). Historically before the introduction of TPM, machine factor and its performance have been studied extensively. The application of optimization and statistical techniques for improvement strategy in this area has matured to a greater degree in the field of maintenance management. However, this situation has changed when the importance of human involvement in maintenance has been proven in many cases. This scope of research is being studied in some depth in a number of industries, and it becomes increasingly clear that human factors in maintenance operations is a topic of growing interest in most industries (Mason, 2000).

2.2 Maintenance in Human Factor Perspective

In general, study of human factor involves gathering information about human abilities, limitations and other characteristics which applied to tools, machines, systems, tasks, jobs, and environments to produce safe, comfortable, and effective human use. In scientific discipline on the other hand, study of human factors involves systematic application of information regarding human characteristic and behaviour to enhance performance of man-machine system (DiMittia et al., 2005). However, when it is viewed from the maintenance scope, human factor is dedicated to a better understanding on how humans can most effectively and efficiently perform their daily tasks and its effects on the overall maintenance system. This understanding is then being translated into design, training, policies, or procedures to help humans perform better. This, in turn, expectantly can increase the equipment reliability and availability thus enabling the companies to make profit.

Human involvement and the importance in maintenance system and maintenance management have been recognized in the past, especially when an aggressive maintenance approach, Total Productive Maintenance (TPM), was introduced in 1971 (Rodrigues and Hatakeyama, 2006). TPM in general is an improvement strategy that builds a close relationship between maintenance and production. It puts a strong emphasis on overall equipment operation and product quality, with active participation of every employee in organization. Besides developing a system of productive maintenance for the entire life of equipment, this approach also focuses on the root causes of failure by taking advantage of the abilities and skills of all individuals in the organization (Ben-Daya, 2000; Cua et al., 2001).

Other studies on human factor in maintenance are mostly with purpose to improve maintenance job quality by focusing on issues such as staffing policies, work scheduling, performance or skill evaluation, training requirement, as well as work environment. An example is Mosley et al. (1998) who examined strategies to reduce the adverse effects of machine downtime by prioritizing a limited number of maintenance personnel to work on breakdown machine which has highest potential impact on factory performance. In their work, the authors described various policies used for scheduling maintenance personnel, studied the different staffing policies, and applied the performance measures to compare the different policies.

Also a research carried out in maintenance management area, Wang and Hwang (2004) tackled production system availability as the criterion in developing a maintenance management model. Maintenance management, which the authors defined as the combination of technical and associated administrative actions which intended to retain an item in a system or restore the item to a normal state, plays a critical role in preventing deterioration and failure systems. The authors also agreed that by keeping up appropriate maintenance management, system availability can be improved thus reducing the costly breakdown. Since human influences system availability as well, the maintenance management model developed in their work integrates human factor (qualitative concept) and stochastic process (quantitative method) to predict the influence of the number of maintenance personnel and maintenance cycle time on system availability. This is to identify the optimal combination of the number of maintenance personnel and maintenance cycle time for improving maintenance management performance.

Other than that, much research and publications which address human factor in the field of maintenance emphasize on human error in various industries with various different purposes. It is because most researchers agreed that other than hardware failure, human error is a primary contributor to equipment and operation system failure, which will give impact on safety as well as plant performance. And, in fact, a significantly large proportion of total human errors occur during the maintenance phase (Dhillon and Liu, 2006). Duffuaa et al. (1999) also claimed that much ineffective maintenance can be traced due to the lack of skilled technical workers, which resulting in various errors.

Human error issues in maintenance have recently received increasing attention in various industries for different purposes. This is supported by Dhillon and Liu (2006) who aggressively reviewed the past studies related to human error with aims to present the impact of human errors in maintenance for practitioners to be aware and thus prepare actions to mitigate effects of the errors. The authors systematically categorized and analyzed the published literature according to six industries; aviation, nuclear power, chemical processing, medical device, mining, and miscellaneous industries. Highlighted that human error rate increases during fatigue period or under stress, Dhillon and Yang (1995) on the other hand developed a stochastic model for performing reliability and availability analysis of a repairable standby system with increasing human error rates and arbitrary failed system repair rates, which applicable for any industries.

