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Conceptual Model of Noise Hazard Assessment System for Construction Workers

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Abstract
Noise hazard is one of the main concerns in construction health and safety. Many construction workers operate their acitivities without hearing protection even though the organization provides the equipment for them. It seems that the supervisors and workers lack an awareness about their health and safety. Currently, noise dosimeters are used for assessing dose of noise in which workers are absorbed during their workday. However, the price of these instruments as shown in year 2010, were expensive. This method may not be the practical solution for reminding workers about their risk. Therefore, current research aims to propose an alternative method for the assessment of noise as a hazard for building construction workers who daily operate around sources of noise. This research paper describes a conceptual model of system development. Under this conceptual model, sound recorders were clipped with those workers in order to record all the sound that occurred during their workdays. Then those sounds were transcribed into sound pressure level by using Matlab computing languages. Also, gathering data was calculated for identifying the level of noise dose, the Time Weighted Average and the hearing protection. Finally, the calculation results were discussed for assessing noise hazard from workers' activities. The outcome of this research is to provide the concept of developing an economical method that could be a usefulalternative for warning workers' about health hazards in the construction industry.

Keywords
Noise Hazard, Noise dose, Sound Pressure Level, Time Weighted Average, Hearing Protection

1. Introduction

Due to the high impact of noise hazards in construction, many research studies were conducted in order to assess the noise exposure. In general, measurements were conducted by using a sound level meter during construction operations. Several research findings indicated the high level of noise in some construction trades/tasks were too high and over the standard. One of the statistics from the US Bureau showed that nearly a half million of the construction workers were exposed to high noise levels above standard of 85 dBA. Estimates also showed that 15% of these workers developed hearing impairments when they were exposed to noise levels of 85 dBA or higher (Koushki et al., 2004).The task base studied by Richard covered four construction trades and five sites. The analysis of 338 samples of all trades indicated the mean exposure level at 82.8 dBA with a range of 61.6 to 99.3 dBA. Moreover, 12.7% of sampled workers exceeded noise level of 90 dBA, OSHA PEL, while 40% of them exceeded an 85 dBA, TWA. Richard illustrated the highest mean of TWA was 83.5 dBA, followed by 83.3 dBA, 82.3 dBA and 82.2 dBA which were absorbed by Operating engineers, Laborers, Ironworkers and Carpenters, respectively (Richard, 1998). Because noise hazard is major problems for construction workers in many trades/tasks, the researches on noise hazard have been carried out to explore the methods for minimizing this problem. Some proposed the guidelines and regulations that protect those workers from noise hazard. Althogh many regulations were stated, it might not be a practical solution in some developing countries. One basic issue is that most construction workers lack education and they do not perceive noise as a problem (Koushki, 2004). Therefore, it means that the future study of construction noise hazards is still needed.

Most of the previous researches needed numerous noise dosimeters in order to assess noise hazard on construction sites. One of the examples is a study by Richard (1998) that used eleven datalogging noise dosimeters for assessment of occupational noise exposure in four construction trades such as carpenter, laborer, ironworker, and operation engineer. In addition, five datalogging, Quest Q-300, noise dosimeter were used in Kyle's research (1999) for assessment noise exposure to electricians in the construction industry. The reasons related to their usage are discussed. One is they need various data from many trades of construction workers who operate in different zones with different sources of noise at the construction site. Moreover, there is a time limitation for data collection so it is necessary to use several of noise dosimeters at the same time. Thus, a large amount of money was claimed in order to conduct such kind of these assessments because the price of noise dosimeter, shown by many manufacturers in 2010, was expensive.

As discussed, the high cost of the noise dosimeter is due to the previous concept that used the inside hardware (circuit) in order to detect sound and transform it into sound pressure level. In contrast, the concepts of this study aim to propose a compatible method by using the devices that can detect noise exposure. This research aims to propose an alternative approach of detecting noise level by using electronic sound recorders to capture the sound of work activities. Then, the electronic file of sound is computed into sound pressure level by Matlab computer programming. In addition, the outcome of this research attempts to develop an alternative system of noise hazard assessment for construction workers.

