CONTINUOUS NOISE MAPPING PREDICTION TECHINIQUES USING THE STOCHASTIC MODELLING

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Dedicated to my beloved family members

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ABSTRACT

A strategic noise map provides important information for noise impact assessment. However, current practices still use the unstandardised way which produces unreliable information for noise exposure monitoring. This research aims to develop new noise mapping prediction technologies in order to enhance the current noise prediction method and noise monitoring practices. The research work was divided into preliminary and primary studies. In the preliminary study, a survey was conducted to investigate current noise exposure problems among Malaysian industries. Questionnaires were designed based on the proposed theoretical framework and distributed to 215 respondents from six workplaces with different industrial background. The finding shows that only 10.7 % of respondents wear hearing protectors regularly, thus implies a high risk of noise exposure problems in these industries. Based on the results of the Chi-square test, the utilisation rate of hearing protectors was not affected by noise awareness and training factors, but it could be increased through supervision and provision of safety information. The primary research study proposed two prediction methods, namely a noise prediction chart and stochastic modelling to be used in the development of both the automation and stochastic simulation frameworks. An automation framework is a system that automatically refers to a noise prediction chart in predicting the noise levels at receiving points. A stochastic simulation framework incorporates a random walk process and Monte Carlo approach to simulate movement and noise emission levels of machinery in a defined mapping area. Two prototyping softwares, namely Prototype I and Prototype II, were programmed using the MATLAB programming software in order to facilitate each proposed framework. Both prototyping software generated outputs such as strategic noise map, noise risk zone, and noise information. For software validation, a comparison of prediction and measurement results from case studies was performed. Eight case studies of field measurements from different industries were used to obtain the prediction inputs and noise levels from control points. The absolute differences between prediction and measurement values at the control points were computed to determine the accuracy of prediction results for each prototype. In general, the prediction results of Prototype I and II had a good agreement ($\leq$ 3 dBA) with the results obtained from measurement for most of the case studies. Both prototypes could reflect the complex and dynamic noise circumstances in a workplace. This study has significantly in advanced noise mapping prediction technologies and the prototypes produced could be beneficial as new noise monitoring tools in current industrial practices.

ABSTRAK

Peta bunyi bising menyediakan maklumat penting bagi penilaian kesan bunyi. Walau bagaimanapun, amalan semasa masih tidak menggunakan kaedah piawai dimana ia menghasilkan maklumat yang tidak boleh dipercayai bagi pemantauan pendedahan bunyi bising. Kajian ini bertujuan untuk membangunkan teknologi ramalan pemetaan bunyi bising yang baru dalam usaha untuk meningkatkan kaedah ramalan bunyi bising semasa dan pemantauan amalan bunyi bising. Kerja-kerja penyelidikan dibahagikan kepada kajian awal dan kajian utama. Dalam kajian awal, pra-selidik telah dijalankan untuk mengkaji masalah pendedahan bunyi bising semasa dalam industri di Malaysia. Borang soal selidik telah direka berdasarkan rangka kerja teori yang telah dicadangkan dan diedarkan kepada 215 responden yang terdiri dari enam tempat kerja dengan latar belakang industri yang berbeza. Keputusan menunjukkan hanya 10.7% responden kerap memakai pelindung pendengaran, justeru ini menunjukkan risiko masalah pendedahan bunyi bising yang tinggi dalam industri tersebut. Berdasarkan keputusan ujian 'Chi-square', kadar penggunaan pelindung pendengaran tidak terjejas oleh faktor-faktor kesedaran berkaitan bunyi bising dan latihan, tetapi ia boleh ditingkat melalui pengawasan dan peruntukan maklumat keselamatan. Kajian penyelidikan utama mencadangkan dua kaedah ramalan, iaitu carta ramalan bunyi bising dan model stokastik yang akan digunakan dalam pembangunan automasi dan rangka kerja simulasi stokastik. Rangka kerja automasi ialah satu sistem yang secara automatik merujuk kepada kaedah ramalan berasaskan carta untuk meramal tahap bunyi bising di lokasi penerima. Rangka kerja simulasi stokastik menggabungkan proses perjalanan rawak dan pendekatan Monte Carlo bagi mensimulasikan pergerakan dan tahap pelepasan bunyi jentera di kawasan pemetaan yang ditetapkan. Dua perisian prototaip iaitu Prototaip I dan II, telah diprogram menggunakan perisian pengaturcaraan MATLAB untuk memudahkan setiap rangka kerja yang dicadangkan. Kedua-dua perisian prototaip menghasilkan output seperti peta strategik bunyi bising, risiko bunyi bising dan informasi berkaitan kebisingan. Untuk meguji ketepatan perisian, perbandingan antara dapatan dari ramalan dan pengukuran dari kajian kes telah dilakukan. Lapan kajian kes pengukuran dari industri yang berbeza telah digunakan untuk mendapatkan input ramalan dan tahap bunyi di titik kawalan. Perbezaan mutlak antara dapatan ramalan dan pengukuran di titik kawalan ini dikira bagi menentu ketepatan nilai ramalan setiap prototaip. Secara umumnya, keputusan ramalan daripada Prototaip I dan II mempunyai persetujuan yang baik ($\leq$ 3 dBA) dengan keputusan yang diperolehi daripada perukuran keatas kebanyakan kajian kes. Kedua-dua prototaip boleh menggambarkan keadaan bunyi bising yang kompleks dan dinamik di tempat kerja. Kajian ini dapat memajukan teknologi ramalan pemetaan bunyi bising dan prototaip yang dihasilkan boleh digunakan sebagai alat pemantauan bunyi bising yang baru dalam amalan industri semasa.