One of industries emphasize on human error issues is aviation industry. According to Kapoor et al. (2005), the ever increasing complexity of aircraft, due to greater demands on human in the maintenance activities, a significant proportion of errors come at the hand of the maintenance personnel themselves. Thus, the authors claimed that it is crucial to take a closer look at these individuals, understand the causal factors for their errors and the possible solutions to counter this situation. Stand with the same opinion, Latorella and Prabhu (2000) reviewed current approaches for investigating human error in aviation maintenance and inspection, focusing on error detection and intervention strategies for controlling and managing the errors. Similar effort was also presented by Mason (2000), who introduced guidance to reduce errors in aviation maintenance and thereby promote safety.

For nuclear power industries, the maintenance activities are for guaranteeing safe, reliable, and cost-effective production of electricity. Oedewald and Reiman (2003) claimed that classifying, predicting, and preventing human errors are the focus of human factors studies in this industry. Those studies in fact are useful for designing barriers against error. In the same work domain, Pyy at al. (1997) on the other hand identified common cause failure mechanisms and generated numerical safety indicators with respect to human error in the nuclear power plant maintenance.

Such like nuclear power industry, transportation industry also emphasizes on safety in operation. According to Su et al. (2000), the time stress due to frequent task varieties and logistic decision uncertainties, maintenance errors can be easily induced. In their studies, the authors developed a fault recovery management mechanism (FRMM) by integrating reliability-centred maintenance method and expert system. This framework mechanism provides a systematic procedure to retrieve fault cases quickly and accurately, which serve as a guide for logistic systems to prevent errors caused by maintenance personnel.

While human errors in maintenance are usually emphasized within high-risk and hazardous industries, a number of researchers who have background in construction industries on the other hand focused their studies on the proficiency of construction plant operator maintenance. Edwards et al., (2002) claimed that international research has predominantly focused upon equipment management, mechanical reliability and cost prediction. Very less research conducted to determine plant operator influence upon machine reliability, even though plant operators have a significant impact upon machine breakdown occurrence.

Edwards et al. (2002) added that unlike maintenance operation within manufacturing sector which most of the machines are integrated with computerized and automated system, construction plant maintenance management is essentially plant operative reliant. This is because, the plant operator maintenance co-exist in a ‘symbiotic’ relationship with equipments they operate (Cabahug et al., 2004). In other word, maintaining a construction plant which is not only productive but also safe in operation is largely dependent upon operator skill and proficiency, especially to manually monitor machine condition, periodic inspection and servicing, repairs, and overhauls (Cabahug and Edwards, 2002). Ideally, construction plant operators have an important role in the delivery of efficient and effective plant performance. The maintenance skill training for construction plant operators was the main concern in their studies to ensure that operators are empowered with sufficient technical skills for well maintaining of plant.

With increasing awareness that human in maintenance create additional value in the effectiveness of maintenance system in any industries, more efforts should be placed on development of these personnel, and the measurement of their performances become essential. It is because, according to Kumar (2006), it is difficult to plan, control and improve the human performance without any formal measures of performance. This was supported by Parida (2007) who claimed that performance cannot be managed without measurement, as measurement can only indicate the present status of performance. Issues on performance measurement and how it can be used to measure performance of humans will be discussed in the following section.

2.3 Performance Measurement and Human Performance Measurement

Performance measurement in general can be defined as the process of quantifying the efficiency and effectiveness of an action or progress against a set of goals and objectives (Neely et al., 1995 and Parida, 2007). According to the measurement, status of the job carried out as well as what actions to be taken there after can be determined (Kumar, 2006). Recently, research dealing with performance measurement has grown to some degree with a lot of efforts that have been developed for evaluating performance of plant operations in a variety of industrial area. Most of the studies however focused on measuring manufacturing and business performance (Bititci et al., 2001; Martinez and Kennerley, 2005; Gomes et al., 2006).

According to Suwingnjo et al. (2000) and Bititci et al. (2001), since customers critically emphasize about quality and customer services; quality, speed, flexibility and cost become imperative attributes in measuring business performance. Agreeing with Neely et al. (1995) that the future performance measurement research agenda should develop techniques to reduce the number of measures into a manageable set, Suwingnjo et al. (2000) and Bititci et al. (2001) thus proposed a quantitative model for identifying, structuring, and quantifying a set of factors that may affect performance.

