A PROBABILISTIC APPROACH FOR MODELLING OF NOISE FROM CONSTRUCTION SITE FOR SUSTAINABLE ENVIRONMENT

Zaiton Haron[1,*], David Oldham[2], Khairulzan Yahya[1], Rozana Zakaria[1]

[1]*Construction Technology and Management Centre, Faculty of Civil Engineering, Universiti Teknologi Malaysia,81310 Skudai, Johor Bahru, Malaysia*
[2]*Acoustic Research Unit, University of Liverpool, UK*

[*] Corresponding Author: zaiton@*utm.my*

Abstract: This paper presents a new technique for predicting noise from construction site using probabilistic approach. The advantage of the method is its ability to predict a set of noise levels during a working day period weighted by their probabilities of cumulative distribution or temporal distribution. This method has introduced different degree of noises according to different indices such as L_{10}, L_{50} and L_{90}. The indices could be used to avoid the annoyance due to construction activities and the complaints from nearby residents during construction activities. The temporal distribution of the model could be applied to predict the equivalent continuous sound level (L_{Aeq}) experienced over a short period as commonly practiced by the local authority staff when checking for conformance with a specified level during the construction process. The method could be used as the basis of an operational management tool for noise abatement scheme towards maintaining a more sustainable environment.

Keywords: *Prediction of noise, Probability, Temporal distribution, Noise annoyance, Equivalent noise level*

1.0 Introduction

In Malaysia, construction activities are the second most contributory sources of noise pollution. Department of Environment (DOE) annual report proclaimed that a high percentage of urban dwellers are exposed to noise over 65 decibels (DOE, 1996). In order to reduce the effects, prediction of noise level needs to be done as early as in the planning stage (Carpenter, 1997; Carpenter et al., 1997) through EIA report for approval of new development. Noise is also concerned during tendering period to ensure the contractor abiding by the limits specified by the local authority and consequently during construction phase for the conformance to a specified limit. The prediction of noise is usually carried out to determine the likelihood of disturbance and therefore worst case scenarios is considered. Over predicting noise level is not seen as a bad thing but it can be costly for developers as well as contractors if they have to scale down their budget or activities because prediction shows the noise level will be too high or will breach limit (Jafferson, 1997).

In recent years, research studied the usages of reasonable accurate prediction in reducing the effect of noise exposure from construction noise. Jafferson(1997) investigated the accuracy of BS5228 method in prediction of noise from piling and excavation. He established that the method was in accurate due to noise source data and proposed for the revision. Carpenter et al.(1997) claimed that LAeq prediction is inaccurate and proposed the possibility of the usages of stochastic modelling to overcome the unavailability of the followings; accurate source data, period of operations, operational locations unknown, all possible noise generating source unknown etc. Waddington et al (2000) developed stochastic model by means of Monte Carlo to incorporate the variation of noise source characteristics and the source positions. They devised the relationship for the variation of the fall of sound pressure level with distance doubling as a function of the aspect ratio. Gilchrist et al (2003) studied the effect of random acoustic power in prediction of noise using the Monte Carlo model. They found overall prediction was in good agreement with field measurement although there were some discrepancies between the prediction and the noise from actual sites due to the equipment data base being conservative compared with the noise emission from the actual equipment on the site. Haron and Oldham (2004, 2005) developed stochastic model based upon simple probability theory to obtain the temporal distribution of noise for a working day period. They proposed the noise level distribution could be used to predict LAeq experienced over a short time period as usually measured by local authority staff when checking for conformance with a specified level during the construction process.

In this work, a new prediction model based upon the combination of probability theory and reciprocity concept was developed to obtain the temporal distribution of noise for a working day period. The determination of basic temporal distribution noise level for single source and multiple noise sources were highlighted. Variation of source position and duty cycle were employed. The model employs important noise sources of earth-moving machinery that move randomly around the site (Koyasu, 1984; Ferguson, 1995 and Beaman and Jones, 1977). All the simulations are carried out using computer models which were implemented in MATLAB 7.2. The results of the simulations using the Monte Carlo method are compared with results obtained from that of BS5228 (1997).