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LIST OF SYMBOLS

a_s	-	New length after s steps
d	-	Depth of sub-area
E_{ij}	-	Expected frequency from the cell (i, j)
$F_X(x)$	-	Cumulative probability distribution function
$f_X(x)$	-	Probability density function between the range from a to b
I_p	-	Machine noise intensity
K'	-	Allowance distance
K_T	-	On-time adjustment
K_1	-	Background noise factor
K_2	-	Environmental correction factor
L_{Aeq}	-	Equivalent continuous sound pressure level
$L_{attenuation}$	-	Noise attenuation level
L_{BG}	-	Background noise level
$L_{correction}$	-	Correction for the characteristic features of sound level
$L_{exceedance}$	-	Exceeded value of rating sound level above the noise criterion with ninety percentile
L_{max}	-	Maximum sound pressure level
L_{min}	-	Minimum sound pressure level
L_p, L_{pA}	-	A-weighted sound pressure level
$L_{p,T}$	-	Energy-average of the time-averaged A-weighted sound pressure level
L_r	-	Rating sound level
$L_{reflection}$	-	Noise reflection level
L_{WA}	-	A-weighted sound power level
L_T	-	Total sound pressure level
L_{10}, L_{50}, L_{90}	-	Noise level exceeded 10 %, 50 % and 90 % of the time
m	-	Total number of the noise data

N_i, N_j, N_k	-	Pseudo numbers
O_{ij}	-	Observed frequency from the cell (*i*, *j*)
Pos	-	Possibility of occurrence
P_{BG}	-	Background pressure
P_{on}, C	-	Possibility of full power mode
P_{idle}, B	-	Possibility of idling mode
P_{off}, A	-	Possibility of off mode
P_T	-	Total pressure
P_{TS}	-	Sound pressure of static machinery
P_{TD}	-	Sound pressure of dynamic machinery
$P(x, y)$	-	Joint probability density function of *x* and *y*
$p_s(r_s)$	-	Probability density function of r_s steps in the interval $(r, r + dr)$
R	-	Ratio of sub-area
rand	-	Random number
Rank	-	Position within a list of ordered values of noise data for the respective percentile in calculation
R_n	-	Final location
R_0	-	Initial location
R^2	-	Squared Correlation Coefficient
r, r_{ik}	-	Radius from each receiving point to the center of the sub-area/machine
$r_{correlation}$	-	Pearson's correlation coefficient
r_s, r_n	-	Continuous random displacements
r/*w*	-	Radius/width ratio
S		Area of measurement surface
S_0	-	Reference area for computation, and equal to 1 m^2
SD_T	-	Total standard deviation
t_n	-	Sequential time
v	-	Variance
v_T	-	Total variance
w	-	Width of sub-area
W	-	Sound power

