

ENVIRONMENTAL NOISE MODELLING USING STOCHASTIC TECHNIQUES

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1 INTRODUCTION

The prediction of environmental noise arising from an open site activities such as construction represents a problem when a number of different processes are carried out at different times in the course of the working day. These typically involve the use of powerful machines that have correspondingly high sound power levels¹. The nature of the sources, coupled with the limited opportunities for the screening of neighbouring sensitive locations from the noise generated, means that complaints often arise from such activities. Problems can be avoided if noise levels arising from these activities can be controlled to comply with the noise limits specified by the local authority at the planning stage. This requires the application of a suitable noise prediction technique, however, the noise experienced at a receiver is affected by factors such as movement of machinery around the site, the operational characteristics of the machinery, distance from the site, ground cover, screening and meteorological conditions. At the planning stage the data regarding these factors are very granular².

Current environmental noise prediction procedures give the typical equivalent noise level (Leq) corresponding to the working day. However, this quantity yields no information regarding the temporal or statistical variation in noise levels arising from site operations. Although Leq, because of its relative ease of use for prediction purposes, has become a preferred unit for environmental noise measurements and standards, the importance of temporal variations on subjective response was recognized in the early days of environmental noise research and a number of complex noise units were proposed which involved temporal parameters. The temporal variation of environmental noise has also been recognized in contemporary work on soundscape where measurements of short Leq are often made and sometimes presented in the form of statistical data³.

For noise sources that are stationary (in the temporal sense) sampled short Leq's will be similar to the sound pressure level sampled with a meter on slow response that was used to obtain noise level distributions in the past. In the context of this paper, however, the need for temporal information relates to the possible measurement of short period Leq values by local authorities when checking sites for conformance with legally specified levels.

2 THE MONTE CARLO APPROACH TO SITE NOISE PREDICTION

The factors which determine the time history of noise levels experienced at a receiver due to site operations can be summarised as follows:

- 1 The acoustical characteristics of each item of noise producing equipment (sound power level, operational cycle, directivity etc.
- 2 The location of each item of noise producing equipment
- 3 The proportion of time during which each item operates concurrently or non-concurrently with other items of equipment.

All of the above can be dealt with in the Monte Carlo (MC) approach as developed by Waddington and Lewis⁴, which is based upon the simulation of the time history as obtained

by sampling the noise from the site operations over the relevant operational period. Each site operation is assumed to take place over a well defined sub area and a noise source is assumed to be able to be located at any point in that sub area with equal probability. Two random numbers, N_i and N_j , are used to locate the random position of an item of equipment relative to the origin at the centre of its area of operation and these two values, together with the source height, z_s , define its location. For equipment working around the site with a known probability distribution for the machine operating at full power, idling or off, the appropriate acoustic power of the equipment can be determined using another random number, N_k .

The noise levels arising from multiple activities are determined by repeating the procedure described above with different source characteristics (source height, working profile, source operational area and associated sound power levels) and summing the intensities at the receiver point. The results obtained consist of a number of "sampled" noise levels which can be statistically analyzed to obtain the Probability Distribution Function, PDF, and the Cumulative Distribution Function, CDF. In addition, it is possible to determine the value of the equivalent noise level, L_{eq} , by summing the sampled intensities and dividing by the number of samples to obtain a mean which can then be expressed as an equivalent intensity level or equivalent sound pressure level.

3 THE PROBABILISTIC METHOD FOR SITE NOISE PREDICTION

The basis of the probabilistic method is the separation of the source characteristics (in particular the duty cycles and associated sound power levels) from the propagation characteristics (determined by the area over which an activity takes place and its position relative to the receiver). The starting point for developing the probabilistic method is the simplest case of a noise source operating continuously. The method can then be developed systematically to consider a single source with a complex operational cycle and then multiple sources operating both concurrently and non-concurrently.

3.1 Single Noise Source Operating Cycle

Considering first the propagation characteristics, it is assumed that the probability that the noise source is at a particular point within its operational sub area is the same for all points in that area. It is then possible to build up the noise level distribution characteristics from division of the operational area into small elements and considering the source to be situated successively in each element in turn. The operational area is divided into a number of equal patches and the centroid of the patch is termed a node as shown in Figure 1.

For a source positioned at the node, assuming hemispherical radiation over a hard surface, the sound intensity at a receiver is given by:

$$I_{ij} = \frac{W}{2\pi r_{ij}^2} \quad (1)$$

Where W is the acoustic power of the source, r_{ij} is the distance from source to receiver and the subscripts i and j relate to the position of the node.

