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NIGHT NOISE CONTOURS: A FEASIBILITY STUDY

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ABSTRACT

This report describes a study of the feasibility of producing night noise contours to depict levels of night-time annoyance around airports. The work was commissioned by the National Air Traffic Services Ltd (NATS Ltd) for the UK Department of Environment, Transport and the Regions (DETR). The report is broken down into five main elements: an examination of the causes of an annoyance response, an investigation of models for predicting night-time annoyance, a review of existing dose-response relationships used to assess effects, an examination of the applicability of existing night-time weights and their adoption in the existing procedures in the USA.

Correlations are found between annoyance reactions and noise exposure levels. There is some agreement on dose-response relationships for the day-time or 24-hour period but evidence for robust and consistent data for night-time remains unconvincing. There also appears to be a lack of evidence on the significance of the contribution of individual effects, such as sleep disturbance and communication interference, to the total annoyance response. Selection of the most appropriate metric is not simple, but should be determined by the need to measure noise dose in such a way as to help define the extent of an effect.

A four stage ideal model for predicting annoyance at different times of day is summarised. This reveals gaps in knowledge which need to be resolved before we can apply it to predicting noise annoyance contours. The work concludes that we cannot, at present, produce night contours that depict levels of night-time annoyance. In order to develop a useful and pragmatic tool on which to base regulatory controls, recommendations are made for consideration by the DETR when prioritising their next actions.

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by Dr G R Torr, Director, Centre for Mechanical and Acoustical Metrology

EXECUTIVE SUMMARY

1. The National Air Traffic Services Ltd (NATS Ltd) requested NPL to examine the feasibility of producing night noise annoyance contours for the UK Department of Environment, Transport and the Regions (DETR). This report describes this study and its findings.

2. The main objective of this work was to address the question "Could night contours be produced that depict levels of night-time annoyance that are equally applicable at the three London designated airports?". Other objectives related to defining independent day and night annoyance reactions, establishing correlations between these reactions and noise exposure levels and to defining new research (section 1).

3. The work was broken down into five areas: investigation of the causes of night-time annoyance, investigation of models for predicting night-time annoyance, review of existing dose-response relationships used to assess affects, examination of the applicability of existing night-time weightings, and the adoption of existing procedures used in the USA.

4. The work strategy was split into four main areas: information collation, classification of articles, formulation of key issues, and consultations (section 3).

5. The causes of night-time annoyance are examined. Cause-effect concepts are explained to relate noise and its effects in a community setting. The key acoustic and non-acoustic factors contributing to an annoyance response are summarised (see page 17). The main factors for annoyance during the night-time period are reviewed. It is not possible to rank these in order of importance (section 4).

6. The role of sleep disturbance in determining night-time annoyance is analysed and presented as a flow chart (see page 27). The level of knowledge about its role is found to be fragmentary (section 4.3).

7. The information on annoyance is used to develop a model for predicting night-time annoyance. The general requirements of a useful model are set out. A four stage ideal model for deriving total overall annoyance at different times of the day is described (see page 31). Information on existing models relating to these various stages is analysed. This revealed many gaps in knowledge requiring investigation before we can use the model to derive night-time annoyance contours (section 5).

8. Dose-response relationships to assess the effects of noise during the night-time period are reviewed. Their reliability and validity is discussed when considering the optimal selection of dose-response relationships for predicting annoyance (section 6).

9. Night-time weights used to predict annoyance during the night-time period are evaluated. In particular, consideration is given to examining the consequences of adopting the wrong penalty/function (section 7).

10. The existing data on night-time weights are reviewed to assess their applicability for predicting night-time annoyance. It is found that these show considerable variability and are not robust. Studies do show however that evening and night-time noise are rated as more annoying than the equivalent day-time noise, even if the magnitude of the difference is not agreed (section 8).

11. The pros and cons of adopting the existing implementation of night-time weights used in the USA are reviewed. It is concluded that it may not be appropriate to adopt such an index in the UK at this time (section 9).

12. It is concluded that we do not currently have enough research evidence to produce scientifically robust night contours that depict levels of night-time annoyance (section 10).

13. The unresolved issues requiring research are set out in terms of information required on the four stage ideal annoyance model. Preferred study options are presented. It is recognised that although this ideal model may not ever be fully realised, we should aim future research towards the provision of pragmatic tools on which to base regulatory controls (section 11).

14. Recommendations are made for the Department to consider in setting future priorities (section 13). These include:

    Aiming research towards providing pragmatic decision making tools.

    Research into the effects of aircraft noise on sleep during shoulder hours.

    More detailed analysis of existing survey data to answer specific questions relating to night-time noise annoyance.

    Identification of currently planned survey work.

    Monitoring of key developments such as EC policy, other research work, findings of the Netherlands Health Committee on a Uniform Noise Metric, ICBEN recommendations.

    Taking into account the direction of EC noise policy and possibly influencing it.

    Consideration of the merits of producing a total combined measure for all effects.

    Continued promotion of technology transfer and dissemination of existing research evidence.

GLOSSARY OF TERMS

A-Weighted Sound Pressure (L_A)	This is commonly referred to by the term "noise level" and is a weighted sound pressure level produced by electronic filtering (or 'weighting' of certain sound frequencies). The A-weighting was designed to approximate the response of the human ear to sound and it has been found to correlate better than the unweighted sound pressure level with the subjective assessment of auditory magnitude of many types of sound.
Actimetry	A method of measuring wrist movements. Instrument used for measuring is an actimeter, worn like a wrist watch.
CAA	Civil Aviation Authority.
CNEL	Community Noise Equivalent Level, dB.
CNR	Composite Noise Rating.
dBA	Levels on a decibel scale of noise measured using a frequency dependent weighting which approximates the characteristics of human hearing. These are referred to as A-weighted sound levels; these are very widely used for noise assessment purposes.
Decibel (dB)	The decibel is a measure on a logarithmic scale of the magnitude of a particular quantity such as sound pressure (p) or sound intensity with respect to a standardized reference quantity. A sound pressure level, L, is expressed as: $$L = 10 \log_{10} \frac{(p^2)}{(p_{ref}{}^2)} \quad \text{dB}$$ p_{ref} is generally taken as 20 micropascals.
Department	DETR (see below).
DETR	UK Department of Environment, Transport and the Regions. Formerly, in the context of this work, the Department of Transport. DETR is referred to as the Department in this report.
Dose-response	A relationship between the noise exposure dose received and the response arising from its effect.
DNL	Day/night average sound level, dB. Also known as L_{dn}.
DORA	Department of Operational Research and Analysis; a department within the Research and Development Directorate of NATS Ltd.
DOT	Department of Transport.
FICON	Federal Interagency Committee on Noise.

Footprint	A noise contour which joins points on the ground which receive the same maximum noise level from an aircraft during take-off or landing.
L_{dn}	Day-night average sound level, dB. Also known as DNL. Example of a day and night index.
$L_{eq,T}$	Equivalent continuous noise level for specified period T.
L_{max}	The highest instantaneous sound level recorded during an event, in dBA (measured using a standard 'S' time weighting).
NATS Ltd.	National Air Traffic Services Ltd.
NEF	Noise Exposure Forecast.
NNI	A composite measure of exposure to aircraft noise taking into account the average peak noise level and the number of aircraft in a specific period.
Perceived Noise Level (L_{PN})	This is a noise level obtained by computation from the sound pressure levels in octaves or third octaves. It employs a frequency weighting based on jury ratings of noisiness and is expressed in perceived noise decibels (PNdB).
Regression	The statistical procedure of fitting a descriptive mathematical relationship to a set of measurements.
SEL, sound exposure	$L_{AE} = 10 \lg \frac{1}{t_o} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_o^2} dt$ where $p_A(t)$ is the instantaneous A-weighted sound pressure; $t_2 - t_1$ is a stated time interval long enough to encompass all significant sound of a stated event; p_o is the reference sound pressure (20 μPa); t_o is the reference duration (1 s).
Shoulder hours	The hours when one is trying to fall asleep and the hours directly before one usually awakens.
Sleep latency	The time between lights out and falling asleep.
Sleep onset	The time of first falling asleep.
Sleep study (UK)	Throughout this report, the UK sleep study refers to the study reported by OLLERHEAD 1992.

Sound level	The magnitude of noise measured on a decibel scale.
The Equivalent Continuous Sound Level (L_{eq})	The level of a notionally steady sound which at a given position and over a defined period of time would have the same A-weighted acoustic energy as the fluctuating noise.
The Single Event Noise Exposure Level (L_{AX})	The level which, if maintained constant for a period of 1 second, would cause the same A-weighted energy to be received as is actually received from a given noise event.
w	Weight, weighting, adjustment, penalty to be multiplied by number of noise events (N) or relative pressure squared. For the night-time, the weight is w_n for the evening the weight is w_e.
w(dB)	Weight, to be added to the single event sound level or single hour L_{eq} before the logarithmic transformation. For the night-time, the weight is $w(dB)_n$. This weight is measured in decibels, dB.

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1 INTRODUCTION

Noise exposure contours are widely used to depict the long-term impact of aircraft noise on people living near airports. 'Noise exposure' is sometimes defined via a straightforward measure of noise energy, such as an energy equivalent continuous noise level, Leq (16 hour). Other indices make allowance for varying sensitivity to noise during different parts of the 24-hour period; for example, the day-night average sound level Ldn (DNL), which weights night-time noise by 10 dB and community noise equivalent level, CNEL, which additionally weights evening noise by 5 dB.

Night weightings have not been adopted in the UK because they have not been validated scientifically. The UK Aircraft Noise Index Study (ANIS) (DORA 1985) could not demonstrate any benefit from introducing weightings to account for a variation in noise sensitivity over the 24-hour period.[1] It was concluded from the DORA night noise social survey studies (DORA 1980) that Leq was probably as good as any alternative index of night noise exposure but no 'dose-response' relationship was proposed.

One reason for arguing that composite day-night indices are inappropriate is that the effects of noise at night are fundamentally different from those during the day - primarily sleep disturbance versus annoyance. This logic led to the use of overlapping contours and footprints as a basis for noise insulation grant scheme (NIGS) boundaries: daytime contours for annoyance, footprints as sleep disturbance thresholds.

The Department's sleep study undertaken in 1991 (OLLERHEAD 1992) indicated that the threshold concept is appropriate but that, above it, aircraft noise induced sleep disturbance during the night is not a strong effect. However, the impact of aircraft noise during the 'shoulder hours', that is when people are trying to sleep or finally awaken, is uncertain. Aside from this area of uncertainty, it seems that annoyance is the principal effect by night as well as by day. Assuming that direct effects of sleep disturbance (as opposed to any that might be caused indirectly by chronic annoyance) are negligible, there appear to be no fundamental objections to defining annoyance-based night contours.

It is within this framework that the National Air Traffic Services, NATS Ltd, have asked NPL to examine the issue of night time noise annoyance for the Department. The objectives of the work were set out as below:

1 By reviewing available research evidence, to address the question:
"Could night contours be produced that depict levels of night time annoyance that are equally applicable at the three London designated airports?"

and either

2. To define independent day and night annoyance reactions.

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[1] In 1990, following public consultation after ANIS, a 16-hour daytime Leq noise exposure index was adopted to replace NNI.

3. To establish correlations between these annoyance reactions and noise exposure levels

or

4. To define what, if any, new research could be conducted to make 2 and 3 above possible.

The aim of this report is to describe the study and present the findings for the Department of Transport.

This study can be considered as a 'snap-shot' of views of the current knowledge in the subject of night time annoyance, put together to address the key objectives of the work. It is primarily a literature review and assessment. There has been extensive review work carried out over 10 years ago on night time weights and variation of annoyance with time of day. Use is made of these studies and reports, particularly those by Fields and Fidell (FIELDS 1986c, FIDELL 1980). This study can be regarded as a relatively short study in comparison to these studies and as such does not attempt to attack the problem in the same level of details as these extensive studies. It does however attempt to pull out the key information from these studies in answering the work objectives.

To assist the reader to understand many of the terms used in the report, a glossary of terms has been included. A reference list is also provided. This is arranged alphabetically, with details given in the text in brackets using the first named author and year of publication.

2 GETTING TO GRIPS WITH THE PROBLEM

The main objective of this work is set out in terms of the question:

> "Could night **contours** be produced that depict levels of **night time annoyance** that are **equally applicable** at the three London designated airports?"

Let us look at this question more closely in order to set out what we are trying to achieve. In doing this, we will examine the parts of the question that are highlighted above in bold.

2.1 HOW DO WE DERIVE CONTOURS ?

Contours can be regarded as lines on a map around an area (e.g. an airport) that depict lines of equal amounts of noise exposure or severity of community reaction. These are used to monitor noise exposure trends around airports, compare airports or for the planning of new airports. To derive such contours we need to know

(1) data on the noise sources,
(2) receiver exposure.

Information about effect(s) of exposure is required to derive noise limits or interpret the severity of an impact of a noise source on a community. To interpret the impact of the noise levels shown by the contours, we also need to know the effects of exposure on the receiver. In order to link the physical exposure to the human response an intervening step is used, based on a cause-effect model incorporating dose-response relationships. Such a model can incorporate a number of factors. One of these is a time of day factor for which one needs to know how people respond to noise at different times of day.

In examining the main objective of this work, it will therefore be necessary to investigate models and dose-response relationships at different times of day. Without this information, we cannot derive contours to depict levels of response to a noise source during the night time period.

2.2 WHAT IS NIGHT-TIME ANNOYANCE ?

Annoyance has been defined by the World Health Organisation (WHO 1980) as *'a feeling of displeasure evoked by a noise'*. The annoyance-inducing capacity of a noise depends upon many of its characteristics, including its intensity, spectral characteristics, and variations of these with time of day. Annoyance reactions are sensitive to non-acoustical factors such as those of a social, psychological or economic nature. Community annoyance also varies with activity (speech communication, relaxation etc) (BERGLUND 1995).

Let us define night time annoyance as *'a feeling of displeasure evoked by a noise occurring during the night-time period'*. We would expect that the annoyance-inducing capacity of a noise during the night-time period to be dependent on many of its characteristics and how these change during the night-time period. It would be sensitive to non-acoustical factors and vary with interference with night-time activities.

A key requirement in defining night-time annoyance is one of defining the night-time period. Night-time could be regarded as a specific time window, eg between 2300-0700 or could be split into evening and night. However, in defining the night-time period, we must understand why we are doing this. In choosing a night-time period, we can examine what activities may be potentially interfered with and how the noise characteristics may vary during these time periods. For example, if we are defining a night-time period to protect sleep, then we must choose the relevant sleeping hours.

This process could equally work the other way around, by examining the activities interfered with and how the noise characteristics vary over the night-time period, then we may be able to define our night-time period. In Fidell's study of time of day weights (FIDELL 1980) he followed the line that the human activities rather than time of day at which they occur were the substantive issue. The time of day was merely a convenient surrogate susceptible to regulation.

To summarise, to successfully develop a night-time annoyance response model on which to base contours, we need to consider the main causes of annoyance at night (the critical activity interference), their dose-effect relationships, and to chose a night-time period that can be associated with the activity that any regulations may be trying to protect.

2.3 APPLICABILITY AT THE THREE LONDON AIRPORTS

A requirement of the work is to examine how the results could be applied at the three London airports of Heathrow, Gatwick and Stansted. This would have to take into account source noise, receiver exposure and effects of exposure. These would be determined, amongst other things, by the flight operations and socio- and demographic factors. A comparison study would have to be carried out of the three airports and environs to determine differences and how these would impinge on a model used to define contours. This topic was not considered a priority from the outset of this work. It could form a later stage of the study. It will not therefore be examined in any detail in this report.

2.4 WHAT IS THIS WORK IS TRYING TO ACHIEVE ?

In this section we have tried to clarify the work objectives. The crux of the work appears to rest with determining a model to explain night-time annoyance upon which to base contours. In doing this, we must investigate the main causes of an annoyance response at night. In order to meet our work objective we need to understand:

The causes of night-time annoyance

Models for predicting night-time annoyance

Dose-response relationships used to assess the effects of noise at night

The applicability of night-time weightings to the problem

How we could adopt existing procedures used elsewhere to predict annoyance at night.

The work described in this report sets out to examine these key issues in turn. It investigates the state of knowledge to date on each issue and identifies the gaps in knowledge. In the light of this information, the key objective can be re-examined and research needs identified. The rest of this report describes the work to this end.

3 WORK STRATEGY

3.1 STAGE 1: INFORMATION COLLATION

3.1.1 Literature search

A literature search was carried out at NPL's main library in order to review the available research. The key words that were used included noise, annoyance, sleep, night, time of day, and aircraft. Over 120 articles were identified with around 22 found to be particularly relevant to the work objectives. In addition, a number of back issues of the Proceedings of various conferences were scanned for useful articles.

3.1.2 Preliminary contact with key researchers

Personal contacts were used to request information on key articles. These persons included Dr James Fields of NASA Langley Research Center, USA and Dr Larry Finegold of USAF Armstrong Laboratory, Ohio, USA.

3.2 STAGE 2: CLASSIFICATION OF ARTICLES

After obtaining the articles, each was classified using the classification sheet given in Appendix I. These sheets were used as a quick reference guide for organising information on the available research relating to the work objectives.

3.3 STAGE 3: FORMULATION OF KEY ISSUES

A listing of key issues and questions in relation to the work objectives was formulated. These are given in Appendix II. These were used for later consultations and to put together the findings presented in this report.

3.4 STAGE 4: CONSULTATION PHASE

During the course of the work, it was noticeable that there were several key researchers who had been involved in the issue of night-time annoyance. To make best use of the project time, it was decided to consult directly with these persons where possible. At this stage, use was made of the summary of key issues formulated in stage 3. Table 1 summarises the extent of consultations.

During the consultation phase, we benefitted from NPL's representation on a recently set up committee investigating metrics. An International Committee on Uniform environmental Noise exposure metrics has been formed by the Health Council of the Netherlands. It is working towards the presentation of uniform metric(s) for noise exposure which are clear, simple and practical. It is likely that their recommendations will be based on equivalent sound levels. Annoyance and sleep disturbance are both being considered. Future work is considering the definition of evening and night-time and the division of the 24 hour period into day, evening and night with respect to annoyance.

Many of the consultations led to confirmation of existing conclusions from earlier work, often reported in some of the literature. The consultations helped to update these conclusions or to re-affirm them and to identify more key literature. Distinction is not always made in the text between the consultation findings and the literature.

Table 1: Details of Consultations

Person	Type of Consultation	Stage of work as given in section 3.1
J Fields NASA Langley Research Center, USA	face to face	1,4
J Ollerhead NATS Ltd, London, UK	face to face	throughout
C A Powell NASA Langley Research Center, Hampton, Virginia, USA.	E-mail	4
P Schomer CERL, Illinois, USA.	E-mail	1
L Finegold USAF Armstrong Laboratory, Ohio, USA	E-mail	1
M Vallet INRETS, Lyon, France	E-mail, fax, telephone	4
S Fidell BBN, California, USA	E-mail	4
H Miedema TNO, Leiden, Netherlands	face to face	4
W Passchier-Vermeer TNO, Leiden, Netherlands	face to face	4

4 THE CAUSES OF NIGHT-TIME ANNOYANCE

4.1 WHAT FACTORS CAN LEAD TO AN ANNOYANCE RESPONSE ?

Let us consider a very simple model for annoyance as shown in Figure 1. A listener in a noise environment will be exposed to noise. He/she will evaluate the noise based on the noise itself and non-acoustic factors. Depending on the listener and his/her own individual frame of reference, he/she may then be affected by the noise in some way. If the listener feels a sense of displeasure, then he/she may be annoyed by the noise. This is the fundamental process behind dose-effect relationships, i.e. a listener is exposed to a noise (a noise dose), and is affected by the noise (and responds).

Let us now look at how annoyance fits into the relationship between noise and noise effects in a community setting. Figure 2 (taken from NELSON 1987) presents a general model of the most important relationships between physical noise levels, the social context and the effects of that noise. Annoyance can be a *direct effect* along the path called A. Alternatively noise can cause some immediate effects (such as activity disturbance) which can lead to annoyance via the *indirect* path B, (for example sleep disturbance can lead to annoyance when a person is tired the next day). The non-acoustic factors such as personal and attitudinal factors can also have an effect on the extent of the annoyance response to noise. These usually serve to increase the variability of response to noise when comparing individuals.

Analysis of cause-effect relationships is often modelled by examining the different paths, termed path analysis. Taylor (TAYLOR 1984) looked at this approach for modelling the annoyance due to aircraft and traffic noise. He used the model shown in Figure 3 which demonstrates the complexity of the issue.

Our aim is to define noise annoyance contours. Mediating factors make this task more difficult. Simplistically, if we could understand the main causes of an annoyance response for a particular time of day, then we could predict the extent of annoyance for those particular circumstances using this type of path analysis model and the relevant dose-response relationships. If there was a simple relationship between noise level and annoyance, then we may expect a straight line graph of noise level versus annoyance. Due to the non-acoustic factors which form the role of *mediating variables*, eg personal attitudes, we can get considerable variability both between and within a population. There is therefore usually a spread of data points around the straight line.