W_{on}	-	Sound power in on mode
W_{idle}	-	Sound power in idling mode
W_{off}	-	Sound power in off mode
W_0	-	Reference power
X	-	Width of mapping area
Xr	-	Real-valued random variable evaluated at x
$x(\theta_{\text{s}})$	-	New displacement with respect to x-axis
$\overline{x}$	-	Average measured noise level at a control point
Y	-	Depth of mapping area
$y(\theta_{\text{s}})$	-	New displacement with respect to y-axis
$\chi^2, \chi^2_{\text{test}}, \chi^2_{\alpha,(\text{r}-1)(\text{c}-1)}$	-	Chi-square value
ΔL_{p}	-	Different value between sound pressure level at measurement position and background noise level
ΔL, ML	-	Mean level deviation
θ, θ_{ik}	-	Angle from each receiving point to the center of the sub-area
θ_{s}	-	New angle after s steps
β	-	Reduction factor
σ, SD	-	Standard deviation for the noise data
(x_i, y_i)	-	Receiving location
(x_k, y_k)	-	Center of the sub-area

LIST OF ABBREVIATIONS

AIR	-	Accident Incidence Rate
ANSI	-	American National Standards Institute
CDF	-	Cumulative Distribution Function
DOE	-	Department of Environment Malaysia
DOSH	-	Department of Occupational Safety and Health Malaysia
FMR	-	Factories and Machineries Regulations
GPS	-	Global Positioning System
GUI	-	Graphical User Interface
GUIDE	-	Graphical User Interface Development Environment
HCP	-	Hearing Conservation Program
HPD	-	Hearing Protection Devices
IEC	-	International Electrotechnical Commission
JPEG	-	Joint Photographic Experts Group
MATLAB	-	Matrix Laboratory
NIHL	-	Noise-Induced Hearing Loss
NIOSH	-	National Institute of Occupational Safety and Health
NRR	-	Noise Reduction Rating
OSHA	-	Occupational Safety and Health Administration
PDF	-	Probability Density Function
PNG	-	Portable Network Graphics
PPE	-	Personal Protective Equipment
SAE	-	Society of Automotive Engineers
SLM	-	Sound Level Meter
SOCSO	-	Social Security Organization
SPL	-	Sound Pressure Level

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Occupational noise exposure problem has been increasing dramatically every year. Thousands of workers from different industries are exposed to high noise levels that are above the permissible limit. The increase of occupational noise-induced hearing loss (NIHL) cases has burdened the governments in term of compensation claims of occupational disease. In Malaysia, noise exposure problems are increasing every year due to the rapid growth of industries and the expansion of recruitment. An environmental noise assessment study revealed that the expansion of industrial project has increased existing background noise, and the noise level was expected to increase in other regions in Malaysia through the continuously rapid growth of industrial and urban areas (Ismail *et al*., 2008; Ismail *et al*., 2009).

The management of industries plays an important role to control the noise levels in the workplaces to be below the permissible limit as stated in the industrial regulations. In fact, improper noise management could cause negative outcomes to the industrial operation. For instance, the noise can damage the workers' hearing system and bring harmful effects to their safety and health. Also, noisy workplaces would receive complaints from the public because of the annoyance of noise from the machineries, and consequently delay the project and cause loss of costs.

In current noise exposure regulatory system, every country has enforced mandatory regulations for occupational noise exposure and environmental noise for the industries to cope with noise exposure problems from the workplace and surrounding environment. In Malaysia, all industries shall comply with the Factories and Machinery (Noise Exposure) Regulations 1989 (FMR, 1989) in monitoring noise exposure in the workplaces. These regulations have stated the permissible exposure limit, exposure monitoring, methods of compliance, hearing protection devices, audiometric testing programme, employee information and training, warning signs, record keeping and miscellaneous. Noise exposure monitoring is a mandatory practice for the industry to determine the noise exposure level from the workplace. According to the Factories and Machinery Regulation (FMR), a person must have the certificate of competency to conduct noise exposure monitoring at workplaces. A competent person or noise practitioner is trained by the National Institute of Occupational Safety and Health (NIOSH) and certified by the Department of Occupational Safety and Health Malaysia (DOSH) (NIOSH, 2016; DOSH, 2016).

The monitoring report will then be submitted to DOSH for compliance verification and documentation. According to the requirements by DOSH, a noise monitoring report should include the results of noise map and personal noise exposure level. Although the noise mapping practice does not have a standardised plotting method and the requirement of this practice is also not be mentioned in the FMR, the competent person must conduct the noise mapping measurement and include this result in the noise exposure monitoring report. A noise map can be used to assess the occupational noise exposure problem, identify high risk areas, and show the location of noise sources in a workplace. Noise practitioners refer to the noise mapping information to identify hazardous area and select workers for personal noise measurement. It can also provide information for noise control, noise impact assessment and noise abatement strategy. Some industries disseminate this information to the public in an attempt to increase the awareness of workers, and assist them to perceive the risk of chronic noise exposure and implement preventive action.