Probability approach has been used by Nelson (1972, 1973a, 1973b) to obtain quantitative data with which to rate a noise problem from traffic noise. The approach that has been adopted has been to employ noise units based upon the statistical treatment of noise levels which include the noise level exceeded for 10% of the time, L_{10}, and the equivalent continuous noise level, $L_{eq.}$ Construction sites are similar to road traffic in that each involves a number of different noise sources, possibly operating simultaneously, each having different acoustical characteristics (sound power, spectra), operating under different conditions and not having a fixed location.

2.0 Basic Modeling Approach

The model consider a single noise source operating over a hypothetical rectangular construction site of width, w and depth, d with a receiver position at A as shown in Figure 1. The model takes into consideration the variation of source position, the characteristic power of the equipment (duty cycle and power level), the number of items of equipment and the possibility of operations being concurrent during the course of the working day. In this model variations of source are measured by employing reciprocity concept in which the source and receiver are interchanged, thus resulting a source with sound power W_a watts positioned at A whilst the receiver at any point in the rectangular area in the range of $r_{\min}$ to $r_{\max}$ .All receivers located along an arc at a distance r from source will have the same value of sound pressure level.

The noise level at receiver is calculated from the mathematical relationship between the acoustical characteristics of the source and distance between receiver and source. The minimum noise level occurs at two furthest corners and can be expressed as follows;

$$L_{\min} = 10 * \log_{10}(W_a / 2\pi r^2{}_{\max}) - 10 * \log_{10}(10^{-12}) \quad (1)$$

The maximum noise level occurs when the receiver is directly opposite at $r_{\min}$ is given by;

$$L_{\max} = 10 * \log_{10}(W_a / 2\pi r^2{}_{\min}) - 10 * \log_{10}(10^{-12}) \quad (2)$$

For a sound pressure level, Li falls between Lmin and Lmax or $L_{\min} < L_i < L_{\max}$ a distance r is determined from the relationship between the instantaneous sound pressure level, L at the receiver position and acoustic power, W_a as follows ;

$$r = \sqrt{\frac{W_a}{2\pi (10^{L_i} . 10^{-12})}} \quad (3)$$

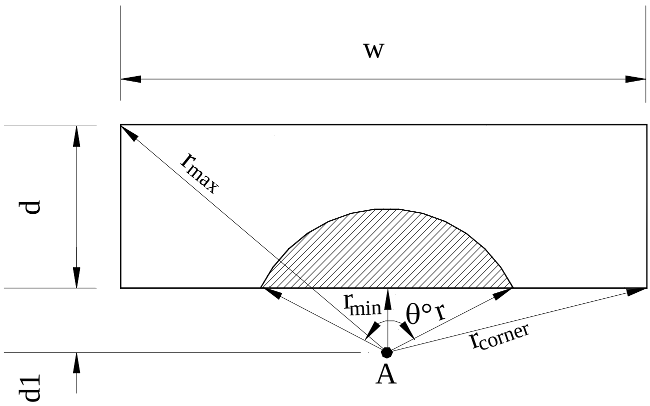


Figure 1: Model configuration

From the figure the percentage of time, t% when the sound pressure level is exceeded is defined as ratio of shaded area to total site area as;

$$t\% = \frac{shaded \quad area}{d.w} \tag{4}$$

A number of sample of t% can be obtained from a series of receiver position, r determined by varying value of Li between Lmin and Lmax. The temporal distribution in term of cumulative distribution function, CDF then can be determined and expressed as 1-t% . The probability distribution or PDF is derived accordingly and can be plotted against sound pressure level, dB. The mean level or equivalent sound pressure level, L_{Aeq} and standard deviation can also be found. However, the calculation of the shaded area are dependent on r and θ . It was found that the shaded area are according to the five cases as shown in Figure 2.