2. Methods of Noise Measurement and Instrument Measurement

The measurement of noise in construction site is generally to identify the degree of risk that workers may face with noise hazards. Basically, this measurement can be divided into two methods, *direct method* and *indirect method*. The direct method concerns a continuous measurement of noise exposed in the whole working time. In addition, results from this method precisely illustrate the workers' risk of noise hazard. On the other hand, the indirect method is a measurement of noise that conducts in the shorter time than the actual source being assessed. Then, mathematical formulas were used for the estimation of noise that the worker exposures (Engel et al., 2006). This research applied both methods for evaluating noise dose.

National Institute for Occupational Safety and Health (NIOSH), in 1998, presented the most common instruments which were the *Sound Level Meter* (SLM) and Noise Dosimeter for measuring noise exposure. SLM is an instrument basically used for noise measurement and the evaluation of noise exposure level in dB SPL. A sound level meter contains a microphone, an indicator, and a selective amplifier (NIOSH, 1998). Measuring noise with SLM is relatively simple when the worker remains stationary and when the noise exposure level is continuous during a working task. Noise dose and Time-Weighted Average (TWA) is automatically calculated by the integrating function with SLM. On the other hand, *Noise Dosimeter* is an instrument used for measurement and storages of data of noise levels during a period of noise exposure and which computes the output into the percentage of dose or TWA. It is different from SLM with details of time history, additional storage and computational functions. Nowadays, many available dosimeters can provide an output in dose or TWA using various exchange rates. This instrument can be used for measuring exposure to noise levels which consist of impulsive components and vary during the work shift. Moreover, it is suitable for workers who move around frequently during their operations.

3. Standard of Occupational Noise Exposure

Recommended expose limit (REL) for occupational noise exposure is established by NIOSH. The standard REL is equal to 85 decibels, A-weighted, as an 8hour times-weighted average. Exposures at and above this level are considered hazardous. In addition, exposure to noise shall not exceed 140 dBA (NIOSH, 1998). The below section will describe more about the criteria for the recommended limit of exposure.

3.1 Exposure Levels and Durations

Occupational noise exposure shall be controlled so that worker exposures are less than the combination of exposure level (L) and duration (T).The exposure duration can be calculated by the following formula (1) where T is maximum exposure duration in minutes, L is exposure level in dBA, 3 is exchange rate in dB, 85 is recommended exposure limit in REL, 480 (8hr) is time-weight average in minutes.

$$T_{hour(s)} = 480/2^{(L-85)/3} \quad (1)$$

3.2 Daily Dose of Noise

Daily Dose of noise can be calculated according to formula (2) when the daily exposure of noise contains periods of different noise levels. Where $C_n$is total time of exposure at a specified noise level, and T_n is exposure duration for noise at that level. In addition, the daily dose (D) should not equal or exceed 100, otherwise it becomes hazardous.

$$D = [C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n] \times 100 \quad (2)$$

3.3 Time-Weighted Average (TWA)

TWA is the averaging of different exposure levels during an exposure period. It can be calculated by formula (3) when noise is given an exposure limit with 3 dB exchange rate where D Daily dose of noise. In accordance the daily noise dose, the REL for an 8-hr (480 min) work shift is a TWA of 85 dBA using a 3-decibel exchange rate.

$$TWA = 10.0 \times \log (D/100) + 85 \quad (3)$$

4. Research Framework

To fulfill previous gaps in research, the framework for a noise hazard assessment system is designed and arranged as shown in figure1. First of all, source of sound was produced in a control room by using white noise. Then both of our devices, sound recorder and noise dosimeter, were placed in the same position near that source in order to detect all sound. After that, data collected by both instruments were individually downloaded and stored in a computer via their own software. In addition, it was separated into two parts. One is wav file that is the output of sound recorder. This file would be inputted to Matlab script in order to compute the sound pressure level. Another one is the results from the noise dosimeter which automatically generates via the software supplied by their manufacturers. This result also contained sound pressure level. The final output of these parts would be used for finding the mathematical model that explained their relationship. Furthermore, it illustrates the relationship between sound pressure level as computed by our system and generated by standard equipment, such as the noise dosimeter.