Field measurement is another important practice in measuring noise level from a workplace to the surrounding environment. Two types of machines can be seen in a workplace: static machines and dynamic machines. Field measurement is normally applied in workplaces with dynamic and complex activities or as requested by the employers and local authorities. For instance, it is difficult to construct noise mapping for construction processes because of variations in activities and random movements and duty cycles of earth-moving machines. Field measurement is used in construction activities by selecting several critical locations, measuring the noise levels, and comparing them to the permissible levels for further preventive actions. This measurement method is normally used during construction activities operation, but it is not possible to obtain actual noise levels during the planning process, before construction activity starts (Zhang *et al*., 2014).

FMR can be used to monitor occupational noise exposure in workplaces only. By determining the impact of noise on the environment, the Department of Environment Malaysia (DOE) has established the planning guidelines for environmental noise limits and control (DOE, 2007). These guidelines are crucial to assess noise level against the permissible limits for environment and evaluate the community annoyance response. The environmental noise impact assessment is always done by referring to this standard for assessment and evaluation.

In the past, many researchers had studied the methods for predicting noise level from workplaces. These include the discrete-event simulation method, artificial neural networks, regression analysis, probabilistic approach, noise prediction chart method, and Monte Carlo method (Zhang *et al*., 2014; Hamoda, 2008; Manatakis and Skarlatos, 2002; Haron and Oldham, 2005; Haron *et al*., 2008; Haron *et al*., 2012). The stochastic approach can be especially reliable to predict noise level by considering the randomness and complexity of the working environment (Haron and Oldham, 2004). Some studies have shown that the consideration of dynamic factors is required in the noise prediction process, especially the random movements and duty cycles of machines.

1.2 Statement of the Problem

Severe NIHL problems were found among the industrial workers due to expose to loud noise in the workplaces. According to Malaysia Social Security Organization (SOCSO), it had reported the number of NIHL cases was increasing from 53 cases in 2005 to 360 cases in 2014. Occupational NIHL was also the highest occupational disease (82%) in Malaysia as reported by DOSH (Yahya *et al.*, 2016). Lacking of noise concern and carelessness from the management has brought ineffective noise abatement in their workplace. The management is responsible to maintain a moderate noise level in their workplaces, but many of them did not pay much concern on this issue. Practically, most of the management prefer to provide hearing protectors for their workers because it is a cost-saving strategy and an effective way to protect workers at the working area which has high noise exposure level. However, previous research revealed that workers have bad attitude and behaviour in the adoption of hearing protector. Many of them are unwilling to wear the hearing protector regularly during the working period. Workers have low awareness on the risk of hearing loss and low self-efficacy in using the hearing protector. They cannot self-perceive the risk of hearing loss due to the lack of noise information, such as warning sign and noise mapping information, about the noise circumstances in the workplaces. It can be due to ineffective noise monitoring that causes many workers to be exposed to excessive noise in their workplaces. It can also be due to management not appropriately plan for the activities. Therefore, the development of a managerial tool is important to assist the management of occupational noise exposure level. The tool can be especially utilised for predicting noise levels during the planning stage for maintaining a moderate noise levels for new activities.

Previous research has found that stochastic modelling technique has been proven to give a good performance in the noise prediction modelling. Few prediction methods are used in this technique, such as noise prediction chart method, probabilistic and Monte Carlo approaches (Haron and Oldham, 2004; Haron *et al.*, 2008; Haron *et al.*, 2012). Previous studies employed these stochastic methods for predicting construction noise exposure levels from dynamic noise sources. These methods have not yet been applied on other industries, especially in the manufacturing industry. Meanwhile, the latest development of stochastic modelling technique focuses on the prediction of noise level at a selected receiving location. This technique is laborious in predicting a noise level at a new receiving location. For instance, user applies a similar procedure that is by using the noise prediction chart method, referring to the charts for obtaining new inputs and computing the noise level at any new receiving location. The repetitive process is time-consuming and inefficient.