Even though attributes such as quality, speed, flexibility and cost as mentioned above are vital in improving organization's business performance, it is noted that the "soft" side of engineering, especially human-related issues such as human performance and reliability should not be ignored. Supporting this fact, Albayrak and Erensal (2004) claimed that in the business world, it is expected to identify solutions that align human performance to business results. Thus, in order to 'hitting the target' or tackle the best approach to improve human performance, the authors employed Analytical Hierarchy Process (AHP) multi-criteria decision making tool to model and structurally decide the best management style for improving employee's or human's performance.

Human performance in general is considered as a measure of human functions and actions under some specific conditions. The measurement is usually concern with what people do, why they do it, how they do it and the consequences of doing it (Bates, 1999). According to recent research, more modern commercial and industrial organization nowadays need to develop better methods for assessing the human performance rather than simply using performance measures such as efficiency and effectiveness (Albayrak and Erensal, 2004). In most cases, the assessments are carried out with a purpose to better understand and quantify human role in system performance and reliability by applying structured methodologies.

Apart from that, there is another approach for evaluating the human performance in the previous studies, which is identified, analyzed, and evaluated the contributing factors that lead to human inappropriate actions. This approach is taken in order to find the most appropriate strategies to prevent the recurrence of those actions. For instance, identification and evaluation of factors that influence to human performance; Performance Shaping Factors (PSFs) in the study of human reliability, that will be discussed further in Section 2.4.4. Toriizuka (2001) extended the use of PSFs, where the author investigated those factors not only from the standpoint of human reliability but also from the viewpoint of work efficiency and workload. This author examined the priorities of PSFs and proposed a set of PSFs for improving workforce performance in maintenance tasks.

Similar but in quality management context, Soltani et al. (2004) stressed that the primary purpose of performance evaluation should help the employees improve their performance, where the workers should be judged by absolute rather than relative standards of performance. The authors also highlighted guidelines for good evaluation systems that were needed to meet observability, measurability, job relatedness, importance to job success, controllability, practicability, consistent and congruent with organizational context.

In fact, numerous predictive models have been constructed and used to generate performance prediction, where the models are developed for human performance measurement (Glenn et al., 2004). Basically, the performance measurement whether using modelling methods or not is applied with the purpose to evaluate the actual human performance with aims to improve overall operational system performance. Details about modelling methods and the development for various applications in the study of human factor will be further discussed in the next section.

2.4 Modelling Methods for Evaluating Human Performance

A model in general is a representation or description of a process, system, or concept, which is usually in a simplified form. According to Young (2003), a model to an engineer is normally an abstraction that involves an explicit mathematical formalism of the process being studied. On the other hand, to a cognitive psychologist, a model is often a verbal or analytic description which depicts the information processing stages, required information, and system constraints or limitations of the process being studied. Depending upon how one defines the term, models can be ranged in a variety of types for diverse purposes. Some of the primary purposes of model development are for (1) optimization, which is to find the best values for decision variables; (2) justification, which aids in selling decisions and supporting viewpoints; (3) controlling purposes, which provides better understanding of system; and (4) performance prediction, which modelling tools are used to check potential plans and sensitivity (Askin and Standridge, 1993).

Development and application of models for evaluating human performance; or the Human Performance Models (HPMs) have been around for many years with various different techniques and purposes. Not only HPMs can either represent individuals or aggregate human performance (Young, 2003), they can also be used to symbolize how human interact with the system. According to Young (2003), HPMs can be used to support training, mission analysis, and simulation-based acquisition.

In addition, Zinser and Henneman (1988) agreed that modelling approach will contribute to a better understanding of human performance in the task being studied.

Although the effectiveness of many types of models can vary from one application to another, some of them are being used quite successfully to study various types of real-life problems in the industrial sector, either in qualitative or quantitative forms. The emphasis of qualitative models is on subjective understanding, discovery, collection, judgement, and classification rather than on prediction and control. However, quantitative models are used predominantly especially in the field of engineering. These types of models are usually used in the form of specific data and they generate a set of numerical outcomes that represent the result. The descriptions as well as advantages and drawbacks of the qualitative and quantitative model are described in Table 2.1, by referring to Wang and Hwang (2004).

Table 2.1: Qualitative versus quantitative models (Wang and Hwang, 2004)

	Qualitative Model	**Quantitative Model**
Description	Basically concerned with meaning rather than with measurement.	Related to the measurement and expressible as a quantity or numerical measurement.
Advantage	May describes the important concepts that are not easy to quantify.	Can simplify a realistic situation so that the tasks can be managed easily, and system performance can predict precisely.
Drawback	Lack objective numeric analysis to estimate a system precisely.	Mathematical models are difficult to understand and to interpret. Mathematical results and structures of optimal equation might be difficult to be practiced.
Applications	Accident/incident investigation Analysis of equipment breakdown record Simulation study on human behaviour under various conditions.	Prediction for probability of error occurs for various events in the form of relative data or absolute data.