2.1 Effect of Duty Cycle of Equipment

An item of machinery might typically generate a number of different sound power levels in the course of working day depending upon its pattern of use. It might be completely off for A% of the working day, be on idle for B% of the working day and operate at full power for

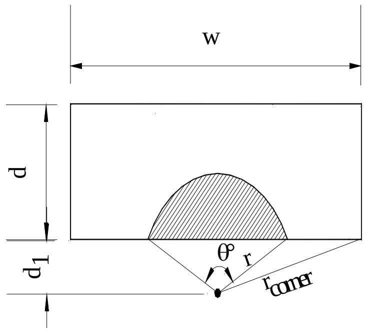
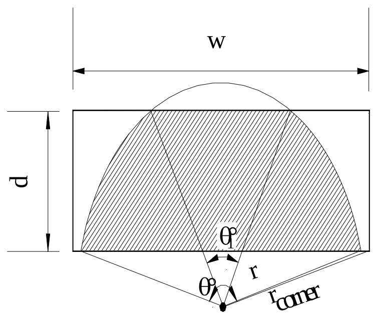
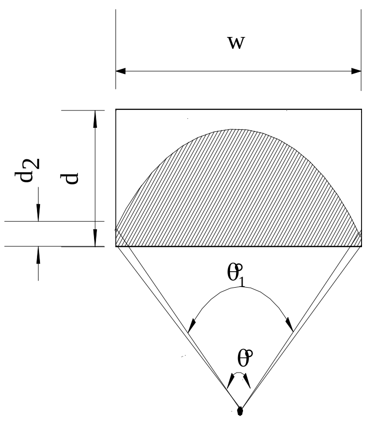
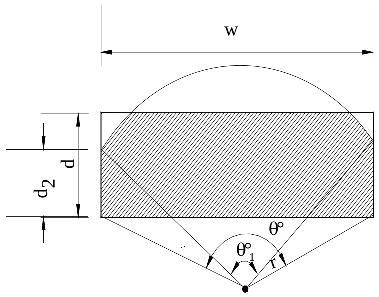
	Case i- $r < d_1 + d$ $Area = \frac{1}{2} r^2 (\theta - \sin \theta)$ $\theta = 2 \cos^{-1}\left(\frac{d_1}{r}\right)$
	Case ii- $r_{corner} \geq r > d_1 + d$ $Area = \frac{1}{2} r^2 (\theta - \sin \theta) - \frac{1}{2} r^2 (\theta_1 - \sin \theta_1)$ $\theta = 2 \cos^{-1}\left(\frac{d_1}{r}\right)$ $\theta_1 = 2 \cos^{-1}\left(\frac{d_1 + d}{r}\right)$
	Case iii- $r_{corner} < r < d_1 + d$ $Area = d_2 . w + \frac{1}{2} r^2 (\theta - \sin \theta)$ $\theta = 2 \sin^{-1}\left(\frac{b}{2r}\right)$ $d_2 = r . \cos \frac{\theta}{2} - d_1$

Figure 2: Calculation of possible shaded area in each case



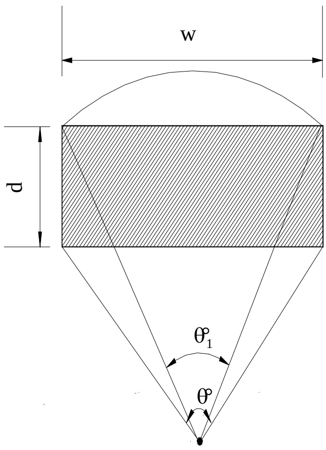
Case iv- $r_{corner} > r < r_{max}$

$$Area = d_2.w + \frac{1}{2}r^2(\theta - \sin\theta) - \frac{1}{2}r^2(\theta_1 - \sin\theta_1)$$