Indeed, the current development of stochastic modelling technique can effectively predict noise level by considering the randomness of movement and duty cycles of machineries from a workplace. Yet, this technique is still inefficient to apply in complex and dynamic workplaces due to the laborious prediction process. Further exploration of stochastic modelling technique is needed in order to enhance this technique for spatial and temporal noise prediction for complex and dynamic working environment. The application of the prediction methods should have features including simple, fast, precise and accurate in predicting the results. So, the development of automated and simulation systems for noise prediction are very important to turn them into more advanced prediction technologies. Furthermore, the accuracy, reliability and efficiency of the stochastic prediction methods are required in order to obtain a reliable result for occupational noise monitoring.

The improvement in noise mapping technology is needed as the current industrial practice provides inaccurate and unreliable information. The current industrial practice does not have a standardized procedure or method for developing a strategic noise map in workplaces. For example, using the current noise mapping practice, the noise level is measured from few locations based on noise intervals, such as 80 dBA, 85 dBA and 90 dBA, and the contour lines are simply drawn to connect similar noise interval from the selected locations. This practice can be applied on the machineries with static property only, and it is difficult to plot a strategic noise map in a dynamic and complex working environment. The random operation and random movement of dynamic machineries have caused continuous variation in noise level in a workplace. Unreliable noise mapping information without the consideration of dynamic noise sources can lead the management to decide a wrong strategy to monitor noise exposure in their workplaces. This can be another reason to cause occupational noise exposure problems to increase every year.

1.3 Purpose of the Study

The main purpose of this study is to solve the current occupational noise exposure and noise mapping problems. New strategic noise mapping prediction technologies for workplaces will be developed and specifically designed for the industries to enhance the effectiveness of current noise mapping practice. Strong evidences have proven that the application of stochastic modelling is efficient and effective to predict noise level in a dynamic working environment. This study will further explore the advanced development in stochastic modelling for noise mapping prediction. It focuses on the development of automated process in utilizing the noise prediction chart method. The laborious application process of noise prediction chart method will be eliminated through the proposed automatic process. More importantly, this study proposes a new stochastic prediction method, by applying the random walk and Monte Carlo approaches, to simulate the random movement and duty cycles of machineries in predicting noise level. In this simulation process, it is expected that the prediction of strategic noise mapping can be more precise to reflect the actual noise circumstances of dynamic and complex working activities. This study will compare the actual measurement data with the prediction data in order to validate the results of each prediction method. It is crucial to study the accuracy and reliability of the proposed noise prediction methods.

Moreover, the developed technologies in this study can be used as managerial tool to assist the management in planning the working activities and enhance the effectiveness of noise management in a workplace. Ergonomic design is significant in current industries to ensure all workers are working in comfortable, safe, healthy and sustainable workplaces. These technologies support the ergonomic design by designing strategic placement of machineries in order to maintain the occupational noise at a moderate level. This study is expected to develop strategic noise map with more informative, high accuracy and high reliability. Definitely, the strategic noise map with these properties can increase the awareness of workers on the adverse effects of occupational noise exposure towards their safety and health. The prediction technologies are also incorporated with risk assessment function to plot a noise risk zone as new safety information. A noise risk zone is developed to assist workers in perceiving the risky area in their workplace and increase the self-efficacy of workers in using personal protective equipment to protect their hearing system from noise damage. So, this is another essential purpose to reduce occupational noise exposure problems through the assistance of advanced noise mapping information from the prediction technologies. The costs of noise-induced hearing loss compensation will definitely be reduced. It also minimises the burdens of government and industries on occupational noise exposure issues.

1.4 Aim and Objectives of the Study

The aim of this study is to develop new noise mapping prediction technologies in order to solve the current occupational noise exposure and noise mapping problems. The followings are the research objectives to achieve the aim of this study:

i. To investigate the problem of hearing protector usage among industrial workers in Malaysia.

ii. To establish two frameworks for noise mapping prediction technique.

iii. To develop an automated noise mapping prediction software by using noise prediction chart method.

iv. To develop a strategic noise mapping simulation prediction software by applying random walk and Monte Carlo approaches.

v. To validate the accuracy, the reliability and the efficiency of the prediction results from case studies.

