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ADVANCES IN SIGNAL DESIGN AND THEIR VALUE IN MINIMISING ENVIRONMENTAL NOISE

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INTRODUCTION

Of the many problems of environmental noise nuisance, those arising from auditory signals can often be the most intractable. There is a fundamental conflict between the recipient's requirement (audibility) and the residents requirement (inaudibility).

Impositions from legal and statutory authorities can be unclear. While dB(A)/Leq limits for annoyance can easily be set, specifications for signals are often vague (see the example cited in [1] and directed towards the goals of the signals, not their precise character. Signal requirements may be couched in terms of "audibility" or "suitability" with no firm guidelines explaining to what proportion of the population the signal should be audible, when, where and under what ambient noise conditions. Indeed, methods for determining audibility itself are seldom specified.

In these circumstances, the solutions are limited. Visual signals form one possibility (but they only gain attention when the intended recipient is looking in the right direction). Another possibility is to accept lower standards of safety. Cessation of the particular activity requiring a signal is the final, unpalatable, alternative.

Fortunately, research and development carried out by the Institute of Occupational Medicine [2] has enabled the production of a signal design procedure which can give a clear understanding of the above problems and lead to satisfactory solutions for all involved.

This paper outlines the principles of the signal design procedure and gives an example of its practical application to a particular case where the conflict between signal audibility and neighbourhood noise nuisance was apparent.

SIGNAL DESIGN

To be effective a signal must be:

- Audible
- Attention gaining
- Recognisable

It must also:

- Make the minimum contribution to noise dose
- Have minimal startle effects
- Produce minimum interference with other task

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A comprehensive ergonomic assessment or design of signals must take account of all of these factors, and in the process any conflicts between these goals must be minimised.

To have a practical signal design scheme the IOM needed accurate prediction procedures, so it set out to devise a method incorporating the latest techniques and adapting them to the needs of industry. The new method was shown to be a significant improvement upon these previously available.

This method is the culmination of considerable experimental and field work which is not described here. A full description of its development is contained in [2] and [3] and further examples of its use can be found in [4] and [5].

We recommend a two-stage approach to signal design. Stage 1 is the determination of the range of permissible physical characteristics in terms of frequency and signal level. Figure 1 demonstrates the principles. It shows the spectrum of a noise, it has sound pressure level as the ordinate and frequency as the abscissa. A masked threshold can be calculated from this noise, the level of signal required for a listener to just hear it. In practice we must also consider the range of hearing abilities in the working population; and an absolute threshold criterion derived from an audiometric survey of the population in question must be combined. The threshold is now a composite, governed by masking noise at some frequencies and hearing ability at others. The MINIMUM EFFECTIVE SIGNAL LEVEL, which is that required for clear audibility, is obtained by adding 15 dB to the composite threshold. Above this line are marked a maximum level to avoid startle, and a damage risk criterion. The enclosed area reflects the constraints imposed by the requirements for minimisation of startle effects and noise exposure commensurate with the achievement of clear audibility. This area we describe as a DESIGN WINDOW. Spectral components of a signal which fall within this window should be effective.

Stage 2 is the design of signals within this window to ensure recognisability in relation to noise fluctuations to ensure discriminability between signals, to minimise interference with other tasks, and to maximise attention gaining effects.

To use the procedure we tape record the noise at the appropriate workplace, together with any signals present, and then analyse the recordings with a computer which presents us with final output similar to Figure 1. We thus have a field-usable method in which the principles outlined are translated into routine ergonomic practice.

PRACTICE

The procedure was applied to a wide range of operations to determine its practical utility, initially for the mining industry.

A typical example is discussed below.

An auditory pre-start warning signal had been installed in a process plant in the mining industry. The signal was reported as being too loud both by men and management. There were also complaints about it from residents living near the plant. The plant management and operatives modified the signal but the results were unsatisfactory. It now failed to fulfil its primary safety role.

Figure 2 shows the design window from a typical workstation, together with the spectra from the warning signals. The original warning within the plant is shown by the two solid lines. It clearly exceeded the design window. Moreover, noise levels from the signal at the perimeter of the industry boundary were well in excess of the ambient environmental noise, being measured at 70 dB(A). The modification is shown by the dotted line. This warning was below the design window.

We thus explained the subjective deficiencies in the signals, but more importantly we had guidelines for an improved replacement. A recommendation for a signal 15-20 dB less intense, was made, which would still meet the safety requirement.

Alternative devices were considered and one produced characteristics which were near ideal according to the criteria available. Figure 3 shows its components falling within the design window. Levels at the site perimeter were below the ambient environmental noise and the signal spectral components contributed 50 dB(A). We therefore had a safe signal which was also unlikely to produce complaints from people living nearby.

The IOM procedure demonstrated the limitations of the existing signals, provided a means to evaluate alternatives, and gave recommendations closely in tune with the requirements of the site personnel.

To appreciate the potential power of the procedure, it is necessary to understand the economic impact it could have. Neighbourhood noise complaints once triggered tend to continue, and the solution can involve great costs. Indeed, had the above preparation plant signal been correctly specified initially, then the mining industry might well have saved £120,000, which amounts to approximately 60% of the total budget for this research.

The flexibility and applicability of the IOM procedure is much wider than the simple example given here. It has been applied to forklift trucks in workshops [5], locomotive warning horns, control rooms [6], and earthmoving vehicles [4]. In the last case, environmental noise was again a major concern and it proved possible to optimise the choice of signal characteristics.

