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AN ACOUSTIC FEATURE MODEL FOR THE ASSESSMENT OF ENVIRONMENTAL NOISE

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1. INTRODUCTION

This paper examines the role of noise measurements in noise rating and control. It looks at some of the limitations of current rating methods and introduces an approach based on the acoustic features of the noise. The acoustic feature model is different from current methods in that it does not attempt to combine separate features into an overall combined noise index and aims at providing as complete a description as possible of the physical magnitudes of all the significant acoustic features present in the noise.

This paper sets out the requirements of the acoustic feature model, describes the model, suggests a rating method based on the judgement of noise quality and finally discusses further work required to develop the model.

2. BACKGROUND

Noise is a problem which affects everybody and is likely to continue as a major environmental issue well into the next century. In order to address this problem we must understand noise in its various forms, its effects on people, and the various methods which are used to measure noise and its effects.

The effects of noise can be physiological and psychological. Although there is general agreement on the levels of noise which are capable of causing physical harm, despite many years of research there is much less agreement on the relationship between noise level and adverse reaction e.g. annoyance. This is because subjective response to noise is extremely complex and shows considerable variability both between and within different exposed populations.

However it is difficult to use anything other than simple noise level measurements and predictions for the purposes of noise assessment and control. This has led to the current practice of setting noise criteria and standards in terms of average noise levels. Discussion arises continually about various penalty or correction factors applied in these simple methods with respect to (a) differences in community response between noise sources and (b) noises with different acoustic features such as tonality or impulsivity.

In order to develop improved measurement methods, research has attempted to relate objective methods of assessing noise to subjective response. However, if objective ratings can never truly relate to the complex and variable subjective response then what is the precise role of noise measurements in noise assessment and control? The key issue is to define this role. Noise measurements are a means of describing the noise exposure, not of predicting response. A noise assessment method should

* provide an accurate and comprehensive description of the noise
* allow for objective comparison between different situations to encourage fair treatment across similar cases and allow future decisions to be based on precedents and lead to consistency in decision making
* target cost effective noise control and aim for an equitable trade-off between lowest cost and maximum benefit to the community.

We now look at the limitations of some current rating methods and introduce an approach based on acoustic features of the noise, taking more account of the complexity of the subjective response and of the role of noise measurements.

3. AN INTRODUCTION TO THE ACOUSTIC FEATURE MODEL APPROACH

Let us examine the general procedure that may be adopted when investigating an existing noise problem and identify the main difficulties that may arise using some existing procedures and how they may be addressed using a different approach.

Stage 1 - talk to complainant
The usual procedure is to talk to the complainant to ascertain more information about the nature of the noise. For example, the Institute of Gas Engineers (1) recommends that a description of the noise should be sought, to establish which aspects of the noise are annoying etc. Penn (2) points out that to satisfy the requirements of common law principles, an investigating officer should interview the complainant to ascertain various facts including the nature of the noise - continuous, intermittent, frequency characteristics (rumble, whistle, whine, clatter, etc). The results of interviews will often establish in the officer's mind the kind of noise source he has to investigate, and in many cases it will be clear from the outset that he will be seeking to control specific sources.

Stage 2 - visit site of complaint
The officer may then listen to the noise to determine whether in his view there is a problem and establish subjectively the annoying aspects of the noise responsible for the adverse community response. In fact at this stage he may already have formed an opinion of whether, in his view, the complaint is justified, and identified the aspects of the noise which are annoying.

Stage 3 - noise measurement survey
He should confirm objectively the presence of these annoying characteristics by supporting his case with noise measurements so as to reduce the reliance on his own subjective opinion. Furthermore noise measurement data are often useful in providing a basis for noise control solutions.

A problem may arise at this stage when objectively measuring and assessing these characteristics. What is needed are measurement methods of the actual annoying aspects of the noise which objectively identify the physical features causing the problem. Many of the existing methods for rating noise "add together" separate measures of different acoustic features into a combined noise index. These methods often conceal or even lose information about the true dominant feature responsible for annoyance. Furthermore they may provide an incomplete description of the noise, may not be fair or consistent and do not always target cost effective noise control.