$$\theta = 2\sin^{-1}\left(\frac{b}{2r}\right)$$

$$d_2 = r.\cos\frac{\theta}{2} - d_1$$

$$\theta_1 = 2\cos^{-1}\left(\frac{d_1 + d}{r}\right)$$



Case v- $r \geq r_{max}$

$$Area = d.w$$

$$\theta = 2\cos^{-1}\left(\frac{b}{2r}\right)$$

Figure 2(Continued): Calculation of possible shaded area in each case

C% of the working day (Waddington and Lewis, 2000; Gilchrist et al., 2003). If an item of machine operates full power for 100% of the working day the PDF obtained is called PDF100% on. .In order to consider the effect of this operational cycle, two distributions are then derived corresponding to the sound power level of the source for idling power for B% of the day and for full power for C% of the day. For idling mode, it is assumed that an item of machine operates idle power for 100% of the working day and the noise level can be obtained by incorporating idle mode sound power level into equation 3. The $PDF_{100\%idle}$ can be determined and the PDF for B% idle mode is expressed using the following;

$$PDF_{B\%idle} = \frac{B}{100}.(PDF_{100\%idle}) \quad (5)$$

The PDF for C% full power mode or $PDF_{B\%on}$ then can be expressed using the following;

$$PDF_{B\%\,idle} = \frac{B}{100}.(PDF_{100\%\,idle}) \qquad (6)$$

The probability distribution for equipment with A% off, B% idle and C% on time is then given by:

$$PDF = \frac{A}{100} + PDF_{B\%idle} + PDF_{C\%on} \qquad (7)$$

2.2 *Effect of a Number of Items of Equipment*

Normally a number of noise sources are in operation, therefore it is possible for an item of equipment to be operating concurrently with any other item of equipment. To obtain the temporal distribution, probability laws i.e. intersection are employed. The combined probability distribution for equipment operating concurrently can be determined using a method first proposed by Nelson (1972, 1973a, 1973b). Noise producing equipment are called events "An" where n is number of equipment. Consider a simple case of two items of equipment A1 and A2, respectively working concurrently. The total working period is T hours, known as the sample space, whilst $PDF(A_1)$ and $PDF(A_2)$ are the PDF for events A1 and A2, respectively

The combination method was first proposed by Nelson(1972, 1973b) for the combination of noise level distributions in traffic noise prediction. Each PDF is represented by a set of number pairs, one relating to a noise level (centre of class interval) and one to the corresponding probability such that ;

- L_{1i} and P_{1i} where i=1,2,5..m for $PDF(A_1)$
- L_{2j} and P_{2j} where j=1,2,5..m for $PDF(A_2)$

Subscript 1 and subscript 2 refer to $PDF(A_1)$ and $PDF(A_2)$, respectively, as shown in Figure 3. L refers to the level, P to the probability of that level and i and j refer to particular samples of the first and second distribution respectively.

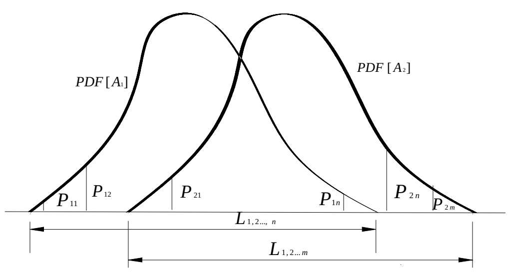


Figure 3: Division of two PDF for concurrent combination operation

The combined probability that the noise level from PDF(A_1) is L_{1i} when the level from PDF(A_2) is L_{2j} is given by:

$$P_{ij} = P_{1i}.P_{2j} \quad (8)$$

The combined noise level arising from the contributions of both distributions is given by:

$$L_{ij} = 10\log_{10}\left[\ 10^{(L_{1i})/10} + 10^{(L_{2j})/10}\ \right] \quad (9)$$

The combined PDF is obtained by defining new class intervals and summing the probabilities associated with the levels that fall within these class intervals. This technique is not limited to the combination of levels from two sources but can be applied to any number of sources.