If the non-acoustic factors play a very significant role in decision making, use of a simple model based on quantifiable measures and effects may be irrelevant. As Fidell points out (FIDELL 1996), politicians and regulators would like to have neat dose-response relationships to work with. Understanding annoyance as a simple neat process is however compounded with a whole host of variables which can serve to "muddy the issue".

A Model of Annoyance

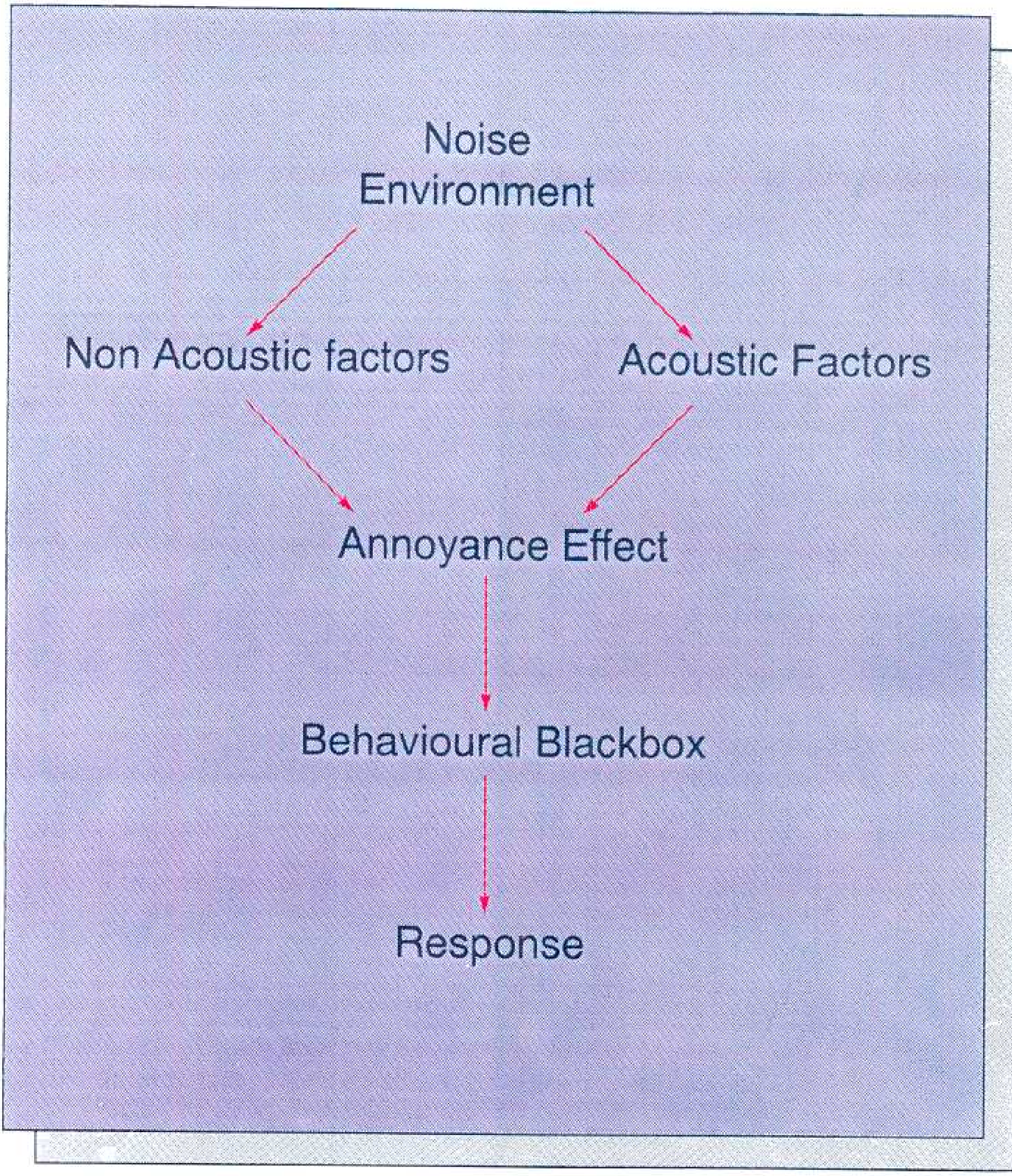


Figure 1: A simple model of response to a noise

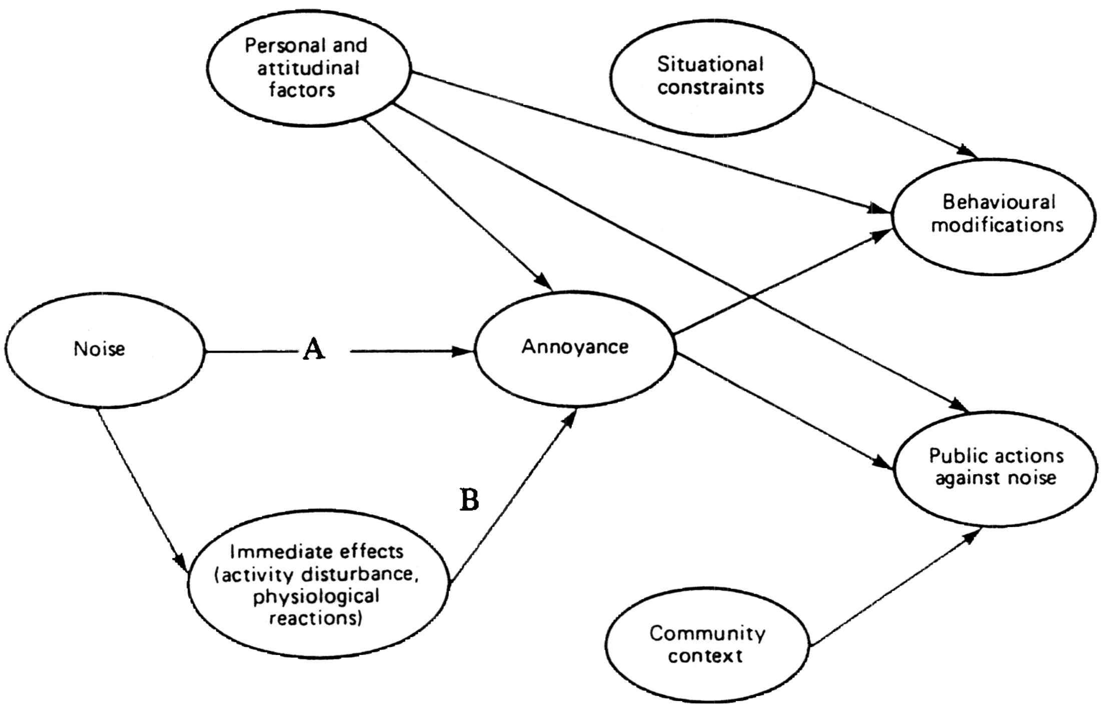
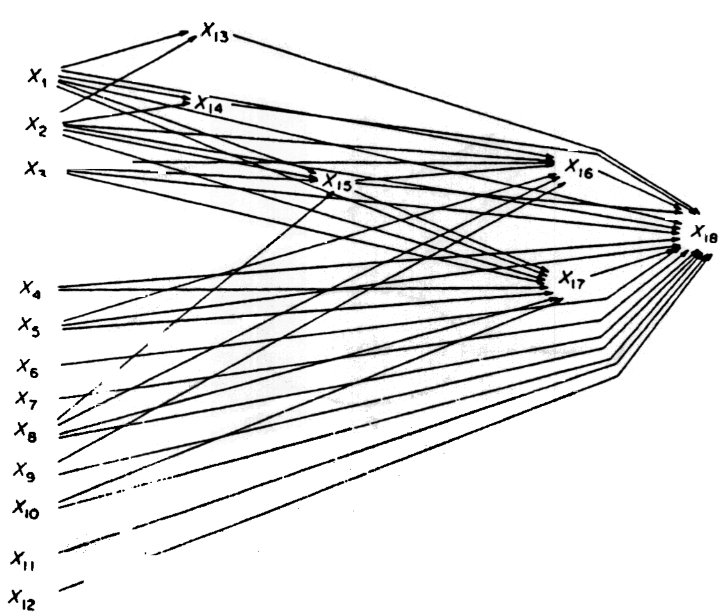


Figure 2: Relationship between noise and noise effects in community settings (taken from NELSON 1987)



- Path model of aircraft noise annoyance. X_1, Aircraft $L_{eq(24)}$; X_2, flight path location; X_3, background $_{q(24)}$; X_4, sex; X_5, age; X_6, education level; X_7, children at home; X_8, sensitivity to noise; X_9, hours spent itdoors on weekends; X_{10}, length of residence; X_{11}, attitudes to a/c operations I; X_{12}, attitudes to a/c erations II; X_{13}, perception of non-noise effects; X_{14}, concern about a/c accidents; X_{15}, windows closed to duce noise; X_{16}, speech interference; X_{17}, sleep disturbance; X_{18}, aircraft noise annoyance.

Figure 3: Path analysis model for aircraft noise annoyance (Source TAYLOR 1984)

For now let us simply review from the literature the acoustic and non-acoustic factors which can contribute to an annoyance response. These are listed in Tables 2 and 3. Table 4 provides some examples of studies or reviews of specific activity interference which can be related to annoyance.

Table 2: Some key acoustic factors which can contribute to an annoyance response

Acoustic Factors	Comments
Average noise level	Usually described as an energy equivalent level of a specific time interval, ($L_{eq,T}$)
Event level	This can be described as the noise level of one event eg Maximum (L_{MAX}), single event level (SEL) (averaged over the duration of the event and normalised)
Number of events Frequency of events Duration of noise Duration of events	These can be used to calculate an average noise level over a specified time period $L_{eq,T}$.
Noise level in other periods	This could mediate response to a noise event.

Table 3: Key non-acoustic factors (mediating variables) which can contribute to an annoyance response

Non-acoustic factor	Some example evidence
Age Gender	) Both reviewed as significant) by Fields (FIELDS 1985a)
Extent of disturbance or activity interference caused	See Table 4 for examples of types of activity interference
Interference during 6-9 pm	Found by Bullen and Hede (BULLEN 1983)
Type of residential setting (urban, suburban, rural, etc)	Found by Bradley (BRADLEY 1979) and Vallet (VALLET 1983)
Attitudes and opinions towards noise source (see below)	Proposed by Borsky in his framework for human response to noise (BORSKY 1971). Also recognised by Taylor as an important annoyance determinant (TAYLOR 1984)
Feelings about its necessity or preventability of the noise	(Borsky 1971) "
Feelings about importance of source and the value of its primary purposes	"
The extent to which there are other things disliked in residential environment	"
Belief in effect of noise on general health	"
Fear associated with noise source	Also covered by Hazard (HAZARD 1968) and Fields (FIELDS 1986c)
Awareness of noise during particular hours	Proposed by Hazard in his work to predict annoyance from aircraft as <u>primary</u> factors for annoyance (HAZARD 1968)
Type of noise exposure zone	(HAZARD 1968)
High individual noise susceptibility	"
Perception of changes in noise environment	"
Knowledge of how to complain effectively	"
Social status	Proposed as <u>secondary</u> factors by Hazard (HAZARD 1968)
Length of residency	"
Knowledge of neighbours leaving area to 'escape' noise exposure	"
Attitude towards aircraft industry and importance to economy	"

Table 4: Some examples of studies and reviews of activity interference and noise annoyance

Example study reference	Activity interference/disturbance investigated or reviewed
Hall (HALL 1985) (examined activity interference and noise annoyance from aircraft, road traffic and train noise)	Indoor speech interference Outdoor speech interference Difficulty in getting to sleep Awakening
Ollerhead (OLLERHEAD 1978) (discussed types of disturbance that could lead to an annoyance response to aircraft noise)	Startle Sleep disturbance Concentration Watching TV
Miedema (MIEDEMA 1992) (review of response functions for environmental noise)	Communication Sleep interference Startle Vibration
Fields (FIELDS 1985b) (analyses of general population time use surveys)	Sleep Aural communication Being at home (any activity)

4.2 THE MAIN FACTORS FOR ANNOYANCE DURING THE NIGHT-TIME PERIOD

Having reviewed the concept of annoyance generally, let us now examine the key factors that may contribute to a difference in annoyance between the night-time and day-time periods.

Let us at this stage examine the night-time period as one that includes the evening period but consider how the importance of these factors depends on the choice of a night-time period.

From literature and discussion, the main determinants of annoyance at night-time as opposed to day-time are shown in Figure 4 and explained below. There appears to be no agreement about the ranking of importance of these factors.

1 Increased noticeability of noise (VON GIERKE 1993, NELSON 1987, HAZARD 1968)

It has been found that generally the outdoor ambient noise during the night may decrease by around 10 dB. In addition, noise generating activities in the home are reduced. Even without considering increased sensitivity to noise at night, from these two effects alone, one can observe that the same noise heard at night as opposed to during the day, will be more intrusive and noticeable. Hazard, in a study on annoyance from aircraft noise during the day and night, reported that the main predictor of annoyance due to aircraft noise was the awareness of the aircraft between midnight and 6 am (particularly between 12 and 3 am).

2. Activity Interference (NELSON, 1987,ÖHRSTROM, 1993a/b, FIDELL 1980, FIELDS 1986c, 1985a)

Noise may be more annoying during the night-time period because of the prevalence of noise sensitive activities. These can be split into sleep disturbance during sleeping hours and communication interference during the evening.

(a) Sleep Disturbance

People become annoyed if they feel that their sleep has been interrupted. The effects can be psychosocial, eg tiredness, headaches, mood change, nervous stomach, which in turn can lead to annoyance. It has also been reported that sleep disturbance in the early part of the night and the hours before usual awakening is more annoying than in other hours (NEMECEK 1981). The role of sleep disturbance in night-time annoyance will be examined in section 4.3.

(b) Communication interference

In the evening, before a person goes to bed, annoyance due to noise can occur if conversation is interrupted, listening to radio or television becomes difficult, etc. In fact the noise levels which can cause this type of activity interference may not have a significant effect on sleep.

3 Expectation of lower noise levels (FIELDS 1986c, FIDELL 1980)

It can be argued that a person will expect their home to be a restful haven, particularly after a busy (and possibly noisy) day at work. Individuals may expect a good environment for rest and relaxation. The same noise during the day would therefore have the potential to lead to a greater annoyance than the same noise heard during the evening or night-time period.

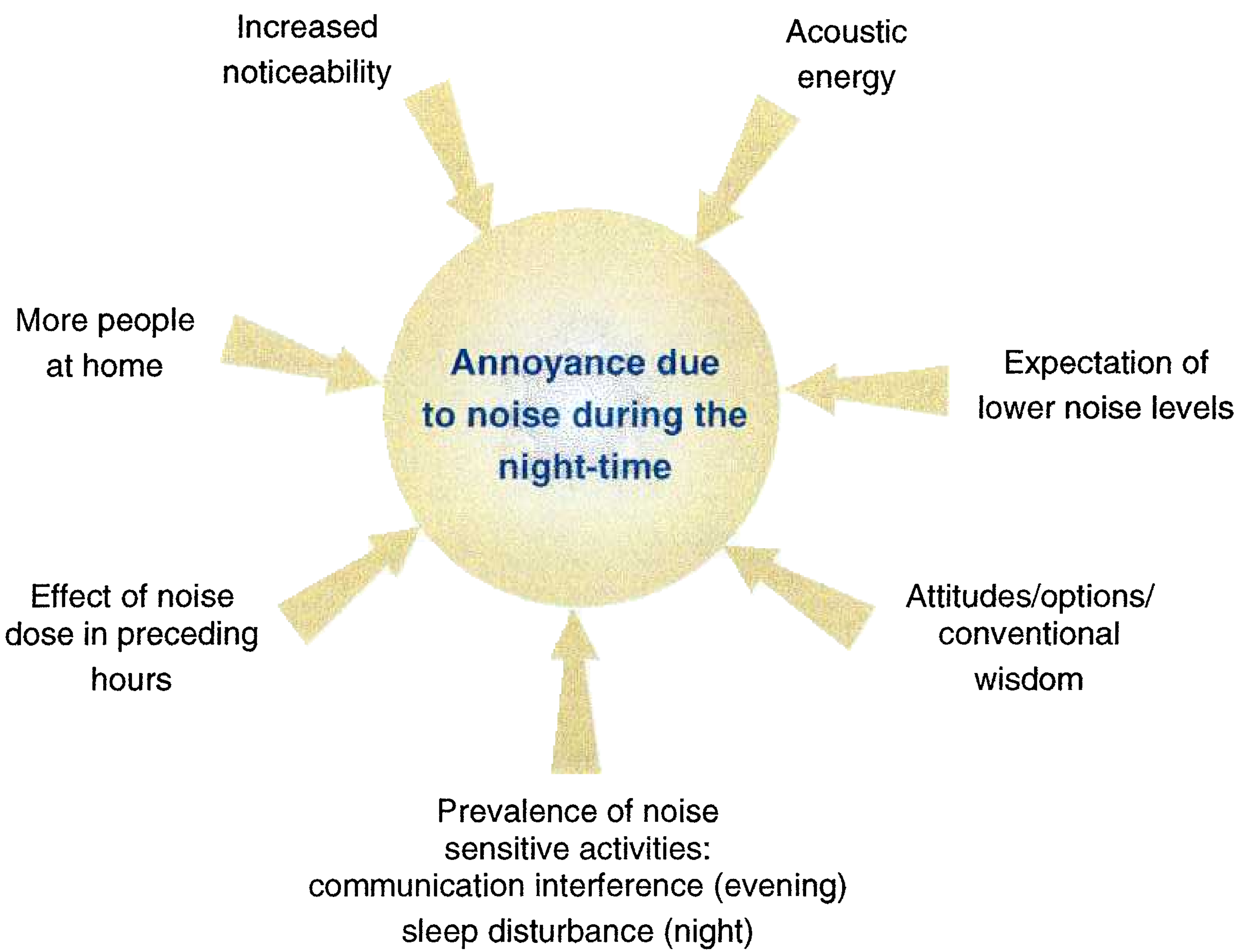


Figure 4. Main determinants of an annoyance response during the night-time period

4. More people are at home during the night (FIDELL 1980)

Noises heard at home during the day may affect less people than during the evening/night-time hours. Noises heard at home in these hours may therefore result in an increased overall community annoyance response.

5 Noise heard during preceding hours (VALLET 1983, BERTONI 1993)

It has been argued that the response to a noise environment during a particular time period is not independent of the noise heard during other periods. Annoyance could therefore be cumulative under certain conditions. An example of this was reported by Bertoni who reported that the noise dose received in the work place was a significant factor in determining the annoyance from road traffic noise outside the home during the night-time period.

6. Attitudes and opinions/intuition/conventional wisdom (FIDELL 1980, FIELDS 1986a and 1986c)

If the average person were asked whether a noise is worse at night than during the day, the response would almost invariably be "at night". Fields terms this belief as "conventional wisdom" and defines it as the belief that:

'noise is worse at night because being kept awake by a noise is worse than anything noise can do during the day'.

As Fields points out, the limitation of conventional wisdom is that it only considers noises that are noticed. If the person is asleep then noises are unnoticed. During the day-time or evening, many residents are awake and more likely to notice or be annoyed by a noise event. He suggested that although awakenings are disturbing, if they are infrequent, the impact of the average day-time noise event can be as great or greater than that of the average night-time noise event.

7 Acoustic factors

In considering the main factors that lead to annoyance during the night-time/evening period it is worth mentioning some of the acoustic factors. It has been argued that, for sleep interference or communication interference, there is a need to consider not only the overall equivalent sound level but also the event levels (SEL, L_{MAX}), the duration and frequency of the events.

Although the study was not designed with the objective of investigating the specific relationship between sleep disturbance and annoyance, it would be possible to use the data for this purpose; ie the subjective reports of annoyance could be correlated with the objective sleep measurements. However, as the subjective annoyance ratings were collected in a one off social survey, rather than on a nightly basis, the findings may be limited.