Some practitioners may select the relevant standards or parts of standards to back up their subjective impression of the features present in the noise. Unfortunately, in some situations the investigating officer, using the measuring and rating "tools" he has available, may disagree with the objective assessment of the situation. Examples of this have been reported in the NPL Data Sheet Study (3) with respect to British Standard BS 4142:1990 (4).

Let us examine in more detail the limitations of some procedures using combined indices, giving examples and looking at how an approach based on acoustic features may address some of these problems.

Loss of information - Efforts to merge separate measures conceal information, some of which may be vitally important in a particular situation. The simplest example of this is the day night index, L_{dn}, as used in the USA (5). This upweights night-time measurements by 10 dB as compared to day-time, on the perfectly reasonable assumption that people are generally more sensitive to night-time noise than day-time noise. The weakness of this combined index is that large changes in either day-time or night-time average noise levels can be represented either by small or large changes in the index, depending on the relative day and night levels.

A further example of an approach which may lose vital information is the rating method of BS 4142 (4), whereby a measurement of a specific noise is first corrected for character based on a subjective impression and then compared against the pre-existing background noise to determine the "likelihood of complaint". The method goes some way towards identifying the features or characteristics likely to heighten the annoyance response. However, the main difficulty arises when all the contributions are combined together at the end. The method places too much significance on the comparison of the "combined" rating level with background noise level and valuable information may be lost about the annoying characteristics by including them as a rather arbitrary correction to the specific noise level.

To illustrate this example, consider a low level tonal noise from a fan at an industrial premises where the tonal property of the noise is the feature responsible for the annoyance response. Why are we adding a correction to a measured level when it is because the noise "whines" it is annoying ? Using a combined index approach, one loses the information that it is the tonal nature that is the main source of annoyance. In fact, can the effect of impulsivity or tonality ever be accurately defined in terms of a correction to a measured or predicted level ? Perhaps this is where methods such as BS4142 break down and can never truly relate objective prediction to subjective response and therefore be 100% successful.

The acoustic feature model approach suggests that each feature should be examined **separately.** Using this method and not combining the measures of the separate features, information is not concealed about the main cause of an adverse reaction to a noise.

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Incomplete description of noise - It makes little sense to combine separate measures of various features such as level, spectrum content, temporal variability, and relative level above masked threshold level, etc., into any combined additive noise index if the descriptive and therefore analytical power of the complete description is thereby lost.

For example, average noise levels above L_{eq} values of 65-70 dB(A) during the day, and above say 55 dB(A) at night, are likely to provoke annoyance, irrespective of any additional acoustic features present. Additional penalties for tonality, etc., would then be largely meaningless. On the other hand, night-time noise below an L_{eq} value of 40 dB(A) can provoke complaints where the acoustic features present serve to identify the source to the complainant. In this case absolute noise level is irrelevant, but tonality or impulsivity, or some other measure of information content is highly relevant.

The primary emphasis of the acoustic feature model is to concentrate on the role of noise measurement in providing an accurate and comprehensive description of the noise, including a complete description of all significant acoustic features that might influence a reasonable person's attitude to the noise in any particular case.

Fairness and targeting cost effective noise control - A noise assessment method should be fair and target cost effective noise control. The principal difficulty is that the initial cause for complaint is likely to be due to the most dominant feature of the noise (eg that it contains a pure tone) and that any combined noise index could conceal this fact. We must consider that practical decisions on noise control or noise insulation are based on practicability and cost. It is false economy to attempt to describe the rich complexity of alternative possible types of noise exposure by any single number descriptor.