With the descriptions and application of the qualitative and quantitative models as shown in Table 2.1, those types of model that are usually used in the studies of human performance are illustrated in Figure 2.1. The qualitative model includes simulation models and human error assessment models. Human reliability models, mathematical models and technical skill assessment models on the other hand are categorized under quantitative model. Details on each type of the qualitative and quantitative models with the applications in previous studies will be discussed in the following sections.

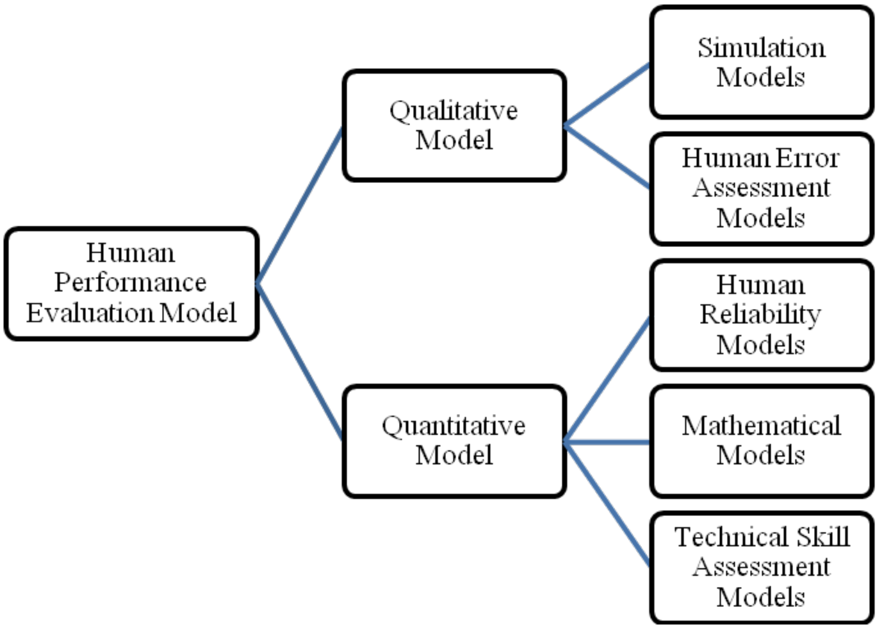

Figure 2.1: Classification of human performance evaluation models

2.4.1 Simulation Models

A simulation is usually defined as a computable method for running a model over time, where the model can be implemented using various different computational techniques such as neural nets, rule based systems, or mathematical formalism using different algorithms (Young, 2003). This type of model is typically applied in complex and huge systems for controlling and monitoring purposes. An example that relates to the study of human performance is carried out by Zinser and Henneman (1988) who proposed and evaluated a behaviourally valid model of human performance in monitoring and controlling communication network, which is a large, complex engineering system. Because of the complexity, simulation tool is chosen in their studies.

Gore and Corker (2002) also preferred modelling software tool, termed Man-machine Integrated Design and Analysis System (MIDAS) with the emphasis to increase safety in aviation operations. This is particularly apt with regard to dangerous situations, where simulation tool is useful to study how humans perform under various conditions. Similar software tool is also discussed by Gore and Jarvis (2005), where the authors used that integrated human performance modelling software tool to simulate the effect of stressors on performance through workload and timing exceedance. In other word, the authors study the effect of the increasing of workload to work quality and error probability. This was carried out to predict operator performance in the face of advanced display designs or new rules of operation and procedural specifications associated with aircraft travel.

However, simulation tool is not well preferred in many other industries. Aside from costly in nature, Nagy (2002) claimed that simulation approach lies in the fact that simulation often cannot fully replicate reality. Thus, the data obtained might not be accurate. Another qualitative technique that used frequently in the past studies regarding to human performance evaluation is the models of human error assessment.