This sound pressure level at the receiver is given by;

$$SPL_{(i,j)} = 10 \cdot \log_{10} (I_{(i,j)} / 10^{(-12)}) \quad (2)$$

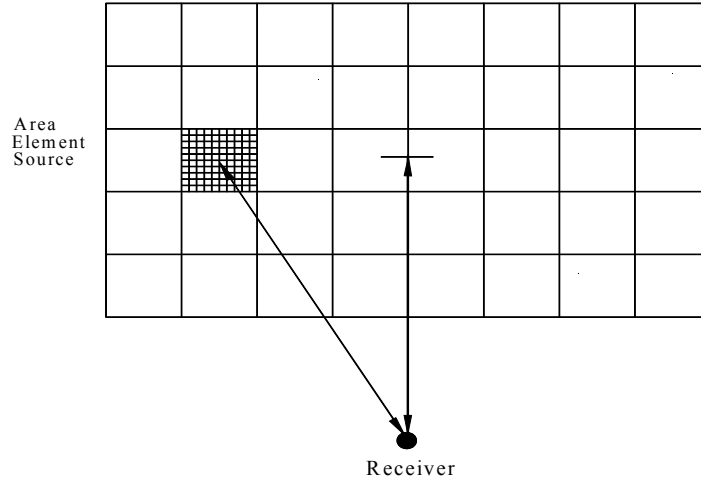


Figure 1: Division of site small area of elements for the probabilistic method

The frequency of occurrence that the noise falls within a specified dB range can be determined. This information can then be used to obtain a cumulative distribution with the vertical axis normalized to a maximum value of one and the horizontal axis relating to the noise levels. The distribution corresponding to a source with a different sound power level can be easily obtained by shifting the levels in the distribution curve by the difference between the sound power level originally assumed and that of the actual noise source.

3.2 A Single Noise Source with a Complex Operational Cycle

An item of machinery might typically generate a number of different sound power levels in the course of working day. For example, 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 C% of the working day. In determining the PDF corresponding to the entire working day, the following procedure is observed. The noise distribution is first obtained assuming a standard source sound power level. Two distributions are then derived from this corresponding to the sound power level of the source in idling mode, $PDF_{100\%idle}$, and full operation, $PDF_{100\%on}$, respectively. The PDF's corresponding to the actual duration of the source in idling and full power mode are obtained by multiplying these PDF's by the fraction of the total time that they occupy as shown below:

$$PDF_{B\%idle} = \frac{B}{100} \cdot (PDF_{100\%idle}) \quad (3)$$

(4)

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

$$PDF = \frac{A}{100} + PDF_{B\% \text{ idle}} + PDF_{C\% \text{ on}} \quad (5)$$

By using area of element sources 1mx1m on site dimension of 250 x 100m with an equipment of two duty cycle; 40% idle and 60% fully on and 10% off:20% idle:70% fully on, the obtained PDF and CDF are shown in Figure 2a and 2b, respectively. The comparison with Monte Carlo simulation are shown in dashed curve, using 10,000 sample. It can be seen that the two approaches produce very similar results but earlier investigation⁵ showed that for a relatively small site MC also requires the same number of sample to yield the same curve as the probabilistic method.