As an example, again let us consider the rating method of BS4142. A recent study has shown (3) that of 113 cases reported as part of the recent DoE sponsored NPL survey, 81% of complaints were cases of noises with specific characteristics such as tonality, irregularity and impulsivity. Noise level, per se, merely determines audibility of these characteristics, and does not directly contribute to the annoyance response. Therefore, what may be required in many cases, for practical noise control, is not necessarily a reduction in noise level per se, but a reduction of audibility or prominence of the feature which is primarily responsible for determining the adverse response. For example, reducing the overall level of our fan noise by 5 dB would not reduce its annoyance if the tonal nature is not reduced.

The acoustic feature model takes account of the complexity of subjective response by not attempting to combine separate features into overall combined 'noise indices'. It aims to identify the most dominant feature present that needs to be controlled. In fact the main test of any new model for noise assessment is whether it can successfully be applied to target effective noise control in such a way as to bring the greatest benefits to the exposed community while maintaining fairness and consistency.

4. THE REQUIREMENTS OF AN ACOUSTIC FEATURE MODEL

The acoustic feature model is required to examine noise quality. It should be non-scaling and non-additive in as much as it does not add up penalties in a quantitative way. It should take account of the complexity of subjective response by not attempting to combine separate features into overall combined noise indices.

A rating method based on the acoustic feature model approach is required to be directed at the feature of noise which is the main stimulus for the annoyance response. One specific feature of a noise alone could determine the amount of annoyance response to the noise, for example in the case of a noise which is tonal or impulsive.

In essence, the acoustic feature model requires that as complete a description as possible is provided of the physical magnitudes of all those significant acoustic features which are actually present. It is then desirable that the model should go further and attempt to identify which of these features is the most dominant, since this should then be the first candidate for noise control, all other things being equal. However, it is not essential that the model should be explicitly capable of determining this step under all possible conditions, as human response is probably too complex for a universal and meaningful prescription in this way.

Finally, the model should ideally be capable of determining the next most significant feature remaining after practical noise control action to remove the most significant feature. The practical possibilities for this are probably even more limited, but it is important to recognise these limitations if they exist, and not continue under false assumptions regarding the true representativeness of any existing procedures.

5. THE ACOUSTIC FEATURE MODEL APPROACH

5.1 Characteristics and features

A characteristic of a noise can be defined as the subjective attribute of the noise perceived by the listener. A feature is the actual physical attribute of the noise giving rise to the perceived character. The character of a noise could be a result of a combination of features. Features do not always correlate with character.

For example, tonality is a characteristic perceived from the presence of tonal properties (spectral prominence) and impulsivity is due to the presence of an impulse (short term envelope fluctuations). The characteristic of intermittency is perceived from long term envelope fluctuations with the noise present for periods of time. Harmonicity is due to the presence of a number of tones with a given frequency separation. Loudness is due to masked level and spectral shape. Characteristics and therefore features may be of different levels of importance in determining the impact of a noise on the listener, i.e. for a low level tonal fan noise, tonality may be more dominant than perceived loudness.

Objective measurement methods need to be developed to provide a means of identifying whether any features are present and to rank the importance of each feature in determining an adverse response. The methods should provide an objective means of describing each feature.

5.2 The sensory magnitude of a characteristic and the physical parameters of a feature

The sensory magnitude of a characteristic can be defined as a measure of its perceived strength with respect to subjective noise evaluation. The sensory magnitude of a characteristic and hence the relative importance of it in determining response can be affected by varying the physical parameters of the features of the noise giving rise to that characteristic. For example, the perceived impulsive nature can be affected by changing the parameter of rise time of an impulse.

5.3 Thresholds and threshold zones

Let us consider the response to an annoying characteristic of a noise. There is an absolute detection threshold below which the feature would not normally be detectable, even under controlled laboratory conditions. For example, the detection threshold for a continuous pure tone component in broadband masking noise is known to be of the order of 4 to 6 dB below the 1/3-octave band level of the masking noise.

The importance of a feature depends on its level above the detection threshold for that feature. We can identify two further levels above the detection threshold which could be significant for annoyance and for informing noise control decisions. These are the significance and annoyance thresholds.