3.0 Computation

The simulation of PDF and CDF for an activity/activities can be carried out using MATLAB 7.2. The coding was carried out according to the flow chart shown in Figure 4. Figure 5 shows PDF and CDF of an excavator with sound power level 117dB operating full power continuously for working day period. The site area is of width, 200 m and depth, 100m and the receiver was positioned at 60 m from the site centre. It can be seen that PDF has uni-modal distribution skewed to the left due to the closeness of receiver to site boundary. Note that as the receiver's position farther away from the site boundary the noise level distribution becomes symmetric. Besides the mean level and its standard deviation, indexes such as L_{10} and L_{90} can easily be determined. L_{10} is the noise level exceeded 90% of the working day period which can be associated with peak noise. The calculation of the sound level due to the equipment on idle or on full power can be obtained using the outer 'loop'. Figure 6 shows the PDF and CDF for an excavator with duty cycle of 10% off; 20% idle and 70% on. It was found that the effect of duty cycles is to change the PDF into a bimodal shape with two peaks as a result of idle mode, full power mode and distance factor.

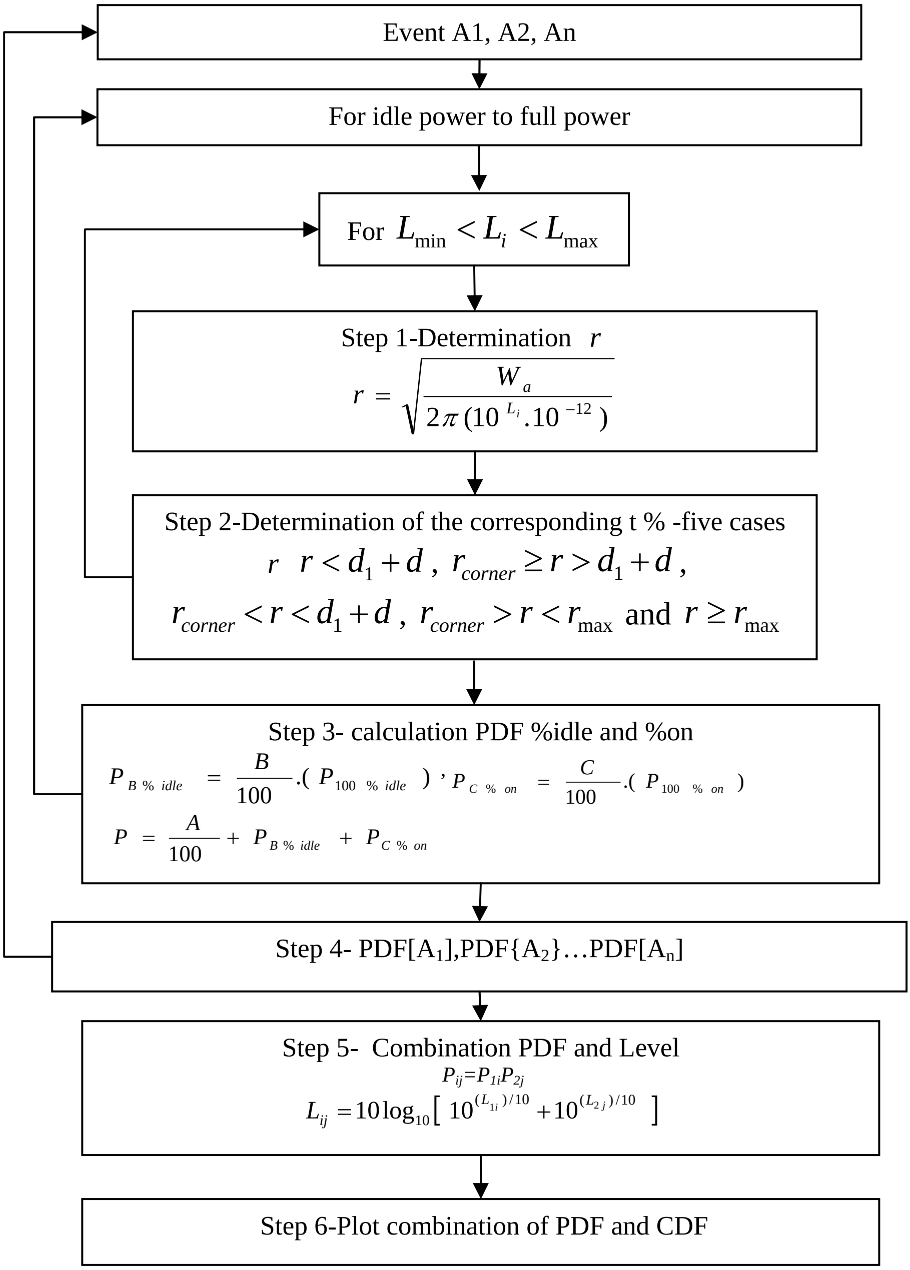


Figure 4: Flowchart for the computation of temporal distribution using probability approach