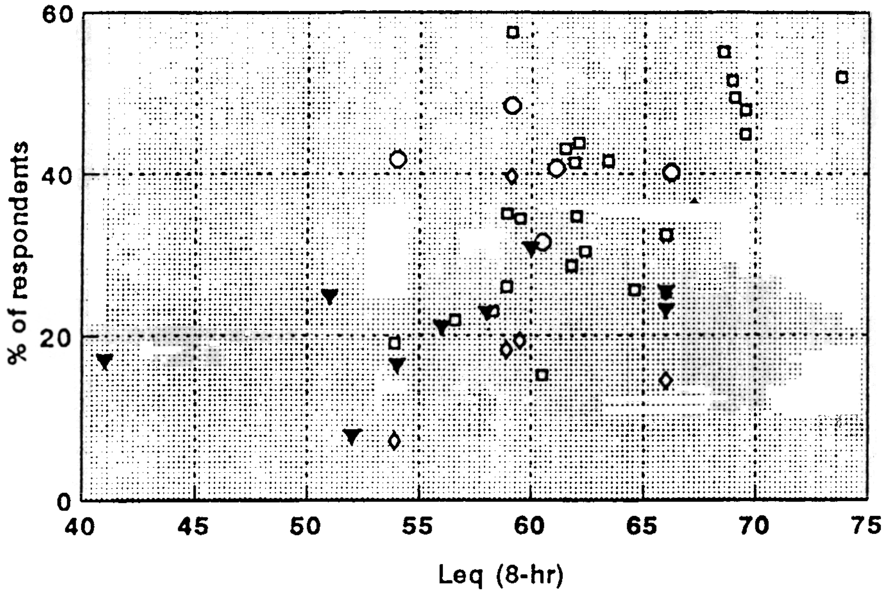


Figure 5: Aircraft given as reason for awakening in UK studies (source OLLERHEAD 1992)

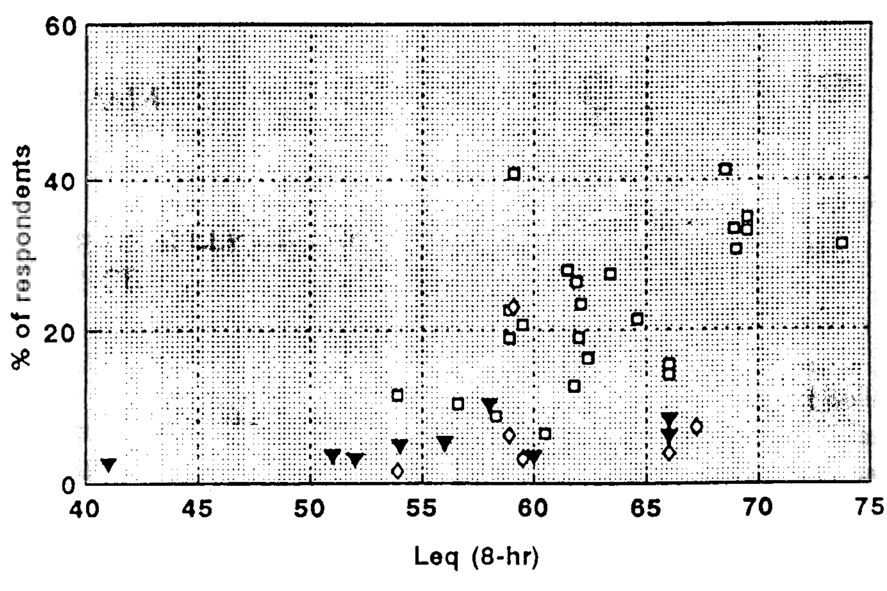


Figure 6: Aircraft given as reason for having difficulties getting back to sleep in UK studies (source OLLERHEAD 1992)

Key:

● OLLERHEAD 1992

○ BROOKER 1985

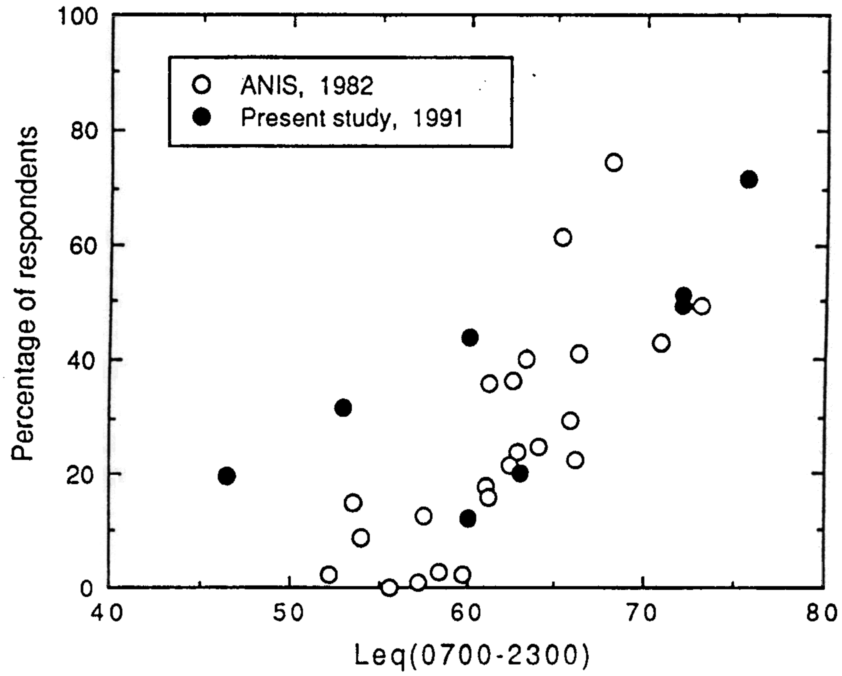


Figure 7: Proportion of respondents citing aircraft noise as a reason for disliking their neighbourhood in UK studies (source: OLLERHEAD 1993)

Key:

● OLLERHEAD 1992

○ BROOKER 1985

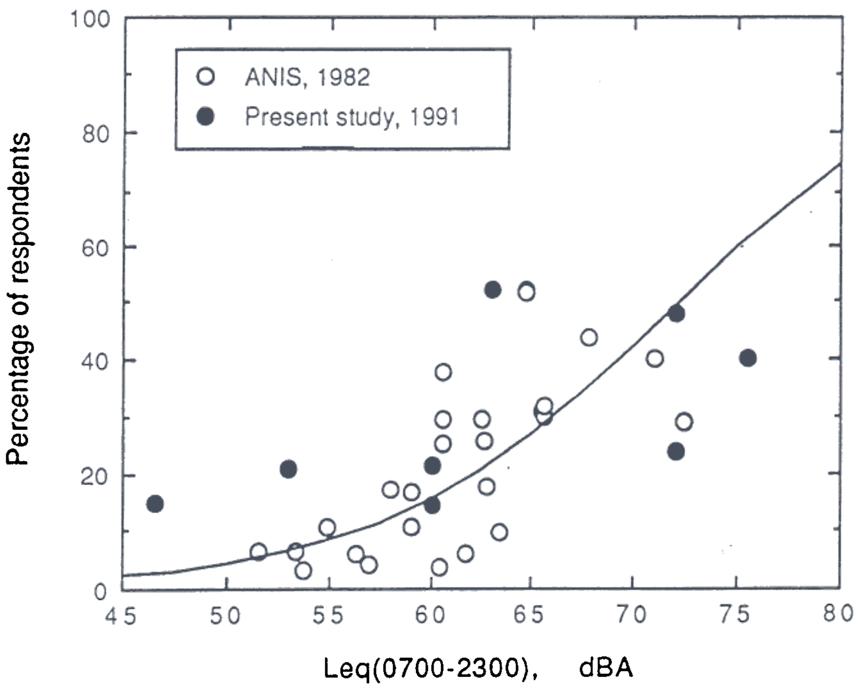


Figure 8: Proportion of respondents who find aircraft noise 'very much' annoying in UK studies (source: OLLERHEAD 1993)

4.3.2 Distinctions between sleep disturbance and night-time annoyance

To understand the role of sleep disturbance in night-time annoyance, we need to make a clear distinction between the two. Fields (FIELDS 1986c) neatly summarises this in his work as follows:

> *"The distinction between sleep disturbance by noise and annoyance from night noise has implications for both research and policy makers. Policy makers who set night-time regulations are most concerned about minimizing sleep disturbance, thus some type of a threshold or single-event criteria is likely to be considered. On the other hand, policy makers who set overall 24-hour criteria (eg, land use planners) are most concerned about minimizing total annoyance, thus some type of weighted 24-hour index is most likely between those studying sleep disturbance and those studying night-time annoyance. <u>Both researchers and administrators tend to assume that sleep disturbance is the basis for understanding or reducing night-time annoyance.</u>*

He then discusses sleep interruption and noise annoyance:

> <u>*Sleep Interruptions in the Absence of Noise*</u>*. - It is conventional to think of the night-time period as consisting of a continuous uninterrupted sleep period. However, evidence shows that about half of the population awakens at least once a night in the absence of any particular environmental noise problems. The average number of awakenings per night is almost 100 per 100 people. Thus interrupted sleep is not an unusual pattern. Difficulty in getting to sleep and waking up early also occur in the absence of noise.*

> <u>*Sleep Disturbance Due to Noise*</u>*. - Pre-existing disturbances in a discontinuous sleep period thus provide a base upon which disturbances to sleep due to noise are overlayed. Some, perhaps most, of the genuine disturbances due to noise fit the popular conception that people who would otherwise remain in uninterrupted sleep for an extended period are brought to consciousness or change sleep stages because of the presence of loud, or at least distinct, noise events. In such cases there is a clear reduction in the amount of sleep time or an increase in the number of awakenings. However, there must be another large number of cases in which people who would awaken anyway are awakened at an earlier time than would have otherwise occurred (either during the sleep period or at the end of the sleep period). In some such instances there may be no change in the total number of awakenings and only a very small change in the length of the sleep period.*

> <u>*Noise Annoyance at Night*</u>*. - Noise annoyance at night concerns perceived experiences with noise during a defined number of night-time hours. This annoyance could well be a function of factors other than the ones which disturb sleep.*

He concludes that sleep disturbance and night-time annoyance differ in the following ways:.

1. A single definition of the "night-period" (eg 23:00 to 07:00) will include some times when a large proportion of the population is normally awake and engaging in normal late evening or early morning activities. It should be expected that the experience during these relatively short periods of consciousness will have a large impact on the perception of the night-time environment.

2. Noise may cause annoyance while a person is falling asleep, lying awake or awakening in the morning, even if the noise does not disturb sleep at the time.

3. A person may actually be awakened by something other than noise, but then notice a noise event and thus assume that the noise event was responsible for the awakening. This increases night-time annoyance without disturbing sleep.

4. Sleep may be disturbed by noise but a person may be unaware that noise is responsible. Thus there is sleep disturbance but no noise annoyance.

5. Some people may not have a distinct concept of night-time annoyance, so that the so-called "night-time noise annoyance" is no more than a respondent's general feeling toward the noise source.

6. "Night-time" annoyance may be as strongly determined by the belief that night-time noise must be worse, as it is by actual experiences with night-time noise."

Fields examines whether it is actually important to make a distinction between the two when deriving time of day effects. He looks at a hypothesis that sleep interference and night-time annoyance are related to noise levels in different ways. It is suggested that slopes of curves relating noise level to amount of total reported sleep interruption would be less steep than those relating noise level to the amount of noise-source attributed sleep interruption. He examined various surveys and concludes that distinctions between night-time annoyance and sleep disturbance are indeed important.

Powell expressed the opinion that although sleep disturbance may not cause a great increment in awakenings or arousals, it still may be an important factor for night-time annoyance. Even if a person is rarely awakened, he/she may be highly annoyed and/or biased against the offending source for a long time.

4.3.3 Explaining the role of sleep disturbance in night-time annoyance

The role of sleep disturbance in determining annoyance is not fully understood. However, we do know that:

1 After-effects of sleep disturbance can lead to psychosocial effects, eg tiredness, headaches, mood change, nervous stomach (ÖHRSTROM 1993b)

2. The effect of sleep disturbance can be mediated by familiarity with noise source (FIELDS 1986a)

3. The role of sleep disturbance in chronic annoyance depends on the distinction between the two (as discussed earlier by Fields).

4. The role of sleep disturbance in chronic annoyance depends on defining the time period of interest, how much sleep disturbance is conscious, and how the person feels about the aircraft (FIELDS 1985a).

5. Sleep interruption was shown as one of the strongest direct effects on individual annoyance towards aircraft noise (TAYLOR 1984).

6. Getting to sleep and awakenings were shown to be significant factors (at 5 % level) in determining an annoyance response (HALL 1985).

7. Response functions for non-specific annoyance and specific effects, eg sleep disturbance, exist. It is as yet unclear how these are linked.

Figure 9 attempts to place sleep disturbance in the context of night-time annoyance. It pulls together the above findings and factors discussed in this section.

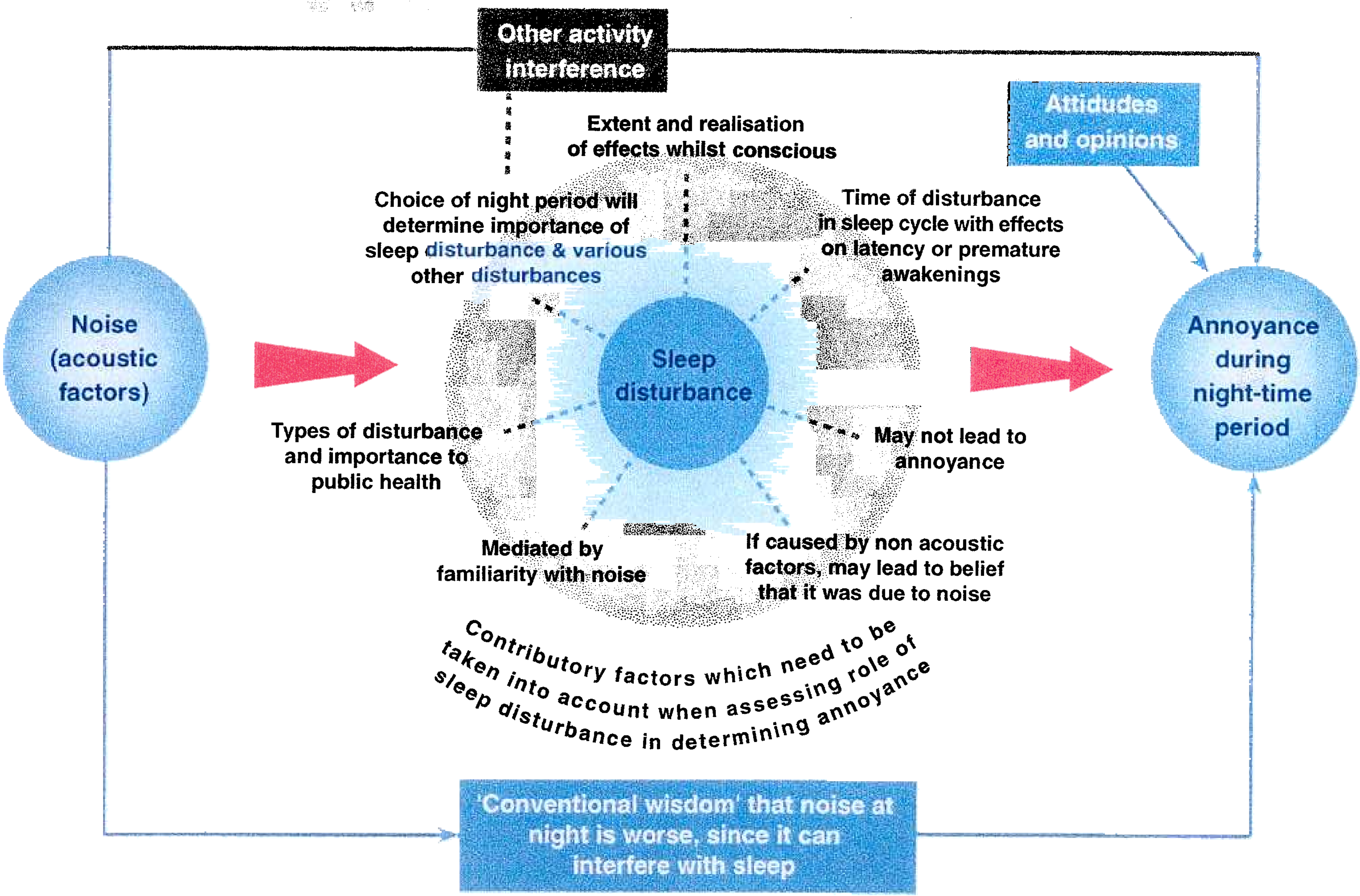


Figure 9. Placing sleep disturbance in context of night-time annoyance to investigate its role in chronic annoyance

4.4 PROBLEMS THAT WE NEED TO RESOLVE TO EXPLAIN ANNOYANCE DURING THE NIGHT-TIME PERIOD

In this section, we have demonstrated the complexity of annoyance. The main determinants of an annoyance response have been summarised. Although there is no consensus on the relative importance of these factors, their existence is none-the-less largely agreed. On looking at one of these factors, sleep disturbance, the level of knowledge about its role in determining an annoyance response is fragmentary. Dose-response relationships for sleep disturbance exist but agreeing these during the shoulder hours will still involve more research work. The following appear to be unresolved problems:

> If sleep disturbance is a strong effect during the shoulder hours, can contours be produced based on annoyance data rather than sleep data?
>
> How annoyed are people who experience sleep disturbance during the shoulder hours?
>
> What are typical sleep patterns around the airports?- ie when do people usually go to bed and get up?

The following are therefore unresolved problems:

1 Ranking the order of importance of the main determinants of annoyance during the night-time period,

2. Dose-response relationships for sleep disturbance during shoulder hours, and

3. How to combine the contributory factors for sleep disturbance and annoyance together.

5 MODELS FOR PREDICTING NIGHT-TIME ANNOYANCE

5.1 WHY DO WE NEED A MODEL?

The objective of this work is to determine the feasibility of producing night-time annoyance contours. To do this, we require a framework on which to base these contours. This framework can be regarded as a model for predicting night-time annoyance. In section 4 we examined the main determinants of an annoyance response at night-time. We now need to use this information to see how such a model can be formulated.

5.2 WHAT ARE THE GENERAL REQUIREMENTS OF A USEFUL MODEL?

1 Simplicity. Section 4 showed that annoyance is a complex issue. A model for annoyance needs to be simple enough to facilitate its application but not too simple to render it useless under conditions other than the basic. As Wesler said about using a model based on L_{dn} (NASA/FAA 1980) "can a single simple number find happiness in today's complex world of aviation?".

2. Width (breadth) of application.

3. Robustness.

4. Practicality and pragmatism.

5. Consideration of all significant factors and ability to combine them in an agreed way.

6. Provision of functions based on agreed arguments and evidence.

7. Provision of a tool for enforceable rules.

8. Independence of day and night annoyance reactions.

Marazzo summarised these neatly in his recommendations to the NASA workshop in 1980 (NASA/FAA 1980):

> *"One should not lose sight of considerations of simplicity, uniform application and value to planning and enforcement, especially at local government levels."*

Furthermore, Ollerhead reflected these requirements in discussion whilst commenting on the needs for suitable indicators of noise effects:

> *"They should be measurable, robust and sensible indicators of impacts."*

5.3 WHAT ARE THE BASIC ELEMENTS OF SUCH A MODEL?

The ways in which characteristics of noise come to impact humans is exceedingly complex and not fully understood. In order to deal with these characteristics, scientists have developed very simple theories about how noise characteristics affect humans. These simple theories can be considered as crude representations or 'models' of the actual complex process. A model will infer with it, its own set of assumptions about how each element is related.

Let us consider a very simple model as below :

NOISE EXPOSURE ⇒ EFFECTS ⇒ ANNOYANCE RESPONSE

Taking this a little further, Figure 10 shows the elements of a four stage model to predict annoyance at different times of the day. This is an idealised model and could provide a framework on which to base annoyance contours.