Figure 1: Framework of Noise Hazard Assessment System

5. Research Methodology and System Development

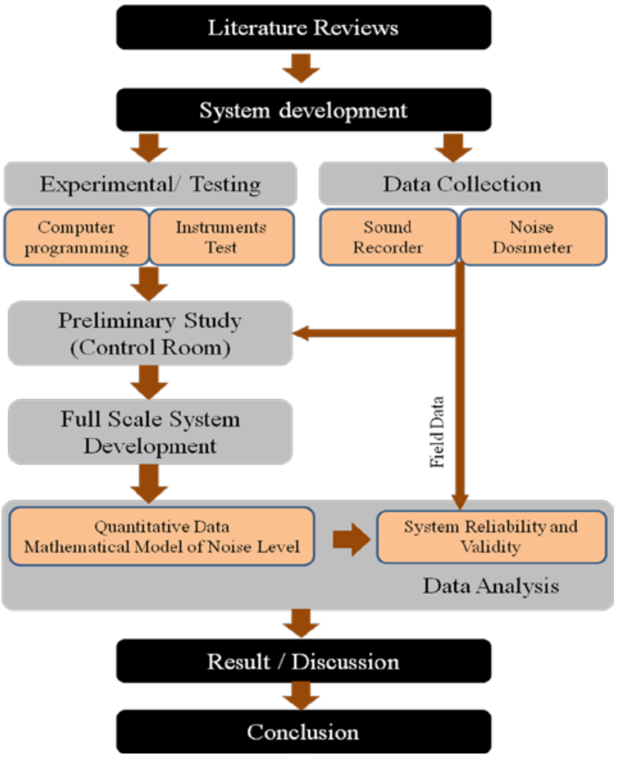

Figure 2: Research methodology

The research methodology process in figure 2 is the overall procedures which are used as a guide to achieve the research objectives. This process is classified into categories based on the purpose of the research project including conceptual system development. In addition, this conceptual system is used to systemize the relevant knowledge to define the research gaps, clarify the problem statement, and setup a clear objective to explore the new topic. The research aims to develop a system of noise hazard assessment for building construction workers. The next section will discuss the whole process of system development.

A system development process involves many stages which require many activities over a long period of time in order to identify the potential requirement. In addition, the result of the final system needs to be fully implemented and accepted by the end user. The main stages of system development are highlighted in the section below. As mentioned in this research, system development is designed into four steps (figure 2) as presented in following sections.

5.1 Experimental and Testing

Experiments and testing are considered to be a starting point of our noise hazard system development. It is conducted to identify and check the ability of instruments involved with computer programming languages. In addition, the experiments and testing were not only used to find the appropriate tools, noise dosimeter and sound recorder for data collection but also developed a brief explanation of programming for evaluating the quantity of noise hazard.

5.1.1 Computer programming

From the experimental and testing process, Matlab computing language is considered the appropriate programming for development in our system. This language is selected because of many reasons such as an ability to read the properties of wave sound recording, to transform time domain to frequency domain, to link with various functions, to export results to another parties, and to display the results in many formats. Especially, Matlab programming also allows users to develop their own interface. Based on our objectives, this research attempts to develop noise hazard assessment system. Therefore, a brief script of system programming was developed as a trial of noise assessment system using Matlab computing languages.

5.1.2 Sound recorder

Focus on the system requirements, the specification of various sound recorders was reviewed and the comparison was simultaneously performed. Significantly, a selected sound recorder was tested in the control room. First, we generated white noise as the source of sound. Then, the sound recorder was placed near that source in order to capture the generated sound. The selection was based on their playback sound.

5.1.3 Noise dosimeter

On the other hand, the noise dosimeter is an instrument that can be used to measure exposure noise levels which consist of impulsive components and, vary during the work shift. Moreover, it is suitable with workers who move around frequently during their operation. It is a sound level meter with additional storage and computational functions to automatically calculate the percentage of noise dose or TWA (NIOSH, 1998). The selection of noise dosimeter would be performed by reviews from previous research. We should select any models which had the capacity to collect more than two channels of data. It allows us to measure noise with different exposure rates. Secondly, it should be suitable for worker to wear clipped during their workday.