For multiple sources, Stages 1-4 are repeated and from these data a combination of probability versus noise level curve, PDF and CDF can be plotted. Figures 7 and 8 show the result for the three equipments with data shown in Table 1 working concurrently over a period of 12 hours on site area of 200m x 100m. Again, the receiver was positioned at 60 m from the site centre. In this case the combination of temporal distribution is nearly in unimodal shape. The most vital output is the content of sound during working day period that can be easily obtained**.**

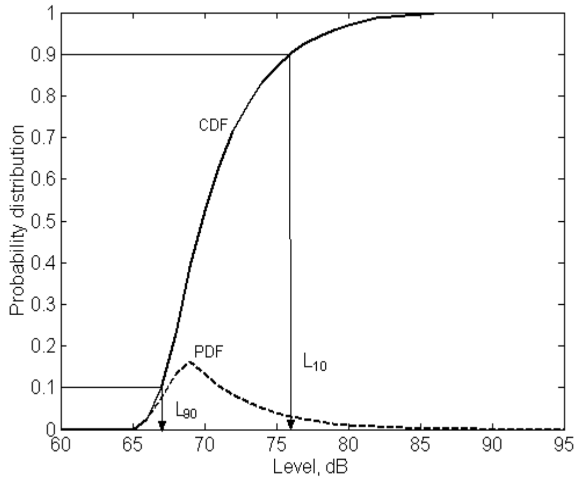


Figure 5: Temporal distribution of noise level from Excavator working full power

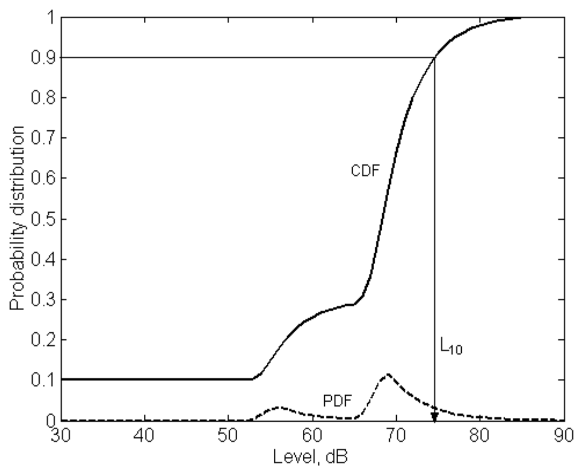


Figure 6: Temporal distribution of noise level from Excavator working with duty cycle

Table 1. Acoustic characteristics.

Equipments(duty cycle)	Sound power level
Excavator-1 (10%off:20%idle:70%on)	117dB-full; 111dB-idle
Excavator-2 (20%off:20%idle:60%on)	111dB-full; 101dB-idle
Excavator-3 (10%off:10%idle:80%on)	109dB-full; 104dB-idle