The feature might not become significant under everyday conditions unless it exceeded the absolute detection threshold by a certain margin, for example, 5 or 10 dB. In fact noise would cease to be a problem if its features were reduced to magnitudes where the sensory magnitude of the resultant character no longer protruded significantly above the detection threshold. The significance threshold takes into account that average sensitivity under everyday conditions is unlikely to be as high as under controlled laboratory conditions. Of course, some people can become sensitised to a particular feature of a noise and it might then be significant right down to the absolute detection threshold, but on the other hand, a higher significance threshold seems to be more appropriate in the case of average conditions.

There is a strong possibility of hysteresis in the case of noise sources newly introduced into a community, in that they might have to be reduced to a greater extent once complaints have been generated, than would have been the case if the situation had never been allowed to develop to the complaint stage.

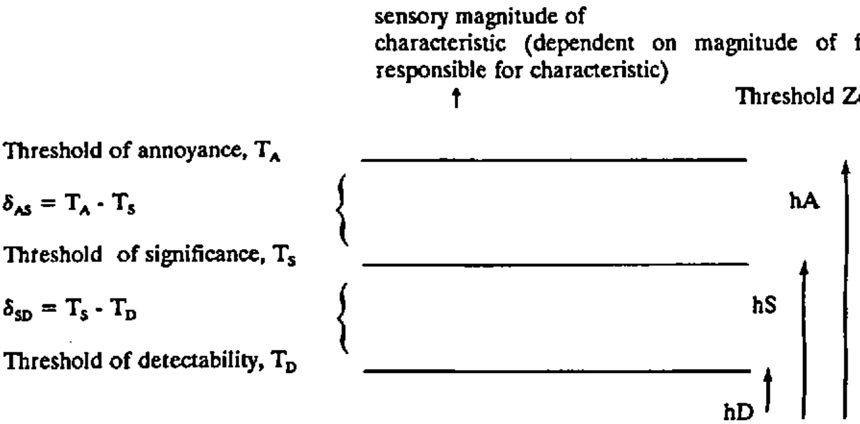
Finally, the level of a particular feature above the absolute detection threshold might become such that it constitutes the principal source of annoyance. It seems likely that the annoyance threshold will lie some way above both the detection and significance thresholds. The precise level increment required to generate annoyance will probably depend on the overall situation and the extent to which other non-acoustic features are present. The three threshold levels defined above are illustrated in Figure 1.

The distinction between the thresholds may not always be clear cut. A characteristic may become significant when it is detectable. Alternatively it may become annoying when it is significant or even just detectable. A threshold zone defines the area in which a threshold can occur. If the variability of these thresholds between listeners and situations is examined, then the variability of the threshold of detectability can be assumed to be less than that of the other two thresholds. Decreasing the sensory magnitude of a characteristic (by decreasing the magnitude of the features giving rise to the characteristic) towards or below the threshold of detectability should be the ultimate aim when considering effective noise control measures.

It should be noted that the variability of the points at which the annoyance threshold and significance threshold occur (i.e. the widths of the threshold zones) may be affected by non-acoustic factors. At times these factors alone may be the main cause of an annoyance response. For example: loss of value, connotation of noise, socio-economic factors, etc.

A rating method should take into account all the factors, both acoustic and non-acoustic and describe the whole situation when investigating a noise problem. For planning purposes, this would be in line with an Environmental Impact Approach (EIA) (6).

FIGURE 1: THRESHOLDS AND THRESHOLD ZONES



$\delta_{AD} = T_A - T_D = \delta_{AS} + \delta_{SD}$

If the variability between listeners for a threshold is denoted by $\Delta_{D/S/A}$,
it is assumed that $\Delta_D \leq \Delta_S \leq \Delta_A$
Also if the width of a threshold zone is denoted by hD/S/A,
then hD $\leq$ hS $\leq$ hA

6. A RATING METHOD BASED ON THE ACOUSTIC FEATURE APPROACH

The following flow diagram suggests a rating method that can be used to evaluate the impact of a noise based on the assessment of the actual noise quality, i.e. examination of the features of the noise. Ideally, the method should meet the requirements of a noise rating method by providing a means of describing the noise and its features, allowing for objective comparison between different situations based on objective measurements of the features in the noise, and targeting cost effective noise control by identifying the most dominant features.