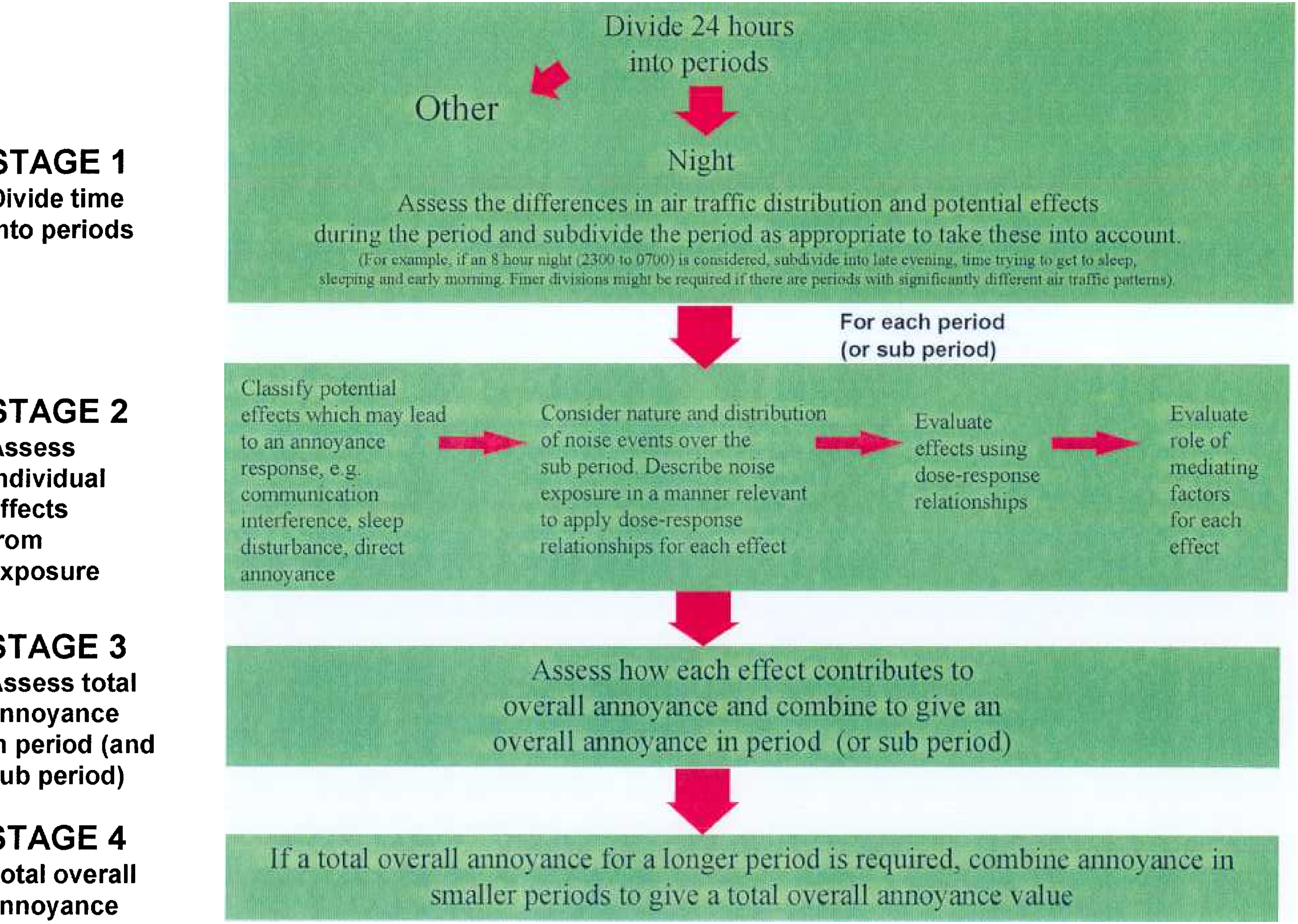


Figure 0: An ideal model for predicting annoyance at different times of the day from one noise source

Stage 1 divides the day into time periods. As Fields suggests, separate time periods are needed when

1 different noise metrics are used,

2. different dose-response relationships are appropriate,

3 different mediating variable effects exist, and

4. different mediating variable values exist.

Separate time periods may also be required where the operating characteristics of the noise source vary leading to changes in noise exposure, eg large changes in air traffic patterns. Effectively, we need to assess the differences in noise exposure and potential effects and to sub-divide the period to reflect these differences. However, it may not be possible at all times to divide the time period up so that only one dose-response relationship is appropriate although one effect may be more dominant than another. Successful division at this stage will simplify stage 2.

Stage 2 assesses the individual effects from noise exposure during each time period. This involves determining the likely effects, describing the noise exposure and its features (typical and atypical), evaluation of the effects using dose-response relationships and assessing the impact of the mediating factors.

Stage 3 considers how each effect may lead to an annoyance response in each period or sub period. This would have to take into account the significance of each specific effect in determining an overall annoyance response, and then combine these in the appropriate manner.

Stage 4 considers how to combine annoyance in each period of sub period to give an overall annoyance response over a larger time period.

The main difference between stage 3 and 4 is that in stage 3, we are combining the significance of each effect to get an overall annoyance, and in stage 4 we are effectively combining relative annoyance values across periods to get an overall annoyance.

This model is idealised. It refers to only one source of noise. In reality, it is usual that more than one noise will be contributing to the noise environment. One would then have to consider whether to assess each source separately or to treat the sources as an ensemble. The model would then have to be adapted to consider the role of mediating factors that may be associated with each source and also to consider how to combine the annoyance from each source if appropriate.

Let us consider how we would apply this model to noise from aircraft during the night-time. Firstly we need to divide the time period up into the hours of interest. These hours may be broken down further if different effects or traffic patterns are anticipated, eg in the evening communication interference may be the main effect and we may wish to consider this period separately, or one may wish to separate early morning arrivals from those during the night. These periods we can term sub-periods.

In stage 2 we need to assess the potential effects during each sub-period. If we have subdivided in a correct way, then may be only one effect will be dominant and need to be assessed. We need to understand the effects which may lead to an annoyance response. The exposure must be described in a manner that is relevant to assessing these effects using appropriate dose-response relationships. For example, for sleep disturbance we may need to consider SEL or L_{MAX} values. For direct annoyance, we may need to consider not only Leq values but the sensation levels of certain acoustic features, eg tones. Using dose-response relationships, we can predict the effects of the noise which may lead to an overall annoyance response during the night-time period. At the end of stage 2, we should be able to say that during a certain period or sub period, these are the potential effects, ie X % will have their sleep disturbed, etc.

In stage 3 we consider how each effect may lead to an overall annoyance response during each period or sub-period. We need to answer such questions as how can we quantify the contribution of sleep disturbance to annoyance during the time period we are considering. Furthermore, how do we add in the contribution of communication interference etc. At the end of stage 3 we should have an indication of the overall annoyance during the time period resulting from the effects that have been considered.

In this work we have been examining noise annoyance and therefore stage 3 is necessary. However, in combining the effects into an overall annoyance response, we may lose information about these critical effects and their extent. For general impact assessment these details could still be important.

In stage 4, we need to 'total' the annoyance across longer periods of interest. This stage may introduce weighting functions which can be used to combine the relative impact of a noise heard in different time periods.

In order for this empirical model to be applied successfully we need to know:

1 Information about the features of the noise environment that would lead to a significant adverse response.

2. The most appropriate method to characterise these features in a meaningful manner that would be tailored towards the effects.

3. Dose-response relationships for the significant effects.

4. The role of the mediating factors.

5. A method to combine the effects into a total annoyance response.

5.4 WHAT MODELS HAVE SO FAR BEEN INVESTIGATED?

Before describing the different types of models in existence it is worth recognising the relationship between indices and models. Inherent in using a particular index such as the day and night index, L_{dn}, is the use of a model. The L_{dn} model assumes that noise can be described as an equivalent energy level and a noise heard during the night is deemed to be of equal annoyance as a noise which is 10 dB greater in level heard during the day. In other words an index may be part and parcel of a model and in some way could be considered a surrogate for a model.

Figure 10 described an ideal model for predicting annoyance at different times of the day. Models already exist which adopt some of the stages of figure 10. A number of models are described in Appendix III. These are split into night-time weighting models based on average energy, models based on single events and models that combine effects.

The classic conventional method (eg L_{dn}) divides the day (stage 1), assumes a dose-response relationship based on energy levels (stage 2) and combines the periods by using a night-time weight (stage 4). We will term these night-time weighting models based on average energy. They are effectively time of day models and are not specifically for night-time annoyance but relate to comparisons of day and night-time annoyance by providing factors called time of day weightings (ie stage 4 of Figure 10). These are devised by considering the difference between annoyance indicator between day and night. For instance, a dB weight can be applied to a night-time level such that the equivalent daytime level produces an equal annoyance. Alternatively, a number weight may be applied to events during the night-time period such that a certain number of night-time events are judged to be equally annoying as one day time event. Inherent in using time weightings is the use of the <u>same metrics for day and night</u>.

We have to consider though that some effects may be better described by different metrics. For example, if we consider sleep disturbance to be a main effect at night, use of SEL or L_{MAX} may be more appropriate than Leq, primarily used for daytime annoyance dose-response functions. This may prohibit the use of weightings. However, SEL could be adjusted to an Leq value using information about number of events, frequency, duration, etc. The committee of the Netherlands Health Council are currently investigating a uniform metric for all effects likely to be based on Leq. We will term these models as those based on single events.

Models also exist for combining the effects or annoyance from different sources and combining effects from the same source (stage 3). No models appear to exist that use all the elements considered in Figure 10. This would require agreement or consensus on the best way to apply each stage of the model.

We can see that a number of models have been proposed based on average energy or single event levels. Some models have been proposed to combine effects. Where the same metric has been adopted for day and night, night-time weights have been derived. Most indices adopting night-time weights use an adjusted energy model - although other types of models exist. The adjusted energy model tends to be the most successful and has received wide usage. This does not mean it is necessarily the best model for all circumstances. However, moving away from this model and its associated accepted indices such as L_{dn} would require a clear and significant demonstration of its disadvantages and inaccuracies against the benefits of any new procedure.

5.5 PROBLEMS THAT NEED RESOLVING TO DERIVE A SUCCESSFUL MODEL TO PREDICT NIGHT-TIME ANNOYANCE

Annoyance is a complex issue. Theories have been developed to take into account the ways in which noise characteristics impact on humans. These take the form of crude models which we can use as a framework for predicting night-time annoyance contours. A successful model for predicting annoyance during the night-time period would have to take into account all the stages shown in the ideal model of Figure 10.

Fields identified a number of unresolved problems relating to his night-time model (FIELDS 1985a). These were:

(1) Does night-time annoyance increase as rapidly with noise level as does day-time annoyance? He found that existing surveys do not consistently support the assumption (implied in the adjusted energy model) that the slope relating annoyance to noise level will be the same in all periods.

(2) How do the number of night-time noise events affect response? Fields found that none of the research provided a definitive answer to this question.

(3) Is there a sharp noise level threshold for night-time response? In general he found that the social surveys do not support the concept of a sharper threshold for the night-time than day-time annoyance.

(4) Is the dose-response relationship the same for the entire night-time period? Fields concluded that the possibility of a different average noise dose-response relationship at different hours could not be dismissed, but the available evidence did not support it. He referred to the difference in sensitivity to effects during the shoulder hours.

(5) Does annoyance (or noise level) in other periods affect responses in the night period? Since day-time and night-time noise levels are often highly correlated, it was conjectured that there may be an acoustical basis for expecting day and night annoyance to be correlated. However, Fields was unable to draw any definitive conclusions from the data set. He surmised that the research did raise enough questions to suggest that it is important that time-of-day studies should control for noise levels at other times of the day. Ollerhead (OLLERHEAD 1978) also recognised the difficulties in annoyance being a potentially cumulative response. If we can never truly have independent day and night responses, can we ever successfully define independent night-time annoyance contours?

Powell commented in discussions that he thought that most of these issues still remain unresolved today. This work has also suggested this to be the case.

These questions were included in the summary of key issues given in Appendix II. When commenting about these key issues, Miedema agreed that the issues represented a good summary of unresolved problems. At present, agreed answers were not available to the majority of the questions.

Although a number of models have been investigated for use in deriving night-time annoyance, there are still many unresolved problems. These are:

1. Choice of periods.

2. Determination of significant effects during a period.

3. Development of best ways to characterise significant acoustic features relevant to effect.

4. Agreed dose-response relationships.

5. Optimisation of methods to combine effects.

6. Optimisation of methods to combine periods within the night or with day periods.

This section has looked at modelling as an empirical issue. The next sections will now look more closely at the existing data. Much work has been carried out on the problem of night-time annoyance in terms of deriving dose-response relationships and developing night-time weights. The rest of this report will focus its attention on these two issues in order for us to assess what data is available for predicting night-time annoyance using the ideal model of Figure 10.

6 DOSE-RESPONSE RELATIONSHIPS TO ASSESS THE EFFECTS OF NOISE DURING THE NIGHT-TIME PERIOD

6.1 INTRODUCTION

A number of reviews have been carried out to investigate dose-response relationships. These include investigations of functions for day and night, for different transportation sources, for annoyance and for other activity interferences. This section therefore summarises the main review work by giving examples of these relationships. Much of the information is taken from Miedema's work (MIEDEMA 1992) and Fields (FIELDS 1986c).

6.2 SYNTHESIS STUDIES OF DOSE-RESPONSE RELATIONSHIPS FOR ANNOYANCE OVER 24 HOUR PERIOD

6.2.1 Work by Schultz (SCHULTZ 1978)

In his 1978 article Schultz discussed a large number of noise annoyance investigations carried out in several countries. These investigations concerned aircraft, railway traffic and various types of road traffic. In order to make the investigations comparable Schultz used the available data to determine L_{dn} levels.

For each of the investigations he drew up a curve showing the percentage of highly annoyed persons as a function of L_{dn}. On the basis of the individual curves he synthesized a single curve as the 'best currently available estimate of public annoyance due to transportation noise of all kinds'. This is shown in Figure 11. No account was taken of time of day.

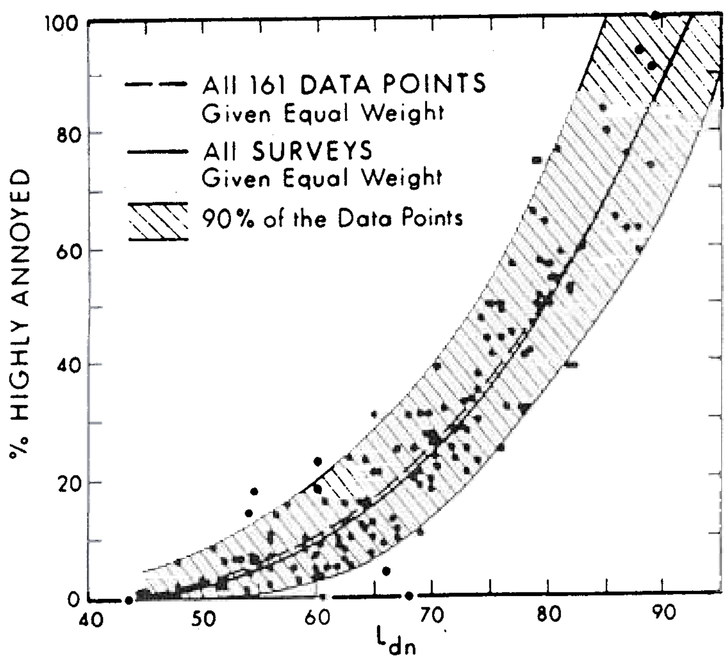


Figure 11: Schultz synthesis curve showing percentage highly annoyed by a noise versus its level (Ldn) (source SCHULTZ 1978)

Work by Kryter (KRYTER 1982)

Kryter argued against using a single curve for all transportation sources. He argued that for ground traffic (ie road and rail traffic) and air traffic, separate and non-identical curves give a significantly better representation of the data considered by Schultz. According to Kryter, for a given L_{dn} the annoyance due to aircraft lies above the value given by the synthesized curve, whereas the annoyance due to ground transportation noise lies below. Again no specific account was taken of time of day.

Work by Fidell (FIDELL 1991) and Fields (FIELDS 1994)

Work in 1991 extended the original compilation by Schultz. This is shown in Figure 12. Their additional data appear to support Kryter's point that at the same exposure level aircraft noise is more annoying than ground transportation noise. Fields reviewed the updated synthesis.

6.2.4 Work of Miedema (MIEDEMA 1992)

Miedema argued for separate dose-response relationships for different sources. He reviews a number of studies and proffers a number of dose-response relationships. He argues that an environmental rating is derived for a source, atypical features are taken into account and then an overall environmental noise quality rating is calculated for combined sources.

In reviewing an EC study carried out in the vicinity of Paris - Orly, Glasgow airport and Amersterdam - Schiphol he derived the dose-relationships shown in Figures 13 and 14 based on L_{Aeq} (24 hour).

6.2.5 US Federal Agency Practice

In a US Air Force study (FINEGOLD 1994) of the re-analysis of annoyance due to transportation noises it was concluded that the day-night average sound level was still the most adequate noise descriptor to assess annoyance in the United States. A logistic curve was adopted in 1992 for use by the US federal agencies as given in Figure 15.

Comments about dose-response relationships based on 24 hour data

Although work has been done by Schultz, Fidell and Miedema to develop dose-response relationships for annoyance, these are aimed towards either all sources or separate sources and principally adopt 24 hour indices. Let us now examine what data exists for annoyance during different time periods.

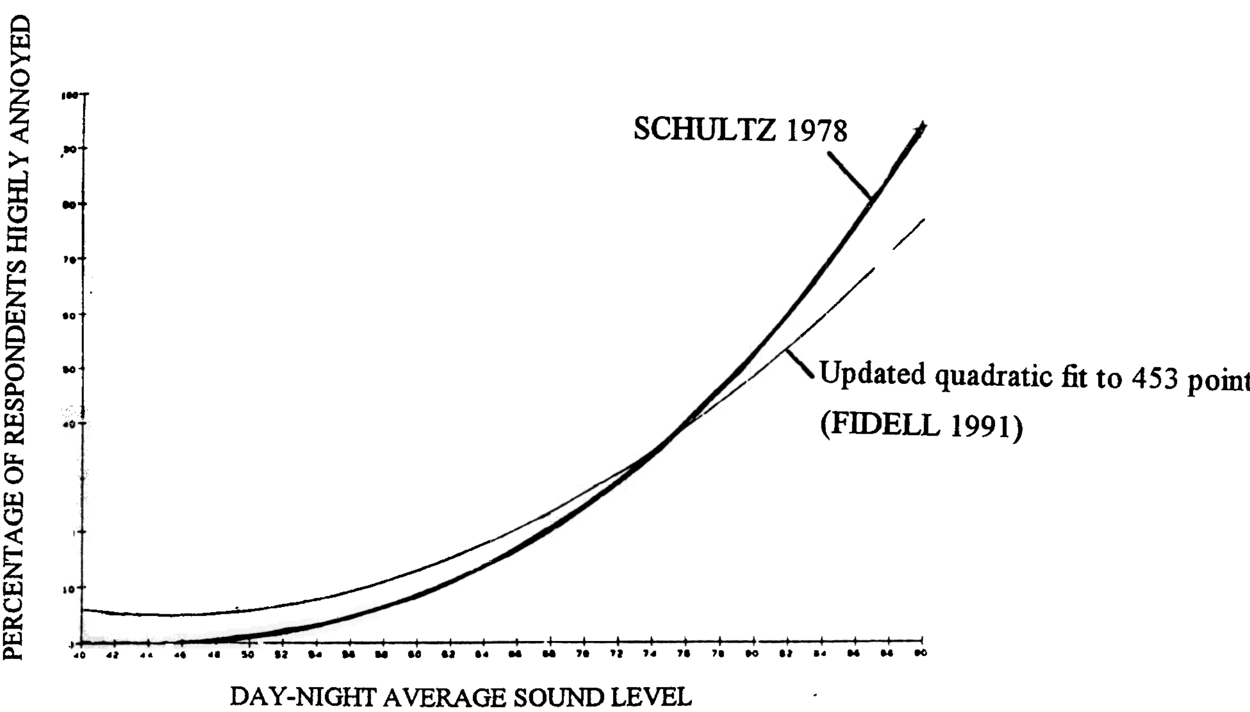


Figure 12: Updated Schultz synthesis curve showing percentage highly annoyed by a noise versus its level (Ldn) (source FIDELL 1991)

6.3 TIME OF DAY DOSE-RESPONSE RELATIONSHIPS FOR ANNOYANCE

6.3.1 1972, Heathrow survey (OLLERHEAD 1978)

A dose-response relationship based on the noise and number index and % disturbance was derived in this survey. The work led to a night-time weighting value in terms of NNI units. Section 6.3.2 gives summary details.