5.2 Data Collection

The data collection method is a key step in influencing the validity and reliability of survey research. The main purpose of data collection is to gather enough data for analyzing the noise hazard assessment system. Moreover, instruments preparation is considered a significant process that is required since the beginning stage of data measurement. Before collecting data, all of the involved instruments/tools are needed to be well prepared. From research methodology, our data collection was divided into two phases. The first group of data is used for preliminary study which performs in control. Another one is used for testing the validity of the final system development which is processed in the field construction site. The following section will describe in detail about both processes.

5.2.1 Control room data collection process

Control room was considered a room separated from the actual environment. This room was designed for the acoustic experiments. It means that all sources of sound were controlled. During the testing, the white noise was generated as source of noise by varying their amplified sound. Next, our sound recorder and noise dosimeter were located at the same position within 1m from the source of sound. When everything was controlled, we simultaneously started our devices for recording data with the duration of each sampling 3 minutes for every frequency. Finally, the dosimeter and recorder were stopped and collected for transferring data to the PC.

5.2.2 Field data collection process

Data collection performed when the construction started. However, noise dosimeter and sound recorder were calibrated prior to and after each measurement. Participating workers wore both instruments for an entire work shift. Noise dosimeter and recorder were clipped on the helmet of the selected workers and located around 5 cm from the worker's ear. Within the dosimeter, it was programmed with a security code to prevent premature instrument shutoff by inadvertent contact or worker tampering. After the instruments were completely setup, the button start of both instruments were pressed at the same time for begin recording data. The sample workers were allowed to work with their normal activities in construction site. During monitoring time, short note about their environmental works have to perform. At the end of workday, our instruments were stopped and collected for transferring data via their individual program supplied by manufacturer.

5.3 Preliminary Study

A preliminary study was conducted to evaluate and check the validity of the brief system development for improving in following research. This study was conducted in control room with a sample describe in section 5.2.1. It started to collect data from control source of noise and input to a brief system for checking the possibilities of our device (Figure 3). However, system in this preliminary study was only developed for assessing generated sound level. The programming inside this trial system used Matlab script and separated into three functions include: (1) the decibel level analyzer, (2) the A-weighting filter coefficient, and (3) the sound signal analyzer.

Figure 3: Path of Preliminary Study

Preliminary study not only focused on the measurement of noise exposure but also made an observation the factor related to variation of sound to our system development. In this study, Noise Dosimeter and Sound Recorder were used to perform data collection in a control room. The way to set up the instrument was shown in above section, "Control Room Data collection process".

Preliminary data getting from sound recorder was inputted into the system. The sound input was written in "Wav" format. System analyzed the properties of sound signal inputs. Next, it estimated the signal to sound pressure level using decibel level analyzer function. After that, this system transformed that pressure level to A-weighting filter as will be discussed in the next chapter; the A-weighting was applied to model the response of the human ear. The final result of sound level presented in dBA and plotted into the graph which functions with working time. As a result, the output of preliminary system development will help to develop full scale system.

5.4 Full Scale System Development

The main objective of the full scale system development was to finalize the noise hazard assessment system with enough reliability. The large scale of system development was designed from the research objective, literature review and lesson learnt from the preliminary study. A brief concept of the system in preliminary study was to assessment the sound pressure level using electronic sound recorder. The testing on this system was also conducted in above study in order to find the possibility of conceptual system. As a result, full scale system can be developed. Final system will be programmed to add the function of noise hazard evaluation for workers at construction site. It will be initiated statistical analysis of the preliminary system output, sound pressure level. Then the histogram of decibel level will be plotted against with number of minute measured. Due to the formulas of noise dose and Time-Weight Average which discussed section 3, both variables are defined in this step. As a result, the evaluation of noise hazard are reported base on the standard that provided by NOISH standard. In conclusion, the full scale of noise assessment system for building construction workers is achieved as set up in our objective. However, this final system needs to qualify with the standard equipment. Therefore, the following section attempts to analyze the results of the system.

6. Data Analysis

In this research, data collected by noise dosimeter and sound record are considered the quantitative data. However, data from sound recorder firstly was inputted into the final system in order to compute decibel noise level. Then the data were interpolated with noise level from dosimeter. As shown in below framework (Figure 4), noise level from both sources was exported to Ms. Excel.