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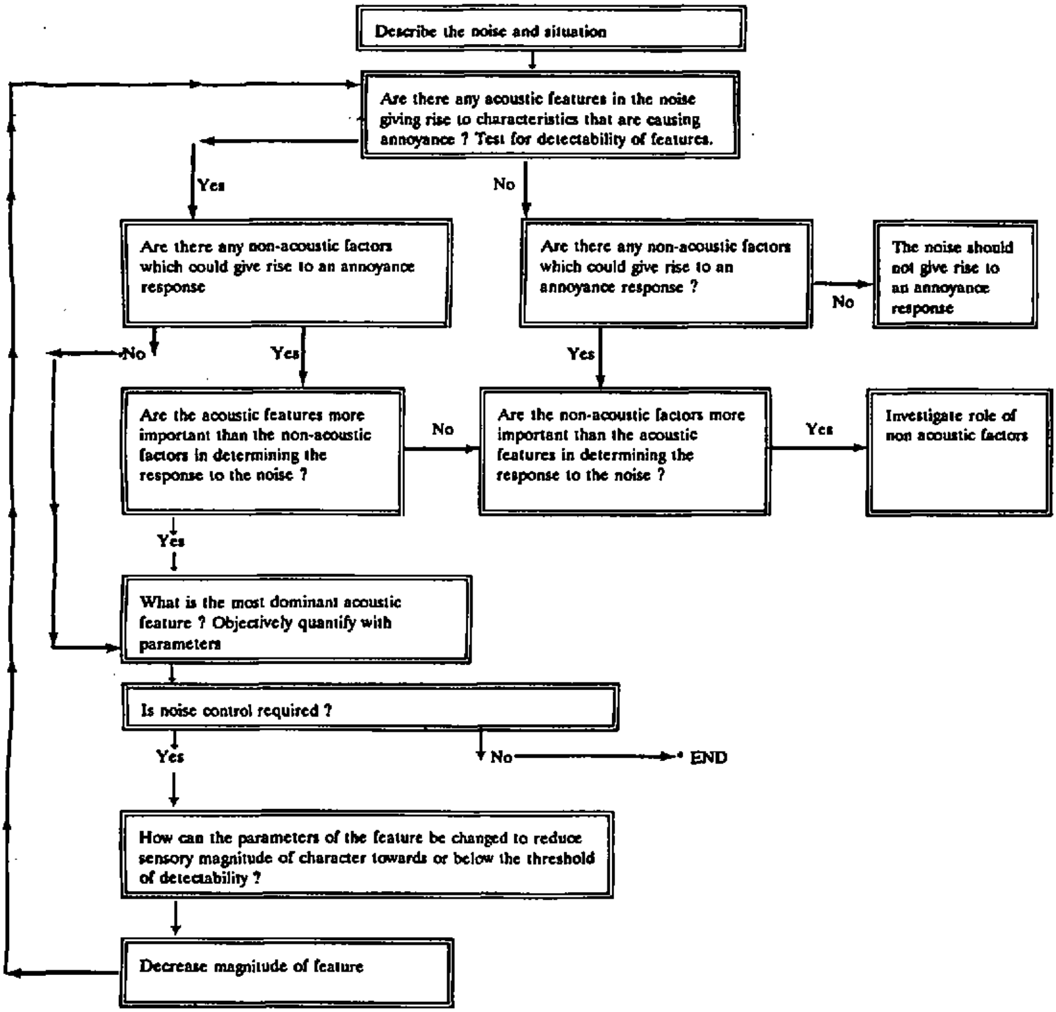

Consider a stamping machine in a factory producing regular impacts. The character of the noise giving rise to annoyance may be recognised as impulsivity and the feature responsible is objectively confirmed. The parameters of this feature determining the sensory magnitude and hence its detectability include peak level, rate of impacts and rise time. For this case the most effective parameter to change to decrease the magnitude of this feature and hence the perceived impulsivity is say, peak level. For effective noise control, ideally peak level should be reduced such that the sensory magnitude of the impulsive characteristic is below the threshold of detectability.