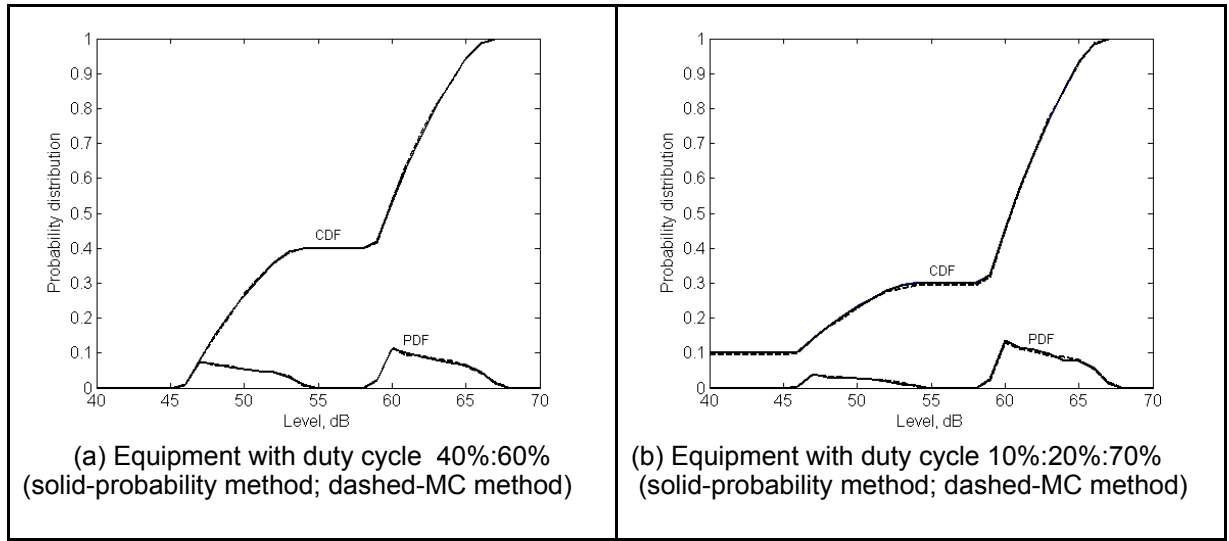


Figure 2: Comparison between predictions of the MC and probabilistic methods for a noise source with complex operation cycle.

3.3 Prediction of Noise Levels from Multiple Sources

When a number of noise sources are in operation, it is possible for an item of equipment to be operating either concurrently or non concurrently with any other item of equipment.

3.3.1 Non-Concurrent Operation

Consider the total working period of t hours to be the sample space, with 2 subset events A1 and A2 where the event space for A1 and A2 are t_1 hours and t_2 hours respectively. The cumulative probability of subset events A1 and A2 are t_1/t , t_2/t , respectively and the cumulative probability of all events is equal to 1.

In the probabilistic method the following approach is employed; the PDF associated with event A1 is equal to the PDF obtained assuming that the equipment operates over the full t hours multiplied by t_1/t and the PDF associated with event A2 is equal to the PDF obtained assuming that equipment A2 operates over t hours multiplied by t_2/t . Therefore the combined probability distribution function for noise level from both items of equipment is given by:

$$PDF[A1+A2] = t_1/t * PDF[A1] + t_2/t * PDF[A2] \quad (6)$$

PDF[A1] and PDF[A2] are both represented by a set of number pairs, one number relating to a noise level (strictly the centre of a class interval) and one to the corresponding probability. Suppose that subscript 1 and subscript 2 refer to the distributions due to events A1 and A2 respectively, both distributions are divided into m samples resulting into a number of levels, $L_1, L_2, \dots, L_m$ and the probabilities corresponding to each level, $P_{11}, P_{12}, \dots, P_{1m}$ for event A1 and $P_{21}, P_{22}, P_{23}, \dots, P_{2m}$ for event A2. The total probability, P_{12i} , corresponding to the noise level, L_i from the two operations can be determined by adding the probability of distribution 1 corresponding to level L_i to the probability of distribution 2 corresponding to level L_i as shown below:

The compactor and dozer operations are A1 and A2, respectively, the sample space is 12 hours, the probability distribution of events A1 and A2 are 4/12 and 8/12 of PDF over the full 12 hours. The PDF associated with A1 and the PDF associated with A2 calculated by both the probabilistic method and the MC method are shown in Fig 3(a). The MC method data was obtained with 10,000 samples obtained; 3,333 samples for events A1 and 6,667 samples for event A2. The PDF and CDF of A1 and A2 and the combination are shown in Fig. 3b. The curves obtained show that both methods give very similar results.

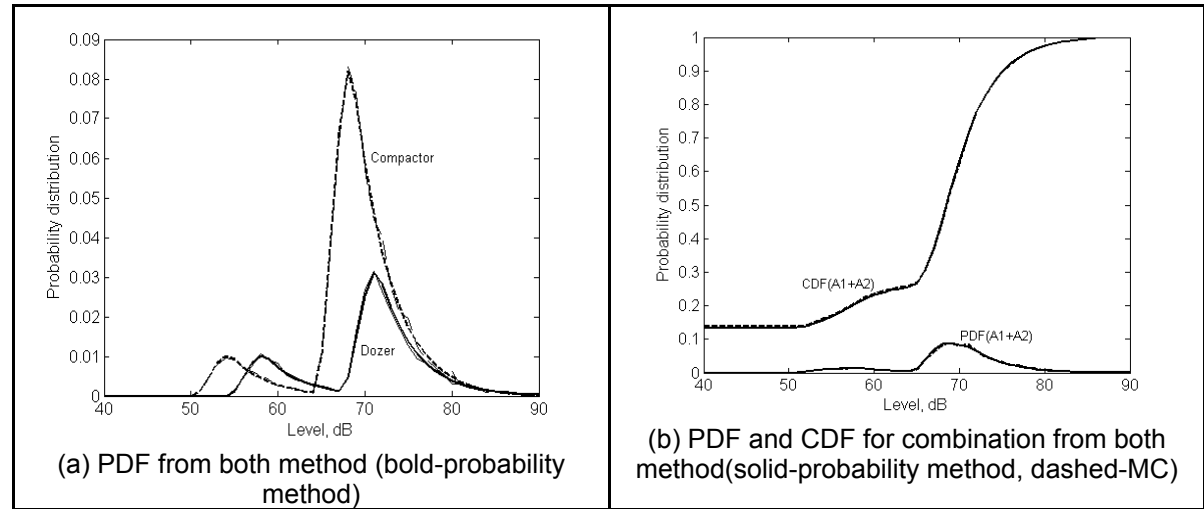


Figure 3: Comparison between prediction of two method for noise from the non-concurrent operation of multiple sources