1.5 Significance of the Study

Strategic noise mapping in workplaces is important to improve the current noise exposure monitoring practice. It is crucial to further develop the noise prediction methods in predicting strategic noise map and noise risk zone. It can enhance the current noise prediction technology into more advanced systems to eliminate the laborious process of repeating the prediction process for any new receiving location. This study contributes novelties in occupational noise mapping prediction technology using the stochastic modelling technique. It predicts a strategic noise map by considering the random parameters, such as random movement and random duty cycles from the machineries. An essential contribution of the study is the development of automated system for the existing simple noise prediction chart method in order to eliminate the repetitive process. In stochastic simulation framework, it is novel in term of the application of the random walk approach to simulate the random movement of machineries, and the application of Monte Carlo approach to predict the random machineries' noise emission level based on the probabilities of duty cycles. It also considers concurrent and non-concurrent activities in a dynamic working environment. This simulation method contributes a new philosophy in the application of random walk and Monte Carlo approaches for a noise prediction framework.

Thus, two noise mapping prediction software were developed in this study, namely the Automated Noise Mapping Prediction Software (Prototype I) and the Strategic Noise Mapping Prediction Simulation Software (Prototype II). Prototype I was developed to facilitate the automation framework for the noise prediction chart method. Prototype II facilitated the stochastic simulation framework in the prediction system. Significantly, both software provide new noise risk information, such as a noise risk zone, which is used to raise the awareness of workers and assist them to identify risky area in the workplaces. Workers can refer to this map to take further preventive action when they work in high risk area.

The target users of these technologies are industrial hygienists, safety officers, noise practitioners, planners, consultants, developers and authorities. The current industrial practice has no standardised procedure guiding toward the proper and reliable ways in plotting a noise map. For this reason, these prediction technologies can be recommended to industries as new noise mapping practice in occupational noise exposure monitoring. It can enhance the effectiveness of noise monitoring by providing good quality noise map, such as plotting the patterns of noise distribution from various sources, barrier effects, and the areas of noise pollution. It can also be used as a managerial tool for strategic planning and ergonomic design in workplaces. The prediction of strategic noise mapping during the planning stage is very important in assessing the adverse impacts of noise on workers and surrounding environments. The information can be applied in noise abatement design and environmental impact assessment.

1.6 Scope of the Study

This study comprised of a survey study and the development of noise mapping prediction models. A survey was carried out to investigate the noise exposure issue from different industries in Malaysia. It adopted the quantitative research methodology by distributing questionnaire to respondents from six factories with various industrial backgrounds, such as construction, oil palm, chemical, shipbuilding, electronic and rubber industries. About 215 respondents were involved in this study. Microsoft Excel software (2010) was used to analyse the collected data and plot them into graphical results. A statistical independent test was also applied to determine the independency of hypotheses from these results. Next, this research studied the development of noise mapping prediction technologies for workplace. The development of noise mapping prediction frameworks applied several noise prediction methods, including the noise prediction chart method, random walk approach and Monte Carlo approach. Two noise mapping prediction frameworks were established in this study, which are automation and simulation frameworks. To facilitate these frameworks, Matrix Laboratory (MATLAB) programming language was used to program the algorithms for the predictions of strategic noise map and noise risk zone. The Graphical User Interface Development Environment (GUIDE) of MATLAB was used to program the Graphical User Interface (GUI) of the noise mapping software (MATLAB, 2010). Two prototype softwares were developed and the prediction results were validated through the comparison of prediction and measurement results from the case studies.

This study limited the scope of case studies to the construction and manufacturing industries. Eight case studies from these industries were carried out, including construction, oil palm production, shipbuilding and rubber industries. For the noise measuring equipment, the sound level meter was used to measure noise level in these workplaces. Also, the measurement tape and distometer were used to measure the distance of measurement locations and site layouts. The purpose of the case studies was to obtain the noise mapping prediction inputs and the noise level at the control points. The noise mapping prediction inputs, such as machinery sound power level and site information, were used in the prototypes to predict a strategic noise map and a noise risk zone for these workplaces. The measurement of machinery sound power was conducted for these case studies by referring to the British Standards BS EN ISO 3744:2010 and BS ISO 6393:2008 (BSI, 2008; BSI 2010). The results at the control points were used for comparison with the prediction results to validate the accuracy of noise prediction methods. Microsoft Excel (2010) was used to analyse the accuracy of the prediction and measurement data. Pearson's correlation coefficient was applied to determine the reliability of the prediction results from the proposed noise mapping prediction methods. In addition, the duration for the completion of this research is aimed to finish within five years.