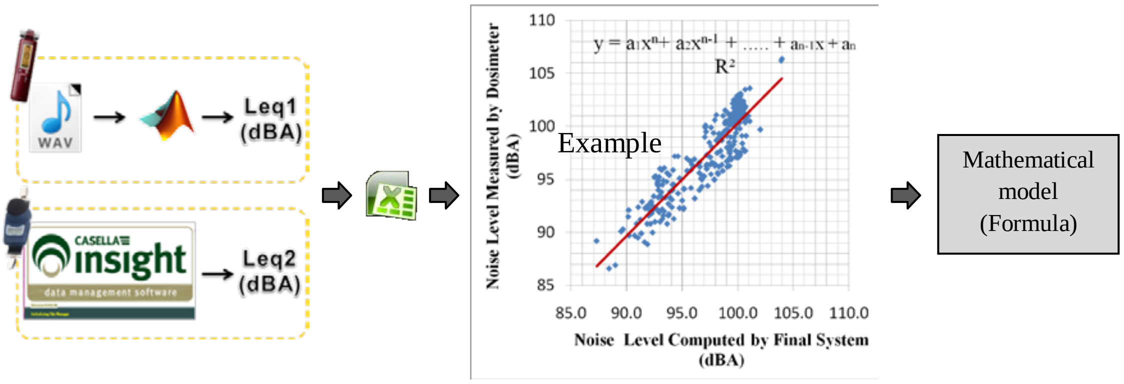

Figure 4: Conceptual Framework of Quantitative Data Analysis

Then it identified the suitable mathematical model that defined the relationship of this paired. The term of mathematical model referred to a description of a system using mathematical language which usually compiled by variables. This model can be classified into linear and non-linear. It was categorized as a linear if all the operators, which can be functions, algebraic, and differential, in the model presented linearity. Otherwise, this model is defined as nonlinear (Wikipedia, 2010).

The mathematical model in this research was developed to estimate the noise level measured by standard equipment, noise dosimeter, as function with the noise level computed by assessment system. The output of this model was an equation that used to define the actual noise level from standard equipment. In particularly, this equation should be the one that can approach the noise level. Therefore, the final system reliability and validity needs to perform. Thus, our purpose in this section was to check and test the reliability and validity of proposed noise hazard assessment system. Reliability is probability that a device can perform its intended function during a specified period of time under stated conditions. It was concerned with meeting the specified probability of success, at a specified statistical confidence level (Wikipedia, 2010). Related to this current research, our proposed system contains two parts that are hardware (sound recorder) and software (Matlab script and Mathematical model). The system reliability testing was performed by checking both of these parts. First, source of noise was simulated in a control room. Then, sound recorder was used to record that noise for five times with a fixed distance and stated duration. The "Wav" files which we got from recording process were inputted to Matlab script in order to compute dose of noise. In addition, we can conclude our system is reliable if all the output of our proposed system, noise dose, presented at confidence level.

On the other hand, the validity of the proposed system was tested by implementation on construction sites. In this validation process, Noise Dosimeter and Sound recorder were used to perform data collection. The way to set up the instrument was shown in the above section, "Field Data collection process". The subject for this study was the workers in building construction site. Moreover, the duration for each sampling is approximately 8 hours, depending on their working time. After that the collected data from the sound recorder was inputted to the final system. Then their output, noise hazard, was compared with the reality as indicated by the noise dosimeter. If our proposed system indicated the same result with reality, we can state that our system is valid. Finally, it is acceptable to use our noise hazard assessment system when the results shown in our system are reliable and valid.

7. Conclusion

This research paper aims to explain the conceptual model of system development for assessing the noise harzard at worker level. The conceptual model explains the development of mathematical models and Matlab functions to transform the electronic "wav" sound into noise level. Then the system can compute and analyze the hazard to workers who perform construction activities. Upon the completion of the study, we expected to get a noise hazard assessment system that is applicable for construction workers. This system will be appropriate to use for reporting their noise hazard from their activities in construction site. Moreover, the final system gathering from this research will be not complicated for the user. It means that workers just input their recording "wav" sound into the system then they can get their noise hazard evaluation.

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