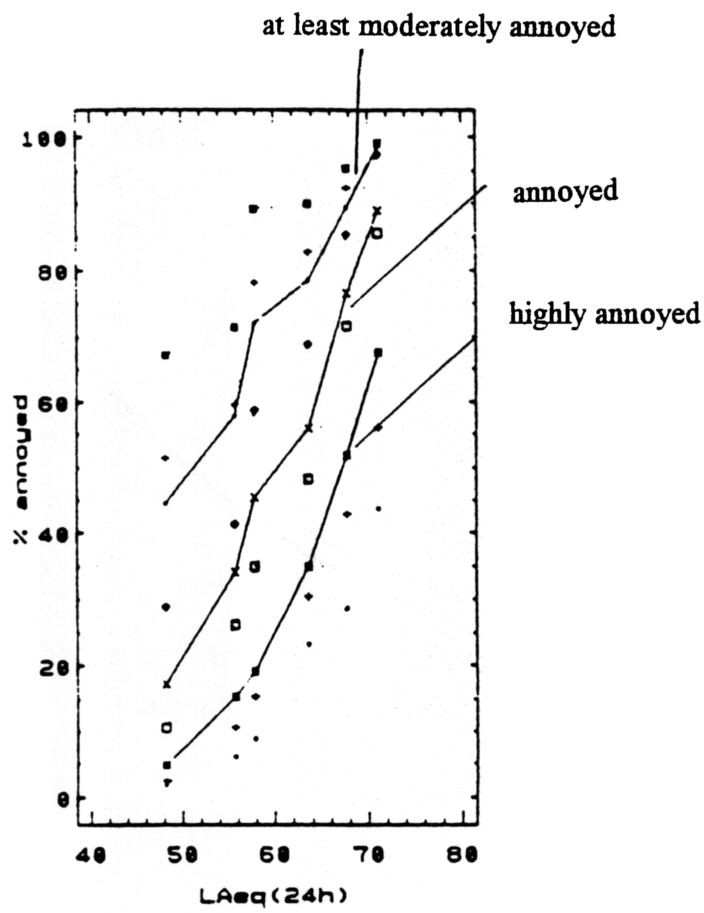


Figure 13: Dose-response relationship for aircraft noise based on L_{aeq} (24h) as reviewed by Miedema (MIEDEMA 1993)

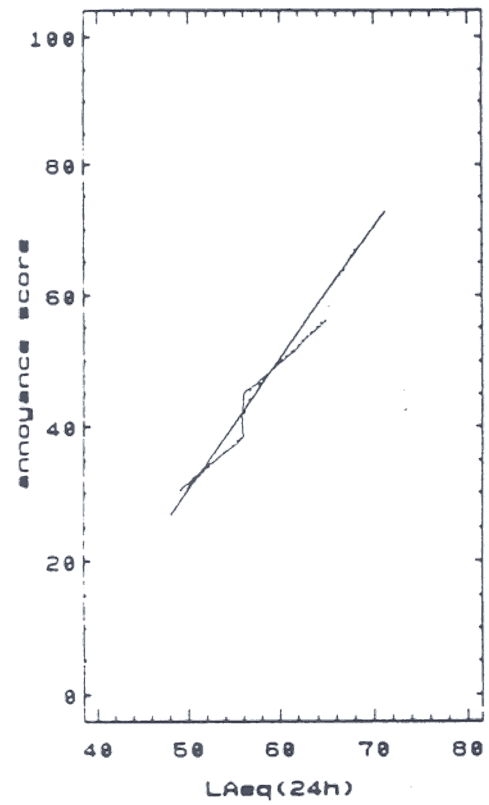


Figure 14: Dose-response relationships for annoyance due to aircraft noise as reviewed by Miedema (MIEDEMA 1992)

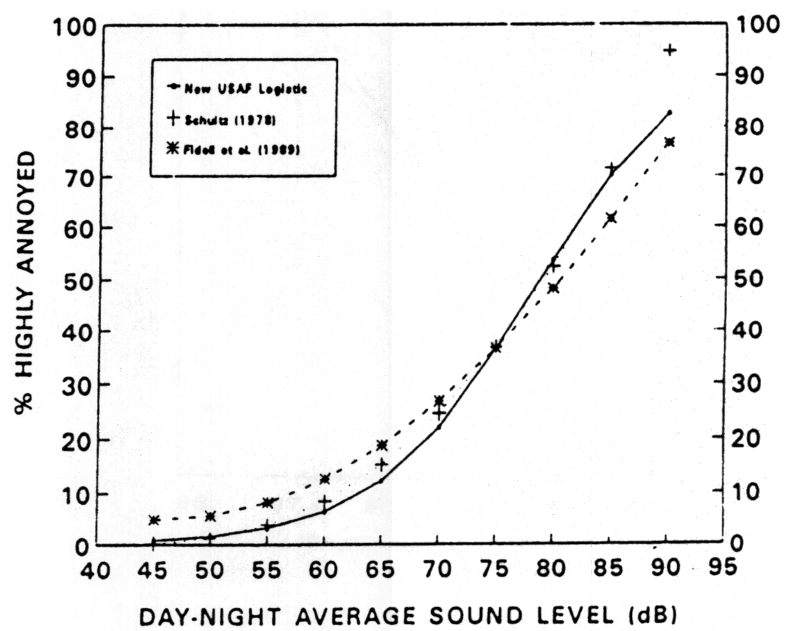
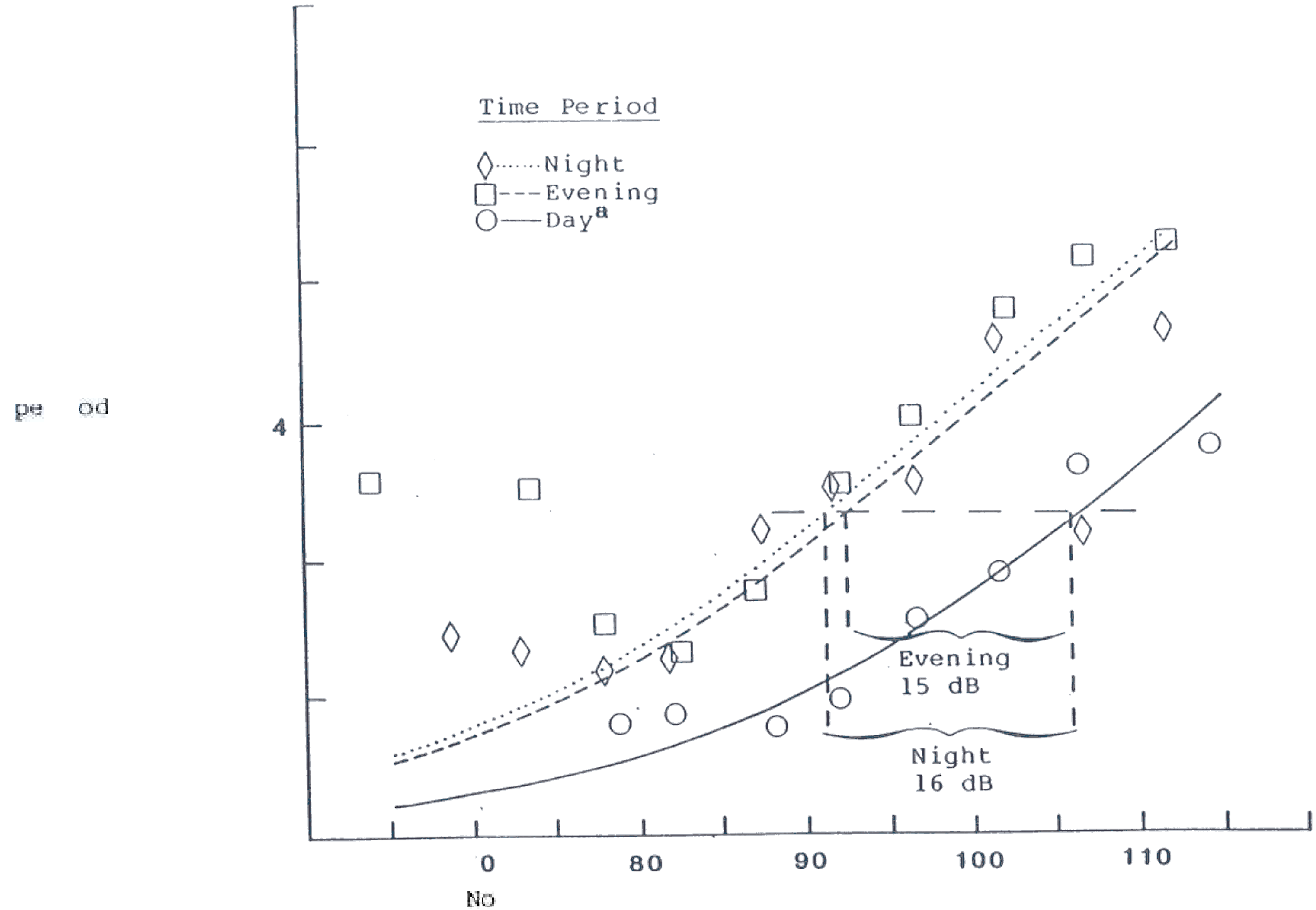


Figure 15: Dose-response annoyance curve recommended for adoption to FICON



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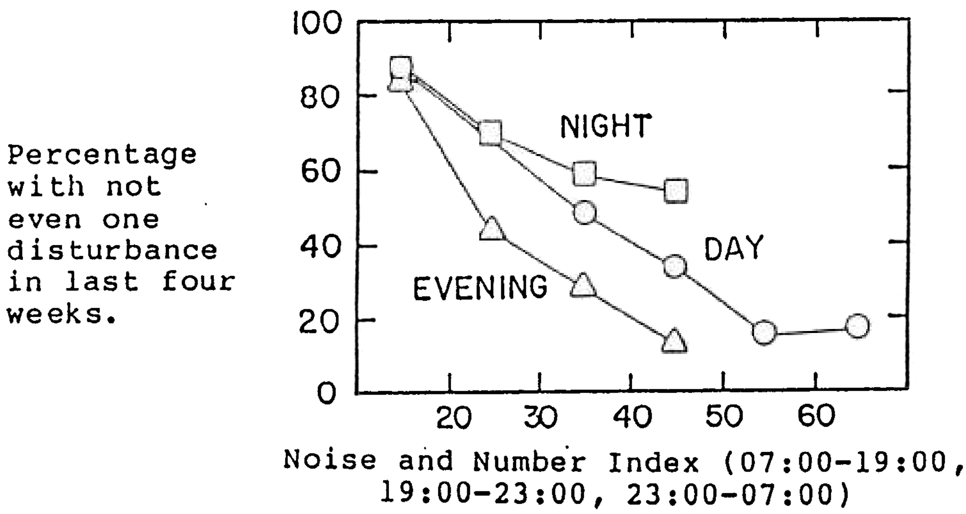


Reports of no disturbance by noise level in three time periods (1972 Heathrow survey).

Figure 17: Dose-response relationship for disturbance at different times of the day (taken from OLLERHEAD, 1978, fig. 4, 1972 Heathrow survey)

6.3.2. Review by Fields (FIELDS 1986c)

As part of Fields' work into time of day weights, he investigated dose-response relationships showing the relevant effect of noise at different times of the day. He presented the results from several surveys. The curves from the 1967 and 1972 Heathrow airport surveys are given in Figures 16 and 17 as reproduced by Fields.

6.3.3 Comments about dose-response relationships based on time-of-day data

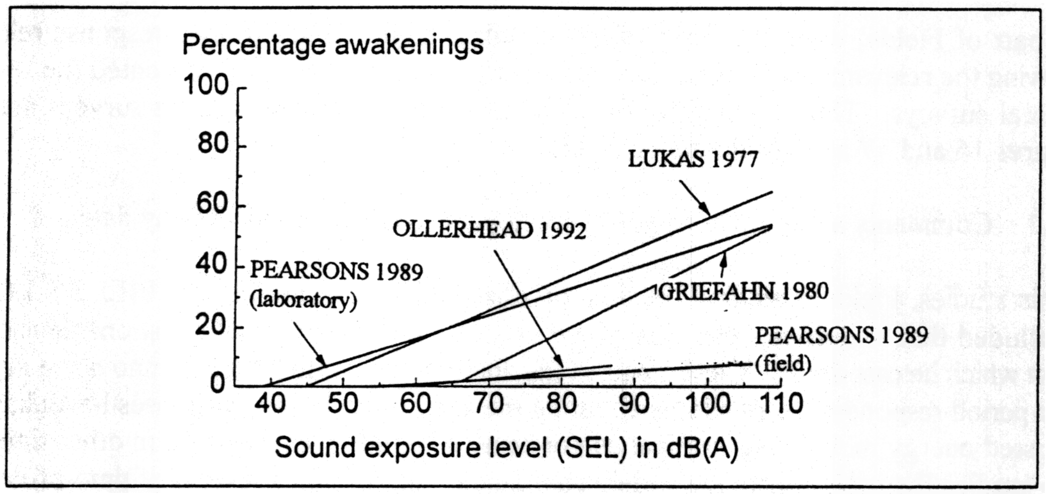
In his studies, Fields evaluated the data on dose-response relationships (FIELDS 1986c). He concluded that in deriving this data, there existed a large number of questionable assumptions upon which he cast doubt. These included the ability to separate 24-hour annoyance into smaller time period responses, respondents all rating the same noise entity, responses being based on an adjusted energy model, and annoyance not being affected by experiences in other time periods. The studies themselves provide widely varying data on the actual extent of time-of-day effects. He found that they do show that, in general, evening and night-time noise are rated as more annoying than day time noise.

6.4 DOSE-RESPONSE RELATIONSHIPS FOR SLEEP DISTURBANCE

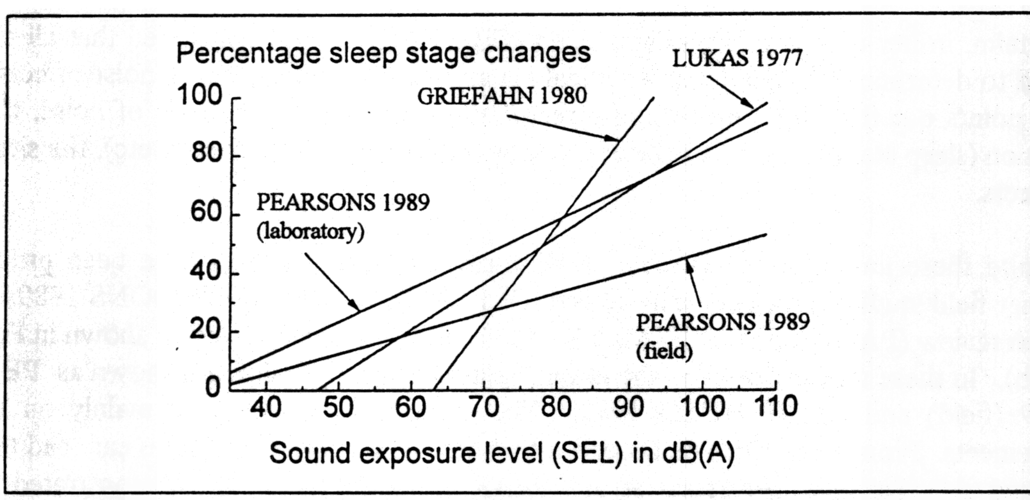
In this report we have examined the role of sleep disturbance in chronic annoyance. Let us now briefly review existing dose relationships for sleep disturbance.

Griefahn, in her review of noise and sleep (GRIEFAHN 1991) concluded that all efforts had failed to determine a general mathematical equation for the prediction of noise effects on sleep. She points out that the dose-response relationships depend on the type of noise, the type of reaction (sleep stage change, awakenings, body movements, after effects, etc), the situation and subjects.

Despite these limitations, a number of dose-response relationships have been proposed and further field studies have been carried out (OLLERHEAD 1992, PEARSONS 1989ab). In the Dutch review (PASSCHIER-VERMEER 1993), these are summarised as shown in Figures 18a and b). In these studies, lines on the graphs relating to field studies are shown as PEARSONS 1989 (field) and OLLERHEAD 1992. The other studies are based mainly on laboratory judgements. From these it can be observed that field and laboratory studies can lead to different derived relationships. Pearsons et al (PEARSONS 1989a & b) demonstrated this clear difference whereby laboratory studies show considerable more sleep disturbance from environmental noise than field studies. Finegold (FINEGOLD 1997) concludes that field settings may be more appropriate for collecting sleep disturbance data to support policy-making considerations because the data more accurately reflects the responses of the population for whom predictions are being made.



A Relations between the percentage of people with awakenings due to a night-time noise event and the indoor sound exposure level of such an event.



B Relations between the percentage of people with sleep stage changes due to a night-time noise

Figure 18: Review of sleep disturbance response curves from different studies (source, PASSCHIER-VERMEER 1993,)

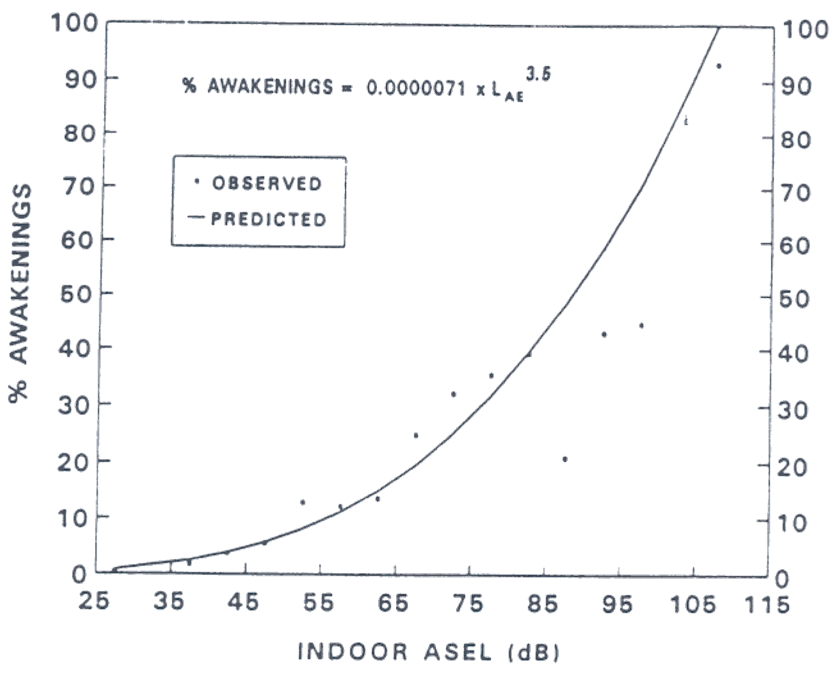


Figure 19: Sleep disturbance curve recommended for adoption by FICON

A curve for predicting night-time sleep disturbance from general transportation noise has been recommended for adoption by the US federal agencies (FINEGOLD 1994). This is a power curve, using A-weighted sound exposure level and is shown in Figure 19. The curve in this Figure is based on data from Pearsons et al (PEARSONS 1989a). It was proposed to use this curve for environmental impact analysis until sufficient data from additional field studies are available.

6.5 DOSE-RESPONSE RELATIONSHIPS FOR OTHER ACTIVITY INTERFERENCES

Miedema has reviewed dose-response relationships for both specific annoyance and non-specific annoyance (MIEDEMA 1993). In his review of non-specific annoyance, he related noise level to certain activity interferences. These included communication disturbance, sleep disturbance, startle and vibration. He examined these for different transportation sources. The functions derived for aircraft noise are given in Figure 18. The relationship between these effects and annoyance was not investigated. However Miedema confirmed during discussions that this may be possible using TNO's database.

Hall (HALL 1985) did examine the significance of individual effects in determining an overall annoyance response. He found that sleep disturbance and communication interference were significant factors in determining an annoyance response.

Von Gierke and MckEldred (VON GIERKE 1993) provide an excellent guide to assessing the effects of noise on people. This considered a number of indicators of noise effects including speech communication. Figure 20 gives a dose-response relationship for speech intelligibility.

6.6 APPLICABILITY OF THESE RELATIONSHIPS TO OUR PROBLEM

This section has presented a large amount of dose-response data which can be considered when assessing annoyance. The obvious questions become:

Which ones do we use?

Are they scientifically robust and valid?

It appears that for annoyance, data based on 24 hour levels seems to be most widely accepted for use in environmental impact analysis. These are commonly based on L_{eq} or L_{dn}.

For this work we are interested in relationships for different times of day and the independence of these relationships from each other. Until we have this information, we cannot proceed in predicting night-time annoyance contours.

If we are to believe the validity of these relationships then we could use them in our model to predict annoyance. Fields questions the applicability of annoyance relationships in his work on night-time weightings (FIELDS 1986c). This work is described in the next section. We have already challenged the role of sleep disturbance in the more sensitive hours. We therefore cannot apply the sleep dose-response functions convincingly for all times of the night until this issue is resolved. In conclusion, many of these relationships may be applicable to developing annoyance contours. However, since some of the relationships are not statistically robust, further work may be required before we can reach an agreement on the optimal selection of response relationships.