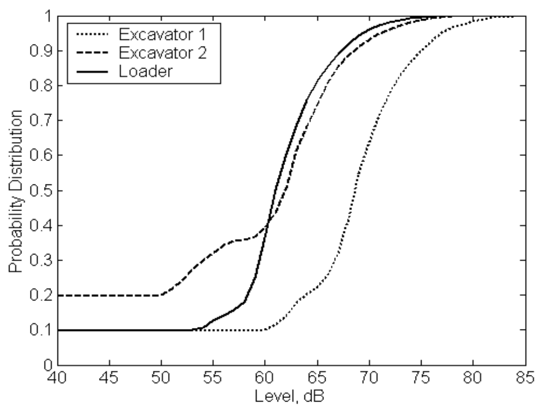


Figure 7: CDF for each activity

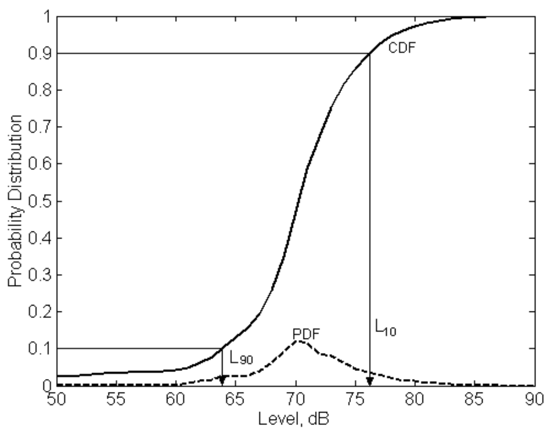


Figure 8: Temporal distribution for combination of all activities

4.0 Comparison with BS5228 model

BS5228 (1997) model is the prediction method recommended by DOE (2004). The code predicts noise at receivers in Annex D, Part 1. The sound level of the plant was used due to the availability of sound power level data in probability approach. Noise levels were collected at receiver based on the noise generated by the items of equipment using calculation steps shown in Figure 9. Correction factors were applied to the sound power level to account for factors such as periods of operation of plant of equipment (step 1), distance between the source and receiver (step 2), any screening between source and receiver (step 3) and whether the receiver is in front of a reflecting surface (step 4). Only the first two factors were available and taken into account in the comparison with probability approach. Three numbers of equipment working concurrently on a site considered in Table 1 were used to compare the result obtained from probability and BS 5228.

One problem regarding the usage of BS 5228 is that it requires accurate distance between equipment and receiver. Since the equipment will move around the site, an average distance was used i.e. the distance between receiver and equipment positioned at site centre. The result obtained from BS 5228 and probability approach has small disparity that is less than 1 dB indicating that probability approach is capable of predicting equivalent noise level. Moreover, the probability approach yielded the content of sound during working day period weighted by their probabilities.

5.0 Conclusion

This paper has described the basis of probability approach to predict the temporal noise level distribution arising from construction site operations due to either individual noise sources or a combination of noise sources. The method has advantages over the present procedure as it enables the determination of any indices required in evaluating the environmental quality. This can facilitate the decision making processes where noise is a potential problem.The method could be used as the basis of an operational management tool. The construction project manager could rapidly establish the probability of a specified limiting noise level being exceeded. The CDF can also be related or could then be used to predict the LAeq experienced over a short time period as usually measured by local authority staff when checking for conformance with a specified level during the construction process (DOE, 2004).