3.3.2 Concurrent Operation

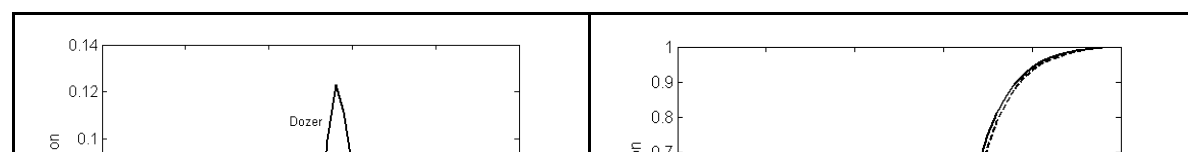
The combined probability distribution for equipment operating concurrently can be determined using a method first proposed by Nelson⁶. Consider two items of equipments working concurrently over a period of t hours. PDF's for events A1 and A2 are determined assuming that both items of equipments work for t hours. Each distribution is represented by a set of number pairs, one relating to a noise level (centre of class interval) and one to the corresponding probability. Suppose that the first distribution is denoted by the subscript 1 and divided into m samples and the second distribution is denoted by the subscript 2 and is also divided into m samples. Components of the two distributions can be written as follows: For distribution 1 the number pairs are L_{1i} and P_{1i} where $i=1,2,3..m$; For distribution 2 the number pairs are L_{2j} and P_{2j} where $j=1,2,3..m$. Where 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. The combined probability that the noise level from distribution 1 is L_{1i} when the level from distribution 2 is L_{2j} is given by:

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

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. An example of the results obtained from the application of this technique compared with results obtained from a Monte Carlo simulation of the same situation is shown in Figure 4. The site considered is same as in the above example except the operation of the two items of equipment is concurrent. For the MC method, a total of $N=10,000$ noise level samples are generated for each event, assumed to occur simultaneously, and the PDF is determined. Both approaches predicted very similar probability distribution curves, however, the MC method requires a very large number of random sample to produce these curves.



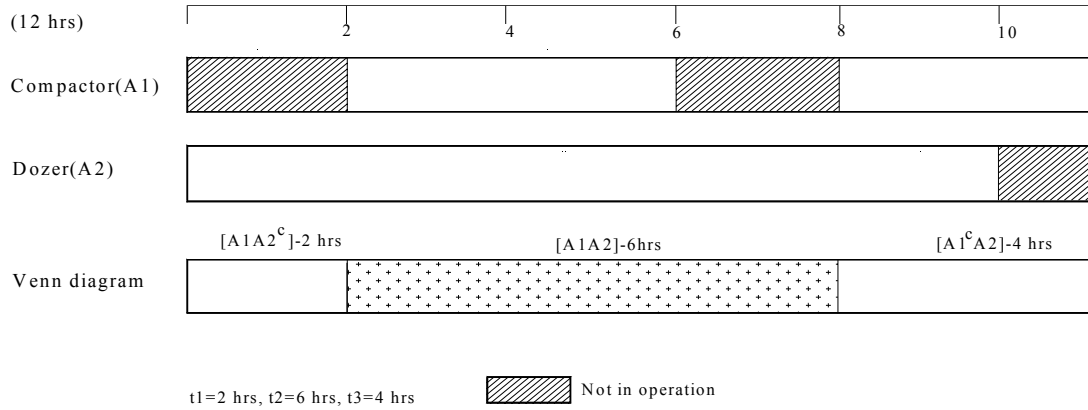


Figure 5: Working schedule involving concurrent and non-concurrent operations and associated Venn diagram