CONCLUSIONS

The applicability of the IOM signal design procedure to situations where the needs of safety and environmental restricts conflict has been demonstrated. In some cases a complete solution can be found, in others the problem can be minimised.

It may be that developments of this procedure could lead to revised environmental noise criteria which take account of intrusive sources in terms of their audibility rather than simple noise levels.

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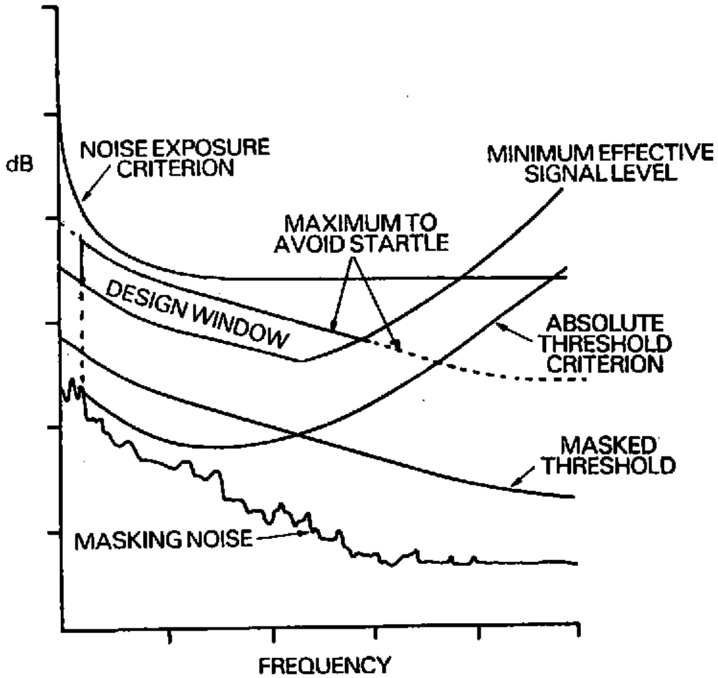

FIGURE 1. Stage 1: Principles of Signal Design

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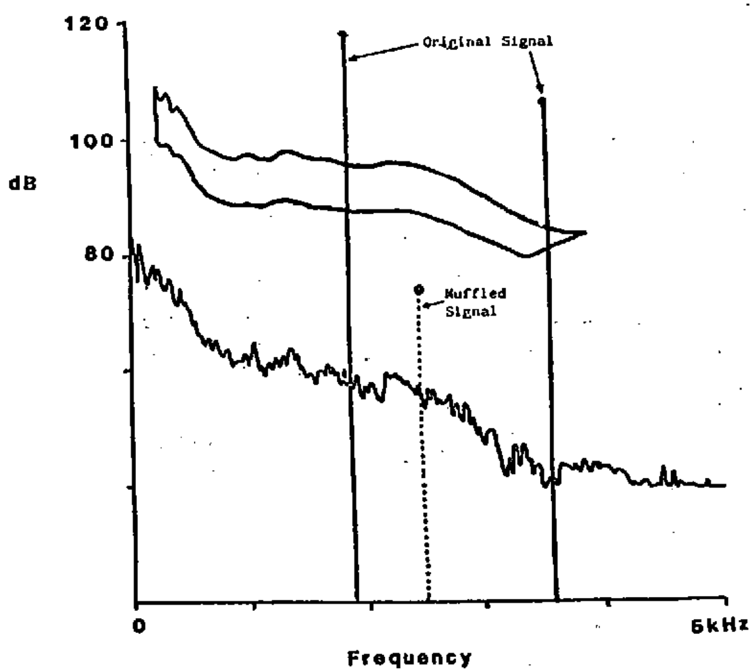

FIGURE 2. Design Window for Coal Preparation Plant Showing Original Signal and Version Modified by Personnel

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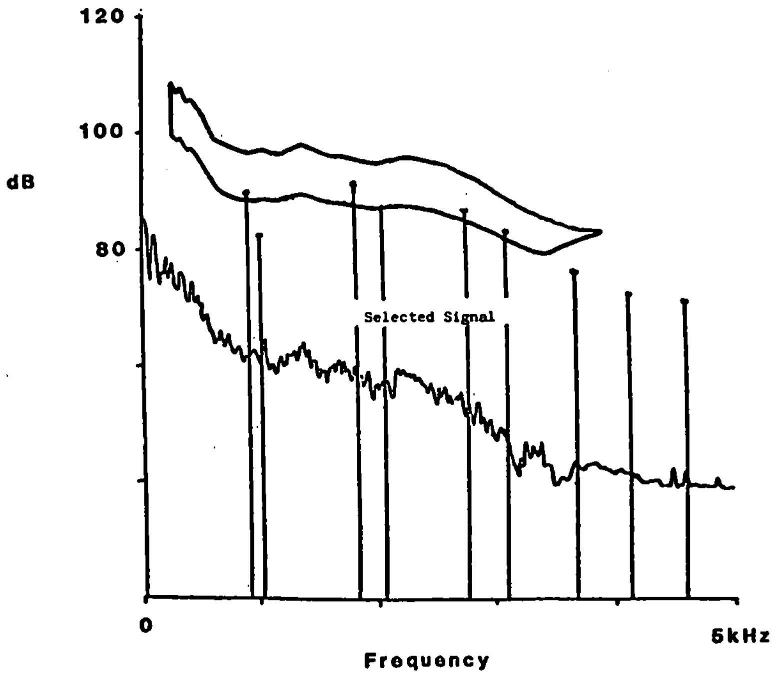

FIGURE 3. Design Window for Coal Preparation Plant Showing Selected Alternative