2.4.2 Human Error Assessment Models

Human error in general can be described as the failure to perform a specified task that could lead to disruption of scheduled operations or result in damage to property and equipment (Dhillon, 1989; Dhillon and Liu, 2006). There is evidence in many studies that human error contributes to more than half of equipment and also operation system failures that lead to downtime, as well as accident and incident at workplace (Ryan, 1988; Lee at al., 1988a; DiMittia et al., 2005; Reinach and Viale, 2006). According to Wang and Hwang (2004), human errors can be classified into two types; critical human error and latent human error. The critical human error will result to the immediate system breakdown. On the other hand, the occurrences of latent human error might be identified before they are getting worse; and the problems occurred can be recovered by maintenance personnel during scheduled maintenance.

In order to get better understanding on human error and its consequences, DiMittia et al. (2005) suggested that it is crucial that any emotional domain of blame and punishment towards human error must firstly be removed. It is supposedly placed in a system perspective. The right viewpoint to the authors is to treat human error as a natural consequence arising from a discontinuity between human capabilities and system demands. Then, the factors that influence human error can be appropriately recognized and managed. This proposition is supported by Grozdanovic and Stojiljkovic (2006) who claimed that the purpose of human error management is not the investigation of past cases, but it is developed for the solution of the future problem on organizational management.

In the efforts of managing human error, a number of human error models and frameworks have been developed over the years especially in the high hazard industrial operations such as aviation and nuclear power. Basically the efforts involve analysis and assessment to not only aid in understanding human error in maintenance area as discussed in Section 2.1, but also in safety and risk mitigation purposes and for accident/incident analysis and investigations. The overall intentions of the models and framework are developed not only to prevent error in the future, but also to predict the occurrence of human error, to compare the errors with risk acceptance level for planning an appropriate improvement and to determine training needs for the workers.

For qualitative techniques, human-error classification and data collection can be performed by conducting a thorough investigation, observation, and judgement by experts on the worker's daily task performance. One of the important frameworks which was originally developed for the U.S. Navy and Marine Corps and has been employed by U.S. military is the Human Factors Analysis and Classification System (HFACS) (Wiegmann and Shappell, 2001). This framework was used as a data analysis tool for investigating errors caused by operators in civil and military aviation accidents and mishaps. The identified contributing factors are then classified into four levels of HFACS; unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. Results from the framework may assist in addressing critical areas of human factors that require safety improvement strategies thus significantly decrease the risks of aviation operations (Nelson, 1997).

The application of the HFACS framework had also been modified by Reinach and Viale (2006) to guide human factors-oriented accident/incident investigations in the railroad industry, which the authors named it HFACS-RR. Also for accident report analysis, Koester (2001) on the other hand suggested three-step methods as an inductive manner to help in identifying central human error problems in the maritime work domain. The method is based on a general method for text analysis, accident analysis and human error taxonomies. In the study, the author described that taxonomies are important in the research on human errors which have been developed as general tools for description, categorization and analysis of human errors in safety critical domains.

However, according to the literature, quantification models and framework are more preferred in studying the human error and its effect on both equipment and system reliability and effectiveness. Although at the beginning there are arguments between some behavioural scientists that quantification in principle is impossible (Hollnagel, 2005 in Maguire, 2005), this however has been changed nowadays when a number of analytical techniques have emerged in quantifying human error probabilities. The quantifications were carried out using human reliability models.

2.4.3 Human Reliability Models

Human reliability is defined as the probability of accomplishing a task successfully by humans at any required stage in a system operation without performing any irrelevant activities that can harm the system (Hollnagel, 2006). Similar to equipment or product reliability, analysis of human reliability provides a base to calculate the probability that a human, as a "component", will fail; where the result is called Human Error Probability (HEP). In other word, analysis of human reliability may assist in making predictions of human performing erroneous activities and their effects to the overall system reliability (Khan et al., 2006).

Human Reliability Analysis (HRA) is one of the most preferred human reliability models and has received much attention since a long time. This model basically predicts probabilities of human error based on the identified error contributing factors or PSFs. According to Grozdanović and Stojilković (2006), application of HRA methods started since in the half of 20th century. The emphasis at that time was on techniques for derivation of HEP in human task-performance via event-tree technology. However, after the worse incident in nuclear power industry in USA in 1979, HRA has been applied aggressively as part of the probabilistic safety assessment of large-scale industry, especially for the nuclear power plants (Grozdanović, and Stojilković, 2006). By applying these models, the potential human errors can be identified, the consequences in conjunction with other human errors and hardware failures can be assessed, and the relative contribution to overall system risk can be calculated (Nelson, 1997).