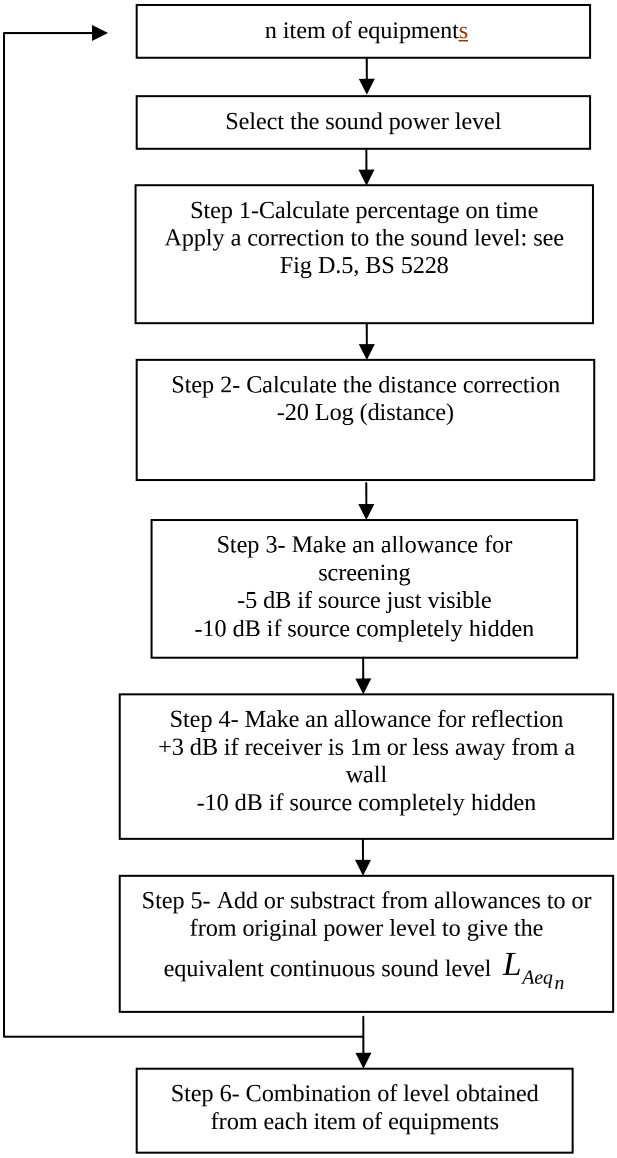


Figure 9: Flow chart for simulation of combination of concurrent activities

Acknowledgement

The authors would like to appreciate to Ministry of Science, Technology and Innovation Malaysia (MOSTI) and Universiti Teknologi Malaysia (UTM) for the sponsorship of the research.

References

Beaman, A.L., and Jones, R.D. (1977). Noise from Construction and Demolition Sites-Measured level and Their Prediction, *CIRIA Report* 64.

BS 5228, Part 1: (1997) Noise and vibration control on construction and open sites.

Carpenter, F. (1997) Construction noise prediction at the planning stage of new developments, *Building Acoustics*, 3(4): p. 239-249

Carpenter, F., Gibbs, B.M., and Lewis, J. (1997) BS 5228: The prediction of noise from construction sites. in *Proceeding of Institute of Acoustics*.

Department of Environment (DOE), Malaysia (1996) *The 1995 Enviromental quality report in Department of Environment.*

Department of Environment **(**DOE**)**, Malaysia (2004) The planning guidelines for environmental noise limits and control.

Ferguson, I. (1995). Dust and Noise in the Construction Process, *HSE Contract Research Report 73/1995*.

Gilchrist, A., Allouche, E.N., and Cowan, D. (2003) Prediction and mitigation of construction noise in an urban environment. *Canadian Journal of Civil Engineering*, 30: p. 659-672.

Haron, Z., and Oldham, D. J. (2004) Stochastic Modeling in Environmental and Building Acoustics, *Journal of Recent Research Development, Sound and Vibration*, 2, 213-234 .

Haron, Z., and Oldham, D. J (2005). Environmental noise modeling using stochastic in *Proceeding of the Institute of Acoustics*, 27(4)

Jafferson, K and Vasudevan R.N (1997) The prediction of construction site noise-an example of the application old and new BS5228 methods, in *Proceeding of the Institute of Acoustics* 19(8):245-250

Koyasu, M. (1984). Evaluation and control of construction noise: The state of art. In *Proceeding of Internoise'84*. Honolulu, USA.

Large, J.B., and Ludlow, J.E. (1975) Community reaction to construction noise. in *Proceeding of the Inter-noise*, Sendai.MATLAB, Version 7.2, The MathWorks, Inc.

Nelson, P.M. (1972). The combination of noise from separate time varying sources. *TRRL Report LR 526*.

Nelson, P.M. (1973a). A computer model for determining the temporal distribution of noise from road traffic. *TRRL Laboratory Report 611*.

Nelson, P.M. (1973b). The combination of noise from separate time varying sources. *Applied Acoustics*, 6(1): p. 1-21. 37.

Waddington, D.C., and Lewis, J. (2000) The preliminary estimation of noise from construction sites. in *Proceedings of the Institute of Acoustics*, Liverpool.