A second example is a low frequency, low level hum from a distant mains transformer. It may be that the tonal nature of the noise is identified as the dominant characteristic causing an annoyance response. It may be that since tonal nature is detectable, it is significant and annoying. Hence all three thresholds of the feature occur at the same sensory magnitude. For effective noise control, the physical parameters of this feature must be changed to make the tonal nature undetectable.

Finally, consider a loud fan noise. This has at least two characteristics that may give rise to annoyance, its loudness and tonality. The dominant features responsible are objectively identified as overall masked level and the presence of a tone. For noise control, the intensity of the overall masked level feature is reduced but it may be found that the noise is still the cause of annoyance. However, the most important feature is now the presence of a tone and reducing the intensity of the overall masked level would give no further benefit to the community. The magnitude of the feature responsible for tonality must now be reduced.

7. THE DEVELOPMENT OF THE ACOUSTIC FEATURE MODEL

What further work is required to bring this idealised model into existence ? We need good descriptors of the physical magnitudes of various features that are meaningful in terms of the subjective characteristics that they are supposed to represent. We need to establish the relative importance of various different characteristics and a knowledge of ways in which features combine to form the character of a complex noise. We need a greater understanding of the precise purpose and limitations of noise measurement and prediction in the context of the very much wider topic of noise assessment and control.

However we are not starting afresh. We already have a wide knowledge of the role of different features in determining subjective response. Much research has been done over the years developing physical descriptors for noise. Some of this work has been in the development of objective measures for the quantification of features. Much of this work has been aimed at building single number descriptors or combined indices and effective penalties have been developed. This work could therefore be used in a different way by incorporating research on particular features but not combining the information into a unified measure at the end point. Therefore we could re-examine this research and use the results to build up information for the application of the acoustic feature model approach. Some examples include work at ISVR examining the detectability of tonality (7) and its assessment using 1/24-octave band analysis techniques (8) and work at NPL developing the Increment descriptor for impulse noise (9).

This work at NPL and ISVR could be used to increase our understanding of this approach. For example, as part of a DoE sponsored study into industrial noise, open discussions have been carried out at NPL with subjects listening to combined features in a noise including impulses and tones (10) (11). Information has been gained about the relative importance of each feature in determining an adverse response, the distinction between threshold levels, and the capability of the listeners in identifying and describing characteristics and ranking their importance. ISVR in their studies of tonality (7) have defined various parameters that need to be considered in order that a noise may be identified as having the feature of tonality. Furthermore, in some recent work at TNO (12) on environmental quality, noises have been subdivided by the parameters of the features e.g. noise can be classified into classes by rise time. In this work it is recognised that certain noises from stationary sources often cannot be adequately described by overall level and more attention should be paid to the features present in these cases.

8. CONCLUSIONS

Since subjective reactions to noise are extremely complex, there is at present no clear agreement about the best way of quantifying the impact of noise on people. Despite the complexity of the subjective response, simple noise measurement methods are often adopted. Some use combined single number indices which often conceal valuable information. The acoustic feature model does not attempt to combine separate features into an overall index. It concentrates on the role of noise measurements in providing a complete description of all those features present that might contribute to the annoyance, and requires that information should be provided on the physical magnitudes of all the significant features which are present. The approach uses methods already adopted by practitioners who tend to adapt current standards around their subjective impression of the features present in the noise. Obviously more work is required to develop these ideas into a more usable and practicable approach to investigate and remedy noise problems, but in the future these ideas could form the basis of refined standards for noise measurement and assessment which provide a more comprehensive description of the noise, encourage fairer treatment, and target more cost effective noise control.

9. REFERENCES

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