1.7 Conceptual Framework of the Study

This section discusses the conceptual framework of the study as shown in Figure 1.1. This research will carry out a survey study to determine the dependency of affecting factors on the usage of HPD. The finding from this survey will be used to support the development of noise mapping prediction techniques in this study. Next, it involves the development of two noise mapping prediction models by using the stochastic modelling methods, such as noise prediction chart method, random walk approach and Monte Carlo approach. This study will develop two prototyping softwares in order to facilitate these models. During the development of prototypes, it involves the establishments of the concepts of prediction model, automation framework and simulation framework. The prediction models are also established by incorporating the local regulations, such as FMR 1989 and DOE planning guideline (FMR, 1989; DOE, 2007), to check the occupational and environmental noise permissible limits. This study will develop the graphical user interfaces for these prediction models. After that, this research will implement the field measurement for validating the accuracy, the reliability and the efficiency of prediction results. The field measurement will be carried out at eight case studies from the construction and manufacturing industries. The equivalent continuous noise levels will be recorded during the measurement. The prediction results will be used to reveal noise circumstances of these case studies, and compare with the measurement results to determine the accuracy, the reliability and the efficiency of the noise mapping prediction models.

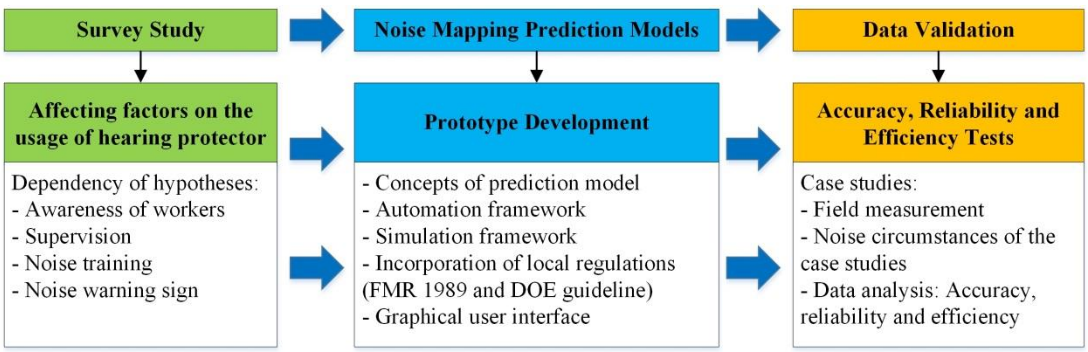

Figure 1.1: Conceptual Framework of the Study

1.8 Layout of the Thesis

This thesis is divided into nine chapters, which are introduction, literature review, research methodology, preliminary study on the occupational noise exposure problem, strategic noise mapping technologies, case studies and data validation, discussion and conclusion. Chapter 1 describes the background, problems and purposes of the study to motivate the implementation of the research by designing the aim, objectives of the study to solve the occupational noise exposure and noise mapping problems. The significance of the study is revealed and the research scope has been designed in order to achieve the objectives and turn this research into success. Next, Chapters 2 and 3 critically review on the topics of noise exposure problems, noise monitoring, noise regulations and standards, noise mapping, noise prediction, stochastic modelling, and the current research gaps. Chapter 4 explains the overall research flow chart, measurement methods and procedures, development of noise mapping prediction technology and so forth.

Chapters 5 reveals the preliminary study on occupational noise exposure problems, including the research designs of the theoretical framework, hypothesis, instrumentation, data collection and analysis, as well as the research results on the perception on current issues, the attitude and behaviour on the usage of hearing protectors and the independent tests for the hypotheses. After that, Chapter 6 explains the establishment of automation and simulation processes, programming algorithms and the procedural applications of the prototype softwares. Chapter 7 describes the implementation of case studies and data validation between the measurement and prediction results. The prediction results for each case study from both prototypes are discussed, including the strategic noise maps, the noise risk zones, accuracy and reliability, and the prediction time. Chapter 8 critically discusses the findings of this study in detail. Lastly, Chapter 9 concludes the findings and recommends future research studies.

1.9 Summary

This chapter discusses the occupational noise exposure, noise prediction and noise mapping problems. The aim of the study is to develop noise new noise mapping prediction technologies in order to solve the current problems. This study established five research objectives to investigate the dependency of affecting factors on the usage of HPD and develop new noise mapping prediction methods using the stochastic techniques. These new methods could significantly enhance the performance of stochastic techniques in noise prediction. They could be used as new industrial noise mapping practice and increase the effectiveness of noise monitoring. The conceptual framework of the study and the layout of thesis are also discussed in this chapter.

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