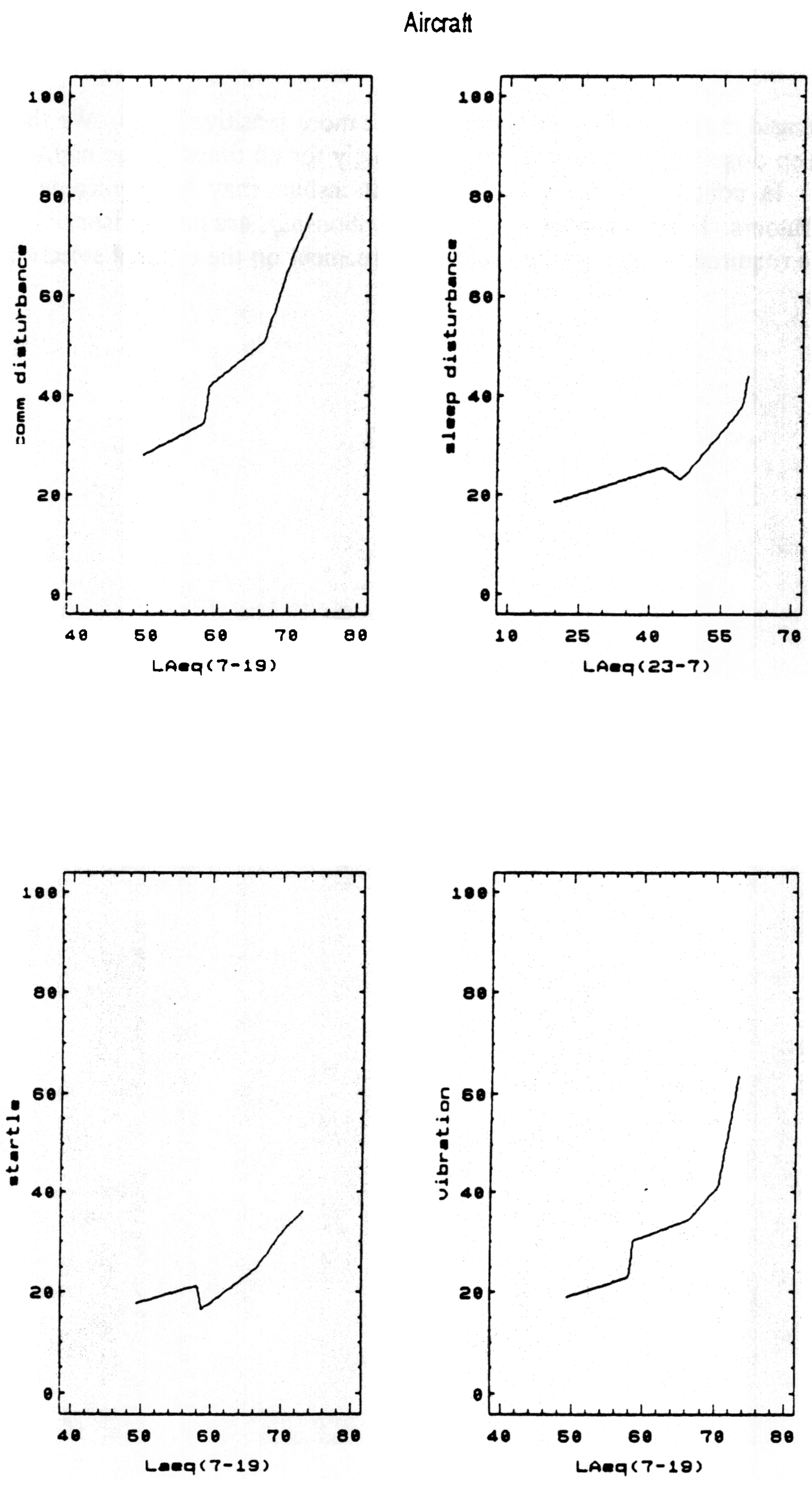
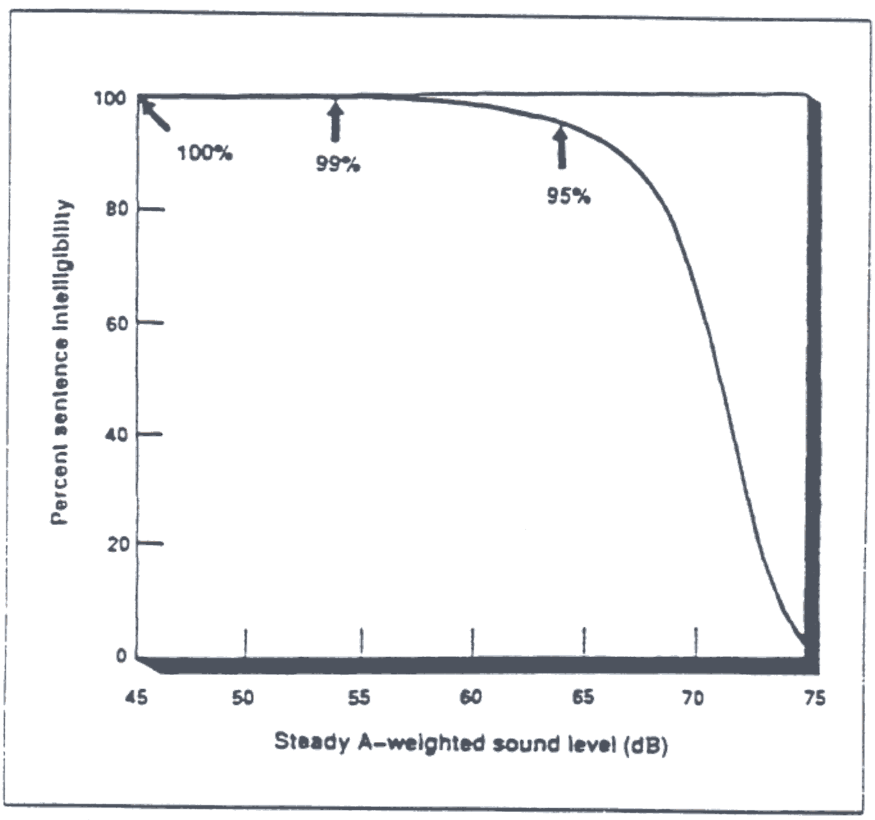


Figure 19: Dose-response functions for specific effects from aircraft noise as reviewed by Miedema (MIEDEMA 1993)



. Indoor speech interference for relaxed conversation with a normal voice level in a typical living room.

Figure 21: The variation of indoor speech interference with A-weighted sound pressure level (VON GIERKE 1993)

7 NIGHT-TIME WEIGHTS TO PREDICT ANNOYANCE DURING THE NIGHT-TIME PERIOD

7.1 WHAT IS A NIGHT-TIME WEIGHT ?

A night-time weight or penalty defines the relative impact of noise during the night-time as compared with its impact during other time periods. It can be defined as a decibel transformation to each individual noise event or to each time period noise level. In this way, the weight is added to the night-time noise level such that the adjusted/weighted noise level would give the same amount of annoyance as a similar day-time noise level.

Alternatively it can be defined as a number weight and be multiplied with the number of noise events or relative pressure squared values of the noise levels during the night-time period. Applying the weight in this way makes an assumption about the equality of impact of one day-time noise event and a number of such events occurring during the night-time period.

7.2 WHY DO WE USE NIGHT-TIME WEIGHTS ?

Night-time weights provide a neat, convenient and simplistic method to take into account the differential impact of a noise at night as opposed to day. The use of weights implies

1. Similar dominant effects during day and night periods

2. Use of the same base metric to define response during the day and night

3. An inherent independence of day and night dose-response relationships.

Section 4 has set out the main factors that contribute to an annoyance response and has summarised the main factors recognised to be important for the night-time period. We found that the process of annoyance is not simple but a complex process. Night-time weights may be considered limited in their application and could be regarded as simple indicators of the relative impact of noise during the night.

7.3 ARGUMENTS FOR AND AGAINST THEIR NEED

Fidell proffers a number of arguments for and against time of day weights (FIDELL 1980). Many of these relate to the factors already described in section 4.3 showing the main factors leading to annoyance during the night-time period.

Some arguments put forward by Fidell, with particular emphasis on L_{dn}, are summarised as follows:

Support for a night-time penalty

Argument Based on Consequences of Release from Restraint

"Since a night-time penalty is often thought to restrain growth of night-time noise exposure, it may be reasoned contrarily that removal of an existing night-time penalty might encourage unwelcome increases in night-time noise levels. The force of this argument rests on the degree to which it can be argued that the penalty is the sole, or at least the major, force that inhibits generation of night-time noise. In the case of aircraft noise, for example, it would seem that public resistance to inconvenient departure and arrival times would also act to restrain the growth of night-time passenger (if not cargo) flights."

The Value of the Status Quo

"Until definite scientific evidence of the inappropriateness of a 10 dB night-time weighting factor is in hand, the probable error of the current (10 dB) night-time weighting factor is tolerably low, and the effort needed to gain an equivalent degree of acceptance for any other weighting factor is almost unthinkable."

Against night-time Penalties

"Community noise ratings that currently impose time-of-day weighting factors lack face validity because they are simplistic and somewhat arbitrary. They are not supported by a systematic rationale or a consistent data base to justify their necessity or magnitude."

"The mode of implementation of existing time-of-day weighting factors is awkward and inflexible. They do not directly accomplish the goal of lowering night-time exposure levels, do not faithfully reflect continuous changes in human sensitivity to exposure, and may produce undesirable side effects."

7.4 WHAT ARE THE CONSEQUENCES OF ADOPTING THE WRONG PENALTY OR APPLYING IT AT THE WRONG TIME ?

The application of night-time penalties can affect many parties. Fidell summarises these parties as (FIDELL 1980):

1. Transportation Industries (including trade association representing airlines and other operators of equipment that generate high noise levels);

2. Related Commercial Interests (including airport operators and businesses involved indirectly with transportation and other high noise level operations);

3 The Public (as individuals exposed to noise, civic action groups, plaintiffs in legal actions, and also as taxpayers underwriting the costs of noise abatement);

4. The Government (executive, legislative, and judicial branches at all levels from local to federal); and

5. The Research Community (both domestic and international).

Each party has its view on the benefits and disbenefits of adopting night-time penalties. For example, Fidell reports on some views of L_{dn} :-

> *"Airlines purport to find energy summation indices that include a night-time weighting factor unacceptably simple and too restrictive. Airport operators, on the other hand, welcome the weighting factor embodied in the Day-Night Sound Level (L_{dn}) as providing a clear limit to their liability."*

> *"Similarly, Federal regulatory agencies seek consistency and universality in noise measures that incorporate time-of-day weighting factors, but federal courts (cf. Santa Monica Airport Association et al. vs. City of Santa Monica, C.D. Cal. No. CV 77-2852-IH) have not felt encumbered by such restraints, and have chosen different noise measures for various purposes."*

The consequences of adopting a certain penalty at certain times of day can therefore have an effect on all of these parties (1-5). This can be in terms of public health impacts, economical factors, etc. The effect on each party will depend on the party's main concerns and, as such, it will be difficult to agree an overall agreed impact or consequence for all.

Collier from the Air Transport Association of America commented on using L_{dn} with a 10 dB penalty for night-time (NASA/FAA 1980):

> *"When you are playing with cumulative noise levels as with the L_{dn} descriptor, you will have a carrier playing paper games with the calculations and really defeating the intent of the regulations, ie protecting the community. These paper games can be really quite dramatic when you are using an energy summation descriptor as a basis for your limit, where 10 operations at 9:59 p.m. are equivalent to one operation of the same airplane at 10:01 p.m. and where 10 operations of an airplane at 90 dB are equivalent to 100 operations at 80 dB. I think those types of paper games really defy logic, and so we are deceiving ourselves and we're deceiving the public, which is very problematical to us."*

In short, he recognises that by applying a night-time penalty one brings into play its use and abuse. This will depend on what party one is representing. Adopting a 'wrong' or inaccurate penalty and at the wrong time can lead the system to being used in beneficial ways to a particular party's interests, eg those which are economical, rather than protecting the public. The form of application as well as its size is important. As Ollerhead (OLLERHEAD 1978) puts it when talking about L_{dn}:

> *"In theory, the implications of this penalty are far-reaching. For example, according to L_{dn} methodology, one aircraft departing at 11:05 PM is as bad for the airport neighbors as ten aircraft departing between 10:45 and 10:59 PM. In practice, noise exposure tends not to follow*

such a precise pattern in any regular way and, largely because nighttime noise exposure levels are usually fairly low anyway, the 10 dB penalty is never put to a severe test. However, this does not mean that it never will be; since very long term outcomes of planning decisions may well depend on the broad validity of composite noise indices, it is important that although built-in penalties cannot be based soundly on scientific principles, they at least represent the best possible guesses."

Using a step function can have an impact on aircraft operations around 'curfew-times'. Some practices have adopted sliding scales over consecutive hours. The size and the form of a night-time weighting function needs further consideration, particularly in terms of how it may be used or abused by the interested parties.

The consequences of selection of a time of day weighting is recognised by Marazzo (NASA/FAA 1980):-

Assessing the impact from all relevant effects of noise

First, we must keep in mind some additional scientific considerations. In considering alternative weighting systems, what will their impact be on our ability to account for all of the relevant effects of noise on people - not only annoyance, but, for example, the disturbing effects of noise on the sleep process? We believe it is necessary to protect against more than just annoyance. Our concern is protecting human health. The descriptors or weights that must ultimately be applied to projections of the effects of noise on people must be representative of those effects.

Selecting noise control options

We should keep in mind the impact of the selection of a particular time-of-day weighting system on the implementation of practical, everyday noise control measures as being applied throughout the United States. Specific noise control choices are being made on the basis of costs versus anticipated benefits of noise control. Of course, the estimates of benefits of noise control depend, in part, on the nature of the noise descriptors being employed. A change in the time weighting in a metric may well lead, right or wrong, to a change in the rank order of preferred noise control options.

Cost consideration

Also, there are some cost considerations that are associated with the selection of different time-of-day weights. These range from the cost of making baseline and assessment noise measurements, to the cost of overestimating or underestimating the amount of noise reduction that may be required in a specific situation to achieve a certain level of benefit.

Social implications

> *The environmental decisions we make have associated with them certain social implications; our assessment methods influence our decisions, and underlying assessment of course is the particular metric or time-of-day weighting used. In selecting appropriate time-of-day weights, we must keep an eye on the possible implications or influence of that selection. For example, any time-of-day weighting that may be selected for use with regard to aircraft noise will undoubtedly transfer for use into community noise programs. Bioacoustic research pertaining to aircraft noise has led the way to our understanding of the effects of noise on people. Any time-of-day weighting that is selected appropriate to aircraft noise must be suitable as well for application to other non-aircraft noise sources.*

Ability of local communities to maintain effective noise control programmes

> *Further, we must consider the implications of alternative time-of-day weighting systems on the ability of local communities to maintain effective noise control programs at a reasonable cost. Moreover, we must consider how alternative methods will affect communities' desires to have the flexibility to find the right noise control solution to fit specific local conditions. We must also recognize the implications of selected alternatives upon the outcome of local planning decisions.*

Time-of-day regulations must consider not only the penalty for the time periods, but also the exact hours during which a penalty must be applied. Fields suggests that one basis for establishing the hours for a noise-sensitive time period is the numbers of people who are engaged in noise-sensitive activities (FIELDS 1985b,c). He reports on a national time-use survey which aims to identify the time periods when large numbers of people are engaged in sleep or communication activities. He found that the 24-hour period can be roughly divided into four noise impact periods. The greatest number of people are engaged in these activities during the night-time period which he defines as 2400-0500. The lowest number are exposed to such activities during the day period which he defines as 0900-1600. The other two periods relate to an early morning transition period and an evening transition period.

Ollerhead (OLLERHEAD 1978) suggested that we could split the night-time period into evening and night (when asleep). He postulated that if activity interference was greater in the evening when people were trying to get to sleep or when communication interference was most prevalent, then consideration could be given to adopting a 6 dB penalty during this time. No penalty or adjustment would be necessary for the night-time period if effects on sleep disturbance were unlikely. This concept was never followed up. However, if we could account for noise disturbance during the shoulder hours, then maybe a low or no penalty during the night-time when the effect of sleep disturbance is not strong may be relevant.

It can be concluded that care needs to be taken when choosing the night-time period for regulatory purposes. Its selection must depend on which activity we are trying to protect.

In summary then changing the UK's current system for night-time impact evaluation to one that is based on annoyance contours can have serious repercussions on all those parties (1) to (5). In changing any system we need to consider:

(1) those parties

(2) the magnitude of any function

(3) when it should be applied, (is a step function appropriate?)

(4) the correct description for describing the main effects (are energy values for annoyance sufficient?)

(5) ability to inform on noise control options

(6) associated costs

(7) social implications

(8) maintenance of noise control programmes.

8 CAN WE USE EXISTING DATA ON NIGHT-TIME WEIGHTS TO DERIVE NIGHT-TIME ANNOYANCE CONTOURS ?

8.1 METHODS TO DERIVE WEIGHTING FACTORS

We have established that night-time weights are often used to predict the relative impact of noise during the night. Let us now examine what data exists on these weighting values. Data on noise annoyance can be obtained from case studies, social surveys and laboratory investigations. The results can be used to derive weightings for the night-time period. Fields uses seven different methods to derive night-time weights (FIELDS 1986c). These are summarised below. More detail information can be found in the full reference document.

8.1.1 Method 1 - Total annoyance regression method

This method uses measured values of day-time and night-time noise levels together with measured values of respondent's annoyance. A multiple regression technique is adopted to predict annoyance scores from the noise level data. The prediction method is chosen to be consistent with the adjusted energy model as described in section 5.4.2.

This method uses each respondent's annoyance score and each respondents' day-time and night-time noise levels to derive a night-time weighting value.

8.1.2 Method 2 - Noise index correlation approach

The ultimate objective of many time-of-day studies is to help to choose between specific environmental noise indices which have different time-of-day weightings. The numerical values of these indices are routinely calculated in community surveys. As a result, investigators often compare the strength of the various indices' correlations with annoyance. This comparison of correlation coefficients is the chief analysis technique used in the "noise correlation" approach.

With this method the total 24 hour annoyance indicator is correlated with noise indices which contain different time-of-day weights. The method aids the choice of alternate indices although it does not provide direct estimates of the optimum values.

8.1.3 Method 3 - Annoyance comparison approach/period response comparison

Instead of providing a single rating for the entire 24-hour noise environment, respondents are sometimes asked to rate the noise in each of the time periods separately. The noise levels in the periods are also measured. The annoyance comparison method compares the relationships between annoyance and noise level in each of the periods.

With this method the period annoyance measures are related to each of the period noise levels and then the number of decibels which separate equivalent annoyance reactions are estimated. An example of this is given in Figure 11 of section 6.

8.1.4 Method 4 - Period ranking approach

Instead of being asked separate questions about each time period respondents are often asked in a single question to identify the time period which is the most annoying. Such a ranking of annoyance with noise in different time periods is the basis for the period ranking approach.

With this method the respondents' own explicit ranking of the relative annoyance of the two periods is used to estimate the difference in decibels which would lead to the judgement that two periods are equally annoying. Examples of these are given in Figures 22 and 23.

In Figure 22, a curve is fitted to the data values. A point of inflection is identified where most people agree that the noise heard during the day is as annoying as that heard during the night. This corresponds to a difference in noise level between the day and night of 3 dB.

In Figure 23, a curve is fitted to the data values. The point where 50 % of respondents consider the night-time noise to be worse than the day-time noise is identified. This point can be considered as where the impact of the noise is judged to be equal for the day and night. The corresponding difference in day and night-time levels gives an approximation for a night-time weighting of 16 dB.

8.2 OTHER METHODS USED BY FIELDS TO DETERMINE TIME-OF-DAY EFFECTS

8.2.1 Ratio of numbers analysis

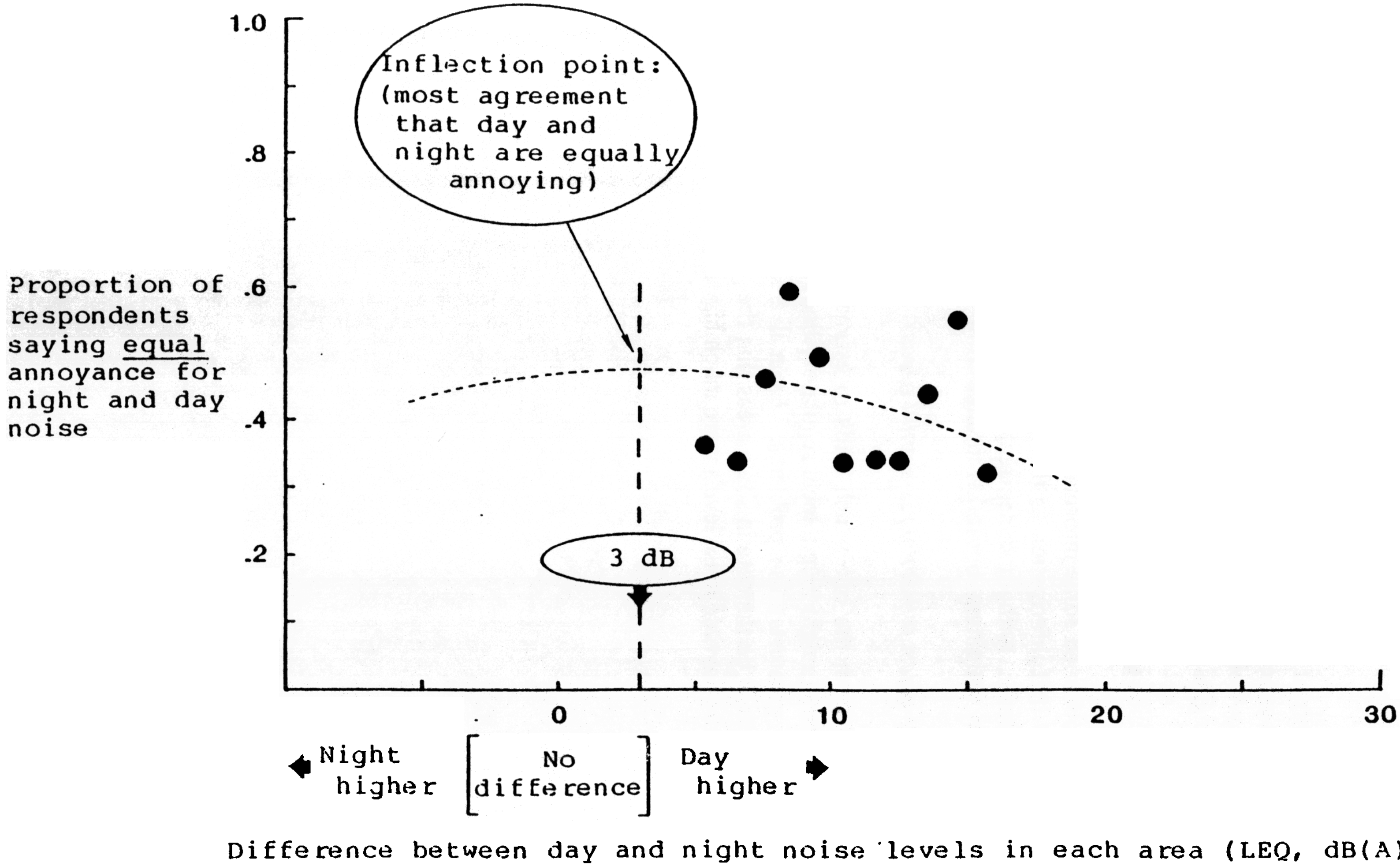
Data on the number of noise events at different times of day are often economically obtained while the data on noise levels are expensive to obtain. As a result several published analyses have attempted to derive time-of-day weights without any information about noise levels. These attempts do not in fact provide weights which are consistent with the adjusted energy model.