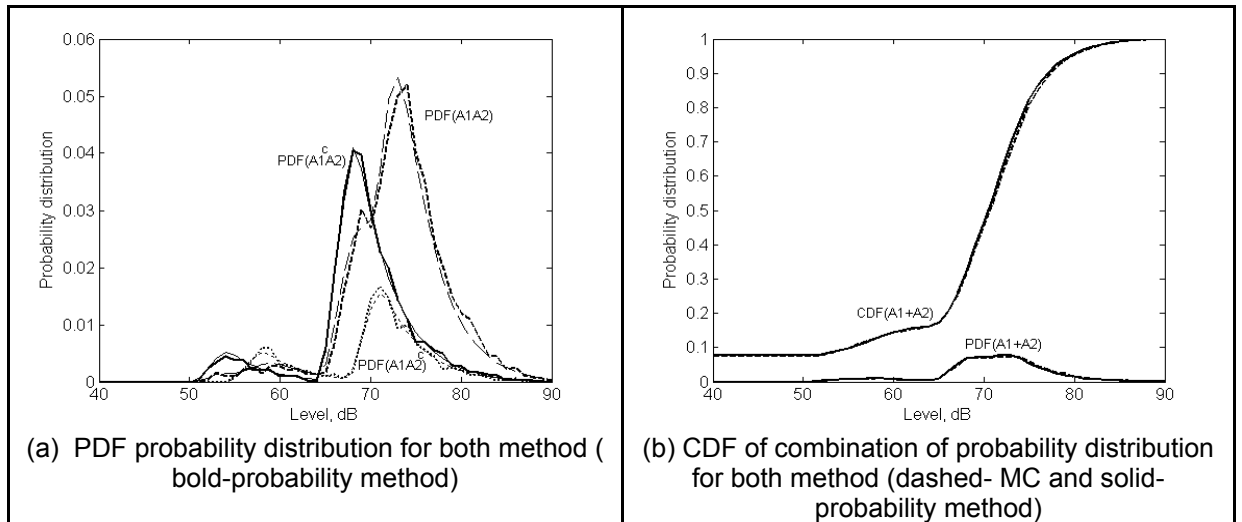


Figure 6: Comparison between prediction of noise level distributions for MC and Probabilistic methods for noise from mixed non concurrent and concurrent operation of multiple sources

Event spaces for $[A1A2^c]$, $[A1A2]$, and $[A1^cA2]$ are t_1 hours, t_2 hours and t_3 hours respectively. The probability distributions corresponding to subset events $[A1A2^c]$, $[A1A2]$, and $[A1^cA2]$ are t_1/t , t_2/t , t_3/t , respectively and the cumulative of combined probability distribution of all events is equal to 1. In the probabilistic method $P[A1A2]$ is equal the PDF obtained assuming that both items of equipment (A1 and A2) work concurrently over t hours multiplied by t_2/t . $P[A1A2^c]$ and $P[A1^cA2]$ are equal to $t_1/t \cdot \text{PDF}[A1]$ and $t_3/t \cdot \text{PDF}[A2]$ as A1 and A2 work separately for t_1 and t_3 hours respectively. The combined probability function for noise level from both items of equipment is given by:

$$\text{PDF}[A1+A2] = t_1/t \cdot \text{PDF}[A1] + t_2/t \cdot \text{PDF}[A1A2] + t_3/t \cdot \text{PDF}[A2] \quad (10)$$

Calculation of the combined PDF involves the procedures described above for concurrent and non-concurrent operations. Figure 6 shows results for the combined level distribution from mixed non concurrent and concurrent activity obtained using the probabilistic method and the MC method. The case involves operations using a compactor and a dozer. The items of equipment have the same duty cycles and sound power levels as above and are employed for a total duration of 12 hours. The sample space is thus 12 hours, the operation consists of three subset events. The probability distribution of events $[A1A2^c]$, $[A1A2]$ and $[A1^cA2]$ are $2/12$, $6/12$ and $4/12$, respectively. In the case of the MC simulation, events $[A1A2^c]$, $[A1A2]$, and $[A1^cA2]$ were sampled 1,667, 5,000 and 3,333 times, respectively. The PDF's and CDF's of $[A1A2^c]$, $[A1A2]$ and $[A1^cA2]$ and the combination are shown in Fig. 6. It can again be seen that both method give similar results.

site and the number of sampling, the probabilistic approach is considerably more efficient and thus more suitable for an investigation of the effect of site parameters on noise levels at receiver locations in the vicinity of the site. It could thus be used as the basis of a prediction technique if employed in a systematic examination of the variation in noise levels with distance for a range of site aspect ratios. Expressions could be obtained to predict the mean sound level and standard deviation as a function of parameters such as distance, site aspect ratio, screening etc and to derive simple design charts for planning purposes. The noise level data associated with the probability distribution obtained using the probabilistic method can also be used to 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. However, more importantly, the manager could identify the source of the potential problem and investigate the effect of possible alternative strategies such as the avoidance of the concurrent operation of the noisiest equipment and perhaps alternative construction processes.

5 REFERENCES

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