8.2.2 Comparisons of periods which ignore noise levels

A large number of surveys have obtained some information about annoyance during different time periods but have not related that information to the noise levels in those periods. The reports of these annoyance responses, without concurrent analyses of noise levels, are not directed at estimating a time-of-day weighting, but rather at answering a related question:

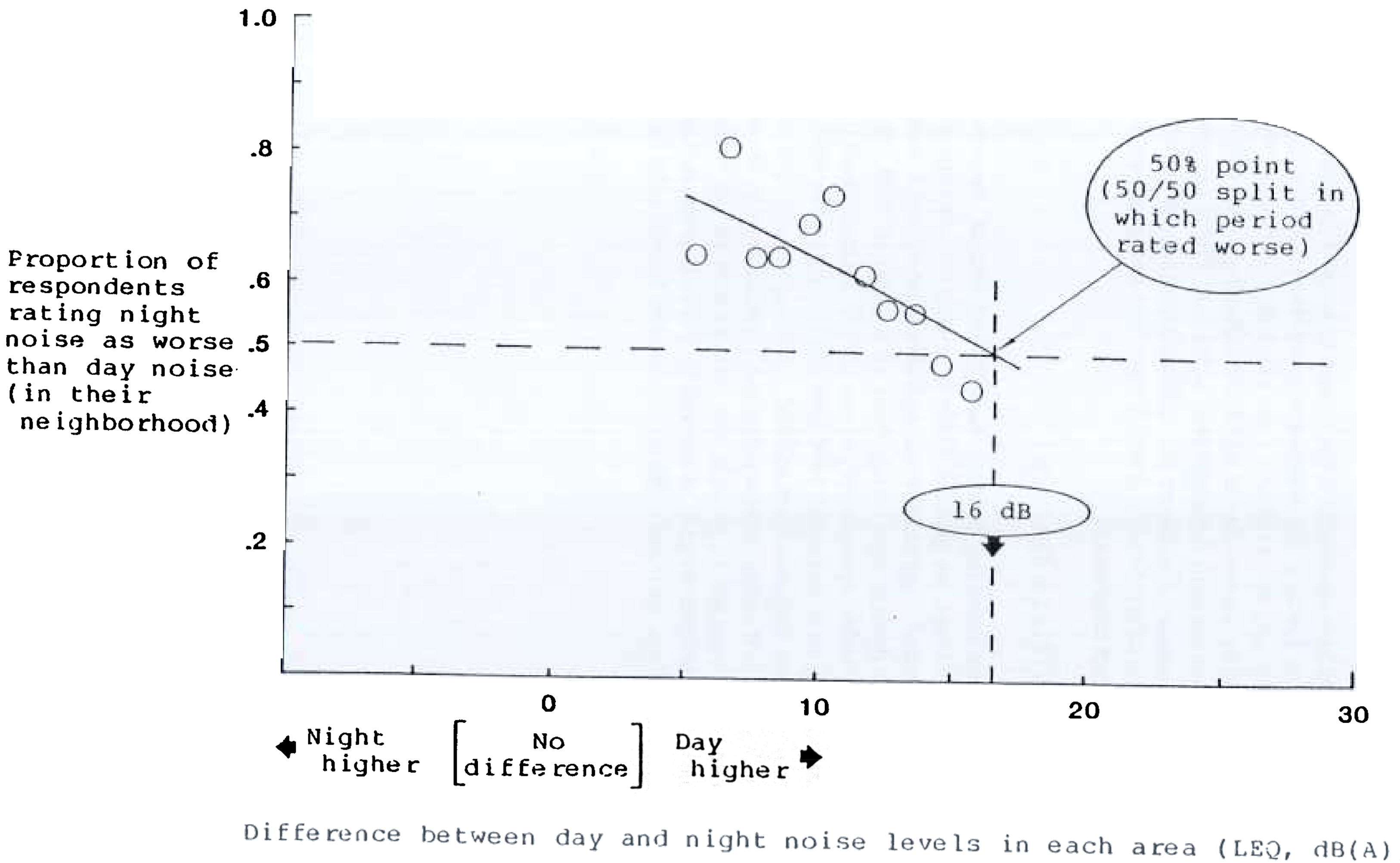
When is noise having the greatest impact in residential areas?

This is quite a different question from the one which leads to estimates of the time-of-day weights. The answer to this question might help a local regulatory body to identify the noise sources which were causing the greatest noise problems. Even if a very high night-time weighting were correct, it could easily be the case in some areas that the greatest noise impact would be during the day because the daytime noise levels were much higher.



Proportion rating daytime and nighttime noise as equally annoying (1967 Heathrow)

Figure 22: Illustration of period annoyance method (FIELDS 1985c)



Proportion rating nighttime noise as worst by difference between daytime and nighttime noise levels (1967 Heathrow)

Figure 23: Illustration of period annoyance method (FIELDS 1985c)

8.2.3 Analysis of complaints

All of the analyses up to this point have measured the response to noise with questions in social surveys. Another method used by Fields is the analysis of complaints. Airport operators and other authorities are routinely exposed to complaints from residents. Personal complaints can usually be categorized according to the time-of-day at which the offending noise occurred. Since these indicators of human response come to the authorities at no cost, Fields suggests that they may appear to be an economical method of studying the relative importance of noise at different times of day. However, it should be stressed that it is well known that complaint data is less well correlated with noise exposure than annoyance.

8.3 WHAT DOES EXISTING DATA TELL US ?

In 1985, Fields analysed the data from ten primary surveys and sixteen secondary surveys (FIELDS 1985a). The aircraft surveys are given in Table 5. Fields has been collating data on additional surveys since this date and suggests that no additional survey work would provide substantive conclusions that would deviate significantly from his findings of 1985. In consulting with others, there does not appear to be an awareness of any definitive conclusions from further work. People's expectations may have increased over time and this may have led to increased annoyance when their expectations have not been fulfilled. Although up-to-date surveys may provide information on this trend, it seems unlikely that the shortcomings in the survey data recognised by Fields have been overcome to provide less variable data on the values of night-time weights. A summary of night-time weights as derived by Fields is given in Table 6. This uses aircraft survey results only. Data on other noise sources can be found in the full reference.

TABLE 5: Summary of aircraft surveys used by Fields in his analysis (FIELDS 1985a)

Study title (Main reference)	Number of interviews	Definition of time period (e = evening, n = night)	Noise metric	Method for determining noise levels
USA nine-airport (CONNOR 1976)	8255	n=22:00-07:00	CNR	Measurements and interpolation
1967 Heathrow (OLLERHEAD 1978)	3755	e=19:00-23:00 n=23:00-07:00	NNI_{10}	Model from measurements at Heathrow
1980 Australia 5-airport (BULLEN 1983)	3575	e=19:00-22:00 n=22:00-07:00	Leq	Predictions and measurements
1972 Heathrow (OLLERHEAD 1978)	600	e=19:00-23:00 n=23:00-07:00	NNI	Prediction from model
1979 US Army (SCHOMER 1983)	2147	e=19:00-22:00 n=22:00-07:00	Ldn	Predicted contours
1961 Heathrow (MCKENNELL 1963)	1731	e=18:00-23:00 n=23:00-08:00	NNI	Measurements, interpolation
1971 Gatwick (OLLERHEAD 1975)	1030	e=18:00-23:00 n=23:00-06:00	NNI	Predictions from observed flight tracks
1973 LAX night (FIDELL 1975)	940	n=22:00-07:00	Ldn	Record of number of flights
1972 JFK (BORSKY 1976)	1465	e=19:00-23:00 n=23:00-07:00	none	Record of number of flights
1971 Swiss 3-airport (GRAF 1974)	3939	e=18:00-22:00 n=22:00-06:00	NNI	Measurements, predictions
1979 JFK Question Devel. (No publication)	40	e=19:00-22:00 n=22:00-07:00	none	No noise data

TABLE 6: Summary of night-time weights derived by Fields for aircraft noise using the adjusted energy model (FIELDS 1985a)

Method (see section 8.1)	Study title (source) (see TABLE 5)	Value of weighting for w_e, w_n (evening and night)
1	USA nine airport	$w_n = 9.2$
1	1967 Heathrow	$w_n = 1.0$
2	1980 Australian 5 airport	$0<w_e<4$ $0<w_n, <2$
3	1972 Heathrow	$w_e = 4$ $w_n < 1$
3	1979 US Army	$w_n = 13.2$
4	1961 Heathrow	$w_n = 25$
4	1972 Heathrow	$w_e <1$ $w_n <1$
4	1980 Australian 5 airport	$w_e > 6.0$ $w_n > 11.5$

8.4 CAN WE USE THESE DATA FOR OUR PURPOSE ?

Examining this question from the statistical point of view, as does Fields (FIELDS 1986c) the answer to this question is 'no, we cannot use this data for predicting annoyance contours at night.'

In our model for predicting annoyance at different times of day, we have demonstrated four stages as shown in Figure 10. Night-time weights only relate to the final stage of our model, the combination of annoyance for different times of day. The unresolved questions from the preceding stages would still need to be clarified for successful implementation of this model to predict night-time annoyance contours.

In order to correctly interpret the meaning of annoyance measurements from social surveys it is important to consider both the validity and reliability of the annoyance measurements. Validity is defined as the extent to which a question actually measures some 'true' underlying annoyance. The reliability is the extent to which repeated measures of the same individual's annoyance are consistent. Analysis of existing social survey data has questioned the level of validity and reliability of the annoyance data.

In setting out the requirements of a prediction model, the needs for a model to be robust with wide applicability, and to use independent of day and night responses were identified. Even the much researched weighting issue does not render reliable results. The derived estimates of night-time weights have shown considerable variability, for different studies and different methods of derivation. This variability has been discussed by Fields as being due to the assumptions made in the derivation analyses, the types and format of the questions asked in the surveys, the lack of equable aims of each survey (the surveys were not necessarily attempting to derive a time-of-day weighting and therefore we are not necessarily comparing like with like), the role of conventional wisdom, and the correlation between day and night noise levels. The estimates therefore do not lead to weighting values which are robust, widely applicable and engender independent day and night annoyance reactions.

The studies do however consistently find that evening and night-time noise are rated as more annoying than day-time annoyance. The magnitude of the difference is not agreed.

Fields prefers the use of the adjusted energy model and the annoyance comparison approach to derive estimates. In his view, using these provide the only real way to estimate independent day and night responses without biases being introduced from conventional wisdom beliefs. He concludes however that reliable independent values for night-time weighting estimates cannot be derived from existing data since the noise levels during the day and night are too highly correlated. Comments are also offered as to the possibility of cumulative annoyance responses crossing across the two periods affecting independence. Fields then evaluates the relationship between day-time and night-time noise environments around USA airports. He does this to evaluate the feasibility of finding sites where the levels are not highly correlated. He concludes that there was little potential in identifying a suitable site in the USA.

Miedema has been collating environmental noise survey data for work conducted over a number of years. He is able to interrogate the database for information about key questions on environmental noise. It was ascertained from discussion that he plans to analyse the data to find evidence for time-of-day factors, both in terms of their existence and magnitude. The results of this work should be available in late 1997. At the time of the final editing of this report, some information was obtained on the preliminary results of this analysis. It should be noted however that it was not possible to analyse these initial findings in any depth. This TNO work uses 8 aircraft noise surveys, some of these are in addition to the surveys used in the earlier Fields analysis. Annoyance ratings and noise level data were analysed using three statistical calculations. Combinations of values for day, evening and night-time weightings were used in the calculations to find the optimal combination for 'best-fit' relationships. The results appear to suggest optimum values for night-time and evening results for various source types. It is not yet known whether these results will add significantly to the scientific debate on night-time annoyance.

An important question can be asked at this stage; do the additional surveys offer more reliable or accurate values of night-time weights? Or are the results subject to the same factors which produced variability in the results of Fields' analysis, eg high correlations between day and night noise levels? At this stage, after some discussion with Fields, it seems likely that there will be the same variability in the estimates due to the same factors.

9 WHY NOT USE EXISTING PRACTICAL IMPLEMENTATIONS OF NIGHT-TIME WEIGHTS TO PREDICT ANNOYANCE, SUCH AS DNL ?

9.1. WHAT IS DNL?

DNL is a practical implementation of a time-of-day weighting used in the USA. There are a number of descriptors used for community noise which adopt weightings. Common to the assumptions inherent in most of these descriptors are three hypotheses as described by Schomer (SCHOMER 1983):

(1) The community response increases monotonically with sound amplitude.

(2) The community response increases monotonically with frequency of occurrence.

(3) The community response to sound exposure at night increases compared with the same sound exposure during daytime.

The Day-Night Average Sound Level, DNL, is a typical representation of these descriptors. Inherent in this descriptor are the hypotheses that the community reaction grows in direct proportion to the growth in sound exposure level (SEL), that the community reaction grows in proportion to the 10 log of the number of events, and that a night-time (2200 to 0700) adjustment or "penalty" of 10 dB is appropriate. The descriptor is typical of a number which are termed "equal energy" models in that a growth of 3 dB in SEL is considered equivalent to a doubling of the number of events. DNL is often termed L_{dn} and is measured in dB.

9.2 THE EVOLUTION AND APPLICATION OF DNL

DNL has evolved over a period of 23 years, between 1951 and 1974. Since this time no departure has been made from the application of this long-established 10 dB value for the night-time penalty in the US. Figure 24 plots the chronological sequence of work that has led to its adoption. This information was reported in the NASA/FAA workshop of 1980 (NASA/FAA 1980).

Figure 24: Evolution of the use of a 10 dB penalty and DNL in USA

1951 Stevens, Rosenblith and Bolt develop CNR (composite noise rating procedure). Using case studies, the physical aspects of noise are related to the expected community response. A 5 dB penalty is suggested for night-time noise, another 5 dB is added to the background noise level at night. An effective 10 dB penalty is therefore suggested for night operation noise.

⇓

1957 Stevens and Pietrasanta develop Technical Note 57-10, a procedure for use in airport noise and land use planning. This used sound level measurements from aircraft to predict noise contours. An energy average level was calculated over 24 hours with a 5 dB penalty for evening noise and 10 dB penalty for night-time noise.

⇓

1961 US Airforce and Federal Aviation Authority (FAA) require a planning guide. A modified CNR is developed that uses perceived noise level.

⇓

1967 1st London Heathrow airport study suggest that 17 units of NNI (Noise Number Index) was required to obtain comparable response in the night-time versus day-time. This was equated to around 11 CNR units. 10 dB penalty therefore unchanged.

⇓

1967 Perceived noise level develops into EPNL (effective perceived noise level). Two studies are undertaken to transfer CNR to take into account noise levels of individual aircraft. This results in the NEF (noise exposure forecast). Exposure and level adjustment start affecting operations more strongly.

⇓

1967 ISO, ICAO, Dutch and others investigate the use of day, evening, night adjustments, eg CNEL (community noise equivalent level), and sliding scales for applications of penalties.

⇓

1970 Title 4 report of the Clean Air Act for EPA (Environmental Protection Act) by Eldred examines topic using 50 case histories. He reduces the standard error of his data fit by using a night-time adjustment and concludes it is better to have an adjustment. (Note that the reduction of the standard error in itself may not have been statistically significant at the 5 % level (OLLERHEAD, 1978)).

⇓

1974 The EPA had to adopt a measure for cumulative noise for use around airports in Noise Control Act. Day/night average sound level introduced. This was based on Eldred's findings, the fact that two or three period models give little difference in results and the previous history of applying a 10 dB penalty.

From the literature, it is evident that the 10 dB penalty has been largely based on intuition and case histories. Its choice is based on a judgement made by a group of people or group of committees and not on decisions made from a lot of hard social survey data. From time to time research evidence is used to test its validity (eg SCHOMER 1993). The results of such work tend to support the retention of a 10 dB penalty. It may not be the most accurate descriptor but is probably no worse than anything else currently in existence. Until evidence exists that clearly demonstrate advantages over the DNL approach, change is unlikely in the USA.

Other implementations of a night-time penalty exist. A current ICAO project is reviewing how different countries take into account aircraft noise occurring during the night-time period. These practices will not be reported on further in this report. Account should be taken of the findings of the ICAO study to understand the basis of the practices in other countries. Further information can also be obtained from Gottlob's review of standards for assessing community noise (GOTTLOB 1994).

9.3 ARGUMENTS FOR USING DNL IN THE UK

If agreement has been largely reached in the US to adopt L_{dn} as a suitable measure to predict community response to noise (FINEGOLD 1994), then why don't the UK jump on the same bandwagon? The procedure, although potentially limited in its supporting research back-up evidence, appears to meet a need, is simple and has gained recognition through its long established application. As Fidell concludes, a 10 dB night-time penalty, while undoubtedly not exactly correct, may well be tolerably close to the truth for most purposes (FIDELL 1980). This was one of the factors underlying the advice given in DoE Planning Policy Guidance Note, PPG24 "Planning and Noise". (DEPARTMENT OF ENVIRONMENT, 1994). If DNL was adopted, Ldn values would replace Leq values. This could be considered to be consistent with PPG24 since this effectively incorporates a 10 dB penalty for the night-time period. Fidell suggests that the struggle necessary to establish widespread acceptance for an alternate time-of-day weighting factor may jeopardise the credibility of such measures that currently incorporate a 10 dB night-time penalty, while gaining only a small increment in precision of quantification of human response to community noise exposure.

9.4 ARGUMENTS AGAINST USING DNL IN THE UK AT THIS TIME

The UK have been proceeding down an alternative route and this has diverged from practices adopted in the US. Any changes to our current system could have significant effects on all the parties mentioned in section 6. We have to consider whether moving from our current system to one that is based on limited research evidence would be a positive step. Maybe the current system is 'no-worse' than adopting DNL and the arguments for retaining our system are the same that hold true for the US retaining DNL.

10 DO WE HAVE ENOUGH RESEARCH EVIDENCE TO PRODUCE NIGHT CONTOURS THAT DEPICT LEVELS OF NIGHT-TIME ANNOYANCE ?

In section 5 we examined an ideal model for predicting annoyance at different times of the day. This consisted of four stages, dividing the day into time periods, assessing the individual effects of exposure using dose-response relationships (and how the mediating factors can affect these effects), combining these effects into a total period annoyance and finally computing the overall annoyance for different periods. We have limited our application of this model to the predicting of annoyance from aircraft noise in order to produce contours for the night-time period.

To determine whether we have enough research evidence to produce night contours, we need to consider the information we have on each of these stages. As we have seen, there are many unresolved problems. Clearly we firstly have to agree how to divide the day into the different periods. We have discussed the potential effects of noise during the night period, but not been able to prioritise these. We have examined some existing dose-response relationships for these effects and shown how these vary depending on source, time-of-day and effect. Furthermore, we have suggested that the role of the mediating factors may be fairly unquantifiable. Although investigated, there appears to be no accepted method to combine these effects into a total annoyance during a time period. Many lessons have been learnt from combining periods using time-of-day adjustments. Their existence is found necessary but the value of their magnitude is a matter for debate. We have been considering producing contours over the night-time period. At present, insufficient data is available on how annoyance may vary over this period. It is likely that response to a noise will be different depending on the type of activity interference and during the shoulder hours. Averaging over shorter time periods to take into account 'worst-periods' could be considered. This could, in effect, be regarded as using finer different time-of-day weightings. More information is needed on what may constitute a 'worst-period' before this type of approach can be considered. Until all of these issues are fully understood, **we cannot successfully depict levels of annoyance during the night using contours.**

Before we look in more detail at these unresolved issues, let us summarise the opinions of some of those directly consulted on this question during the process of this study.

Powell expressed the opinion that we do not know enough about the extent and root of night-time annoyance and therefore cannot agree metrics or dose-response relationships at this time. He generally thought that we do not have enough evidence to define night-time annoyance contours.

Fidell appears sceptical about the underlying strategy of attempting to draw inferences from technical literature on community response to noise to appropriate regulatory action. He is rather cynical about the role of non-acoustic factors such as economic or political concerns driving regulatory decisions rather than these decisions being based on well founded scientific evidence. He may well have a point.

Vallet is somewhat concerned with the importance of sleep disturbance in determining an annoyance response. He is reluctant to accept the conclusions that sleep disturbance is not a strong effect found in Ollerhead's sleep study (OLLERHEAD 1992).

Miedema is interrogating the available research evidence further. From TNO's database of research results he is investigating the existence and magnitude of time-of-day adjustments. He also hopes to be able to look at the significance of individual effects such as sleep disturbance and communication interference in determining a total annoyance response. It may be safe to say that he cannot at present answer this question.

Fields is a leading expert in this topic. Although he has not worked directly on this for a number of years, he has continued to collate information on past survey work. He could not recount a critical survey that would provide any enlightening answers to many of the issues that he raised over ten years ago. As a statistician, he may be accused of looking at the data in a rather stringent manner. He has, however, looked at the data from an informed viewpoint, set out their deficiencies and suggested how we should and should not study the problem. One has to ask whether we could ever design an all encompassing set of studies which may yield statistically acceptable results without the need to use a significant proportion of the UK's GDP!

As Ollerhead surmises, there must be some way in using existing evidence to pull out more of the answers. This study has analysed the problem and examined some of the research evidence. It has been limited by the available time and cost resources. In the time available, we have identified a number of unresolved issues. Investment in re-analysis of survey collation results may be useful, ie a more detailed look than has been possible in this project using tools and data available to persons such as Miedema and Fields. Ollerhead asks whether it is any more difficult to define night contours than day contours. This work suggests that they are only comparable if the main determinants of annoyance are similar. He questions whether L_{eq} is the right descriptor to rely on as a prediction for night-time annoyance. It may be if we can take into account all the effects using relevant metrics. We have seen that L_{eq} may not take into account event levels but could use SEL's in its determination.

It should be noted that we cannot necessarily apply the findings of all research studies on night-time annoyance to the issue of producing night-time contours to UK airports. One has to ensure that the research findings are applicable to the UK situation.

Finally, the author would like to comment on the question itself. Contours are useful for regulatory control. However, if we combine together indicators of the impact of all the effects into one measure or index, we may conceal the information about the dominant effect leading to an adverse response. There is indeed value in creating an all-encompassing annoyance index, but in Fidell's words, are we again searching in vain in the quest for the Holy Grail? Maybe we don't need the Holy Grail, but only realistic, useful and pragmatic tools to do our jobs almost as successfully as if we had found it. After all, if we can never truly relate the subjective response with an objective measure, what are the true values of noise contours. Ideally they could be

1. Useful to predict a level of community response to noise.

2. Useful to provide for objective comparisons between different situations.

3. Helpful in targeting effective noise control options or scheduling aircraft operations to minimise effects on public health.

11 RESEARCH NEEDS

11.1 THE UNRESOLVED ISSUES THAT REQUIRE RESEARCH

During this report a number of unresolved issues have been described which would require attention before we can produce night noise annoyance contours. These are summarised below.

1. Definition of night-time

   Which activity are we trying to protect?
   At what times do these activities occur?
   Can night-time be divided into sub-periods?

2. Assessment of individual effects of aircraft noise at night-time

   Ranking of importance of the effects at night and variation over night-time period.
   Evaluation of mediating factors for each effect, (including number of events, ambient noise, familiarity).
   Agreement of dose-response relationships for each effect during the night-time period.
   Can day and night effects ever really be independently evaluated?
   Determination of effect of other non-aircraft noise sources.
   How do we take into account atypical noise characteristics.

3. Total annoyance during night-time period.

   How do we best combine all effects into an overall measure?
   What significance does each effect have in determining an overall annoyance response? Under what circumstances?

4. Total overall annoyance for different time periods.

   Does annoyance at night-time increase as rapidly with noise level as for day-time.
   Does annoyance or noise level in any other period affect noise annoyance at night.
   If we use the same metric for day and night, what is the best form and magnitude of an appropriate penalty.
   If the adjusted energy model is not appropriate to describe response for day and night, can we adopt night-time weighting penalties?

11.2 TYPES OF STUDY

A number of study strategies are available to find answers to some of these questions. These include:

1 Cross-sectional studies whereby long term noise environments of different areas are compared. For meaningful results of statistical value, assumptions have to be made between the similarity of the socio- and demographic factors. Cross-sectional surveys with limited matched factors are not appropriate.

2. Longitudinal studies to compare responses before and after permanent or temporary changes in noise environment. For any changes to occur, research has shown that at least six months is required after any change to take into account habituation and adaptation (FIDELL 1975). Longitudinal surveys involving short term changes are not appropriate.

3. Comparisons of daily levels with daily annoyance.

4. Studies controlling noise environment using military facilities.

Studies could take the following forms:

More detailed analysis of existing data (for example using database information). This could also include more detailed analysis of UK sleep study data to determine if there is a correlation between sleep disturbance and annoyance (as discussed in paragraph 4.3). Careful planning would be required for this work. The first step would be to establish the breadth of data and formulate clear hypotheses to be tested.

2. Addition of specific questions to already planned survey work, eg studies to be carried out around Amsterdam - Schiphol Airport.

3. New survey work.

11.3 PREFERRED STUDY OPTIONS

The report has shown that numerous studies exist that have already provided information on response to noise during the night-time period. In setting out the way forward, we need to consider how we can get the best returns for additional research efforts. We do not want further research to form another line of the table of studies shown in Table 6. The significance of such results would then be diluted when added to the other research data.

The general consensus from literature and consultation about the preferenced study options reflected Fields' thoughts: he considered long term longitudinal studies to be most suitable. In reality, due to cost considerations and the availability of such locations, relatively shorter term longitudinal studies would have to be considered. Fields recommended that immediate responses should be determined as soon as possible after exposure. This would aim to overcome the problem of conventional wisdom biasing the results. Attention would have to be given to the types of questions. He suggests that linking the periods to other entities other than annoyance may be beneficial, such as equating their choice of preferenced time periods to monetary values. As became evident in Fields' time-of-day work, to successfully use an adjusted energy model and annoyance regression analysis, sites of study would be required where the day and night levels are not highly correlated.

12 CONCLUSIONS

The work objectives were set out as:

1. By reviewing available research evidence, to address the question:

"Could night contours be produced that depict levels of night-time annoyance that are equally applicable at the three London designated airports?"

either

2. To define independent day and night annoyance reactions.

3. To establish correlations between these annoyance reactions and noise exposure levels

   or

4. To define what, if any, new research could be conducted to make 2 and 3 possible.

The work has shown that we cannot at present produce night contours that depict levels of night-time annoyance. Approximations could be used to do this using 10 dB adjustments for night-time levels but there is little scientific data to support this approach. Furthermore this is based on annoyance being related to the average energy equivalent level. This may not be the optimal metric to take into account all the effects of noise during the night-time period.

The main determinants of annoyance reactions during the night have been summarised. These are not ranked in order of importance. Often these factors are outweighed against other concerns when making decisions such as those based on economical or political factors.

Correlations have been found between annoyance reactions and noise exposure levels. These can take the form of dose-response relationships for annoyance, for each time of the day, and for each effect or as night-time adjustment values. There is some agreement on dose-response relationships for the day-time period but evidence for robust and consistent data for different times of day remains unconvincing. Furthermore, there is a lack of evidence on the significance of individual effects such as sleep disturbance and communication interference on the total annoyance response.

A four stage ideal model for predicting annoyance at different times of day has been summarised. This reveals gaps in knowledge which need to be resolved before we can apply it to predicting annoyance contours. Although this ideal model may never be fully realised, we can fill some of these gaps through research. This research should aim to provide pragmatic tools on which to base regulatory controls using annoyance contours. Future research could use existing database sources such as that held at TNO. If the Ollerhead 1992 sleep study data would be a useful input to the TNO's database, then one approach would be to make the data available to Miedema.

Most countries appear to be moving toward descriptors for aircraft noise based on Leq and total energy models. The fundamental question is can we actually rely upon Leq as a predictor of night-time effects? The work has shown that Leq may not always be the best descriptor if we are describing effects which better relate to single event metrics. The questions relating to the use of metrics were found to be difficult to answer by consultees. The selection of the most appropriate metric should be determined by the need to measure noise dose in such a way as to define the extent of an effect. We need to know more information about how to measure and define the extent of the effects.

13 RECOMMENDATIONS

There are a number of study options available to provide data to fill the identified research needs. The following gives recommendations for the Department to consider when setting the way forward in deriving night-time annoyance contours.

1. Further consideration could be given to the use to which night-time annoyance contours are to be put, as this is likely to impact on the noise metric used and the time period they cover. For example, for planning purposes it may be appropriate to consider an 8 hour night period, but if specific activities are to be protected it may be necessary to sub-divide the night into shorter periods. In some instances the use of annoyance contours may not be the best way to assess the effects of aircraft noise.

2. More research is needed to clarify the unresolved issues in working towards an idealised model for predicting night-time noise annoyance. The aim should be to provide a pragmatic tool on which to base predictions of night-time noise annoyance. This research should consider value for money (cost versus benefits), level of statistical significance, cost, use of specialist groups, use of specific social survey techniques, and location of suitable study sites with noise environments without strong correlations between day and night noise levels.

3. The effect of sleep disturbance during the shoulder hours needs further investigation. The results of such an investigation may have an impact both on the assumption that sleep disturbance is not a strong effect and the presumed role or significance of sleep disturbance in determining annoyance during the night-time period.

4. Consideration should be given to further analysis of the UK Sleep Study data to determine if there is a correlation between the measures of objective sleep disturbance and subjective reports of annoyance. Although such an analysis would not resolve the role of sleep disturbance in night-time annoyance it might make a useful contribution to the ongoing debate.[1]

5. Planned survey work must be identified and where possible, additional questions could be added about time-of-day issues, with little extra cost.

6. Monitoring of other key developments in this field needs to continue. Close liaison should be maintained with Team 5 "Noise and Sleep" of the International Commission on the Biological Effects of Noise (ICBEN). Advantage should also be taken of NPL's representation on the International Committee on Uniform environmental noise exposure metrics set up by the Dutch.

[1] It must also be noted that the sleep disturbance issue is only one of the unresolved problems in deriving night-time annoyance contours and thus the findings of this analysis will not alter the conclusion of this report (ie that there is not currently enough research evidence to produce scientifically robust night contours that depict levels of night-time annoyance.)

7 The EU have been considering future noise policy in their recent green paper (EUROPEAN COMMISSION 1996) . A conference was held on 21-22 May 1997 which was attended by delegates from many countries interested in noise issues. This was one of a series of such events designed to give feedback on the green paper to the EU. At this conference, sleep disturbance and noise annoyance during the night-time period were discussed in a special session. The author of this report was responsible for leading some of these discussions and for presenting the findings to the plenary session on the final day. The summary report is given in PORTER 1997. The issues that were looked at included the needs for a special descriptor for the night-time period, tailoring descriptors to the noise effects that we wish to predict, taking into account the importance of non-acoustic factors when determining an annoyance response and providing useful information on the most effective ways to protect human health at night.It is recommended that the Department take into account any EU conclusions and their eventual decisions as appropriate.

8 The Department should continue to promote technology transfer and dissemination of information. This could lead to exchange of ideas and sharing of research data. This is of benefit to both the industry and public. It also serves to minimise costs associated with possible "re-invention of the wheel'. This could involve dissemination of existing research results to database collations.

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Appendix I: Classification of articles: basic questions

CLASSIFICATION OF MATERIAL

ANO90303 - CAA/NATS- Night Noise Contour Study

Reference:

Relevance to work aims (0-5):
(0 - irrelevant)
(5 - most relevant)

Key topics covered:
(Annoyance and noise levels (particularly at night), sleep disturbance and noise levels, setting of aircraft noise limits, noise metrics, time of day factors, footprints for sleep disturbance thresholds, how to account for unevenness of noise throughout the night, etc)

Please complete where information is available:

(1) What factors contribute to annoyance during the day ?

The night ?

(2) Can we assume that there are no direct health affects from sleep disturbance other than chronic annoyance ?

(3) How does sleep disturbance contribute to chronic annoyance ?

(4) If night weighting are used, what basis is adopted ?

Does this article help answer the following: Could night-time contours be produced that depict levels of night-time annoyance ?

Are independent day-night annoyance reactions covered in reference material ?

Are there any correlations suggested between annoyance reactions and noise exposure levels at night ?

Where does work fit or contribute to story chronologically ?

Research needs identified (if any ?)

Are further relevant references suggested?

Appendix II: Identification of key issues for use in consultations

Key Questions

The following lists some issues that need resolving to address the work objectives. Some of these have already been partially addressed through the initial review findings.

Factors for annoyance -	What factors contribute to annoyance during the night?
	Are these different to factors for the day?
	How do the same factors for day and night rank in order of importance?
	Can day and night effects be independently evaluated?
	What factors are quantifiable?
	What factors are unquantifiable?
	In which situations could unquantifiable non-acoustic factors play a significant role and limit the usefulness of quantifiable exposure relationships?
Sleep	What is the role of sleep disturbance in chronic annoyance?
	How important is it in deriving a dose-response relationship?
Metrics	Can we use the same metric for day and night?
	Can the difference in day and night reactions be presented as a weight?
	If sleep disturbance is the main factor, should we use SELLS?
Models	Which time of day model is most appropriate in which circumstances?
	Is annoyance cumulative?
	What are the direct and indirect effects at night?
	What dose response relationships exist for these effects?
	How robust are they?

Models (continued)	How does non-specific and specific annoyance correlate?
	How do we combine overall effects into a measure?
	What variables mediate dose response relationships?
	Does annoyance at night-time increase as rapidly with noise level as for day time?
	How does number of effects affect response?
	What role does ambient noise or familiarity have?
	What shape of curves do we expect for annoyance?
	Is dose response same as for entire night?
	If not, how does it differ?
	Does annoyance or noise level in any other period affect noise annoyance at night?
Research	If there is unconvincing research evidence to define night-time noise contours, we need to plan further work.
	Choice of study?
	Choice of strategy to test appropriate models?
	How to test for independence?
	Which questions and judgements basis is most appropriate?

Appendix III: Models to predict annoyance

1 Night-time weighting models based on average energy

Fields reviewed time of day weights and night-time adjustments using four models (FIELDS 1985a). The first model reviewed was the conventional model found in noise indices based on energy. He found that no publications exist which offer a theoretical basis for the other models or perform empirical analyses to determine which model best explains annoyance.

The following describes the principles of each model.

Adjusted energy model

This is the conventional "energy model" accepted in such indices as LDN, NEF, and CNEL. In this model the noise level within each time period is adjusted before being combined with the noise levels from other time periods to make a 24-hour index. The noise level is adjusted with a numerical weight. This weight is multiplied by the number of noise events or the relative pressure squared of the value of the sound levels.

The majority of existing indices agree with this single, simple theory (model) of how humans react to noise. The indices differ only in how much weight should be attached to a noise in different periods.

It is worth commentating that should people move their understanding away from the adjusted energy concept, the underpinning of currently used indices will be challenged.

Independent period effect model

The differential impact of a noise in different periods is assumed to occur in the form of a more rapid increase in annoyance with changing noise levels in the more sensitive periods. This model, although used to predict total annoyance over the whole day, assumes that there exists independent dose-response relationships for day and night based on the Leq during these times.

Annoyance is assumed to be directly proportional to the noise level in each period, irrespective of the noise level in other periods. Such that:

Total annoyance = constant + (weighting fn x day level) + (weighting fn x night level)

Thus a change in the night-time noise level from, for example, 50 to 44 dB(A) (LEQ) will be assumed to have the same impact on total annoyance whether the daytime noise level is 40 or 80 dB. In the adjusted energy model, on the other hand, the change from 50 to 55 dB(A) (LEQ) would be expected to have important impact if the daytime and night-time noise levels were subjectively approximately equal.

Decibel difference model/energy difference model

Fields calls this the decibel difference model (FIELDS 1985a) but it was previously called the energy difference model by Taylor (TAYLOR 1982).

This model implies that annoyance is independently affected by the value of LEQ for the total 24-hour period and number of decibels which separate the noise levels of the two time periods. Such that:

$$\textbf{Total annoyance} = \textbf{constant} + (\textbf{weighting fn} \times \textbf{LEQ}_{24hr}) + \textbf{weighting fn} (\textbf{LEQ}_{day} - \textbf{LEQ}_{night})$$

An adjustment can then be defined as the difference between the daytime and night-time noise levels which is equivalent to a one decibel effect of 24-hour LEQ.

Ratio numbers

Fields reports several studies which attempt to estimate the weight in the conventional adjusted energy model and have unwittingly used a different annoyance model.

$$\frac{\text{day annoyance/night annoyance}}{\text{no. of day events/no. of night events}} = \text{adjustment for day/night difference}$$

The model uses a ratio analysis which relates the ratio of two time-period annoyance scores to the ratio of the numbers of events in the two periods:

This model departs from all other previously proposed annoyance models in at least two respects: annoyance is directly proportional to numbers of events (not $\log_{10}$ number) and the effects of all additional variables (such as noise level or attitudinal variables) are multiplicative not additive.

2. Other models based on single event levels

The models already summarised use average energy as their basis. The following models suggest that the noise of a single event may be more important in determining an adverse response. The models could lead to time of day weightings if the sensitivity to or noticeability of an event at night is different to that during the day and if the same metric is relevant for each effect in each period. Single event metrics may be better suited to indirect annoyance effects of sleep disturbance as already discussed.

Rylander's Model based on L_{MAX} of noisiest event) (RYLANDER 1980)

Rylander investigated aircraft noise annoyance contours and the role of overflight frequency and noise level. His results showed advantages of moving away from an adjusted energy model to one that was based on the maximum level in dB(A) experienced during an overflight. He used the nominal noise contour for the noisiest aircraft type in the area with at least 3 overflights in 24 hours. The results demonstrated that an increase in the number of aircraft causes an increase in the extent of annoyance but only up to a certain number. Furthermore, the extent of annoyance within each category of exposure events was related to the noise levels from the noisiest aircraft. This type of model could suggest that

Annoyance at night = constant + (function x L_{MAX})

Hall's Model based on SEL and L_{MAX} (HALL 1985)

Hall investigated activity interference and noise annoyance. This work led on from Taylor's path analysis concept already discussed (TAYLOR 1984). This conceptual model showed a basis for a model of noise annoyance in which activity interference are included as the primary intervening factors, eg sleep disturbance and communication interference. These activities may be better accounted for by single event measures.

He examined the use of single event noise levels to describe the noise. He showed that for indoor speech interference, the maximum event level was the strongest predictor.

The suggestion implied for this model is that

Total annoyance = constant + fn (single event characteristics, eg L_{AX})

3 Models to combine effects

From different sources:

In the same way as night weights aim to equate the annoyance from a source between night and day noise events, one can propose a model to equate the impact from different sources by using penalties. This can depend on heightened response due to particular acoustic features or judgements or attitudes towards the sources. Examples of this work are given by Vos (VOS 1992) and Miedema (MIEDEMA 1993). Although the work in this report relates to one particular source, aircraft, it is not always heard in isolation and its impact must be judged relative to the ambient surrounding noise. Assessing combined noise sources has been the subject of several workshops or conference sessions such as that at Internoise '97, Hungary.

Models to combine effects.

In section 4 we discussed path analysis for evaluating annoyance and saw in Figure 2 how the contributory factors converge on an overall total annoyance response. We need to understand how to combine these paths/dose-effect relationships into an overall measure if we are to produce an annoyance contour. Models can examine either the main effect or rank the critical effects in order of importance. Work by Taylor and Hall has looked at the significance of the effects in determining an overall response. (TAYLOR 1984, HALL 1985). In discussions Miedema proposed the possibility of examining the TNO database of survey work to see if it can render an optimum way of moving from the specific effects to an overall annoyance response. It is likely that this process will be fraught with difficulties due to variability of mediating factors and dependence on individual circumstances. Perhaps we should ask at this stage whether we should be trying to produce an overall annoyance response. It may be useful for planning and regulation, but may it not conceal the individual effects impacting the community?